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Forest engineering
Making a positive contribution

Symposium on Forest Mechanization
Linz, Austria 2015

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Forest engineering: Making a positive contribution
48th Symposiom on Forest Mechanization
Linz, Austria 2015

Editors

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December 1, 2015

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Layout: C. Kanzian
Cover image: aboutfoto/fotolia.com

Citation recommendation:
C. Kanzian, M. Kühmaier, & G. Erber (2015). Forest Engineering: "Making a positive contribution". Abstracts and Proceedings of the 48th Symposiom on Forest Mechanization. Linz, Austria 2015. 512 p.

The contributions are not refereed, and many of these papers represent reports of continuing research. It is expected that some of them will appear in a more polished and complete form in scientific journals.

Published by:
Institute of Forest Engineering
Department of Forest Soil and Sciences
University of Natural Resources and Life Sciences, Vienna
Peter Jordan Straße 82
1190 Vienna
Austria

www.formec.org

ISBN 978-3-900932-29-9

Printed in Austria

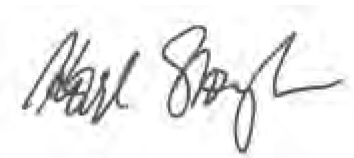
Contents

Preface

Dear Colleagues,

I am pleased to welcome you to the 48$^{\text{th}}$ International Symposium on Forestry Mechanization (FORMEC) in Linz. It is a tradition that every four years we meet in Austria for the FORMEC symposium, the largest scientific forest engineering network which gathers over 200 leading professionals and scientists in all the fields of forest engineering from around the world. This is the fourth FORMEC edition that we organize together with AUSTROFOMA, the leading forestry machine fair focusing on cable yarding technology, where many of the machines on display are also demonstrated in operation. This gives participants invaluable opportunities to have fruitful discussions about the current challenges in forest engineering and the transfer of knowledge to practical know-how.
With the increasing demand for forest products and ecosystem services, decision makers are often confronted with a number of challenges, such as sustainable use of the forest resources and improving the efficiency of the production systems within the wood supply chain, while minimizing the environmental footprint and increasing the social responsibility. It is FORMEC scientific network's role to address these issues based on a multi-criteria approach and to develop and test innovative ideas that are tailored to the needs of the forest industry.
The 48$^{\text{th}}$ FORMEC symposium with the motto "Making a positive contribution" stands for the continuous improvement of the quality of the contributions of our scientific network to the development of smart, competitive and low-carbon forest based industries. FORMEC is a trendsetter in matter of high quality scientific research in forest engineering. Since 2011 we have introduced a Special Issue of the Croatian Journal of Forest Engineering (CROJFE) where selected papers presented at FORMEC are published. Not all of the approximately 100 oral presentations given at FORMEC can be peer-reviewed for the CROJFE Special Issue and thus it is of utmost importance to gather the valuable contributions of our participants in symposium's proceedings for further dissemination and to foster the participation of young and highly qualified researchers. This will increase the quality and the visibility of FORMEC scientific community worldwide.
Finally, I would like to thank all those who have contributed for the meeting in Linz to be a successful event. I look forward to the valuable contributions that all participants can make at the 48$^{\text{th}}$ FORMEC Symposium. A special thanks also to the BOKU Forest Engineering team for preparing the meeting and proceedings.

President of FORMEC,



Prof. Dr. Karl Stampfer

A

Full papers

Topic 1

Plenary Session

Keynotes

Ergonomics and productivity improvements through machine automation

M. Paakkunainen*

Abstract
Wheeled-Cut-to-Length (WCTL) forest machines represent the most advanced working machine technology. At John Deere many of the latest forest machine innovations relate to operator ergonomics and machine productivity. In this presentation three examples of these are presented.
In 2008 John Deere introduced a new rotating and levelling operator station platform. Thanks to this system the operator does not need to turn the seat according to the work phase. The operator can even use a mid-position while working. The operator can select an auto-mode in which the cabin follows the boom rotation. 2-directional cabin levelling reduces the operator fatigue. A control system keeps the cabin levelled during driving over obstacles and in hilly conditions.
More than 50% of the forwarder working time is loading and unloading. The boom user interface plays a crucial role for machine productivity and operator fatigue. John Deere introduced successfully a novel Intelligent Boom Control (IBC) system in June 2013. Such a system has been long waited among the logging society but has not been realized earlier due to challenges related to the system performance, cost and reliability.
In the latest harvester models John Deere introduced the new Processing Power Control (PPC) system. PPC enables the operator to optimize between fuel economy and productivity according to the work site needs. This is carried out by a smart control of the engine and the hydraulics.

Keywords
operator station, boom control, processing control

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1. Introduction

All over the logging world contractors are challenged by the lack of the skilled operators, increasingly stringent environmental requirements and fuel costs. Automation plays a very important role to mitigate those challenges, since it can clearly improve the functionality and performance of the machine. Automation can also have a big impact to the operator ergonomics and stress level. The existing situation has strongly affected to the product development efforts and priorities among the machine manufacturers.

This presentation will introduce some new and outstanding machine automation related features of John Deere forestry harvesters and forwards. Their basic functionality, performance and customer benefits will be presented.

2. Rotating and Leveling Operator Station Concept

The uniqueness of John Deere rotating and leveling cabin concept is due to mechanical separation of the cabin rotation from the boom rotation. This is feasible first because it diminishes the jerk and shock effect from the boom and harvester head to the cabin and the operator. The visibility to the working direction and for driving is optimal. Good visibility helps also the logging work planning. Secondly, the smart rotation control system allows flexible ways to utilize the cabin rotation. With just one press of the button the operator can choose from fixed cabin direction to manual direction control or, most preferably, automatic boom rotation follow up.

Figure 1. Boom rotation and leveling in typical forwarder work site. Operator sees the working site through the front window and sits horizontally.

In the manual turning mode the operator can turn the cabin to desired direction as an example already before stopping to machine for loading. In the auto-mode the cabin does not follow the boom just in a fixed manner. Operator can set the follow-up activity according to the work site and personal needs. This is feasible since many operators are suffering from so called carousel effect that is typical in such solutions in which the boom and the cabin are mechanically fixed to the same rotating platform. Especially in the steep hills this option is very beneficial because the operator does not need to rotate back and forth constantly while the cabin is not fully horizontal.

It is also beneficial that in the rotating cabin all the user controls and display stay at the same optimal position versus the operator. This is not the case in the fixed cabins where the seat is turned.

Figure 2. Boom rotation and leveling in the harvesting work. In spite of working uphill operator can sit stable.

John Deere's cabin leveling concept is outstanding since it works both lateral and longitudinal directions. The lateral oscillation is the most harmful for the operator comfort and fatigue. In John Deere harvesters up to 17 degrees lateral angles can be compensated. This is very beneficial when working on the slopes.

In forwarder application the dynamic response of the leveling function is very important. In John Deere machines the leveling is carried out by state of the art sensor and control system utilizing both inclinometers and gyroscopes. The maximum lateral leveling angle is 10 degrees. The longitudinal leveling angle is ±10 degrees in harvesters and respectively ±7 degrees in Forwarders. Figure 3 shows the main components of John Deere rotation and leveling system hardware.

3. Intelligent Boom Control (IBC)

Despite the fact that electro hydraulic boom control valves have been common in Scandinavian logging machines since the 1980s, no major leaps have been taken in the boom controls area until 2013 when John Deere introduced the Intelligent Boom Control system - IBC - in Elmia Wood Fair in Sweden.

IBC consists of position sensors for measuring the boom orientation, control hardware – which is similar to standard John Deere control hardware – and advanced software. The idea of IBC is that the operator controls the speed and direction of the boom tip. The boom is driven as a complete unit instead of individual degrees of freedom (Fig. 4). This makes the boom handling faster, simpler and easier to learn. All this increases the machine productivity and fuel economy. Thanks to reduced number of tuning parameters the tuning of IBC is also easier than the standard boom.

As a side benefit IBC provides efficient electrical cylinder end damping. This reduces the unwanted physical shocks and thus saves the boom structures. It also facilitates the operator's work and lowers the fatigue.

The cable routing and sensor design of IBC system are designed to be robust. In the case of sensor or cable break, the operator can continue the work in the standard mode because IBC system is redundant. Operator can switch between the modes by just one press of a button.

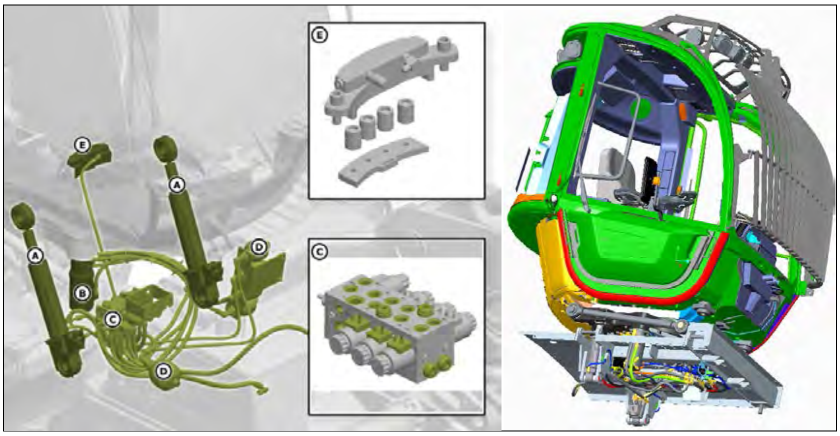
IBC includes also a specific unloading mode which helps the unloading of the heaviest loads by utilizing more the strong lift and jib movements. This mode can be selected easily by pressing a button.

IBC is based on decent control engineering design and has been developed and tested together with the customers. This option has reached very good popularity and today the majority of new John Deere forwarders are equipped with IBC option. Especially with the novice operators the instant benefit is remarkable. In the longer term use - during the work shift and work career - the benefits can even increase due to lower stress level of the IBC user. Typical comment from the IBC customers is that they are able to bring one more load per shift to the road side – and with less fatigue.

4. Processing Power Control (PPC)

In harvesting work the operating conditions and tree species vary, as well as the skill level of the operators. To better optimize the machine performance and fuel economy, John Deere introduced Processing Power Control (PPC) system along with the EIT4 harvester models.

In PPC equipped machine the operator can select between three processing power levels. Level 2 is meant for typical conditions and working speed. It is powerful enough to handle even the biggest trees but it takes in to account also the fuel economy (l/m^3). The system controls engine, hydraulic pressure and pump capacity according to the stem size and species during the processing. While not using the full capacity with the small stems the system saves energy as well as machine structures and components, but still keeps good productivity (m^3/h). Level 1 is so called Eco Mode, in which pressure and pump capacity is decreased versus level 2. This level is suitable for small trees like in thinning and gives even lower l/hour result than the Level 2. Level 3 is the Power Mode. It is meant for the toughest conditions and maximum productivity. Engine power, pressure and flow capacities are available for the most effective work. An "Intermittent PPC Level 3" can be activated for one-stem processing, when a particularly big and difficult stem is encountered while using a lower PPC Level. The intermittent boost mode is deactivated automatically when stem processing is finished. Figure 6 illustrates the control principles of PPC. PPC system has been developed in close co-operation with the customers and is available in all John Deere harvesters.



A. Leveling Cylinder
B. Rotation Motor
C. Leveling and rotation valves
D. Accumulators (in Harvester)
E. Brake

Figure 3. Main components of the Rotating and Leveling system.

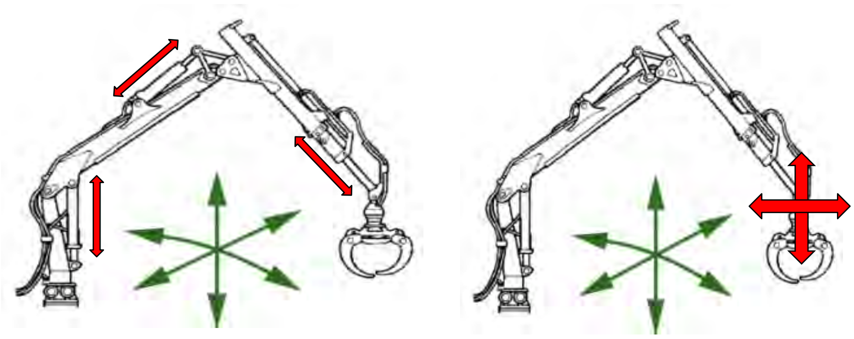


Figure 4. Standard boom control (left) versus Intelligent Boom Control (IBC).

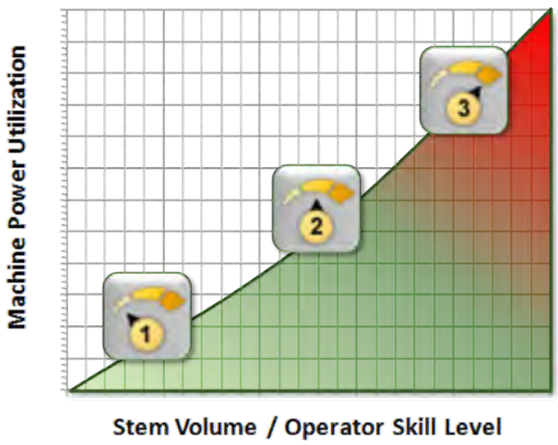


Figure 5. Three power levels of PPC.

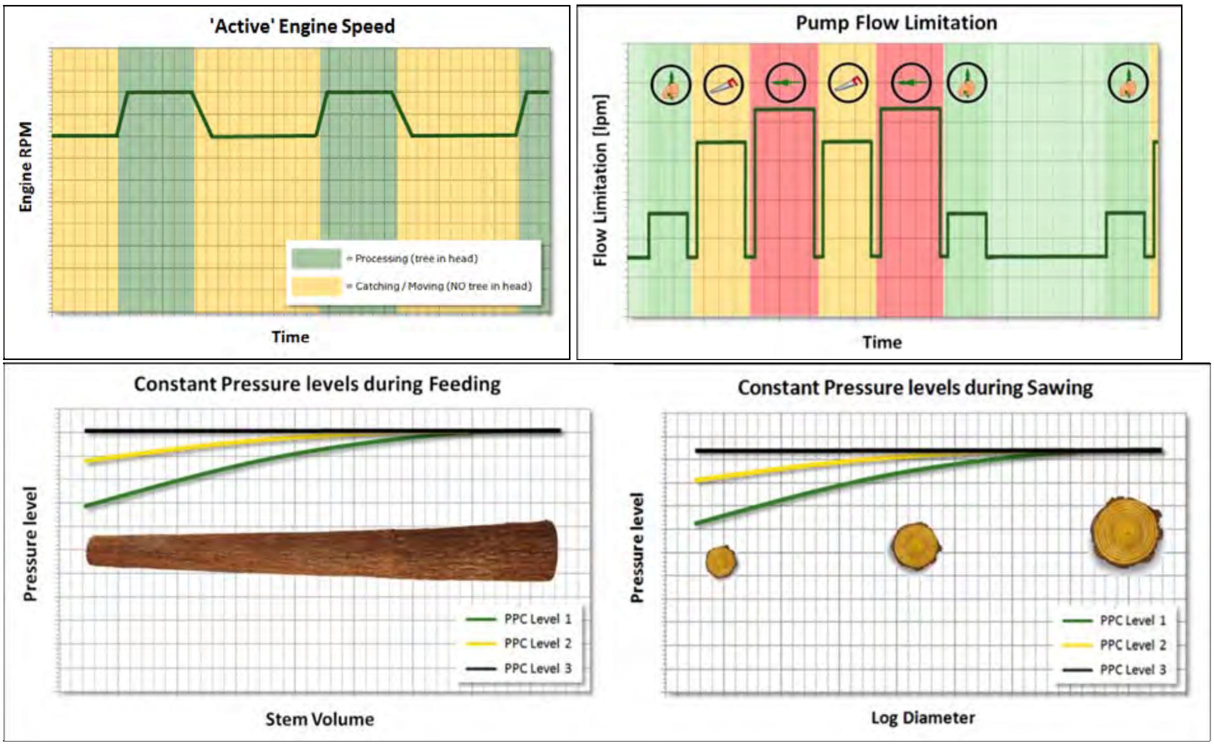


Figure 6. PPC system control principle.

5. Conclusions

Automation based product features play increasingly bigger roles in the forest machines. Automation decreases operator's fatigue and improves the productivity. In this presentation three outstanding John Deere automation features are presented: Rotating and leveling operator station, Intelligent Boom Control (IBC) and Processing Power Control (PPC). Today the majority of John Deere customers prefer to select these options because of their positive impact to their business.

Teleoperation of harvesting machinery for a safer future

K. Raymond

Abstract
Innovative forestry technology is keeping pace with the increasing New Zealand forest harvest to keep forest industry workers out of harm's way. New equipment is starting to be seen out on the slopes as a result of Future Forests Research Limited's Primary Growth Partnership (PGP) steep land harvesting programme.

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1. Challenges of steep terrain harvesting

In New Zealand large areas of forest planted in the 1990s are reaching harvesting age from 2017 onwards and as harvesting increasingly moves into these forests on steeper land and in smaller, more isolated holdings, the challenges of maintaining international cost competitiveness and safe operations will mount. Five years ago the New Zealand forestry sector and the Ministry for Primary Industries identified steep country harvesting as the main bottleneck to achieving greater profitability in forestry.

Worker safety is also a major issue. The forest industry has had a serious safety problem for far too long, with a long-term average fatality rate of five deaths per year and an annual serious harm injury rate of one for every 35 workers. Tree felling and breaking out (hooking tree stems to cables) have been identified as the most common tasks involved in fatalities and serious harm injuries. Steep land harvesting has higher risks than harvesting on flat land, mainly due to the higher work requirements and the difficulty of operating machines on steep slopes. Steep country forests contribute about half of New Zealand's total annual harvest volume and, according to the industry incident reporting scheme, almost 40 per cent of forestry fatalities over the last five years.

Harvesting operations on steep terrain need to keep pace with work demands and technology developments to make harvesting safer and reduce costs. Mechanisation has been seen as the solution to these problems, as it is more productive than manual operations and removes people from the hazards of tree felling and breaking out where most accidents happen.

2. Objectives of the programme

In 2010, Future Forests Research Limited (FFR) developed a business plan to form one of the first Primary Growth Partnerships with the Ministry for Primary Industries. The vision of the PGP steep land harvesting programme is 'no worker on the slope, no hand on the chainsaw'. This is being achieved by developing innovative harvesting technologies to realise substantial productivity gains and improve worker safety in steep terrain harvesting in New Zealand.

The programme is an alliance between forest owners, engineering companies and research providers to develop equipment that will reduce cable logging costs, make harvesting jobs safer, and expand the harvesting equipment manufacturing industry. When fully implemented the programme will reduce cable harvesting costs by 25 per cent. This will create savings of eight dollars a cubic metre of wood produced, resulting in direct economic benefits of over \$ 100 million by 2016, as well as reducing logging injury rates.

3. Achievements to date

In the final year of the six-year programme, 35 industry members have committed to funding the research outside of the Forest Grower commodity levy. A contribution of \$ 0.25 million from the Forest Grower Levy Trust Board brings the total industry funding to \$ 0.75 million, which is matched by the Ministry for Primary Industries, to provide a funding base of \$ 1.5 million in 2015/16.

The development work is split into three programmes – mechanisation on steep terrain, increased productivity of cable extraction and development of operational efficiencies. Five years down the track, there are a number of project achievements that include elements of remote control and teleoperation:

- Alpine Grapple, a lightweight grapple carriage
- CutoverCam advanced hauler vision system
- Teleoperation of a John Deere feller buncher
- Teleoperation of a prototype Tree-to-Tree Felling Machine
- A remote controlled Twin Winch Tail Hold Carriage

3.1 Alpine Grapple Carriage – a low cost option for grapple yarding

A new hydraulic grapple carriage, aimed at improving grapple control, has been developed which increases the productivity of cable extraction and eliminates manual breaking out. The Alpine Grapple carriage is made by Alpine Logging Ltd of South Africa, and was field tested here and modified to make it more suitable for New Zealand logging conditions. As it is non-motorised, the Alpine Grapple has a lower capital cost, is lighter in weight and cheaper to run than conventional motorised grapples. It is suitable for running on existing two-drum cable haulers and swing yarders. The Alpine Grapple is available commercially from LogPro Limited, Alpine's local agent (see www.logpro.co.nz). Six units have been sold in New Zealand to date, with seven more on order.

3.2 CutoverCam – streaming live video into the yarder cab

Breaking-out in cable logging is one of the most dangerous harvesting tasks, often because the visibility of ground operations from the hauler is limited. The next product commercialised as part of the PGP harvesting programme was the CutoverCam, an advanced hauler vision system. This is a camera located on the cutover and linked by Internet Protocol and wi-fi technology to a screen in the hauler cab and streams live video of the hauler operation to the operator. With this system, the days are over of the hauler operator relying on radio and "Talkie Tooter" signals. The hauler operator now has high resolution video coverage of the breaking out zone, and can control the camera remotely to pan from side-to-side, tilt up and down or zoom in and out to see where personnel are on the cutover before beginning the cable inhaul cycle. This product has a very direct safety focus and has the potential to improve the productivity of cable harvesting by reducing delays in positioning cable rigging. The first two units have been sold and it is marketed by Cutover Systems Ltd in Rotorua (see http://cutoversystems.com).

3.3 Teleoperation of a John Deere feller buncher – the future of tree felling?

The initial outputs of the programme involved further developing technology which to some extent was already there, to get early gains for the industry. Over the next year some really exciting and novel products will change the way steep terrain harvesting will be undertaken in the future. Completely new systems are being developed that include remote control and teleoperation – control beyond line-of-sight – of a commercial feller buncher.

Recent focus has been on the installation of a remote control system into a John Deere model 909 feller buncher. The first stage of this remote-controlled tree felling project was achieved in June 2014 and the initial field testing showed promise. The application of remote control to a tracked feller buncher on steep terrain was believed to be a world first, and was reported widely in the news media. This year the next stage of the project is to build a console to teleoperate the John Deere feller buncher, so the operator can sit in comfort, outside of line-of-sight and operate the machine.

3.4 Teleoperation of a Tree-to-Tree Felling Machine – the "Stick Insect"

In a second project, FFR is working with Scion and the University of Canterbury mechatronics programme to develop a prototype sensor guided bi-ped felling machine for steep

Figure 1. Remote control of John Deere 909 feller buncher.

country. This will move from tree-to-tree without touching the ground, using sophisticated sensing and control technology for semi-autonomous teleoperation of the machine from safe working distances, reducing risk to harvesting workers.

Figure 2. Prototype tree-to-tree robotic felling machine.

3.5 Remote controlled Twin Winch Tail Hold Carriage – for efficient skyline shifting

The final product of the programme is an innovative yarding carriage for remote controlled shifting of the cable yarder skyline. Shifting the skyline is a time consuming, difficult and potentially hazardous task. With the development of the Twin Winch Tail Hold Carriage, line shifting will be undertaken remotely from the yarder cab. Construction of the 'beta prototype' carriage is now underway and will be completed by July 2016.

Figure 3. Schematic of prototype Twin Winch Tail Hold Carriage .

4. Programme outcomes

These new products are fulfilling the desired outcomes of the original PGP steep land harvesting business plan, to reduce harvesting costs and improve safety. Removing manual tree fallers from hazards has resulted in many contractor operations using mechanical felling now being accident-free.

Remote controlled grapple extraction has clear advantages over manual breaking out with chokers. These advantages include being very productive over short distances, and being safer by eliminating manual breaking out. An FFR study in 2013 showed that in manually felled (unbunched) trees the productivity of the Alpine Grapple at haul distances of up to 250 metres exceeded that of the manual breaking out system by 35 per cent. The cost of extraction was also lower by three dollars (NZ) per cubic metre. The key to improving hauler productivity is bunching trees for extraction. In this study the productivity of grapple yarding doubled compared to extracting unbunched trees with a grapple, due to 50 per cent larger haul size in bunched wood.

The programme has clearly demonstrated the safety, productivity and cost advantages of mechanised felling and grapple extraction. Forest owners are starting to adopt these systems more widely, wherever terrain and safety considerations allow, as they lead to safer operations, improved hauler productivity and reduced costs.

The PGP Steepland Harvesting programme is starting to change the face of forest harvesting in New Zealand. When FFR began in 2007, there was little innovation in harvesting. Since 2010, the programme has become a catalyst to get others to think more innovatively about all aspects of tree felling and extraction. It has catalysed a new wave of innovation in steep terrain operations.

The emergence of other winch-assisted harvesters, new remote-controlled grapples with camera vision systems and GPS-tracking are all examples of industry innovators seeking to modify operating techniques, improve safety and reduce the cost of harvesting, and this is a promising sign for future innovation.

One example is the development of more than 25 other traction-winch assisted machines in New Zealand, with over 20 more in development. These cable-assist machines are remote-controlled and feature camera systems on the winch drums and sensor warning systems. Over the last five years this major investment in feller bunchers and cable-assist machines by contractors has seen the level of mechanised felling, as recorded in the FFR benchmarking database, run as part of the development of operational efficiencies programme, increase from 23 per cent of all operations in 2009 to almost 40 per cent in 2014.

The use of remote-controlled grapples to mechanise cable extraction, and remove manual workers from hazards, has increased, with development of other grapple carriages such as the Falcon Forestry Claw, from DC Repairs Ltd in Nelson, of which 25 units have been sold. A whole new area of commercial opportunity has also opened up using state-of-the-art cameras mounted to grapple carriages, winch drums and other logging equipment.

The extent to which the programme has been a catalyst for changing industry practice is only starting to be realised across the industry. This programme could become a focus for health and safety as well as productivity improvements in the industry for many years to come.

Topic 2

Challenges in forestry

Critical slope in downhill timber skidding

A. Đuka*, T. Poršinsky, T. Pentek, D. Horvat

Abstract
A skidder's ability to extract timber is defined by; 1) basic dimensional features of the vehicle, 2) the ability to overcome obstacles during movement, 3) traction performance and 4) environmental soundness. Traction performance depends on the ground conditions (soil bearing capacity) and the total effect of all forces on the vehicle. In downhill skidding, the skidder is under great influence from a parallel component of forces, adhesion weight and slope, which combined result in negative traction force, torque and thrust force. When the horizontal component of rope force is equal to zero i.e. the moment when the weight of the load and resistance to traction are in equilibrium, the slope angle α, is a function of load mass distribution factor and skidding factor. This is a »turning point« that can be defined as a critical slope because the load starts to push the vehicle downhill which results in negative horizontal component of rope force. Using an Ecotrac 120V skidder, the center of gravity, load mass distribution factor, skidding factor and previous research five different loads (1 to 5 tons) were analysed, in order to define the critical slope angle for each of them. Critical slope for downhill skidding of 1 ton timber is on longitudinal slope of –26%, for 2 ton timber on –30%, 3 ton timber on –34%, 4 ton timber on –38% and for 5 ton timber on –43% of terrain longitudinal slope. Even though skidding is possible on even greater slope angles, the most important factor in downhill skidding, is to avoid blocking of the wheels, which will lead to a complete vehicle slippage and driver must be constantly aware of that fact. When load pushes the vehicle down the slope, due to the constant thrust of the timber at the back end of a skidder, one can conclude that such performance in a due time will result in fatigue of the material and early damage to the vehicle as well as the negative influence on psycho-physical state of the driver.

Keywords
skidder, downhill timber extraction, rope force, critical slope

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1. Introduction

Terrain trafficability is a property of a terrain to allow vehicle mobility by which various terrain factors (slope, ground obstacles, soil bearing capacity) show their influence on vehicle mobility (Eichrodt 2003, Suvinen 2006, Lubello 2008). From the standpoint of timber harvesting and forest opening terrain slope is the most important terrain factor affecting the choice of a harvesting system. Terrain slope affects vehicle stability because all wheels (i.e. tracks) are »in conflict« with the same macro-topographic conditions. During timber extraction forest road network i.e. forest openness (as an economical and not a physical terrain factor) directly shows its influence on terrain trafficability through average skidding distance and through characteristics of transported timber due to loaded vehicle mobility (Poršinsky i dr. 2014A). Vehicle mobility is its ability to move from point A to point B while achieving its primal goal – timber transport. In timber extraction, vehicle mobility can be considered from two different aspects: 1) extraction on soils of limited bearing capacity (for example lowland forests on gley soils) and 2) extraction in hilly and mountainous forests where slope and ground obstacles define conditions for application of specialised forestry vehicles. Many parameters define vehicle mobility during timber extraction (Šušnjar 2005, Šušnjar i dr. 2010, Poršinsky et al. 2012), by which these four are the most important ones: 1) basic dimensional features of the vehicle (dimensions, turning radius, mass, centre of gravity, longitudinal and lateral angle of stability, clearance, joint movement angle and angle of front axle oscillation, unloading of the front axle, payload of rear axle, tyres payload), 2) the ability to overcome obstacles during movement (ground clearance and lateral vehicle stability), 3) traction performance (dependence of slip, traction power and speed to traction force and soil bearing capacity) and 4) environmental soundness (nominal ground pressure and minimal cone index).

Besides dimensional characteristics defined in ISO standard 13861 (2000), Sever and Horvat (1985) give additional skidder characteristics that allow bypassing and overriding of macro (slope) and micro (ground obstacles) terrain properties during timber extraction: 1) approach angle (defined as the maximal blade lift above ground to front axle), 2) departure angle (defined as the lowest position of rear end to rear axle), 3) break-over angle (depends on vehicle clearance and wheelbase), 4) lateral vehicle radius (depends on ground clearance and tread width), 5) centre of gravity position (height from ground, distance from front and rear axles) which is an important constructional parameter that influence axles load distribution regarding terrain slope during timber extraction.

Rowan (1977) states that border terrain slope for timber skidding is 20 (33)% during movement up the slope and 50% for skidding timber down the slope of terrain.

Silversides and Sundberg (1988) for wheeled skidders, state that limited slope ranges from 20 to 35%, depending on the direction of timber extraction wood and other terrain factors.

MacDonald (1999) gives the highest boundary slope of 35 (40)% regardless of the slope and timber extraction direction.

Heinimann (1999) considers that limiting slope for skidding timber is 50%, but vehicle on terrain slope higher than 35% should move only on secondary forest road infrastructure network.

Inoue and Tsuji (2003) stated restrictive slope of 45% in skidding timber down the slope, and 30% for skidding timber up the slope of terrain. Hippoliti and Piegai (2000) as quoted by Lubello (2008) report that unloaded skidder can overcome the maximum gradient of 40%, but loaded only up to 20% regardless of slope direction. The same authors, note the possibility of skidding timber down the slope of 60%, but only in the case of well-designed and built strip roads. Lubello (2008) states the maximum threshold of 18% in skidding timber up the slope and 23% down the slope of terrain. For application of wheeled forestry vehicles, Kühmaier i Stampfer (2010) claim that terrain slope of < 30% (regardless of slope direction in timber extraction) is average slope boundary that depends also on ground obstacles and soil bearing capacity. Sauter et al. (2012) define the border slope of 55% for the skidder with crane equipped with the additional winch for anchoring the vehicle. Loss in skidder stability can have major consequences, one of which is shown in the report by »Workers' Compensation Board of BC – WorkSafeBC« (Anon. 2008) of skidder accident in July 2007. The report states that border longitudinal slope for wheeled skidders should amount to 35% where the skidder must always move perpendicular to the slope, and in the case of a larger terrain slope it is necessary to restrict the movement of skidders only on skid roads. In the mentioned repot accident occurred by rollover of the vehicle on an incline of 40%. The vehicle was set parallel to the direction of terrain slope. Šušnjar (2005) concludes that the value of the slope that skidder can overcome is in wide range (from 16 to 60%) depending on the soil moisture i.e. soil bearing capacity, skidder type, use of chains on wheels, timber extraction up or down terrain slope and load size. Sarles and Luppold (1986) state that when skidding up the slope, for any increase in the slope of terrain for 1% (above the terrain inclination of 10%), a reduction in quantity of loaded timber must be by 2.5%. Eger and Kiencke (2003) reported that the effect of dynamic changes in load should be also considered as key factors that affect machine stability. Visser and Berkett (2015) state that according to Bell (2002), McMahon (2006) and Raymond (2010) extending the operating range of ground-based machinery onto steep slopes has the potential to decrease harvest costs and improve safety. The same authors conclude that in their study of 22 machines and effect of terrain steepness during harvesting, machines exceed slope limits commonly associated with harvesting operations, and exceed them often and for longer periods of time.

2. Materials and methods

During timber extraction by skidder, the force that occurs in the winch is used for carrying part of the timber's weight (part that is above the ground) so called vertical component of winch force (V) and force which overcomes tractive resistance of timber part that is on the ground is called horizontal component of winch force (H). When skidding, the adhesion weight of the skidder is greater than its static weight as the rear axle of the vehicle is under additional influence of load since vertical component of winch force shows its effect.

Skidding timber on flat terrain begins in the moment when thrust force (brought by transmission system to the wheels) begins to overcome resistance forces (Figure 1A): 1) skidder rolling, 2) rolling of hooked timber and 3) friction of timber on ground (Sever 1980).

When skidding up the slope (Figure 1C), load distribution becomes more complex and traction begins when thrust force overcome resistance forces: 1) skidder rolling, 2) terrain slope, 3) rolling of hooked timber, 4) overcoming terrain slope of hooked timber, 5) friction of timber on ground and 6) overcoming terrain slope of timber on the ground. When skidding timber down the slope (Figure 1B), thrust force overcomes the same resistance as for skidding timber up the slope, only resultants of the three forces of resistance (terrain slope, overcoming terrain slope of hooked timber, overcoming terrain slope of timber part on ground) are now in the opposite direction, i. e. direction of the vehicle movement.

The distribution load on skidder axles changes with regard to volume (weight) of extracted timber, timber hooking orientation, direction of vehicle movement and the size of terrain slope (Horvat 1990, Šušnjar and Horvat 2006, Tomašić et al. 2007, Tomašić et al. 2009). The same authors report that changing the distribution of axle load, changes the dynamics of the skidder during skidding, recognized as the relationship between the forces generated on the wheels and forces that oppose their activities. They further indicate that skidding up the slope of terrain, additionally strains rear axle due to the effect of horizontal components of skidder weight ($G \sin \alpha$) and of horizontal components of the rope force (H). When skidding down the slope load is transferred to the front axle of the vehicle.

Load mass distribution factor (k) shows how much load mass is lifted from the ground, or hooked on a winch rope, and how much is pulled on the ground surface (expression 1). If the load mass distribution factor is 0.5 this means that the same part of the timber mass is hooked by rope as it is pulled on the ground.

$$k = \frac{v}{Q \cos \alpha} \tag{1}$$

Skidding resistance occurs due to the affect of load weight pulled on the ground and skidding factor (μ_p). The

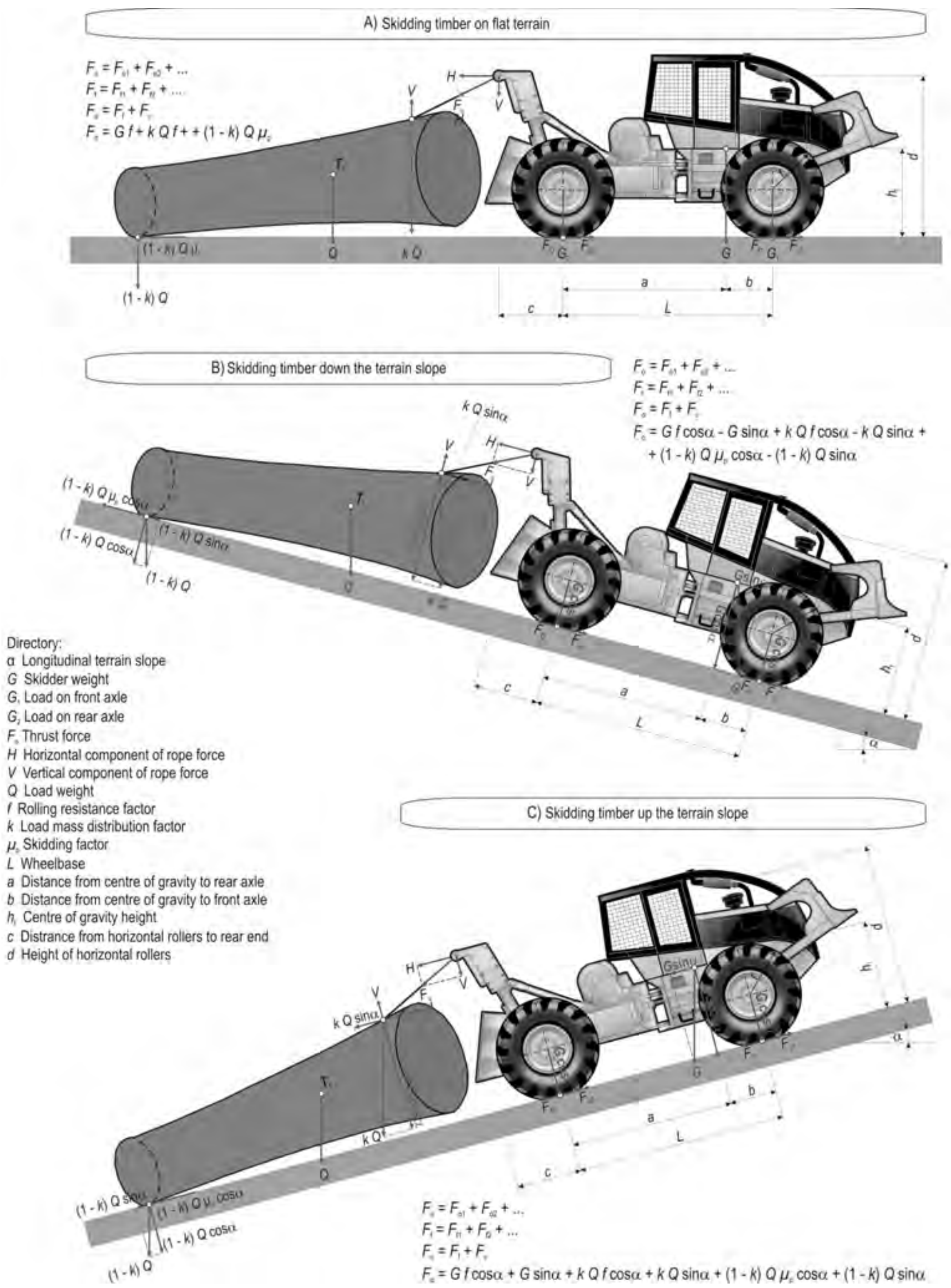

Figure 1. Load distribution during timber skidding.

horizontal component of the rope force overcomes the skidding resistance between load and forest soil and according to known values of the force, weight, load mass distribution factor and terrain slope, skidding factor can be determined (expression 2).

$$\mu_p = \frac{H \pm Q \sin\alpha}{Q(1-k)\cos\alpha} \tag{2}$$

Poršinsky et al. (2012), on the example of skidder Ecotrac 120V (original measurement data by Šušnjar 2005), analyzed the impact of terrain sloping and direction as well as characteristics of the load (mass, weight, volume, cross-sectional area, length, number of pieces) to load mass distribution factor and skidding factor. Correlation coefficients with statistical significance showed: 1) load mass distribution factor is inversely proportional to mass, weight and volume of skidded timber, and 2) skidding factor is negatively correlated only with the terrain slope and direction. Šušnjar et al. (2012) in exploring skidder traction features during skidding down the slope, give some limitations identified through two »turning points« of terrain slope.

The first »turning point« is determined by the angle of inclination of the terrain in which vehicle no longer achieves positive traction thrust force is equal to zero (expression 3).

$$tg\alpha = \frac{G*f + Q*k*f + (1-k)*q*\mu_p}{G+Q} \tag{3}$$

The second »turning point« is determined by the angle of terrain inclination in which hooked timber starts to push the skidder down the slope (expression 4), which occurs at a time when the horizontal component of the rope force in the rope is equal to zero ($H = 0$), or when the weight of the load ($Q\ \sin\alpha$) and traction resistance are in balance $(1-k)\ Q\ \mu_p\ \cos\alpha)$.

$$tg\ \alpha = (1-k)\mu_p \tag{4}$$

Based on skidder Ecotrac 120V dimensions and centre of gravity (Šušnjar 2005), dependence of load mass distribution factor and skidding factor to affecting parameters (Poršinsky et al. 2012) load distribution during timber extraction on different terrain slopes and five different loads (from 1 to 5 tons) was analysed.

Load distribution consisted of calculation and analyses of these parameters: 1) adhesion weight (expression 5), 2) vertical component of rope force (expression 6), 3) horizontal component of rope force (expression 7), 4) load distribution on front axle (expression 8) and 5) load distribution on rear axle (expression 9).

$$G_\alpha = G*\cos\alpha + V \tag{5}$$

$$V = k*Q*\cos\alpha \tag{6}$$

$$H = Q*(1-k)*\cos\alpha*\mu_p - Q*\sin\alpha \tag{7}$$

$$G_1 = \frac{G*\cos\alpha*a + G*\sin\alpha*h_t - H*d - V*c}{L} \tag{8}$$

$$G_2 = \frac{G*\cos\alpha*b - G*\sin\alpha*h_t + H*d + v*(L+c)}{L} \tag{9}$$

3. Result

Skidder's traction performance and force distribution during timber extraction depends of gained forces on wheels and forces resisting them, where adhesion weight is very important parameter. Adhesion weight represents the sum of vertical loads on driving wheels during skidding. Adhesion weight depends on skidder weight (G), longitudinal terrain slope (α) and the size of vertical rope force component (V) which is directly influenced by load weight (Q). Adhesion weight is different than empty skidder weight (G) because the rear axle is additionally loaded with the full amount of vertical rope force component (V) that is dispersed to rear wheels thru horizontal rollers of winch.

Understanding the dynamics of load distribution on skidder's axles regarding weight (mass) of loaded timber, direction of skidding (up/down the terrain slope) and slope inclination (Figures 2B and 2C) is hard to understand without understanding the effect of rope force i.e. its vertical component (V) that carries the hooked load and its horizontal component (H) which overcomes tractive resistance of load part on ground. Analysis of horizontal and vertical components of rope force according to longitudinal terrain slope, skidding direction and load mass is shown on figure 3.

During timber extraction down the slope, horizontal component of rope force increases with increase of terrain slope and load mass, while vertical component of rope force increases only by increase of load mass i.e. slightly decreases with the increase of terrain slope (due to reduction of load part that is hooked by winch rope and increase of load part of timber on ground). During skidding timber down the terrain slope, horizontal component of rope force is greater than vertical component of rope force for load mass of 1 t and terrain slope higher than 45%, for load mass of 2 t and terrain slope higher than 36%, for load mass of 3 t and terrain slope higher than 27%, for load mass of 4 t and terrain slope higher than 19%, for load mass of 5 t and terrain slope higher than 10%.

During timber skidding down the terrain slope, horizontal component of rope force decreases with the increase of terrain slope and with the reduction of load, by which vertical component of rope force is always greater than horizontal component (Fig. 3). Decrease in horizontal component of rope force during skidding down the terrain slope happens because load tends to get closer to rear end of a skidder which makes vertical component of rope force

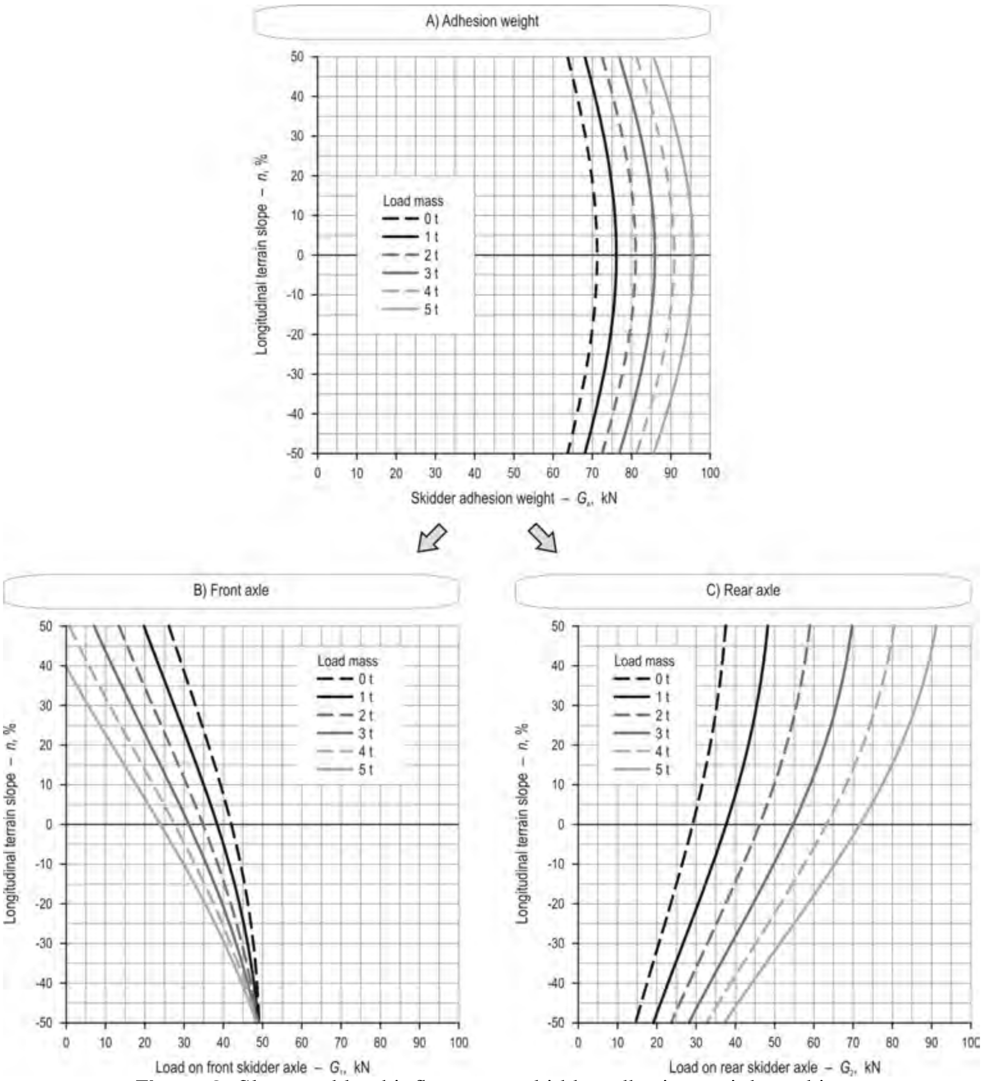

Figure 2. Slope and load influence on skidder adhesion weight and its.

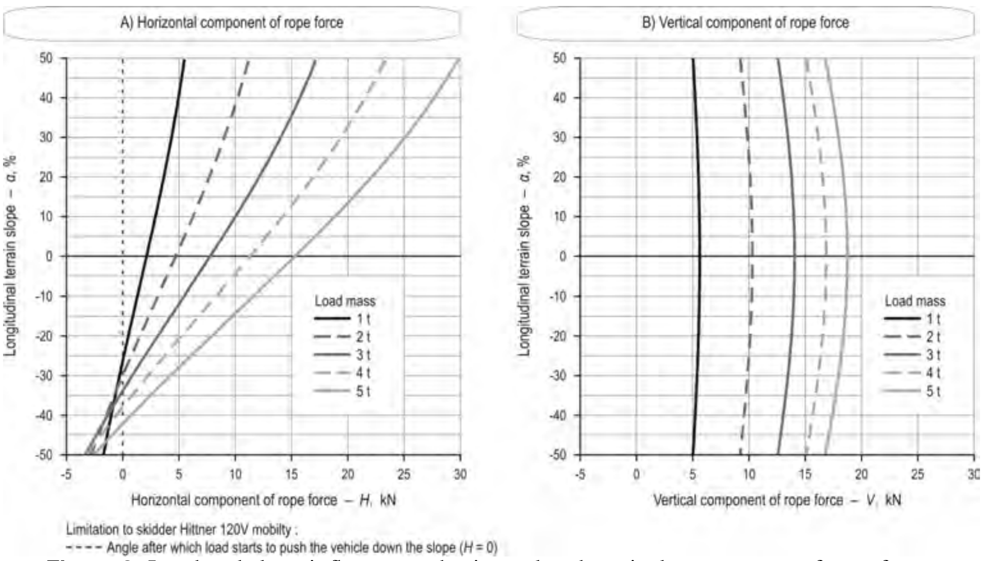

Figure 3. Load and slope influence on horizontal and vertical components of rope force.

more important because it holds the load above the ground. Therefore, horizontal component of rope force is smaller because less load weight is pulled on the ground.

Important parameter in timber skidding down the terrain slope is terrain slope inclination (α) when load starts to push the skidder down i.e. the moment when horizontal component of rope force is zero ($H = 0$). When load pushes the vehicle down the slope, due to the constant thrust of the timber at the back end of a skidder, one can conclude that such performance in a due time will result in fatigue of the material and early damage to the vehicle as well as the negative influence on psycho-physical state of the driver. Turning point when skidding in no longer recommended for skidding loads up to 1 t is on terrain with longitudinal slope –26%, for skidding loads up to 2 t is on terrain with longitudinal slope –30%, for skidding loads up to 3 t is on terrain with longitudinal slope –34%, for skidding loads up to 4 t is on terrain with longitudinal slope –38% and for skidding loads up to 5 t is on terrain with longitudinal slope –43%.

For timber skidding down the slope, traction force needs to overcome the resistance of the load on ground (H), but also resistance of horizontal component of skidder weight ($G\ \sin\alpha$), which pulls the vehicle in the opposite direction. With the growth of the inclination angle, grows traction force with increasing of load weight, due to an increase in the value of the horizontal component of rope force (traction resistance) and the weight of a skidder that traction force needs to overcome (Fig. 4).

In skidding timber down the slope, the horizontal component of the skidder weight ($G\ \sin\alpha$) acts in the direction of the skidder and due to its action skidder overcomes traction resistance of load on ground (H), which causes the appearance of negative traction force (Figure 4) i.e. appearance of braking force.

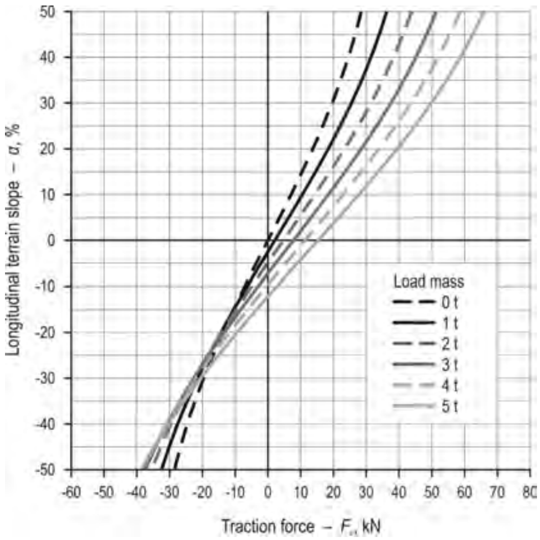

Figure 4. Load and slope influence on traction force.

4. Conclusions

It can be stated that during skidding timber down the terrain slope one cannot talk about achieving real traction force (torques is used for braking) because skidder pulls the load by its own weight, and also the transfer of power from the motor to the wheels is used for braking due to the large impact of parallel component of skidder weight.

Even though skidding is possible on even greater slopes than stated above, the most important in downhill skidding, is to avoid blocking of the wheels, which will lead to a complete vehicle slippage and driver must be constantly aware of that fact. When load pushes the vehicle down the slope, due to the constant thrust of the timber at the back end of a skidder, one can conclude that such performance in a due time will result in fatigue of the material and early damage to the vehicle as well as the negative influence on psycho-physical state of the driver.

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Mechanization of French logging operations: challenges and prospects in 2020

E. Cacot*, S. Grulois, A. Thivolle-Cazat, P. Magaud

Abstract
From a population of about 11,000 professional loggers registered in 2004 in France, a few more than 7,000 remained in 2013. This decrease of 400 chain saw operators per year is a dramatic figure which is already mitigated by the use of foreign manual workforce. As a result, all industrial stakeholders (sawmills, pulp mills, energy…) do face important difficulties to supply wood. The lack of logging capacities is also amplified by the increasing demand from wood-based energy producers. To face these challenges, the mechanization of felling and processing needs to keep on developing. Back in 2004, the mechanization rate of the harvest was 24%; it is currently up to 44%; 80% in softwood against 10% in hardwood. FCBA's industrial board in the field of logging operations requested to carry out a prospective study for 2020. The main objective was to identify potential levels of mechanization, related barriers to be overcome and actions to reach 2020 targets. The chosen methodology of work followed five steps:

- Inventory of the machines with the estimation of the national fleet and annual production (in 2013 and foreseen in 2020);
- Definition of criteria for mechanization and semi-mechanization (when only a part of felling and processing is carried out with a forest machine) of forest stands;
- Calculation of the forest resource available in 2020 and the (semi-)mechanized volumes;
- Definition scenarios for 2020 based on various levels of development for mechanization;
- Definition of the needed workforce in 2020 in the most likely scenario.

Thus in 2020, the marketed harvest in France could be about 46.5 million m^3 among which 34.5 million m^3 (semi-)mechanized. This would represent over 1.000 additional harvesters in comparison with the current fleet. Meanwhile, R&D efforts to improve mechanization now focus currently under-mobilized wood resources: broadleaved stands and slope areas. The presentation will describe the different hypothesis and present the proposed strategies to act upon as soon as 2015.

Keywords
forest machineries, mechanization, scenarios for 2020

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1. Introduction

Twice before, in 1992 and 2004 (Laurier, 2005), the FCBA carried out prospective studies on progressive mechanization of logging operations in France. Indeed mechanization is identified as the main factor to increase productivity in the field of activities and to reach the objectives of development of wood mobilization.

In 2004, the mechanization rate (share of the volume of wood harvested and processed thanks to forest machines) was 24% for all species and 44% for softwood only. Several prospective scenarios foresaw for 2010 an increase in the fleet of forest machines and their productivity. This increase would mainly counteract the drop in lumberjack workforce. Several issues related to the development of mechanization were identified: technical innovations in hardwood mechanization and on slopes, significant training needs.

Recently, tensions emerged in the supply chain through competition for raw material between sawmills, pulpmills and boilers. One of the reasons behind this bottleneck is the continuous decline in the number of lumberjacks, estimated to 400 in less per year during the last decade despite the use of foreign labor (Cacot et al., 2015). Such critical situation gave ground to the repetition of this prospective analysis, this time for horizon 2020. This work, which was realized with the financial support of COPACEL (French association of pulp and paper industry), includes several parts:

- inventory of the forest machines under scrutiny with the estimation of the national fleet and annual production (in 2013 and foreseen in 2020);
- calculation of the forest resource available in 2020

Figure 1. Forwarder equipped with a grapple-saw for the processing of big broadleaved crowns.

Figure 2. Stumps extractor.

and the share of the volume which can be considered (semi-)mechanized, based on criteria for (semi-)mechanization of forest stands;

- definition of mechanization scenarios for 2020, based on various levels of development, and the needed workforce.

As for the two previous prospective studies, the present one focuses only on harvesting machines:

- harvesters used in cut-to-length system, for both soft and hard woods,
- felling heads, with shear or saw disc cutting system, mounted on excavator for whole-tree system and the harvest of wood energy. Such machines are mainly used for broadleaves in France,
- processing heads, mounted on excavators to process trees on the landing site of cable-yarding operations, in steep terrain areas,
- forwarders or small excavators equipped with grapple-saw to mechanize the processing of big broadleaved crowns; it is what we call semi-mechanized system as felling and a part of processing is made by lumberjacks (Figure 1).
- extractors of stumps used for energy (Figure 2).

This study was realized in collaboration with professionals practitioners (wood supplier, entrepreneurs, owners of forest machines) in order to validate the methodology and the assumptions for the calculations. The same analysis could be done for skidding and forwarding operators (carriers, skidders ...), with great similarities in the approach.

2. Inventory of the machineries with the estimation of the national fleet and annual production

2.1 Forest machinery fleet

The national fleet of forest machines, including forwarders and skidders, is currently evaluated in France at 3,100 machines, including 750 harvesters (Bonnemazou and Ruch, 2014), as described in Figure 3. The 2004-2013 comparison of the total fleet of forest machines shows an overall stability but hides a decline in recent years. Indeed, the fleet reached 3.400 machines in 2009, in relation with higher level of harvest and a better economic situation. Compared to 2004, the number of harvesters increased by 40%. In 2013, the fleet includes 670 specific forest machines and 80 harvesting heads mounted on excavators. The number of excavators equipped with harvesting heads has been falling by 30% since 2002 when the number peaked at 150 machines used in windblown stands after the 2 big storms in 1999.

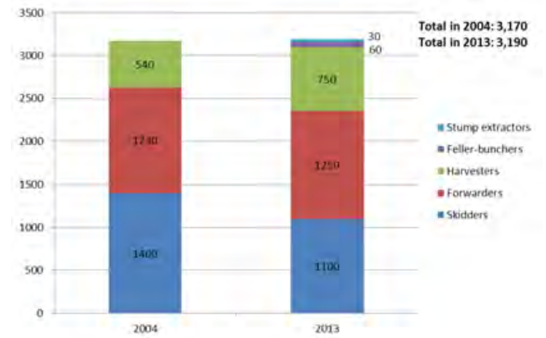

Figure 3. Evolution of forest machinery fleet from 2004 to 2013.

Over the last 3-4 years, the number of feller-bunchers has risen greatly and continues to do from less than 10 machines to 60 at the end of 2013. 45 heads are fitted with shears and 15 with saw discs. These machines are mainly used in broadleaved stands for the production of wood energy.

2.2 Past evolution of annual productivities

For harvesters in softwoods, the range of the annual productivities is very large: from 18,500 m^3/year in Massif Central (Douglas fir, mountainous area) to 56,000 m^3/year in Aquitaine (sandy flat soil, maritime pine, very regular stands) for 1,700 machine hours in average (Peuch and al., 2013; Ruch and al., 2015). Taking into account the harvester fleet in these different regions and the national fleet (Bonnemazou and Ruch, 2014), the average productivity was determined at 23,500 m^3/year. In 2004, the average

Table 1. Evolution of mechanization in France.

	1990	1995	2002	2004	2013
Number of harvesters in softwoods	60	185	500	540	700
Average annual productivity for harvester in softwoods (m^3/year)	8,300	11,000	17,000	17,000	23,500
Annual mechanized harvest in softwoods (Mm^3/year)	0.5	2	8.5	9.2	16.5
Rate of softwood mechanization (%)	3	9	40	44	80
Rate of global mechanization (softwood + hardwood) (%)	**1**	**4**	**22**	**24**	**48**

production was approximately 17,000 m³/ year (Laurier, 2005). Annual production has progressed in 10 years with a strong impact of the machines in Aquitaine with particularly favorable cuts. For harvesters in hardwoods, the number of concerned machines is lower. About 50 harvesters work regularly in broadleaves stands and the average productivity is estimated to reach 14,000 m^3/year (FCBA's data based on national survey and time studies).

Figure 4. Example of feller-buncher equipped with a saw disc for wood energy harvest.

Figure 5. Machines equipped with synchrowinch, with a capability to work on a slope up to 65-70%, are being progressively adopted in France.

For feller-bunchers, a survey, carried out for this study by FCBA, revealed an annual production of 8,500 m³/ year for shears head and 20,000 m³/ year for the disc heads that are more powerful equipment. The productivity of stump extractors is 12,000 m^3/ year in Aquitaine (Villette, SKCDP, personal communication). This technique is hardly used in other forests area firstly because it requires sandy soils to easily extract the stump and secondly because specific equipment is needed for logistics and within the biomass boilers.

2.3 Rate of mechanization in 2013

Based on the previous data and the annual harvest (Memento FCBA, 2014), the mechanization rate was calculated: about 80% for softwood and just below 10% for hardwood (see Table 1.). Therefore, about 48% of the global marketed French harvest is mechanized in 2013. For softwoods, the current mechanization rate corresponds to the "intense" scenario defined in 2004. But this trend should not obviate the fall of marketed harvest and total capacity of mechanization due to the reduction in the number of harvesters in recent years. For hardwoods, developments were disappointing despite the recent emergence of energy wood harvest: in 2004, scenarios foresaw that 5.0 million cubic meters (Mm^3) would be mechanized whereas currently only 1.5 Mm^3 are.

2.4 Evolution perspectives for productivities by 2020

In recent years, technological advances provide improvements with more indirect effects on the actual productivity: embedded computers and management of their data, better accuracy for the processing of assortments, better ergonomic and safety for the operators... Furthermore to massify small logging sites into large units remains a challenge because of the structure of forest ownership in France (Memento FCBA, 2014). This has consequences on the utilization rate of machines that often have to commute between two sites. Although work is underway to propose gathering methods, there is little chance this has a significant impact in the medium term.

Moreover, mechanization has progressed so far in the most favorable areas in terms of stands, topography and accessibility. Harvesting additional resources in areas identified as under-mobilized (slopes, hardwoods) is more difficult technically and with lower productivity for the machines where it is mechanizable (see figure 5). At last, environmental concerns, particularly dealing with soil, will contribute either to have smaller machines (the development of these machines should remain limited because their productivity and cost per m^3 are disincentives [Ulrich and al., 2014]) or adapted machinery (extra wide tires, synthetic tracks, number of axles...) but with constant productivity

(Ruch, 2015). Finally, all these elements lead to estimate that the productivity of softwood logging machines should evolve further, but to a lesser extent than in the last 20 years. Progression approaches an asymptote, as has been observed in some regions (Ruch and al, 2015).

For hardwoods, productivity gains are potentially more important whatever the considered machines (harvesters or feller-bunchers). There are indeed still substantial margins of technical progress (Chakroun and Cacot, 2014): more efficient delimbing systems for harvesting heads, hydraulic accumulator in order to gain power and speed for shear heads, development of small saw-disc heads... The organizations of logging sites are also perfectible, for example by integrating the coproduction of wood industry and wood energy with feller-bunchers. For the "semi-mechanized" systems, prospects remain uncertain given the current level extremely low: mechanized logging of big crowns is still the subject of R&D projects to determine the good systems.

Concerning cable-yarding in France, delimbing on forest roads with processor heads mounted on excavators, this system is very few represented, with only 20-25 teams (FCBA's data based on regional surveys) as the cable culture has virtually disappeared. It is unlikely the number of machines would increase suddenly and their productivity should remain the same as their limiting factor is not their capability but the production of cable-cranes.

Taking into account all these elements, we forecasted the annual productivity of the various machines in softwoods and hardwoods (see table below), in accordance with the professionals involved in the study.

Table 2. Past and estimated future evolution for annual productivities (m^3/year).

Machines	2004	2013	2020
Harvester (softwood, flat terrain)	17,000	23,500	25,000
Harvester (softwood, synchrowinch option, 35 to 65% of slope)	-	15,000	17,000
Harvester (hardwood, flat terrain)	12,000	14,000	16,000
Processor after cable-crane	8,000	8,000	8,000
Feller-buncher (shear head)	-	8,500	10,000
Feller-buncher (saw-disc head)	-	20,000	25,000
Grapple-saw (big broadleaved crowns, flat terrain)	-	8,000	10,000

3. Calculation of forest resource available in 2020

3.1 Definition of criteria for mechanization and semi-mechanization of forest stands

Based on various expertise (Laurier, 2010; Binder and Maier, 2014), 3 criteria were used in order to define the sites where mechanized harvesting is possible:

- Soil bearing capacity: soil practicable all the year or a part of the year / soil never practicable;
- Slope: <35% / 35 to 65% / 65 to 100% / > 100%;
- Average tree volume:
  - For hardwoods: < 0.5 m^3/ 0.5 to 2 m^3/ >2 m^3;
  - For softwoods: <2 m^3/ >2m^3.

The combination of these different criteria helped determine 13 classes of forest stands according to their degree of mechanization and materials used (see Table 3).

3.2 Resource available in 2020

From the definition of these classes, the mechanized volume was calculated by applying the criteria of mechanization to the technical and economic availability calculated for France (Thivolle-Cazat, 2011).

In total, a little more than 42 million cubic meters (Mm^3) could be potentially available annually through mechanized technics in French forests, in addition to 11.7 Mm^3 through semi-mechanized itineraries (see Table 4). However, these figures do not take into account the structure of the forest ownership and wood suppliers:

- 6% of the overall availability stands in small private forests smaller than 1 ha. They are considered non-mechanizable and therefore to be deducted from above volumes (6% volumes less for all categories).
- Moreover, the harvest of firewood (estimated at 21 Mm^3/year of fire log) (Memento FCBA, 2014) is mainly done by non-professionals, farmers or unipersonal enterprises, ie structures that can not or hardly use the mechanization. These 21 Mm^3 are to be deducted from lowland hardwood stands (classes 1, 2 and 3 in table 3) in which most of the woodfuel is harvested by these non-professionals.

As a result, 39.4 Mm^3 could be mechanized or semi-mechanized, after deduction of small properties below 1 ha and non-marketed fire-wood.

4. Definition of mechanization scenarios for 2020

It has been established that between 45 to 100 additional machines are needed per year (depending on the machine, the stands and the silviculture) just in order to compensate for the 400 chain-saw operators in less every year. To go further, two scenarios were developed based on the state of mechanization in 2013, past productivity and expected changes in the machines (cf. paragraph 2), the recorded loss of manual workforce and the increase of the harvest objectives:

- A maximum mechanization scenario. This scenario is quite simplistic, considering that everything that can be mechanized or semi-mechanized will be so in 2020; this establishes an order of maximal machinery fleet in the state of harvesting techniques;

Table 3. Typology of forest stands according to their degree of mechanization and materials used.

Classes	Kind of stand	Level of mechanization	(Semi-)mechanized logging systems
1	Practicable / Slope < 35% Small hardwoods < 0,5 m^3	Mechanizable	Feller-buncher or harvester
2	Practicable / Slope < 35% Hardwoods 0,5 à 2 m^3	No mechanizable	-
3	Practicable / Slope < 35% Hardwoods > 2 m^3	Semi-mechanizable	Grapple-saw for the crowns
4	Practicable / Slope < 35% Softwoods < 2m^3	Mechanizable	Harvester
5	Practicable / Slope < 35% Softwoods > 2m^3	No mechanizable	Chain-saw operator + Skidder
6	Practicable / Slope 35 to 65% Softwoods < 2m^3	Mechanizable	Synchrowinch harvester (or equivalent)
7	Practicable / Slope 35 to 65% All hardwoods et softwoods > 2m^3	No mechanizable	-
8	Practicable / Slope 65 to 100% Softwoods < 2m^3	Semi-mechanizable	Chain-saw operator + cable crane or skidder + processor
9	Practicable / Slope 65 to 100% All hardwoods et softwoods > 2m^3	No mechanizable	-
10	No Practicable / Slope < 100% Softwoods < 2m^3	Semi-mechanizable	Chain-saw operator + cable crane or skidder + processor
11	No Practicable / Slope < 100% Other trees	No mechanizable	-
12	All slopes / poplar plantations	Mechanizable	Harvester
13	Slope > 100% / all trees	Impossible harvesting	-

Table 4. General distribution of mechanizable / semi-mechanizable / no mechanizable volumes (thousand of m^3 over bark).

	Saw wood	Pulp and energy wood	Total
Mechanizable	15,755	26,287	**42,042**
Semi mechanizable	4,638	7,078	**11,716**
No mechanizable	10,627	15,384	**26,011**
Impossible harvesting	8	6	**14**
Total	**31,028**	**48,754**	**79,782**

- A "reasonable" mechanization scenario based on the demands of wood industry in 2020, taking into account the projects of development (new boilers, increasing capacity for sawmills. . .).

In the following scenarios, the estimated amounts of investment necessary to reach the indicated number of machines take only into account the additional materials and do not include the renewal of machines. These estimates are based on the assumptions of machinery cost, defined with the professionals involved in this study:

- Feller-buncher : 220 k€, with 2 thirds of tracked excavators equipped with shear heads (170 k€) et one third of more powerful machines with saw disc (340 k€);
- Harvester : 400 k€ + 70 k€ for synchrowinch option;
- Processor combined with cable-crane: 200 k€(mainly processor head mounted on excavator);
- Grapple-saw: half part mounted on forwarder (330 k€) and half part mounted on small tracked excavator (130 k€), so 230 k€ in average per machine.

Stump extractors are not integrated in these scenarios which concern only aboveground biomass harvest. The potential crop should remain approximately the same, about 400,000 tons/year by 2020, so with a similar fleet as currently (about 30 extractors).

4.1 Maximum mechanization scenario

With the current fleet of harvesting machines in softwoods and the fast progression of feller-bunchers, the maximum fleet for these two types of machines does seem reachable (see Table 5.). On the other hand, given the current fleet of harvesters with synchronized winch and machines equipped with grapple-saw for semi-mechanization (less than ten for both machine types), achieving such levels in 5 years for these machines appears much less credible and even unrealistic for cable-crane. The harvesters in hardwoods present an intermediate situation, given some of the technical obstacles may be overcome through the ongoing research projects (Chakroun and Cacot, 2014). Finally, the mechanization challenges are now focusing on slopes and in broadleaved stands, with various ways of mechanization for hardwoods.

Table 5. Forest machines fleet and investments necessary to reach the objectives of maximum mechanization scenario.

Machines	Hardwoods	Softwoods	Total	Additional machines in comparison with 2013	Investment cost (M€)
Feller-bunchers (shear, saw disc)	320	-	320	260	57.2
Harvesters	210	810	1,020	270	108
Harvesters with synchrowinch option	-	180	180	170	79.9
Processor after cable-crane	240		240	220	44
Grapple-saw	550	-	550	540	124.2
TOTAL			**2,310**	**1,460**	**413.3**

Table 6. Forest machines fleet and investments to do in order to reach the objectives of mechanization scenario based on the demands of wood industry in 2020.

Machines	Hardwoods	Softwoods	Total	Additional machines in comparison with 2013	Investment cost (M€)
Feller-bunchers (shear, saw disc)	290	-	290	230	50.6
Harvesters	170	770	940	190	76
Harvesters with synchrowinch option	-	110	110	100	47
Processor after cable-crane	40		40	20	4,0
Grapple-saw	450	-	450	440	101.2
TOTAL			**1,830**	**980**	**278.8**

4.2 "Reasonable" mechanization scenario based on the demands of wood industry in 2020

This scenario is based on the expected harvest for wood energy by 2020, on harvest increases announced by the professionals in a national working group (CSF-CNI: Wood industry Strategic Committee - National Council of Industry, group 6 "Wood supply") and the current harvest (Memento FCBA, 2014). For this scenario, the volumes harvested in 2020 would be 46.5 Mm^3:

- Sawlogs: 23.5 Mm^3 of which 7.5 of hardwoods. NB: 7.5Mm^3 is a very optimistic assumption for hardwoods considering the current situation but the logs could be used as energy or pulp;
- Pulp wood: 12 Mm^3, 50/50 hardwoods/softwoods;
- Energy wood: 11 Mm^3 marketed (without taking into account 21 Mm^3 of self-consumption for fire wood) of which 80% of hardwoods.

The manual capacity, by chain-saw operators, will be a little over 12 Mm^3 in 2020, taking into account that 400 lumberjacks stop their activity every year (Cacot and al., 2015). This leaves nearly 34.5 Mm^3 to be handled with forest machines, which is not so far from the maximum mechanization scenario. By distributing these 34.5 Mm^3 between the different classes of forest stands, according to their logging difficulties and taking into account the needs for hardwood/softwood and the distribution among saw / pulp / energy wood, the numbers of machines are determined in each category (Table 6).

For many machines, this scenario is close to the maximum mechanization scenario. The exception concerns the processors after cable-crane because current development remains very low for this type of machine. The forecasts for grapple-saw are probably extremely positive. Matters of safety and public health issues for loggers (oak processionary caterpillars making it very difficult processing of crowns) will support these developments. However, it is likely that this level will be difficult to achieve and, if the timber needs are confirmed, that mechanization will progress more in broadleaved stands with 0,5 to 2 m^3 trees than strands with over 2 m^3 trees (where grapple-saw are entitled to process large crowns). Harvesting in hardwood stands of this class 2 (table 3) could be (semi-)mechanized with current harvesting machines even if they are close to their capability limit (Cacot, 2009).

4.3 Needed workforce in 2020

Retaining only the "reasonable" scenario of mechanization based on the demands of wood industry in 2020, 980 additional machines would be necessary in 2020. This generates additional needs of about 1,040 drivers. Indeed, there are 1.2 drivers per harvester and 1 for other machines, based on the recently recorded ratio (Peuch and al., 2013; Ruch and al., 2015). Assuming a linear increase in staff over the period 2014 to 2020, about 170 additional drivers should be recruit each year.

Meanwhile, there is a turnover in drivers that has to be taken into account. In the absence of statistics, it was taken as hypothesis that these logging machine operators remained from 10 to 15 years as drivers (Laurier, 2005). For a current staff of 950 people, this leads to a turnover of 65-95 people a year. So it takes about 70 people a year for driver renewal.

By combining the two, around 240 new operators have to be found and trained each year. This number is to be compared to the 70 annual graduated new drivers coming out of training centers, of which only 30-40 for harvesters. The needs far exceed the supply of the training system.

But this reasoning is to modulate because only 30% of current drivers position received training in a specialized center (Peuch and al., 2013; Ruch and al., 2015). There is no reason to believe that managers would suddenly start recruiting 100% of trained drivers. Many of the new positions will be occupied by staff from skidding, manual logging, agriculture and various other sectors, as at present. Still, the situation should evolve gradually towards a professionalization of the drivers with training centers able to supply 150-200 logging machine operators annually, properly trained.

5. Conclusion and discussion

The development of mechanization remains a major challenge in order to counteract the loss of manual workforce and develop, at least maintain, forest harvesting in France. This mechanization must adapt to social and economic changes: with a "human dimension", in respect of soils and forest ecosystems, in connection with silviculture practices. In parallel, there is still a major issue around the recruitment and training of the drivers.

Two mechanized routes seem to appear to meet the various needs of professionals:

- A "low cost" mechanization with simple and rustic machines for cost reduction and mass production (mono-product);
- A more "high tech" mechanization based on extensive use of embedded computers and ICT to increase the added value of logging operations and wood supply chains.

Whatever the mechanization for the next years, several recommendations should be applied if the French wood industry and the State want to reach the objective of increased harvest. These recommendations concern various aspects:

- Training:
  - Create a specific diploma for harvester drivers;
  - Consolidate the capacities of training centers by concentrating all the means (educational resources, trainers, machines and simulators, financial means...) on 1 to 3 sites and not 10 as nowadays, to provide quality training and sufficient trainees (150-200 machine drivers/year);
  - Develop other training ways: apprenticeship, international Erasmus exchanges...
- R&D:
  - Continue R&D efforts to mechanize hardwood harvesting and logging operations on steep terrain where under-exploited resources are currently located;
  - Change together silviculture schemes and mechanization for mutual adaptation by developing methods for mechanized logging in the main cases (hardwood thinnings and clear-cuts, thinnings in slope area);
  - Carry out a survey (monitoring) of new harvesting practices, test methods and techniques in order to reduce the potential impacts of logging operations on forest ecosystems (particularly dealing with soil issues).
- Organization of logging operations:
  - Promote the development of the double shift system, as in other European countries, for drivers of harvesters which become more and more expensive;
  - Promote everything that will help increase the utilization rate of machinery: increasing the size of logging sites, fewer assortments, better coordination across the supply chain;
  - Develop attractiveness of the jobs by increasing attention to ergonomics, improving logging site organization ... It is important also to keep the chain-saw operators, in addition to machines, and thus alleviate their work harddness.
- State and Regions:
  - Continue financial support for investment in forestry machines, in particular materials to harvest additional resources;
  - Encourage structuring companies to face increasingly consistent investments and meet higher social and environmental requirements.

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The economic situation of forest contractors in Bavaria

H. Borchert*, K. Benker

Abstract
More and more forest operations are carried out by forest contractors in Germany. Thus the importance of forest contractors rises. The quality of their work affects the condition of the forest stands after harvesting. High work quality is important for future stand development and public perception of highly mechanized forest works.
There is only little information about the economic branch of forest contractors in Bavaria. Thus we investigated the economic situation of this branch. Data about the basic population was obtained from the compulsory accident insurance for forest contractors. We developed a standardized questionnaire and interviewed more than 200 entrepreneurs.
In total there are nearly 2,800 forest contractors in Bavaria. Most of them are very small-scale enterprises. Often, only the entrepreneur and/or some family members are involved. Less than 20% of the enterprises have employees. Most forest contractors assess the profitability as poor. They feel a strong competitive pressure. If they participate in tenders, they need at least three bids for receiving one contract. The machinery is mostly old. Harvesters are on average nearly 9 years old and forwarders 9.5 years. However, only few forest contractors plan to invest in new machinery within the next three years. There is a risk that more and more outdated machinery will be operating in the forests. The progress in engineering is not incorporated into everyday practice. Opportunities to raise quality and productivity of forest works might be missed.

Keywords
forest contractors, enterprises, machinery, overcapacity, return on investment

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1. Introduction

So far we have only little information about forest contractors and their economic situation. Some information gives the turnover tax statistic of the Bavarian Statistical Office. Unfortunately this statistic does not distinguish between enterprises offering technical services and those offering consulting, evaluation and inventories. We consider only those enterprises as forest contractors, which offer technical services. Furthermore the turnover tax statistic assigns an enterprise to that branch where it makes the main turnover. But frequently forest services are only a sideline of the entrepreneurs. In addition the statistic only includes enterprises making a turnover of more than 17,500 Euro per year. Thus the statistic doesn't record all forest contractors. Also the statistic includes those forest owners who pay a turnover tax. In fact only few forest owners in Germany pay a turnover tax, but the revenues from selling timber are much greater than the earnings from services. So these few forest owners may affect the statistic significantly. According to this statistic the number of forest enterprises has more than doubled between 2005 and 2013. This increase goes hand in hand with a boom of firewood delivery from forestry (Gaggermeier et al., 2014). There seems to be a great dynamic within the market of forest service's whereof we hardly know anything. The associations of forest enterprises also have only little information because they have few members. Only about 180 forest enterprises are organized in associations. So we decided to survey the market of forest services.

2. Material and Methods

The study is based on data of the compulsory accident insurance for forest contractors (SVLFG) and on the results of a telephone survey. The results refer to 2013. Forest contractors are compulsorily insured at the SVLFG. Thus this insurance knows the total number of forest contractors, has information about the regional distribution, the number of workdays and the wages. We obtained the address information of forest contractors from our Internet database (http://udb.bayern.de/). The regional forest offices of the Bavarian State Forest administration added this list so that we finally had the contact details of 1,310 contractors. We selected the fifty largest forest enterprises systematically and the rest at random. The larger enterprises were identified by the machine stock. We interviewed a sample of 212 forest contractors whereof 188 interviews were usable. The SVLFG gave us the number of forest enterprises with employees grouped by classes of gross salaries (Tab. 1). We used this information of a part of the basic population for extrapolating our sample. From data of the SVLFG we calculated which mean portion of a full-time job the employees have. 1,753 employees worked 143,308 working days. Assuming 220 days per year in a full-time job the quota of the employees is 37.2%. We multiplied this quota with the number of employees we find out by the interview and with the mean annual salary of farm workers in the former West Germany (Federal Statistical Office, 2011). Thus we estimated the paid salaries of each forest enterprise that had employees. As the data from the Statistical Office for the annual salary refers to 2010 we adjusted it according to the wage increase (6.7%). We assigned the forest enterprises to classes of gross salary in Table 1. For extrapolating attributes we multiplied the mean value of an attribute within a salary class with the number of enterprises registered by the SVLFG. In case of the enterprises that didn't pay salaries we multiplied the mean values with the number of those enterprises given by the SVLFG. Within this group there are also some enterprises with unpaid family workers beside the owner.

Table 1. Number of forest enterprises with employees registered by the SVLFG by classes of gross salary paid in 2013 in comparison to the enterprises that had been interviewed.

Gross salary Euro	SVLFG n	Survey n
Up to 10,000	204	22
10,001 to 50,000	177	59
50,001 to 100,000	54	14
100,001 to 200,000	36	9
More than 200,000	15	3
Total	486	107

As we have interviewed only a small portion of enterprises without employees (4%) the results regarding this group are uncertain. This might be the reason why the extrapolation gave implausible results in case of some attributes. This concerns in particular the output of different services and the number of different kinds of machines. Because the results regarding enterprises without employees are uncertain, most results will be presented separately for both groups.

3. Results

There existed 2,779 forest enterprises in Bavaria in 2013 according to the data of the SVLFG. This is by far more than the 1,096 enterprises according to the turnover tax statistic. Arithmetically there are almost 1,000 hectares forests for one forest enterprise. Nearly 5,000 persons including the owners worked in these enterprises. If we account 220 working days for a full time job, there were 1,575 full-time jobs. On average one person worked one-third of a full-time job. This seems to be very little seeing that 84% of the forest contractors with employees said that it is their main occupation and even half of the rest said this too. Those entrepreneurs who offer forest service's only part-time mostly have the main occupation of a farmer. According to the definition of the European commission nearly all forest enterprises are micro enterprises (European Union 2003). Even the largest companies rank among small-scale enterprises. In total 486 forest contractors paid wages. Among the paid workers there are often family members. The sum of salaries was about 21 million euros.

Nearly all persons working in the forest enterprises had a vocational training. About one quarter had training in forestry. More owners than employees had an education in forestry.

According to the last national forest inventory 56% of the forests in Bavaria are privately owned. Corresponding to this, private owners are the main principals of forest services. But the orders of forest services are distributed between the different kinds of forest owners rather proportionately to the volume of growing stock than according to the area of forest property. Private and communal forest owners often are organized in forest associations. The forest associations procure 40% of all orders for forest contractors who have employees and one third of all orders for the other contractors. The state forest draws up contracts mainly by competitive tendering. Two third of forest enterprises with employees offering felling and logging participate in a tender. Enterprises without employees only participate to a little more than a third. Both groups have to submit three bids on average to be successful once.

About one half of the forest contractors carry out the work solely with their own staff and own machines. Thus they are doing services only on their own account. A portion of 15% of the forest contractors also work as subcontractors, 13% engage subcontractors and work themselves as subcontractors and 23% offer service on own account and only engage subcontractors. The last once mentioned are mainly the largest forest enterprises. Most of the forest contractors offer felling and logging of timber as Fig. 1 shows.

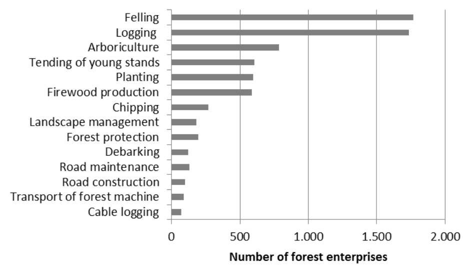

Figure 1. The number of forest enterprises offering different services.

On average they offer 2.8 different kinds of services, whereas 15% of the enterprises are working in five and more different activities. A quarter of all enterprises only offers one service and is thus very specialized. Enterprises that are planting, tending young stands and practice arboriculture often are offering a broad range of different services. Road construction, road maintenance, cable logging, wood chipping and transport of forest machines are services offered by rather specialized enterprises. Those enterprises who are felling and logging and who have employees, mainly have orders between 100 and 500 m³ of timber. The smaller enterprises mainly have orders up to 100 m³. These enterprises mainly work within a radius of 20 km whereas the larger enterprises mainly work within a radius of 50 to 100 km.

45% of forest enterprises with employees also trade with timber as they buy timber on the stump, thus they have a relevant bundling function within the value-added chain. From the rest of forest enterprises only 18% buy timber on the stump.

According to the results of the enquiry the forest enterprises had a turnover of about 580 million euro in 2013 two thirds of which concern enterprises with employees.

We asked some questions about the mood among the forest contractors as for instance: “There are so many legal provisions we have to follow (labour legislation, tax law, dangerous goods, water protection, and nature protection) that we lose the overview and worry about it.” The interviewed person could state “true”, predominantly true”, “predominantly not true”, “not true” or “doesn’t concern me”. More than two thirds of the enterprises stated “true” or “predominantly true” (Fig. 2). Forest contractors with forwarders agreed higher than average (84%) with this statement. This might reflect the conflicts regarding soil protection. Another statement was: “The pressure of competition in the area of my activities is currently very high.” Again more than two thirds of the contractors agreed with this statement. Particularly contractors with employees and those having harvesters or forwarders agreed with this statement.

Figure 2. The mood among forest contractors.

“Forest enterprises can currently make reasonable profit” was another statement. Two thirds of the forest contractors refused this statement. Again particularly contractors with employees and those having harvesters or forwarders refused this statement. Another statement was: “For the next twelve month we have enough orders”. 58% of all forest contractors agreed with this statement. “Our forest enterprise shall grow within the next five years” was also a declaration. Only 21% intends further growth. Those with employees intend a growth more often. Forest enterprises having harvesters or forwarders very seldom intend further growth whereas enterprises with chippers more often see a growth potential. We also asked the forest contractors whether they intend to purchase machines within the next three years. Only 20% of forest contractors without employees and 47% with employees are willing to invest in the near future. This modest willingness must be seen against the background that most of the machinery is old. The mean age of harvesters of Bavarian forest enterprises was 8.9 years in 2014 (Stölzner and Borchert, 2014 and Fig. 3). The mean age of forwarders was even 9.5 years.

The forest contractors rate very differently, if the financing of machines (purchase or leasing) is difficult. Slightly

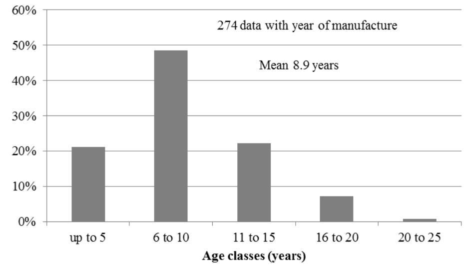

Figure 3. The age structure of harvesters owned by forest enterprises in Bavaria in 2014.

more than half (rather) doesn’t see difficulties, if we are disregarding those contractors who don’t feel concerned. The rating differs in terms of enterprise size and machinery. Forest enterprises with employees complain considerably to a lesser extent difficulties in financing. Also contractors possessing harvesters, forwarders or chippers (large machines) complain only little about such problems. The pre-financing of contracts might have been another difficulty. The contractors should rate the statement: “We have problems with the pre-financing of contracts”. 30% of the respondents didn’t feel concerned in this case. Particularly forest contractors without employees and those who aren’t possessing large machines didn’t feel concerned. The vast majority of the other contractors don’t claim difficulties in pre-financing.

A quarter of the forest enterprise owners were already 55 years old or even older. The majority of these persons had already made arrangements regarding business succession. In case of forest enterprises with employees mainly family members shall continue the business. Some owners want to sell the enterprise, few intend to close. Owners of enterprises without employees mainly intend to close. Only in second place range enterprises where family members shall continue the business. These owners very seldom consider a sale. Owners of enterprises possessing harvesters or forwarders are rather younger than the rest. Of the few older ones who had already made arrangements for succession one half want to hand over the ownership to a family member, the other half intends to close.

4. Discussion

According to the data of the SVLFG, all 5,000 persons working in the forest enterprises only work on average one-third of a full-time job. This seems to be not reliable. All forest contractors we know personally, rather work seven days a week and not only two days. The working hours of the owners and family workers which the forest enterprises report to the SVLFG have an impact on their financial contribution. For this reason they might underestimate their own working time systematically. The salaries of the employees affect the contribution in fact too, but this data the SVLFG can check in the accounting of the enterprises. Thus the results regarding the salaries may be reliable and our extrapolating shouldn’t be biased.

The turnover of forest enterprises amounting to 580 million euro seems to be very high, if we compare it, e.g. with the contract volume of 52 million euro of the state forest for felling and logging (Bayerische Staatsforsten, 2014). There are two reasons why this great turnover might still be plausible: On the one hand many contractors also trade with timber as described above. The revenues from selling timber are much greater than the earnings from services like felling and logging. On the other hand there is the intensive exchange of services between the forest enterprises. If one contractor works as a subcontractor for another enterprise, the payments are posted in both accounting. However the turnover might be overestimated due to overestimating the number of forest enterprises without employees which are harvesting timber fully mechanized. The turnover tax statistic records a turnover of more than 860 million euros in 2013. But this value is presumably biased by the turnover of some forest owners who are included as described at the beginning.

Although the machine stock of Bavarian forest enterprises is old the willingness to invest is low. Difficulties in financing don't seem to be an obstacle. Wippel and Vierguz (2014) asked forest contractors in Baden-Wuerttemberg also regarding difficulties in financing of forest machines. The results were quite similar to our findings. Thus the financing of machines isn't a major constraint for investments at the moment. Of course this can change quickly, if the cheap money policy ends. The results regarding prefinancing differ in Bavaria considerably from the results in Baden-Wuerttemberg. There a majority of forest contractors complained about a tight liquidity. Probably the time span between executing an order and payment is shorter in Bavaria or the contractual partners have found a solution satisfying both, e.g. advance payments. If the willingness to invest is low although financing is no obstacle it must be the little prospect regarding the return on investment that prevent contractors. The complaints upon low profits and high pressure of competition particularly from forest enterprises with great capital expenditure support the assumption that the return on investment is very low currently. Apparently there is an overcapacity of forest machinery and the market has to adjust. There is a risk that more and more outdated machinery is operating in the forests. The progress in engineering is not incorporated into everyday practice. Opportunities to raise quality and productivity of forest works might be missed.

Surveys from other countries indicate that the rising age of the forest machinery is not limited to Bavaria. Stölzner and Borchert (2014) found a similar age of harvesters in other federal states too. 111 harvesters of Thuringia registered in the database had a mean age of 8.8 years, 33 harvesters in Baden-Wuerttemberg an age of 8.9 and 19 harvesters of Hesse 8.1 years. Only 30 harvesters registered of Saxony had been 6.8 years and were thus a bit younger. According to Mederski et al. (2014) the mean age of harvesters in Poland is 7 years. Ruch et al. (2015) determined a mean age of 5.8 years of 54 harvesters and 7.8 years of 90 forwarders operating in the Bourgogne. This is significantly lower than the age of machines in Bavaria. But the machine age in the Bourgogne rose considerably during the last years. In 2008 only 29% of the harvesters had been 6 years old or more, 2015 half of all machines belong to this age-class and 55% of the forwarders were 7 years old or more by now. The market of fully mechanized harvesting in Central Europe has been growing for about two decades. Now the market seems to be saturated in many countries. The statistic of KWF about the sales of forest machines shows a decrease of harvesters and forwarders sold in Germany in 2012 and 2013 (Wehner, 2014). But in the last year the number of machines sold of both types increased again (Wehner, 2015).

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Topic 3

Improved planning

Evaluation of RFID UHF tags for electronic marking of standing trees

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Abstract
Precision forestry is one of the mainstreams of future forest engineering development. Optimized operations rely on efficient and exact transmission of information regarding forest stands up to the single trees. Radio Frequency Identification (RFID) tags with Ultra High Frequency (UHF) technology are a promising tool for linking information to a single tree or log along the timber supply chain. Nevertheless their use poses several challenges, one of most relevant being the moisture content of wood which can influence the readability of tags. The present study shows the results of a test exploring the effect of different levels of moisture content, different positions of the tags on the tree (below and above bark, on bare wood) and different distances between tag and reader. The results will serve as guidelines for addressing the following practices of electronic tree marking in the frame of the EU project SLOPE.

Keywords
RFID UHF, tree marking, hauling, traceability

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1. Introduction

Forest engineering has the mission to constantly optimize and improve the current timber production systems, identifying bottlenecks and providing alternative solutions. Different work areas and natural environments will require different solutions for the same activity. Harvesting and hauling operations on flatland forests (Central and Northern Europe) are based on a fully mechanized and cut-to-length (CTL) systems like wheeled harvesters and forwarders. This work system guarantees excellent productivity rates, and thanks to a good standardized level it allows the application of several control systems for real-time management of the whole supply chain, from harvesting to purchasing and delivery, further increasing its overall efficiency. In the near future the productivity and profitability of flatland forest operations and timber supply chains are expected to increase rapidly by implementing the tools and methods of precision forestry (Holopainen et al. 2014). On the contrary, forestry operations in mountain areas are seldom performed by fully mechanized systems, such as the harvester/forwarder system. Because of difficult terrain conditions, the sector is still characterized by manual felling and extraction of timber (or whole trees) by cable cranes, supported by excavator-based processors at landing, which can be regarded as a completely different working system (Tsioras et al. 2011; Spinelli et al. 2013). Due to the limits posed by steep terrain conditions, typical poor road network of mountain areas and limited storage and operational room (pads, roadside areas, yards, etc.), those harvesting systems are more expensive and less flexible compared to the CTL system based on wheeled machines (Stampfer and Sessions 2009). Consequently, the assortments produced in mountain areas are often more expensive and thus less competitive in a timber market characterized by a strong international trade.

Due to the high share of mountain forests in several EU countries, more powerful and intelligent machines must be developed for forest works in steep terrain. A recent review study analyzed the research trends in mountain harvesting, and addressed the most important development trends for cable yarding (Cavalli 2012). Among them the author highlights the need to implement mechatronic applications designed for increasing the work efficiency of cable yarding systems, as well as the importance of empowering the human-machine interface. Exactly these are the goals of the project “Integrated processing and control systems for sustainable forest production in mountain areas” (SLOPE), funded by the EC under the frame of the Seventh Framework Programme and involving 10 partners from 5 EU countries.

SLOPE project aims at setting up an integrated system for the optimization of the forest production in steep terrain by mean of digital data generation coupled with the use of intelligent cable yarders and processors. For this purpose forest surveys will be performed using terrestrial laser scanners (LiDAR) for the acquisition of georeferenced 3D data on the standing trees. Such techniques are capable of returning the position of each single tree, as well as a number of inventory data such as DBH, stem profile, crown height and characteristics (distinguishing among living and dead branches). By coupling this data with aerial sensors, such as LiDAR scans or high definition EO images provided by UAV (Unmanned Aerial Vehicles) it is possible to gather a comprehensive set of information, which can integrate the former with tree height and above ground crown conformation, further refining the detail of information for the whole stand and the single trees.

The stem profile and the additional data generated can be fed into commercial software for returning the optimal bucking (Murphiy 2008; Dassot et al. 2011), thus maximizing the value of the extracted timber according to the specific and up to date market requirements. In forest operations the balance among high productivity and the care (and time) necessary for the optimization of trees bucking is often regarded as incompatible or at least colliding (Nurminen et al. 2009; Tolan and Visser 2015). This is even more evident in mountain forest operations, where an optimal bucking is time consuming and the reduced size of the cable yarder landings makes it necessary to clear the landing of the extracted trees shortly, which calls for fast processing and well synchronized logistics. This problem can be solved, at least partially, by means of a traceability system that relates the digital information generated for the single standing tree to the actual item being harvested and transmit this data to the forest machines, making available in real time bucking instructions for each tree. The same traceability architecture can be used to assign an ID to each log produced and link this to all the available information (measures, quality). For this purpose several solutions have been used for actual marking of trees and logs in forest operations or timber logistics, such as color marking, barcodes, QR codes and RFID technology (Tzoulis and Andreopoulou 2013). The latter seems to be the most promising tool for supply chain management, particularly for the capacity to be red at considerable distances and to be relatively insensitive to dirt. In fact in forest operations and timber logistics logs may be easily exposed to mud, dust and other staining substances, which could hinder or completely prevent the automatic control with visual systems.

For the purposes of the project the UHF (Ultra High Frequency) RFID tags were chosen because of the desired reading range (from close contact to a distance of 12 meters depending on the reader strength, tag size and environment conditions) over the LF and HF types. These work at an operational frequency of 868 MHz (frequency allocated in Europe according to the EPC Class 1 Gen 2 ISO 18000-6C protocol) and feature a theoretical read range of several meters (up to 12 m) with fixed readers and up to 2-4 meters with handheld readers. The difference among embedded and portable readers is basically given by the allowed maximum irradiating power/field strength, which in Europe is 2 W of Effective Radiated Power (ERP), while for handheld devices the ERP is reduced to a maximum of 500 mW for safety of the operator. This difference is clearly reflected in the reading distance, which, as stated previously, is significantly higher for readers with higher ERP.

Within the SLOPE concept the RFID tags play an important role, linking the information available in the database to the actual trees standing in the forest. By mean of RFID the information can be related to each tree all along the supply chain, and once the tree is processed for producing the final timber assortments, those can be again identified with a unique ID by mean of RFID tags, relating to each log its quality and volume characteristics as well as all the info relating it to the original standing tree and forest parcel. Throughout the harvest and extraction operations the RFID tags will keep and provide information to the different operators or machines involved, optimizing the process by enhancing the flux of information.

For a real feasibility of this system, the RFID UHF tags should be always readable in the harsh operative conditions, and in any case it is essential to know under which conditions the reading rate decreases, for planning accordingly remedial options. Namely, the main challenges for the use of RFID tags in forestry are the environmental conditions (rain, air moisture, low and high temperatures), a variable reading distance and angle between tag and reader, and the presence of several dielectric materials that can cause tag detuning, altering and reducing the "visibility" of the transponder (Ghahfarokhi et al. 2011). In forest such dielectric materials are specially represented by living tissues with a characteristic moisture content, such as leaves, branches and the very timber.

The present study investigates a number of operative solutions and factors with the aim to maximize the performance of RFID UHF tags in keeping and transmitting information in a timber supply chain. Namely the aspects studied are the following:

- in order to set up an effective system for marking standing trees, RFID UHF tags and the application system shall be reasonably easy and inexpensive, furthermore the selected RFID UHF tags must endure open air conditions (air moisture, water, resins, high and low temperatures) for a relatively long time since tree marking may occur several months prior to the actual felling operations;

- the position of RFID UHF tags must allow both ease of application and maximum readability by mean of RFID readers.

- the capacity of the readers deployed along the supply chain (portable readers in the forest, fixed readers installed in forest and logistics machines and in sawmill facilities) to detect the installed RFID tags must be ensured in most working conditions, with particular regard to the variability of reading angles and distances and the dielectric properties of wet wood.

2. Material and Methods

2.1 Selection of RFID UHF tag model and application system on standing trees

The basic structure of RFID tags is the transponder, a metallic element built in different shapes according to the purpose and the manufacturer, and the integrated circuit. These elements are fixed on a simple plastic tape structure (eventually with one adhesive surface for application), or protected and supported with different type of cases, according to the final application. Clearly the complexity of the final RFID structure is reflected in the size and the unitary cost.

The datasheets of a considerable number of UHF RFID tag models had been compared in order to identify the most suitable types for tree and log marking. Ideally a unique tag model should be used all along the whole timber supply chain, from tree marking to logs marking at the landing. This would lead to a great simplification in all the processes, and reduce the unitary cost of the tags, since a single model would be purchased in a larger quantity. The screening phase led to the selection of 7 tag models (Table 1), which were tested during common marking operations on standing trees, gathering the opinions and suggestions of expert professionals. As a total 53 trees were marked traditionally (debarked spot) and with UHF RFID tags, simulating the actual procedure that an operator shall perform for visual and electronic marking in a unique operation.

Tags were applied in July 2014 and in August 2015 their operative capacity was checked in the forest by mean of a portable RFID UHF reader.

Table 1. UHF RFID tag models tested for the first evaluation.

Number	Manufacturer	Model
1	Omni-ID; Exo 600	Exo 600
2	HID	Slimflex
3	Confidex	Ironside
4	Synometrix	SMLM-8200
5	Confidex	Ironside Micro
6	Confidex	Pino
7	Smartrac	Shortdipole

2.2 Reading capacity according to RFID UHF tag and reader position

For this test a unique Norway spruce (Picea abies) log was used, with a diameter of 30 cm and a height of 21 cm. The log had been collected during a forest hauling operation, and featured a moisture content of about 48% at the moment of the tests.

The RFID UHF tag model "Shortdipole" (n. 7), selected as the final model for the study, was applied on the log in three different positions (Figure 3):

1. transverse surface or cross cut section of the log
2. tangential surface, over bark
3. tangential surface, below bark

A RFID UHF portable tag reader CAEN R1240I - qID was deployed for the tests. The emitting power was set to the maximum capacity, corresponding to 489 mW. The reader was used at three distance levels (a): 0, 10 and 30 cm. The first two distances are expected to be obtained more probably when RFID identification is performed with manual readers, while the last distance level was tested simulating the probable position of a reader installed on a timber processor.

Also different reading angles (α) were tested: 0°, 30°, 45°, 90° and 180° (i.e. reading through the timber, perpendicularly to the tag). According to the reading distance evaluated some reading angles were not possible due to the size of the reader, for instance at 0 cm just 0° and 180° reading angles were possible, while at 10 cm all angles were possible with the exception of 90°. The maximum distance posed no limits to the reading angles, which could be entirely tested.

The quality and strength of the signal returned by the RFID UHF tags was evaluated recording the Received Signal Strength Indicator (RSSI) provided by the readers. This indicator is expressed in negative values of decibel-milliwatts (dBm) and returns the power of the signal backscattered by a tag and measured by the reader and its antenna ports. It is important to note that for an equal emitted power (e.g. 500 w) the antenna model and cable type and length (connecting the antenna to the port) may reduce or increase the final signal power arriving to the receiver.

Tag detection and RSSI measurement was performed with 5 seconds long reading frames. These were replicated 10 times per each factor combination.

2.3 Moisture content influence on RFID UHF reading capacity

For testing the dielectric capacity of wood at different moisture content three logs were collected from Norway spruces (Picea abies) felled on purpose. All logs had length of 40 cm and diameters of 45, 35 and 25 cm. The initial moisture content was 51%, 40% and 45% respectively and was calculated ex-post by comparing the green weight as measured the very day of tree felling and the weight evolution while drying gradually the logs in non-ventilated oven at 100°C to constant weight. The initial difference in moisture content is probably due to the diverse health condition of the trees, which suffered severe wind damages about 5 months before felling.

The RFID UHF tag model "Shortdipole" was applied on the crosscut section of the logs, placed lying on a paved surface at open air. The RFID UHF portable tag reader deployed for the tests was the CAEN R1240I - qID set to a power of 218 mW (about 50% of the available power). This solution was chosen in order to simulate the probable working setting of an operator working in forest, where a reduced reader power may be necessary in order to assure single reading of the selected tag, without interference of the tags applied on the surrounding trees or the blank tags carried by the operator for the marking operations (similar requirements would have a processor head with the capacity to read RFID tags and apply new tags on the produced logs).

Reading was performed at a fixed distance of 30 cm. As for the previous test, each reading cycle (logs' diameter and drying cycle) was constituted by 10 reading replications. Reading was activated for 5 seconds, after which the reader was interrupted for recording the RSSI value.

Figure 1. Layout of the tested RFID UHF tag models.

Figure 2. Application of RFID UHF tags, with staples (top) and strew (bottom) on trees visually marked with debarking method.

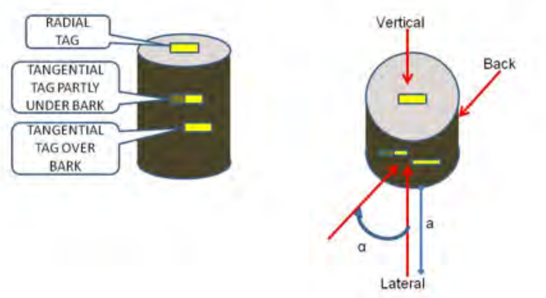

Figure 3. Position variables considered during the reading tests.

Figure 4. Logs used for the test.

Figure 5. Selected tag model applied over bark on standing tree.

3. Results and discussion

3.1 RFID UHF tag long term testing, selection of tag model and application system

Analyzing the comments of professional foresters and the experience gathered during tree marking, a rough division among RFID UHF tag models can be made according to the application modality:

1. RFID tag models with hard shell, requiring a screw or rivet for application (tags 1,3,4 and 5);
2. RFID tag models with soft cover, allowing gluing or stapling (tags 2 and 7, partially tag 6).

The models grouped in 1) have a higher unitary price (above 1 €), are heavier, more protected and probably less sensitive to the dielectric influence of wood. On the other hand they require a common or electric screw driver and a longer operation for fixing on standing trees. For this purpose they need steel screws which presence may severely damage the sharp tools at the sawmills. Alternative resin-screws have been considered, but cannot be driven directly into the solid wood, requiring a time consuming pre-drilling, while the alternative to recover the RFID tags and screws at the end of the supply chain seems unfeasible from the practical and economic point of view.

The tags of group 2) are lighter, simpler and with a unitary price around 0.2 €. The different configuration allows for a larger transponder size, which feature a longer reading distance. Furthermore if the plastic cover exceeds the transponder size, the tags may be simply stapled on the solid timber by mean of a common mechanical stapler. Commercial staples are made in aluminum, and have a very low unitary mass. Compared to steel screws, these have a negligible impact on the sharp tools of the sawmill and can be placed on the timber without main consequences.

The low cost, minimal impact and long reading range make the tag models of group 2) more suitable for a traceability system based on disposable items.

After more than one year on standing trees all RFID UHF tag models were operative. The model Pino (n. 6) suffered a strong reduction in signal strength, due to the fact that the fixing staples perforated the transponder structure. Some hard shell models suffered damages in the case structure due to the wood tensions, but such damages seemed not to reduce the protective capacity of the shell. A further factor observed was the abundant resin emission in some debarked areas (where the tags were applied). Apparently, the tags covered by resin had a weaker signal than clean tags, but it was not possible to measure this difference in the field since the RSSI is not available for the portable interface of the reader (running on Android OS). Finally the tag model 7 (Smartrac Shortdipole), protected by a PET EVA plastic cover was selected as the best suited for the purposes of marking standing trees and logs.

3.2 RFID UHF tag reading factors

All the factors tested in the study resulted to have a statistically significant effect on the reading capacity of RFID UHF tags.

The position of the tag had a relatively high influence on the reading capacity, being the most effective position on the cross cut section (position 1), which means perpendicularly to the timber fiber. In this position the signal returned is particularly strong, but even transmission of signal through the wood is enhanced, in fact it was possible to read the tag posing the reader in contact with the opposite cross cut section of the log (21cm long) and even when reading at a distance of 10 and 30 cm from the log (respectively at a total distance of 31 and 51 cm from the tag). With the other tag position, reading through the log was not possible, even in the case of contact reading, which represent a distance from reader to tag of 30 cm. The most unfavorable position was over bark, tangentially to the log. This is probably due to the rough and irregular surface of bark, which bends and sets in variable angles the tag posed over it.

The reading distance had clearly a great influence on the RSSI level. Contact reading (0 cm) returned the most powerful signal, which is reduced to almost half the value by increasing the distance to 30 cm.

Reading angle also showed very important effects. As expected, reading tags with an angle of 90° is not possible, since in this condition the transponder offers the minimum emitting surface. Increasing the angle from 0 to 30 ° reduces significantly the returned signal, but a further increase to 40° does not causes significant changes in terms of RSSI recorded. Surprisingly it is possible to detect the RFID tag through the log, as previously mentioned, but this occurred only if transponder and reader are working perpendicularly to the wood fiber.

3.3 Moisture content influence on RFID UHF reading capacity

The moisture content of wood showed a significant influence on RFID UHF tags, decreasing the strength of the signal returned to the reader (Table 3). No significant difference could be detected for the different diameter of logs, thus we can exclude that the size or mass of the logs where the tags are applied may represent a further factor in the efficiency of RFID UHF technology.

The signal strength improved about 20% when the moisture content was decreased from 50 to 40%. The total gain in signal power was about 37% when tested on the oven dry log. Nevertheless the minimum average value registered (-57.8 dBm) was still easily detected by the reader, which can identify returning signals weaker than -70 dBm. This is confirmed by the successful tag detection in all reading replications, while in difficult reading conditions, such as with unfavorable reading angles, not all the 5 second reading cycles (replications) detected the tag.

4. Discussion

According to the results of this study, RFID UHF tags are suitable for being deployed in a complete timber supply chain with full or partial degree of mechanization.

Marking standing trees with RFID tags is relatively easy and inexpensive, and all models of tags, even the most simple, can endure long periods in the forest without losing their operative capacity.

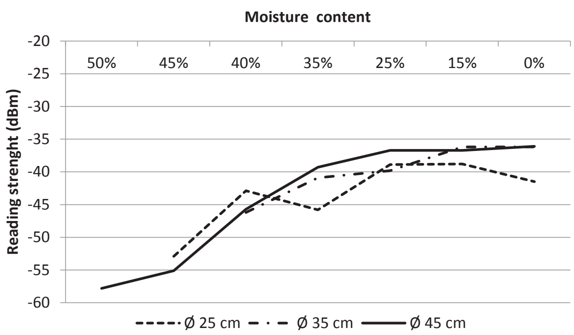

Figure 6. Reading strength of RFID UHF tags according to moisture content and size of logs of the logs (Ø 45, 35 and 25 cm).

Reading the tags on standing trees may pose a number of challenges if a random position between tag and reader is to be expected. This could be the case of a reader installed on a feller head when grabbing a tree marked with RFID UHF tags. In fact tags placed over the bark of a standing tree provide the lower reading performance, and in this condition reading angle and distance cannot be suboptimal if a high reading rate must achieved. A remedial solution is to position the RFID UHF tag slightly below the bark (uplifted with a sharp tool), increasing the reading capacity and at the same time pro

In the case of manual identification of RFID tags on standing trees the possibility to position the reader at minimum distance and perpendicular to the tag assures a 100% of reading rate. If manual felling is performed, the RFID tag originally placed on the standing tree should be moved to the cross cut section (or paired with a new tag in this position). The cross cut section provides the most reliable reading conditions, and is more protected during hauling, reducing the risk of accidental removal of the RFID tag from the tree. The same position should be chosen for the logs processed from the tree in order to facilitate the bulk reading of RFID tags on the timber transported and piled during the logistic and storage operations.

The moisture content of timber has a clear influence in reducing the power of the signal returned by the RFID UHF tags. Nevertheless the detuning effect of the dielectric properties of wood is not strong enough to represent a limit to the system, particularly if an appropriate position is chosen for the RFID tag and for the reader. Furthermore, it is even possible to read tags through the solid wood, if this operation is done positioning tag and reader in a perpendicular position with respect to the wood grain.

The results of the study also suggest that the RFID UHF tag is not influenced by the moisture content of the whole log, being the detuning effect limited to the surface of wood in contact with the transponder. Given this behavior, even short storing periods after felling may lead to a reduction of moisture content on the surface of the crosscut section, quickly enhancing the received signal strength.

Table 2. Reading strength of RFID tags according to the studied parameters.

Level	Count	RSSI (dBm) Mean	Stnd. Error	Lower Limit	Upper Limit
GRAND MEAN	190	-53.4			
Position of tag					
1 (on cross cut section)	100	-44	2.26	-44.5	-43.6
2 (tangential over bark)	40	-58.9	3.94	-59.7	-58.1
3 (tangential below bark)	50	-57.3	3.53	-58	-56.6
Distance (cm)					
0	40	-40.3	3.95	-41.1	-39.5
10	100	-54.6	2.27	-55	-54.1
30	50	-65.3	3.61	-66	-64.6
Angle (°)					
0	80	-48	2.43	-48.5	-47.5
30	40	-51.5	3.82	-52.3	-50.8
45	40	-53.6	3.82	-54.4	-52.8
180 (reading through the log)	30	-60.5	4.57	-61.4	-59.6

Acknowledgments

This work has been conducted within the framework of the project SLOPE receiving funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under the NMP.2013.3.0-2 (Grant number 604129).

The authors wish to thank Mrs. Carolina Lombardini and Mr. Giovanni Aminti for their important support in data collection.

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Terrain evaluation model to identify landing locations in mountain areas

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Abstract
Appropriate evaluation of terrain capabilities to find a feasible zone for landing location is an important task in forest operations, especially in mountain terrains where land is finite and scarce resources need to be allocated wisely. Even through a variety of numerical and mathematical techniques have been evolved, role of environmental factors and stand attributes in concert with topographic conditions were less evident in feasibly allocating of landings at the mountain areas. Therefore, this study as a pilot experiment is steered to describe a Multiple-resource Analysis and Geographic Information System (MAGIS) to evaluation the potential of terrain for finding feasible landing locations in mountain forested areas. Owing to uncertainty in available information, we introduce a Hierarchical fuzzy analytical network process called "Hfanp" as new framework, to handle the fuzziness condition, particularly where science has not yet been able to define quantifiable relationship in an analytically manner. We applied the model to a 50 km2 of forests in the highland of the Hyrcanian forests, north of Iran. Results showed that the proposed approach successfully could find the landing locations, and characterized by full tradeoff among all factors, average risk and offers much flexibility solution rather than the Boolean approach that currently don around the world.

Keywords
forest planning, ground-based skidding, fuzzy set theory, mountainous area, decision support system

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1. Introduction

Harvesting steep slopes is more difficult and expensive than harvesting flatter terrain; it can involve a multi-objective process that influenced economic and ecological services of forests over a relatively long period of time (Krag and Webb, 1987; Troncoso et al. 2011). Efficient harvest planning comes from well-identified site-specific terrain conditions, established harvest systems, configured landing locations, and instructed experienced crews (Stückelberger et al. 2007; Kühmaier and Stampfer, 2010; Narayanaraj and Wimberly, 2013). A great deal of attention in the literature has been paid to syntheses of timber harvesting activities, but economic efficiency was target and received the most criticism to date (Kühmaier and Stampfer, 2010).

Non-consideration of environmental and ecological perspectives of such activities may impose negative side-effects and risk that revoke the economic advantages. Harvest planner should operate in a planning environmental not only concerned about the negative impacts of harvesting activities, but also must be provided a trade-off for the economic advantages. Terrain conditions can significantly influence harvesting system selection and landing configuration with slope being the most important, so under this condition, the most of good options reduce than the gentle terrain (Parker and Bowers, 2006). Finding fusible solutions in these cases would be difficult challenge and is still an open avenue of researches. According to Adams et al. (2003) terrain evaluation model should form the basis for the preparation of a detailed terrain suitability map in concert with other resources to guide forest harvest planning.. In general, a terrain evaluation model is necessary to address which part of harvesting area is available for harvesting with witch type of machines and also identify suitable zones for landing locations under ground-based skidding operations. This could have a significant role in success of operation, increase efficiency, and reduce land-use conflicts more specifically in steep slope terrains (Adams et al. 2003). According to Boyland et al. (2004), partitioning of a terrain into the smaller management units will bring economic and ecologic yields as it provides practical framework for the layout of land-use planning activities.

Traditionally, decisions on location of landings were more contingent on engineer's field experiences and they were relied on topographic map or occasionally "rules of thumb" to determine best option over a given site. However, many forest engineers fail to make good decisions because of meeting several possibly and conflicting goals at the same time.

It seems that a multi-criteria decision making approach (Van Delden et al. 2011) links with geospatial analyses could be able to cope with overwhelming amount of data able to provide not only a good but also a feasible solution in addressing these complexities in real-world problems.

Therefore, to fill out this gap, the present research attempts to address the challenge of steep harvesting operations in finding feasible landing locations by incorporate environmental factors and stand attributes into the objective along with terrain conditions. Specifically, the purpose of this research is outlined as a combined approach in basis of a multi-criteria decision analysis linked with fuzzy spatial analyses called FSMCDA model to evaluate the current potential of terrain for preliminary identifying terrain conditions and finding suitable zones for landing-locations regards to in-depth analysis of terrain factors, environmental conditions, and stand attributes simultaneously, in a steep slope forested area.

2. Material and Methods

Before generating the models in forms of spatial maps, we tried our best to identify the most important criteria that are involved in determining potential of land suitability for harvesting and finding feasible landing location. This comes out through the literatures review and discussions with field engineers who are employing in timber harvest activities. After identifying the criteria, due to complexity with problem for analysis and sometimes conflict criteria, we developed an analytical network process (ANP) to analyze the real-world problem in context of decision tree hierarchy (Fig. 1). Next decision-makers were asked to use a set of systematic procedures to pairwise comparison of criteria with respect to parent node.

Four stages were assumed to in-depth analysis of model as follows; (*i*) deriving local priorities through a group pairwise judgment (*ii*) making the initial unweighted supermatrix by normalized the local weight vector (*iii*) raising the weighted supermatrix by weighting clusters in each column of the supermatrix, (*iv*) and finally calculating the limited supermatrix (Shahin et al. 2005).

All syntheses of the ANP model were made with SuperDecisions 8.4. The input data were generated from raster files using digital elevation model (DAM) with a 20-m resolution as well as field surveys as a proxy to develop the spatial models. After deriving the weights of criteria, we tried to combine the criteria in forms of spatial data to identify the most feasible zones for landing location. We used the weighted linear combination (WLC) to combine the MCDA results with the spatial data.

At the first step, because of the different scales of considered criteria, it is necessary that the factors be standardized before combination. We used different fuzzy membership functions such as sigmoidal and triangular according to decision maker's consultancies for standardization between 0 to 1 byte scales. The raster layers were then combined and intersected with regards to their weights to generate spatial composite polygon maps in a visualize style (Eastman, 2001) Eq. 1.

$$C_{s,i} = \sum_{j=1}^{k} w_j x_{i,i} \tag{1}$$

where $C_{s,i}$ is the suitability index of each cell i in the final layer, w_j is a weight assigned to k factors, and $x_{i,i}$ is the value of each grid cell i and for each factor j; k is the total number of factor/or criteria that are considered for analysis. Finally, land suitability of a zone for composite map is generated by calculating the average of the suitability of the cells belonging to a zone (Eq. 2.). A higher value for a cell indicates a higher suitability for the site.

$$S_z = \frac{\sum_{i=1}^{k} (L_i)_z}{n_z} \tag{2}$$

where S_z is zonal land suitability, L_i is local suitability of the cells i from k cell group belonging to the zone z, and number of cells in the zones n_z. To improve readability of the suitability index maps, zones with less than 0.5 ha in area were eliminated from the allocation process. The spatial maps were then classified into four categories based on natural break classification scheme for visual interpretations. After building the terrain feasibility map and identify the suitable area for timber harvesting, in a same way, we identified the suitable zones for landing location by combine the main important criteria such as natural slope of land, landslide susceptibility, distance from riparian zone, and soil erodibility index. These criteria were pointed out from the previous researches (Anderson and Nelson, 2004).

2.1 Model application

The model is implemented to a mountain-forested area of approximately 50 km² in the north of Iran. The forests are situated in rough topography condition and manage under an uneven-aged silvicultural system within the context of sustainable strategy. The research site extends between 36°29' to 36°33' N latitude and 51°40' to 51°46' E longitude. Elevation ranges from 175 m to 2,200 m above sea level. The ground-based skidding system is common harvesting systems that involved in transporting woody products from stump to given log-landing locations.

3. Results

The proposed model for analyzing of terrain is outlined in Table 1. A three level of hierarchy was constituted for solving the problem. The top level of hierarchy is devoted to the goal, which in this study is terrain evaluation for harvest feasibility in mountainous terrains subject to criteria and sub-criteria. Pairwise comparisons among the strategic criteria (second level) showed that terrain factors were the most important criteria (0.494) whilst stand attributes (0.196) were the least important in identifying terrain capability for timber harvest operations. The relative weights for other criteria regards to their interdependence relationship were shown in Table 1.

By combining the relative importance value, and complete the super-and limit matrixes, the global priorities of criteria were derived (Figure 1). Results showed that the slope of land, the lithology formation, and the distance from landslide prone area were recognized as most important criterion in assessing the terrain capability.

By combining the relative weight and completing the supermatrixand limitmatrixes, global weight of criteria were

Table 1. Proposed model of terrain evaluation based on multi-criteria decision making approach.

Strategic criteria	Main criteria	Node/sub criteria
Environmental factor -0.31	E-C1. riparian zone (0.332)	
	E-C2. Landslide susceptibility prone **0.528**	L-C1a. hillside aspect(0.054) L-C2b elevation gradient(0.050) L-C3c. fault features(0.142) L-C4d. rockiness volume (0.144) L-C5e. lithology formation(0.110) L-C6f. natural slope of land (0.252) L-C7g. slope failure(0.137) L-C8h. soil texture(0.071) L-C9i. topographic wetness index (0.040) L-C10j. canopy cover(0.157) L-C11k. stand type(0.250) L-C12l. stand volume(**0.593**)
	E-C3. Soil erosion index -0.14	S-C1a. canopy cover (0.250) S-C2b. stand type(**0.750**) S-C1a. hillside aspect(**0.393**) S-C2b. elevation gradient(0.147) S-C3c. natural slope of land(0.369) S-C4d. soil texture(0.266) S-C5e. topographic wetness index (0.077)
Terrain conditions **0.494**	T-C1.hillside aspect(0.050)	
	T-C2.elevation gradient(0.520)	
	T-C3.fault features(0.181)	
	T-C4.Rockiness volume(0.122)	R.C1a.elevation gradient (0.200) R.C2b. lithology formation(**0.800**)
	T-C5.Slope failure(0.092)	S-C1a. fault features(0.325) S-C2b. rockiness volume(0.125) S-C3c. lithology formation(0.193) S-C4d. natural slope of land(**0.357**)
	T-C6.natural slope of land(**0.192**)	
	T-C7.lithology formation(0.198)	
	T-C1.Soil texture (0.080)	S-C1a. natural slope of land (**0.540**) S-C2b. topographic wetness index(0.163) S-C3c.slope failure (0.297)
	T-C1.Topographic wetness index(0.033)	T-C1c. stand type(**0.750**) T-C2d. canopy cover(0.250) T-C3e. hillside aspect(0.170) T-C4f. elevation gradient(0.250) T-C5g. natural slope of land(**0.593**)
Stand attributes -0.196	S-C1. canopy cover (0.122)	
	S-C2. Stand type (0.320)	S-C1.a. canopy cover S-C2.b. elevation gradient S-C3.c. natural slope of land
	S-C3. stand volume (**0.558**)	

** The bold values refer to the greatest importance value among the other criteria within each cluster.*

derived (Figure 1). Results showed that the slope of land, the lithology formation, and the distance from the landslide prone area were recognized as most important criterion.

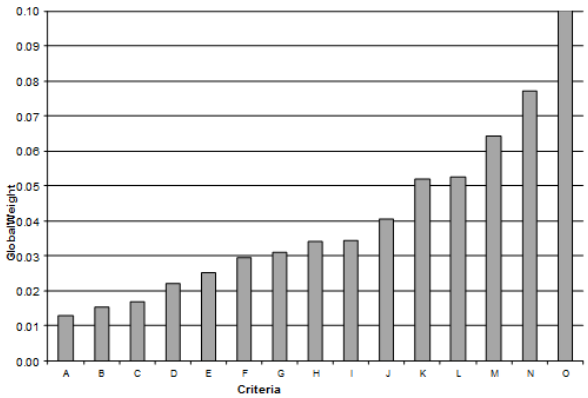

Figure 1. Converged super-matrix of most important criteria in terrain evaluation model. A=topographic wetness index, B= hillside aspect, C=Soil erodibility index, D=Soil texture, E=Canopy cover, F= Elevation gradient, G= Slope failure, H, Stand type, I= Rockshare volume, J= distance from riparian zone, K, Fault feature, L= stand volume, M= distance from landslide susceptibility, N, Lithology formation, O= Natural slope of land.

Combining all spatial layers (Figure 2) showed that by about 44% of the project area is classified in category levels A & B as a good potential for ground-based harvesting activities, whereas the area is predominantly falls into category level B (1,905ha), (Table 2).

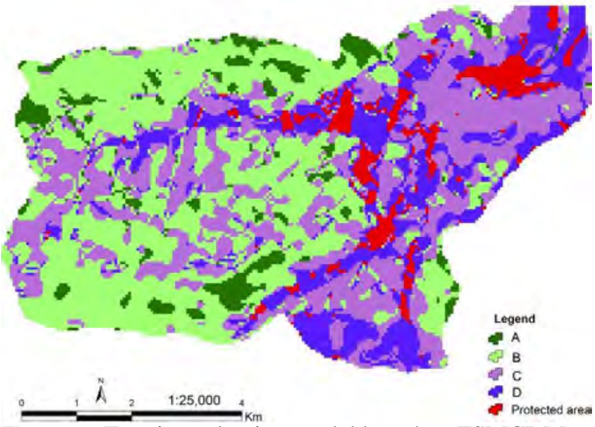

Figure 2. Terrain evaluation model based on FSMCDM approach.

By about 22% of the total area was recognized as less appreciate zones for harvesting planning that is highlighted it at the two aftermost category levels (Table 2).

Four criteria include, soil erodibility index, distance from riparian zone and landslide prone area and hillslope were screened by decision committee in order to identify the most suitable zones for landing locations. The importance weight score of the criteria were calculated in a sub-ANP model (Figure 3). The greatest and lowest values were associated with the hillslope and the soil erodibility criteria, respectively.

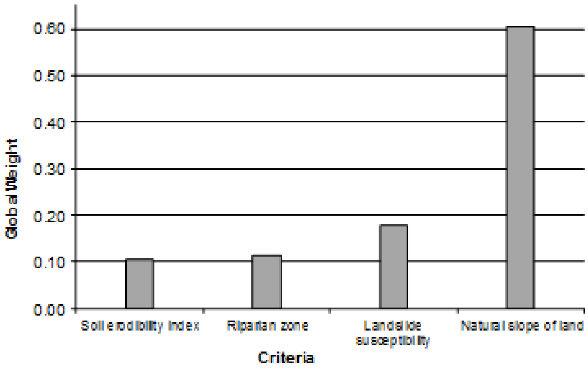

Figure 3. Converged super-matrix of most important criteria in identifying feasible landing location.

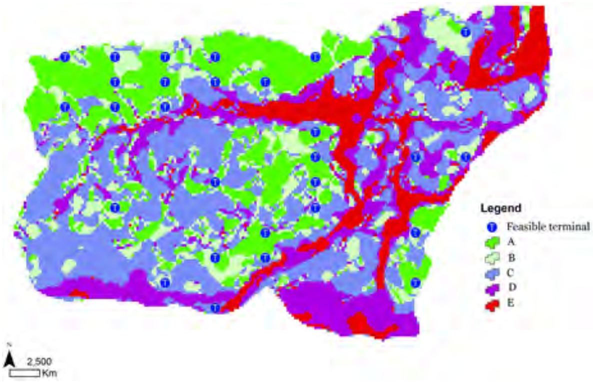

Figure 4. Feasible landing locations based on FSMCDM approach for study area.

Grid location with systematic distance 50ha was provided to identify the candidate area for landing location over the area. Results confirmed that there are potentially 28 feasible locations for construction of wood terminals (Figure 4), with the s_z values from 0.61 to 1.00 for each pixel.

According to suitability map of the area for landing location (Figure 4), by about 25% of the total area (1174 ha), (i.e. category labels A & B) is recognized as most suitable area (Table 3).

4. Discussion

Terrain evaluation model is a necessary tool in forest harvest planning efforts. It enables the planner to quickly evaluate the potential capability of terrain and identify the feasible areas for harvesting, allocate harvest machinery and recommend suitable zones for landing locations. The combined fuzzy set theory with MCDA (Hfanp) may help engineers to make sensible decisions under fuzziness condition, especially where huge number of information is subjective and there is not a quantifiable approach for measuring them. Such a decision support tool could be utilized as a practically tool to quick analyzes of terrain conditions (Adams et al. 2003) and provide a feasible trade-off between economic objective and environmentally soundness through planning of timber harvesting. Having this information along with economic objectives may result in increasing harvest pro-

Table 2. Statistical information of terrain evaluation model based on SMCDm approach.

category	Number of pixel in the domain	Frequency ratio of occurrence	Area occupied (ha)
A	1233	6.18	298.71
B	7565	37.95	1905.11
C	6652	33.37	1660.72
D	3397	17.04	845.92
Protected	1089	5.46	270.44

Table 3. Statistical information of feasible landing location model.

category	Number of pixel in the domain	Frequency ratio of occurrence	Area occupied (ha)
A	855	4.25	211.14
B	3873	19.24	962.99
C	9529	47.33	2389.96
D	3752	18.63	930.35
Protected	2126	10.56	534.69

ductivity and reduce the environmental damage caused by appropriate assigning of harvest equipment and landing locations (Boyland et al. 2004; Kühmaier and Stampfer, 2010).

Finding the most appreciate zones for locating of landings could be crucial to success of operation in steep forested terrains. Spatial arrangement of landing locations could significantly influence timber harvest cost, and more accessibility of skid-trail network (Kühmaier and Stampfer, 2010).

The proposed framework in this research could be served as a practically management tool for forest engineers to better analyze the terrain conditions and suggest specific treatments for a given site condition before economic considerations. The results of modeling efforts should be further strengthened by field- verifications for large-scale planning. Extending the primary results of this study to the mathematical modeling approaches is of interests as a valuable research project in future operational and tactical scheduling at the mountainous areas.

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Development and implementation of new features in a route selection and distance measurement system

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Abstract
In Sweden, road transport payments in the forestry sector are based on the distance driven. Since 2010, the Calibrated Route Finder system has been in practice, a system developed jointly within the forestry sector. A number of road features and weights for road attributes are used to establish the preferred route and distance. To find accurate weights, 'key routes' are used as the optimal solution to define an inverse optimisation problem where the unknown weights are variables. The system uses road data from the national road data base.
Deviation reports over time from haulers have identified certain areas that need improvement. Examples are curvature and topography, stop and start in junctions, all of which increase both time and fuel consumption. Improving the system is essential for accurate distance measurement and for the credibility of the system.

Keywords
route, forest road transport, optimisation, road feature, geometry

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1. Introduction

Finding the most efficient route from the landing in the forest to the delivery point at mill or terminal requires many decisions. There are a number of objectives to balance, e.g. time, fuel consumption, topography, traffic safety and working environment (Figure 1). Also, establishing the correct travelled distance is important because distance (km), together with payload (ton or m^3sub - solid under bark), forms the basis of payment to the hauler. Therefore, the route selection must be agreed between the hauler and the forest company ordering the transport.

Figure 1. Finding the most efficient route from landing to mill is a matter of balancing several objectives, some of which are shown in the illustration. Illustration by Margareta Nilsson.

Historically, forest companies have used a number of different ways of measuring travelling distance. This lack of standard procedures caused problems for haulers working for different forest companies because an identical assignment could be paid differently depending on customer. The distance was also often determined manually, leading to unnecessary administration and possible errors.

Table 1. NVDB, the Swedish National Road Data Base contains road feature and attribute information about all roads in Sweden.

Roads managed by	
Government	102 000
Local authorities	56 000
Private owners	384 000
(of which forest roads	240 000)
Total	542 000

Since the first pilot project in 2009, a system called Calibrated Route Finder (CRF) has been in operation in Sweden. CRF was developed as a joint project by forest companies in order to improve uniformity for payment, but also to establish a transparent, automatic and objective distance measurement and routing system on which all stakeholders could agree. A prerequisite for the development of CRF was the emergence of NVDB, the National Road Data Base managed by the Swedish Road Administration, which came into use in the 1990s. NVDB contains road feature and attribute information about all roads in Sweden. Table 1 shows the road management structure in Sweden.

CRF has been developed over the years, incorporating

Figure 2. 1500 'key routes', evenly spread over Sweden, represent best practice in finding the most efficient route from landing to delivery point.

an increasing number of road features. CRF is owned and managed by SDC, the IT company of the forest industry. SDC manages and administers forestry data and acts as an independent organisation, ensuring that accurate information is used in invoicing between forest companies and haulers.

2. System design

An important component and first step in the design of CRF were the 'key routes', 1500 routes, evenly spread over Sweden. The key routes are negotiated between forest and haulage companies, and provide examples of which route should be chosen from landing to mill (Figure 2). By representing best practise in finding the most efficient route, the key routes capture the objectives mentioned above.

The next step in the design of CRF is to assign weights to different road features available in the NVDB. In the weight setting, the key routes are crucial; they capture the objectives mentioned earlier, and they can be described by road features (Figure 3). The weights are derived through an inverse optimisation process where the key routes act as the optimal solution.

Not all road feature information needed in CRF (Figure 3) is explicitly available in NVDB. For curvature and hilliness, coordinate data in NVDB (x, y and z) was used to derive measures for how topography affects travelling time and fuel consumption of logging trucks. For curvature, maximum travelling speed for negotiating curves was estimated, and deceleration and acceleration in relation to curves was calculated (Figure 4). The difference in time taken between a curved road section compared to if the same section had been straight was used in the subsequent weight setting.

Finally, the established weights for all road features on a certain network arc (4.4 million in Sweden) are added together and then multiplied by the length of that arc. The result of this calculation is a number of points, which comprise a measure of the relative resistance if the system uses this arc. The CRF network is now ready to be used.

The use of weights for a large number of road features enables fine tuning of the best route from a large number of possible route alternatives. Commercial route selection devices also use weights, for example road section length or posted speed limit, but lack most of the resolution and complexity inherent in CRF.

Figure 5 shows a number of alternative routes from a landing (the triangle in the southeast) to a mill (the star in the northwest). The black route is the shortest path, and the green route is the fastest. Red routes are generated by using different weight settings in CRF, and the green route represents the current weight setting in CRF, KV3.1. The shortest and fastest paths are both much shorter and faster than the CRF route (see Table 2), but the reason for not using either of them is seen in the other road features; the amount of curvature, hilliness and gravel road is much lower for the CRF route, which would reduce, for example, fuel consumption. The route is mainly on roads that are wider and of higher class, improving both road safety and the working environment. The overall quality improvement in route selection can be seen in the lower total resistance.

Table 2. The CRF route improves the quality of the route selection compared to the shortest or fastest paths. A longer and slower route by CRF is compensated by less driving on lower-class roads.

Feature	Shortest path	Fastest path	CRF
Distance (km)	84.3	85.8	105.6
Total resistance (points)	2094	2407	1492
Time (min)	74.7	72.6	87.1
Curvature (points)	161	190	55
Hilliness (points)	74	36	3
Road width 3-3.5m (km)	8	19	0
Gravel road (km)	20	33	9
Road class 0 – 3 (km)	1	2	74
Road class 4 - 6	71	56	20
Road class 7 - 9	13	27	10

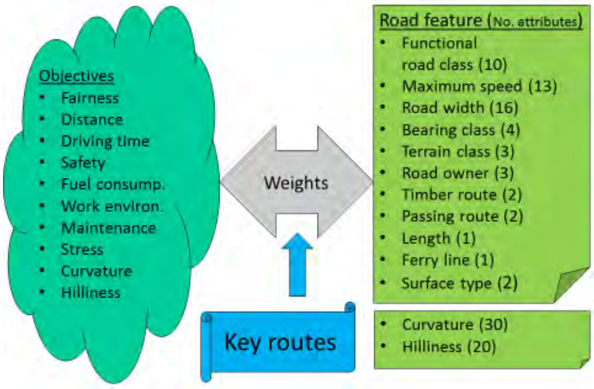

Figure 3. The key routes are essential in the process of establishing weights for the different road features used to capture the route selection objectives.

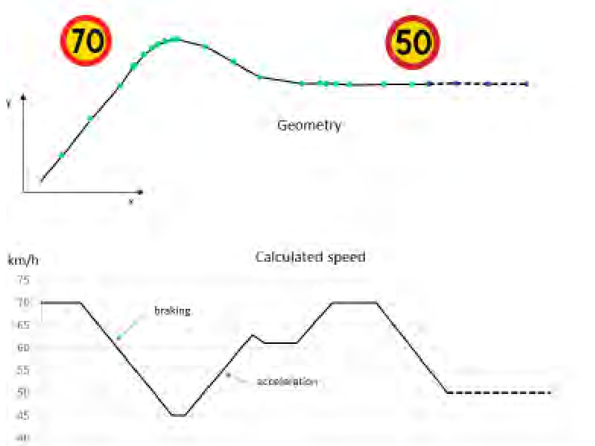

Figure 4. The effect of curvature on travelling speed (lower diagram) for the logging truck is calculated on the basis of x and y coordinates (green dots, upper diagram) to describe road geometry in the National Road Data Base.

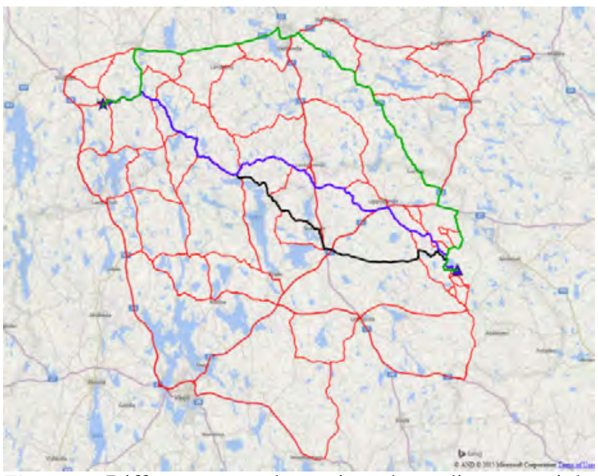

Figure 5. Different route alternatives depending on weight setting principles. Black is the shortest path, blue is the fastest. Red and green are CRF routes for different weight settings, where green represents the current setting.

3. System improvement

The experiences of the system users, such as the driver or a transport manager, sometimes suggest that some routes are not the best. In these cases, a deviation report can be submitted to VMF, the impartial Swedish timber measurement organisation. There may be a number of reasons for the deviation, such as data quality, road contruction or road maintenance. Sometimes the deviation reports indicate where improvements are needed in the system. One earlier example was deviations regarding hilly and curved sections of a suggested route that the users wanted to avoid due to increased time and fuel consumption, as well as road safety aspects (Figure 6).

The objective of the inverse optimisation process is to find a weight setting that provides the key routes as the solution to a minimum-cost route problem. In Figure 7, different versions of weight settings in CRF applied on the key routes are compared to the length of the 1500 key routes, whose length is normalized to 1. The shortest and fastest paths are also presented. Even the 2009 weight setting was successful in obtaining the same length as the key routes for many routes, and the improved 2015 weight setting is even better. The average distances of deviant routes are close to zero. It is also clear that neither the shortest nor the fastest path is the desired route in these examples. One explanation of this is that CRF involves many more objectives than the shortest or fastest path.

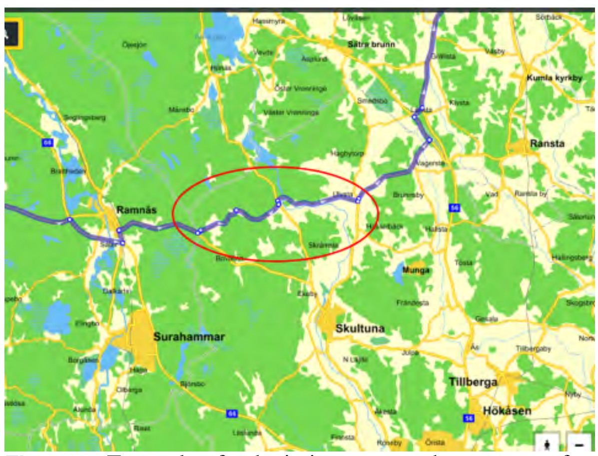

Figure 6. Example of a deviation report where a user of CRF feels that the suggested route is not suitable, in this case due to a high degree of curvature and hilliness.

Deviation reports have initiated the current work to improve the system with regard to narrow roads and impossible and/or illegal turns. We are also analysing the effect on route selection if retardation, stopping, waiting and acceleration related to different kind of junctions, which increase fuel and time consumption, is included in the system (Figure 8).

4. System usage

When CRF is used in practical operation, the system, hosted by SDC, is retrieved from either a web solution or from a company system integrated with SDC. When start and

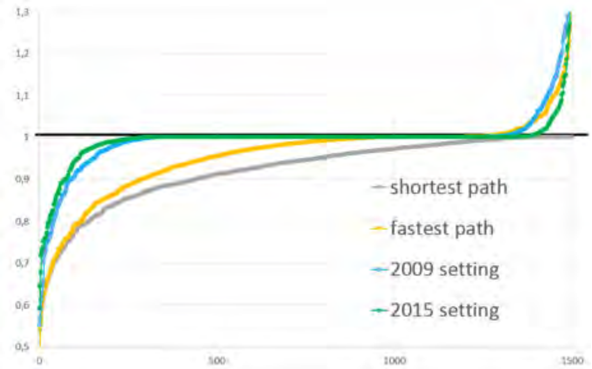

Figure 7. Key routes on the x axis, length (y axis) normalised to 1, compared to different weight settings. The shortest and fastest paths are normally shorter than the key routes. 2015 weight setting corresponds better to the key routes than the 2009 weight setting.

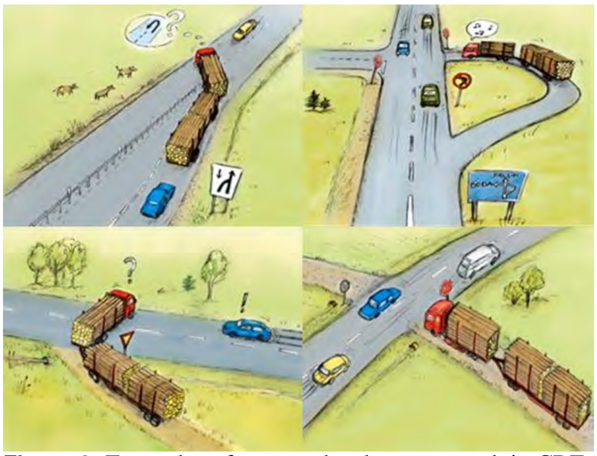

Figure 8. Examples of current development work in CRF: illegal turns (upper diagrams), impossible turns (lower left) and the effect of junctions on route selection (lower right). Illustrations by Margareta Nilsson.

Figure 9. Since the start of the system, a number of companies have joined, and use has increased over time. Light green is confirmed usage as distance measurement, dark green is an educated guess.

end coordinates are provided, for example representing the landing in the forest and the delivery point, CRF finds the combination of arcs that minimises the total number of (resistance) points. The length of the route is measured, and the route can be visualised on a screen, also in in the cab of the truck if available.

The first pilot projects, involving a limited number of forest companies, started in 2009. Since then an increasing number of companies have joined the system and, today, most forest companies are using the system (Figure 9). Fifty percent of the invoiced distances are currently directly based on CRF, but the system is also indirectly involved in a number of other measurements used in decision support.

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Harmonizing measurements from wood harvesting machines to support near real time spatio-temporally enabled dashboards for process control

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Abstract
Based on the idea to enhance the cost optimization effects in the forest industry, within the EU funded, multinational project ("FOCUS") a promising harvesting monitoring approach will be realized. The introduction of technical and semantical interoperability efforts shall provide an important building block for enhancing the collaboration capabilities. This is going to be achieved by sharing harmonized production sensor-measurements between the different stakeholders of the forest-based supply chain. As the activities are performed by various entities of the supply chain, e.g. forest enterprises, harvest companies, haulage companies and the forest product processing industry, we will introduce new technical concepts for sharing sensor-measurement information between the actors to enhance the situational awareness between the stakeholders.

Keywords
interoperability, GIS, harvesting, measurements, dashboard, visualization

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1. Introduction

Due to a large number of different players along the forest-based supply chain (e.g. forest owners, harvesting and forwarding entrepreneurs, and logistic companies), a ubiquitous availability of data and information is needed. Therefor it is useful to monitor and to control harvesting/forwarding and transportation processes. In particular, four systems will be integrated to the FOCUS platform: (1) control hub, (2) machinery status, (3) logistic control and (4) logistic optimization. Despite the observed and expected benefits that collaboration provides, forestry literature reporting successful implementation of collaborative strategies is still scarce. Most reports are about implementing collaboration with the purpose of improving transportation, planning and reducing its cost. The Forest-based Supply Chain comprises of the activities from the forest to the customer and describes the transformation of the raw material wood to marketable/end forest-based products. Based on the idea to enhance the cost optimization effects, within the EU funded, multinational project ("FOCUS") a promising monitoring approach will be realized to enhance the technical collaboration capabilities by sharing production sensor-measurements between the different partners of the forest-based supply chain. By exploiting the possibilities of seamless data integration, processing and visualization a transparent integration of harvesting-machine sensor data into monitoring systems is possible, providing a real-time overview of the harvest and transport operations of the supply chain.

2. Material and Methods

Nowadays most actors in the forest-based supply chain are aware of available ICT solutions, although in many cases they don't have a detailed knowledge of the different technologies available and which of them are available as specialized COTS software products for the forestry domain.

2.1 State-of-the-art data integration standards

The forest supply chain can considered as a workflow planning and control system of operations (Bettinger et al., 2008) linking the chains for timber stock evaluation, harvesting, transport and processing. In the forest industry the identification of the assets is quite challenging as wood is a natural material with varying properties, and the processing takes place outdoors often in adverse weather conditions. To bridge the gap to technological implementations, the Object Management Group (OMG) developed a standard Business Process Model and Notation - BPMN 2.0 - from design to process definition and implementation for planning and control (OMG, 2011). This standard was acknowledged in its version 2.0.2 as ISO/IEC 19510:2013. The utilization of this concept for forest supply chain planning and control shall support the better understanding from business users to technical developers for creating, implementing, managing and monitoring the initial drafts and iterative solutions of the processes and required data interface standards. Thus, BPMN can be explained as a semantic and technological bridge to the gap between the business process design and process implementation for forest supply.

As part of high level optimization strategies, these approaches gain more and more interest by the stakeholders of the forest-based supply chain. They are willing to increase the technical level in order to get rid of monitoring gaps and make use of the advantage provided by digital media and tools. Especially industrial producers like sawmills, pulp and paper industry are willing to establish or already using different ICT solutions and may be the spearhead in "digitizing" the supply chain accordingly. Especially by introducing de facto standards like StanfordD 2010 (Arlinger et al., 2012) for wood harvesting machinery data, ELDAT (Urbanke, 2010) in Germany and FHPdat (Austria) show and undermine the strength and advantages of leveraging ICT (information and communication technology) e.g. for data exchange interfaces in the forestry domain. E.g. the StanForD standard is used in several countries and constitutes a de-facto/industry standard even though it has not been afforded any official status. As industry standards differ in content and application new platforms like Cosedat (https://www.cosedat.com) evolve which try to bridge the gap between these country-wide standardization efforts including at least the cross border data exchange needs at least for the German speaking countries.

A prerequisite for allowing applications and systems to communicate with each other in an agile and flexible way is the interoperability between the systems and interfaces used. The OGC (Open Geospatial Consortium) and the ISO have created web service interface standards for publishing, accessing and visualizing spatio-temporal information like the standards emerging from the Sensor Web Enablement Initiative enhancing spatio-temporal data with machine control information from forest management like StanForD -Standard for Forest machine Data and Communication 2010 - to business modeling using XBRL (eXtensible Business Reporting Language – XBRL.org). After years of development and work in progress, OGC/ISO standards are now considered mature enough to serve as the basis for most of the web-based spatio-temporal planning and control systems that are currently developed.

OGC standard enabled web services have been developed for standardizing the exchange and integration of geospatial vector (OGC, 2010) and raster data (OGC, 2006) for planning and the command and control systems used for monitoring the forest supply chain. The Sensor Web Enablement (SWE) standards family extends the OGC web services and encodings framework by providing additional models to enable the creation of web-accessible sensor assets through common interfaces and encodings. SWE enabled services will be designed to support the discovery of sensor assets (Harvesters, trucks etc.) and capabilities, access to those resources and data retrieval, subscription to alerts, and tasking of sensors to control observations (Bröring et al., 2011). As part of the FOCUS project we'll focus on data integration components relevant for planning and monitoring the desired industrial processes and mobility/logistics. Therefore a common set of semantics will be defined being used for harmonizing the sensor data exchange for the forest supply chain. Especially for communicating near-real time harvesting status information for some cases it also makes sense to communicate some auxiliary status information using apps by collecting information from the personnel. This so-called 'people-as-sensors' (Resch et. al., 2011) data might be e.g. helpful to report e.g. barrier information on the transport network.

2.2 Harmonizing sensor measurements for cross-domain utilization

As a new approach in the forestry domain we introduce the standardised way to transmit the required sensor measurements in a technically and semantically harmonized manner according to the Open Geospatial Consortiums' (OGC) Sensor Observation Standard (SOS) 2.0. As one of the OGC's SWE standards, this standard evolved within the last years as a general approach to standardize spatio-temporal measurements. The standard is heavily used by environmental domains (e.g. weather, climate, air quality stations etc.) and yet reliable as it has been chosen to be used for reporting the sensor measurements of 'Environmental monitoring facilities' defined in the EC INSPIRE directive. In comparison to the de-facto industry standards for the forestry domain like Stanford D 2010 (Arlinger et al., 2012) the OGC Sensor observation standard is open and is leveraging the ISO 19156:2010 standard for domain agnostic encoding of any sensor measurements. As mentioned the advantage of the proposed OGC standard is its openness for easy integration of position information, an important variable identified by the expert users questioned. A further idea is to archive these data to make the results available and comparable over a specific time period e.g. for subsequent analysis, simulation and documentation purposes.

In order to monitor harvest machinery and trucks – which are both part of the forest-based value chain – there are a number of approaches mentioned in scientific literature (Castonguay and Gingras, 2014; Scholz, 2015, 2011, 2010; Scholz et al, 2008). Generally, monitoring trucks in (near) real-time involves the gathering of the position and other status data and sending them to a central server, where those data are stored for visualization and analysis purposes (Castonguay and Gingras, 2014; Devlin et al., 2008; Menard et al., 2007; Scholz, 2011, 2010). The analysis and visualization can be achieved with online or offline Geographical Information Systems (GIS) (Longley et al., 2008). The first option – web-based GISs – have the opportunity to be accessible via the Internet, thus offering the possibility to instantly visualize the current position and other relevant data.

The approach to transmit data from the vehicles to a central server, most solutions in literature use the Location-based service metaphor – although not always explicitly mentioned (Adams et al., 2004; Brockfeld et al., 2007; D'Roza and Bilchev, 2003; Wang et al., 2008). Location-based services are services that utilize the self-positioning capabilities of mobile devices – which can be mounted on trucks, and submit or receive information based on the position. A generic system architecture for that purpose is presented in literature (Castonguay and Gingras, 2014; Scholz, 2011, 2010), which can serve as blueprint for the FOCUS project. The architecture for such Location-based services can be either proprietary or follows open standards, which are defined in an open manner.

The sensors that gather data of the vehicles are sensors for self-positioning capabilities – i.e. Global Navigation Satellite Systems (GNSS). For Europe the future Galileo system is of highest interest, but for 2014 GPS and GLONASS are the favorable GNSS. For gathering other vehicle relevant data, the CAN Bus of vehicles offers a number of data relevant for the project. Coupling CAN Bus data and GNSS with the Location-based service metaphor seems like a possible strategy to gather location aware data of timber trucks (Rao and Rao, H., 2013).

2.3 Communicate with spatio-temporally enabled dashboards

In today's decision making processes the integration of near real-time information is highly valuable in the field of integrated management. The challenge is to bring the different data from various sources together in a convenient manner and deliver them at the right time, to the target audience, in a user-centric way. Especially for the monitoring of business processes within and across different organizations and institutions these aspects very important.

At this point management dashboard systems, in some domains like safety and security also called 'Common Operational Picture' (COP) systems come into play to combine all relevant information into contextualized interface views for enhancing the situation awareness and collaborative planning in and between these institutions. Dashboards are composed of so called widgets, which are a reusable piece of software (W3C, 2012). Examples of widgets are data tables, histograms, pie charts, bubble charts, topological and choropleth maps, etc. As mentioned in COPADATA (2014), the ISO 9241-110:2006 standard defines such an user interface view as a synonym for HMI, as "all parts of an interactive system (software or hardware) that provide information and control that is necessary for the user to complete a certain task with the interactive system". The User Experience (UX), more formally defined in ISO 9241-210:2010, is the perception that results from using such a user interface and its underlying systems or services.

Therefore it is goal of the overall FOCUS project to develop 'Dashboards' interfaces to support the monitoring of the forest supply chain integrating maps and multimedia information like pictures, videos, audios and (structured) text. This information will be integrated with near real-time insitu (like weather station data) and mobile sensor data from harvesting and transportation units to support the requirements for near-real-time monitoring of the forest harvesting chain.

3. Results

As a first part of the work it was necessary to learn about the needs, which ad-hoc information layers are important for the forestry user groups to support an enhanced forestry production picture in dashboard style.

3.1 Guided interviews

Therefore guided interviews including a survey handout are a suitable tool to collect information from specialized user groups collecting the required (Moser, 2012) using a mixture of predefined and open questions. When performing such interviews the interviewer has to address his audience in an individual manner to make sure to appeal not to formal. As part of a FOCUS project requirements analysis we used this formalized expert interview strategy also for elaborating the needs for near-real-time information needed from forest harvesting and further auxiliary data needed for the woods' transport.

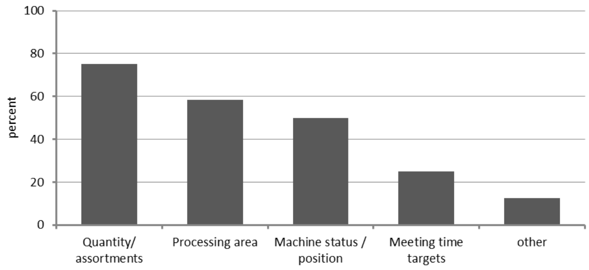

Figure 1. Importance of different aspects for the platform integration.

If you look at the results from the guided expert questionnaire, which reflects the response from 24 forest domain experts presented in Figure 1, it is evident that besides knowledge about quantities/assortments there is a great need to also have information on processing area and machine status available in a proposed platform like FOCUS.

If we go a bit more into detail with regard to sensor-data from harvesters following groups of measurement phenomena have been identified as valuable for monitoring and subsequent analysis and simulation.

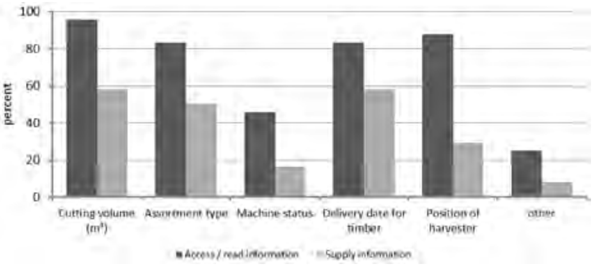

Figure 2. Important monitoring information provided from harvesters.

The same question has been performed for forwarders with following results.

Additionally following phenomena of interest have been identified for wood-trucks.

Summing up, the results of the guided survey shows, that the extensive use of ICT in the forest supply chain is not common in general. When taking a closer look about the underlying issues, common response by the experts have been the facts of the financial costs which form barriers, as well as different or not existing data exchange standards and last but not least the low ICT integration and use in forestry companies in general.

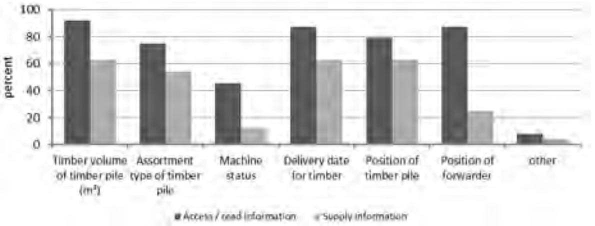

Figure 3. Important monitoring information provided from forwarders.

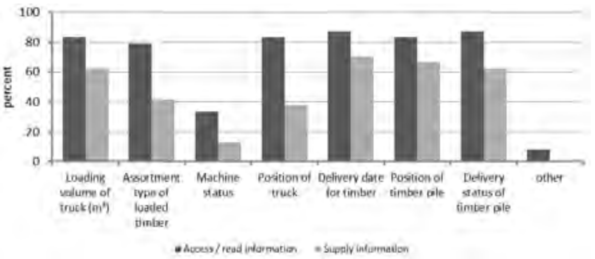

Figure 4. Important monitoring information provided from wood trucks.

Additionally, the transportation industry in Austria – according to industry experts in Austria- fear an overall control of the transport supply chain by the powerful wood processing industry in Austria. In general, e.g. transport companies in Styria are relatively small, and thus don´t have sophisticated planning systems or the resources – financial and personal – to develop or to improve their forest management planning process and/or the financial background to invest in ICT planning tools.

The general impression regarding the transport supply chain is, that there is almost no cooperation between different transport companies (i.e. return freights for other haulers, mutual transport planning), but rather high competition. Hence, it is difficult to gain an accurate overview of the state of the supply chain in real-time – in detail: where is the timber currently, what is the state of the transport processes, how much timber will arrive in the saw mill(s) in the next hour(s)/day, etc. Thus, in the contemporary supply chain the degree of uncertainty is relatively high. Furthermore, sawmills and pulp/paper mills also don´t cooperate with each other regarding resource allocation and transport planning. Hence, there is a problem that the transport processes could be optimized easily, just by sharing of information and finally resources.

3.2 Harmonized sensor measurement integration

One of the seven standards is the OGC Sensor Observation Service (SOS), which defines a standard interface for a Web service client that makes it possible to organize current, simulated or archived sensor data over a network such as the Internet. Sensor Observation Services (SOS) are essential parts of Spatial Data Infrastructures (SDIs), which are mainly organized in open or distributed IT-architectures today. The Sensor Observation Service (SOS) is a web service to integrate and query real-time sensor data and sensor data time series and is part of the Sensor Web. The offered sensor data comprises descriptions of sensors themselves, which are encoded in the Sensor Model Language (SensorML), and the measured values in the Observations and Measurements (O & M) encoding format. The web service as well as both file formats are open standards and specifications of the same name defined by the OGC. Therefore SOS enables to integrate geo-referenced and harmonized measurement information gathered in line with the 'Observation and Measurement' standard (OGC O & M – EN/ISO 19156) in GI systems.

The SOS defines a programming interface for the management and value retrieval of sensor data installed in situ or mobile in the field. Like other OGC Services it provides three essential core operators for clients:

- GetCapabilities which returns an XML service description with information about the interface (offered operations and endpoints) as well as the available sensor data, such as the period for which sensor data is available, sensors that produce the measured values, or phenomena that are observed (for example air temperature).
- GetObservation which allows pull-based querying of observed values, including their metadata. The measured values and their metadata is returned in the Observations and Measurements format (O & M).
- DescribeSensor that provides sensor metadata in SensorML. The sensor description can contain information about the sensor in general, the identifier and classification, position and observed phenomena, but also details such as calibration data.

The sensor measurements of the FOCUS projects will be sent automatically to organization specific datastores via a standardized service interface using a Transactional Open Geospatial Consortium (OGC) Sensor Observation Service 2.0 organizing measurements according to space, time, context and phenomenon. Therefore following functions are being used:

- InsertSensor to provide auxiliary information for each sensor system (e.g. from a truck)
- Update Sensor Description to update sensor descriptions
- InsertObservation to insert the distinct sensor measurements organized logically

Following figures show a SOS transactional InsertObservation 2.0 SOAP request shows an example of integrating a measured phenomenon (truck velocity) conducted with its auxiliary information like location, time, context (featureOfInterest), units of measurements and quality measures into the harmonized OGC data model (Figure 6 simplified).

Each sensor system and its associated phenomena in FOCUS are being described according to the above described OGC SensorML and O & M standards. As also other streaming data sets like meteorology information are also organized and stored in a comparable technically and

Figure 5. SOAP Example for inserting truck sensor data using OGC InsertObservation.

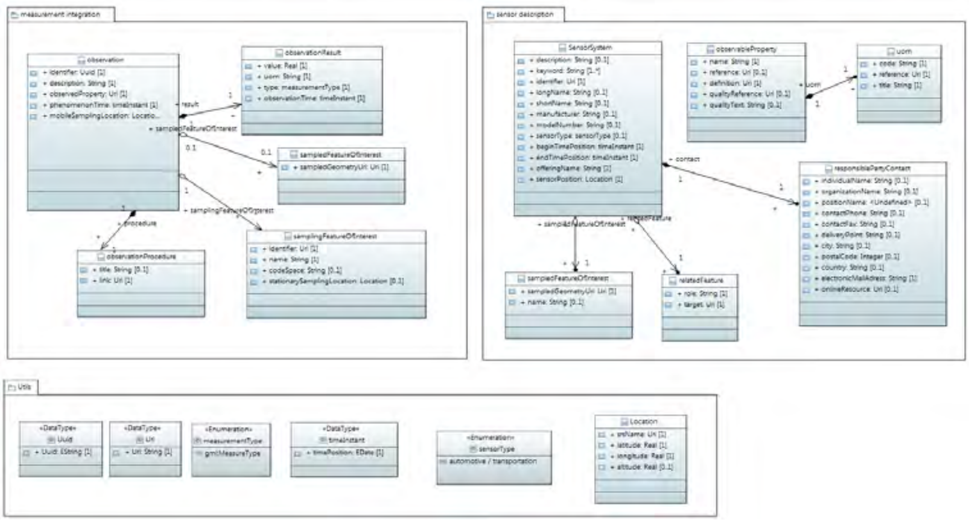

Figure 6. Simplified data-model for OGC SOS measurement integration.

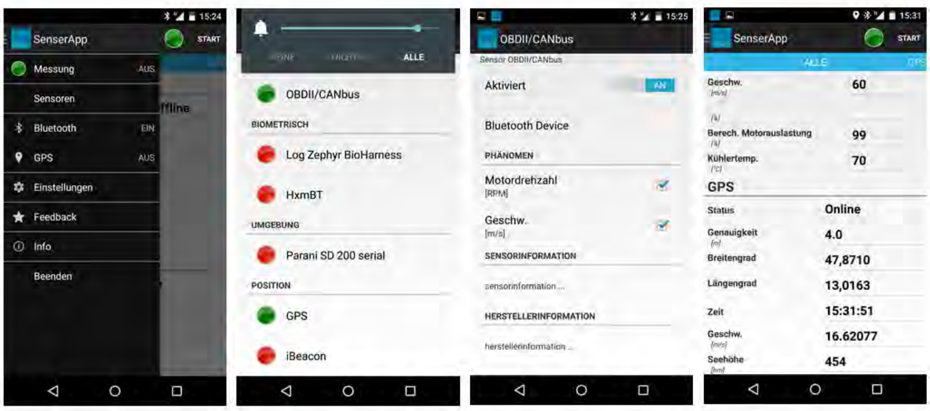

Figure 7. Example of truck monitoring app.

semantically harmonized manner, it is way easier to combine these information layers with existing datasets in a subsequent stage.

To simplify this data collection on the harvesting machinery extension for existing telemetry software is being developed by the consortium partner Wahlers. To ease the integration of truck data a custom Android based application is being developed which allows collecting the necessary truck related sensor information.

Originally it was planned to use the Onboard Diagnostic unit (OBD) interface standard for trucks to extract also engine data. When testing with different trucks, we dropped this approach, as due to the lack of standardization of this interface across truck vehicle vendors; there is right now no cost effective solution for trucks available, comparable to cars where Bluetooth modules can be applied to extract engine sensor data information. The upcoming new WWH-OBD (ISO 27145) standard for heavy-duty vehicles which conforms to the requirements of the Euro-VI emissions will serve as such comparable standards, so as soon as such modules will become available for trucks, as vehicle manufacturers are obligated to implement a WWH-OBD capable diagnostic system interface, we'll also integrate this data.

In addition to the sensor measurements there will be additional data containers, upon request in an on premise installation at the partners IT-site, organizing additional datasets identified for usage within FOCUS. For auxiliary spatial data one or more data containers will be established serving the required data using standardized mapping - OGC Web Mapping Services, OGC Web Coverage Service for raster data and feature download web-services - OGC Web Feature Services for vector data.

To support privacy and security the data-sharing components will be exposed using SOA based Triple-A-System to secure distributed (geo-) web services strategies. Triple-A-Systems are described: authorization, authentication and accounting. Within FOCUS we'll focus on authentication and authorization. In addition to the RBAC mechanism described above technologies like the OASIS SAML (Security Assertion Markup Language) standard, XACML (eXtensible Access Control Markup Language) will be evaluated and according to their fitness of use implemented as part of the FOCUS architecture.

3.3 Dashboard visualization strategies

One major component for communicating the sensor measurements from machines and personnel as part of the FOCUS project, prototype map-enabled dashboards will be developed, that aims to communicate the shared information in a spatially and temporally aware manner within and between forestry companies and organizations. Management Dashboards provide the relevant information in the form of specific views that enhance the situational awareness and collaborative planning. Introducing linked dynamic maps with 'classic' dashboards shall enhance the users experience when working with these datasets by providing an additional 'map-centered' interface and even more important by introducing special filtering options for spatial and temporal tailoring of the dashboard interfaces. This new approach is especially suited to be used when monitoring spatially distributed sensor-data providers in the forest harvesting chain. The dashboards with their enhanced 'spatio-temporal' capabilities assist local operation managers to investigate and monitor the situation on site and to provide decision support. The visualization of this information in a spatio-temporal way is based on standardized web services leveraging OGC's widely acknowledged WebMap-Service (OGC WMS) standard, Web Feature Service Standard (OGC WFS) and WebMap-Tile-Service standard (OGC WMTS). Both the georeferenced Raster-Image Standard OGC WMS and the georeferenced Vector-standard are also available as ISO standards ISO 19128 (OGC WMS) respectively ISO 19142 (OGC WFS).

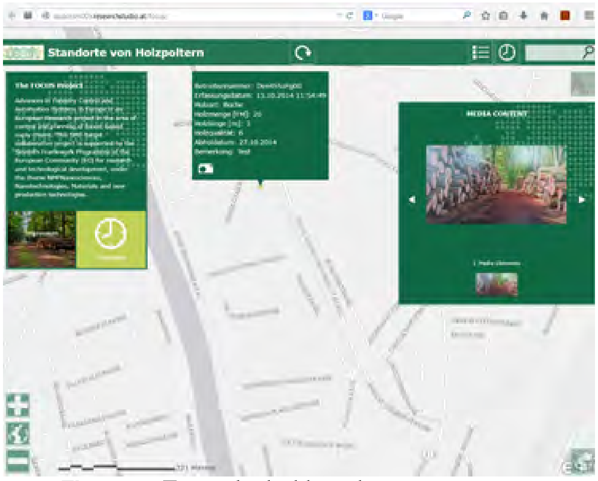

Figure 8. Example dashboard map component.

As a result Figure 8 shows an example of one proposed outcome, a visualization component for the open-sourced parts of the FOCUS platform, providing a spatio-temporal enabled web map integrating available existing auxiliary spatial information, which is being feed with measurements provided by forestry machines and forestry personal that are required for the near-real-time monitoring needs.

4. Summary and Discussion

One of the main chances in the supply chain is the improvement of the cooperation between different actors along the supply chain (vertical cooperation) as well as between actors on the same stage (horizontal cooperation, e.g. between different haulers resp. between different sawmills). Since a lot of data (e.g. position data of trucks, harvester data etc.) are automatically captured in different points of the supply chain but are often not used, they, if technically and semantically harmonized, provide a great basis for the improvement of the forest-based supply chain with regard to monitoring, analysis and simulation purposes. As part of FOCUS we develop prototype to demonstrate how innovative sensor technologies and sophisticated software solutions can integrate control and planning processes across the forest-harvesting process chain ensuring efficient communication mechanisms between the multiple companies and organizations.

Acknowledgment

This work was supported by the FP7 FOCUS project - Advances in the Forestry Control and Automation Systems in Europe, grant agreement no: 604286.

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Towards better pre-clearance guideline of undergrowth in first thinnings: Case study Stora Enso Wood Supply Finland

K. Kärhä*

Abstract
The aim of this survey was to identify the present level of pre-clearance of undergrowth in first thinnings and to research the direction which the pre-clearance guidelines should be taken. The main goal was to construct one functional guideline for pre-clearance of undergrowth in first thinnings at the Stora Enso Wood Supply Finland (WSF). The survey material (153 interviews) was collected by phone interviews in 2013. Based on this survey, a process for constructing new pre-clearance guidelines was launched at the Stora Enso WSF in autumn 2013. The novel guideline was applied in 2014. One uniform pre-clearance guideline has boosted our operations in first thinnings: It has more precisely directed the pre-clearings in first thinnings obviously having a real need of pre-clearance. Moreover, the quality of the pre-clearings has improved thanks to the unambiguous pre-clearance guidelines. All of this has had a positive impact on our harvesting productivity and costs of first-thinning wood.

Keywords
first thinnings, pre-clearance, undergrowth, wood harvesting

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1. Introduction

1.1 First thinnings in Finland

During the 2000's, the average annual area of first thinnings carried out in Finland has been 184,000 ha (Juntunen & Herrala-Ylinen, 2014; Suomen virallinen, 2015), and around 7–8 million m^3 solid over bark (sob) of first-thinning wood has been harvested. In the National Forest Programmes (Kansallinen metsäohjelma, 1999; National Forest, 2008) the targeted first thinnings has been set to 250,000 ha per year. Thus, the Finnish forests are embodying cumulative first-thinning areas of, on the average, 66,000 ha annually.

Consequently, the Natural Resources Institute Finland (Metsävarat metsäkeskuksittain, 2015) has calculated the annual amount of first thinnings to be 350,000 ha throughout the whole next decade in order to manage to clear up the areas of first thinning. If first thinnings would be conducted according to the set objectives (250,000 ha/y), the annual amount available for harvesting would be approximately 10–11 million m^3 sob of first-thinning wood.

The weak interest in first thinnings can be seen from the background of their high harvesting costs: small size, low roundwood removal per hectare and per stand, as well as dense undergrowth indicate low cutting productivity and high costs when cutting and furthermore harvesting (e.g. Kärhä et al., 2004; Kärhä & Keskinen, 2011). In 2014, the average harvesting costs in first thinnings carried out by the Finnish forest industries and Metsähallitus were 17.7 €/m^3 when the average stem size was 78 dm^3 and the average roundwood removal 45 m^3/ha (Strandström, 2015a; 2015b).

To rise the areas of first thinnings from the present level calls for improvement of harvesting conditions: Primarily, the seedling stands have to be tended punctually and vigorously enough so that the seedlings of the production tree stand to be raised will have chances to reach the dimensions of roundwood before first-thinning operation.

Additionally, the harvesting conditions of first-thinning stands can be improved by pre-clearance of the dense undergrowth harmful for the harvesting. According to the research by Oikari et al. (2010), wood procurement professionals consider pre-clearance of undergrowth as the most significant method of boosting the harvesting of roundwood at first thinnings. Substantial undergrowth hinders the harvester operator's visibility by selecting the stems to be cut. Furthermore, a dense undergrowth brakes saw chains and bars and hydraulic hoses, as well as blocks the operator for bringing the harvester head to the butt of the stems to be cut (Hakkuutyömaan ennakkoraivaus, 2001). All these factors degrade the cutting work productivity and quality.

In Finland, statistics on pre-clearance areas of first thinnings are not compiled separately; instead the Natural Resources Institute Finland does compile statistics on the total pre-clearance area of intermediate fellings: in the early 2000's the annual pre-clearance area of intermediate fellings in Finland amounted to about 30,000 ha. Compared with the early 2000's this kind of pre-clearance has doubled in the last years (Juntunen & Herrala-Ylinen, 2014; Suomen virallinen, 2015). If presumed that the major part of pre-clearance of intermediate fellings is made on the first thinnings, then almost every third of the first-thinning stands has been pre-cleared during the last years.

1.2 Pre-clearance guidelines at Stora Enso Wood Supply Finland

At Stora Enso Wood Supply Finland (WSF) almost one million m^3 sob of first-thinning wood is annually harvested – about half of it cut in the forests of Tornator Oyj and the other half in non-industrial private forests. On the first thinnings harvested in 2013 Stora Enso WSF applied three different guidelines for undergrowth pre-clearance:

1. Tornator's guidelines for pre-clearance. On Tornator's first thinnings of roundwood, pre-clearance guidelines were introduced for testing in autumn 2012. These guidelines presented exact pre-clearance limits as to when the pre-clearance of undergrowth has to be done: if there are more than 2,000 trees/ha being higher than 2.0 m spruce undergrowth, or more than 8,000 trees/ha higher than 2.0 m deciduous undergrowth. The guidelines recommended pre-clearance of a circular area (1 m radius) around each merchantable stem and from elsewhere in the stand (i.e. intermediate areas) of the undergrowth higher than 1.5 m and less than 5 cm of diameter at breast height ($d_{1.3}$).

   The clearance limits and the way of applying the clearance given in the partly for testing used pre-clearance guidelines were subject to criticism. Therefore, several review meetings on Tornator's first thinnings on the operation areas of Stora Enso WSF were arranged during the spring and summer 2013 to find out, whether the pre-clearance made by the Tornator lumberjacks had been well conducted according to the pre-clearance guidelines, and on the other hand, if the first-thinning stand was eventually not pre-cleared, should have been cleared. The forest machine contractors of Stora Enso WSF and their harvester operators, as well as the officers of Stora Enso WSF and Tornator were actively involved in these review meetings.

2. Metsäteho's pre-clearance guidelines. On the first thinnings of other forest owners – and also on Tornator's first thinnings before autumn 2012 – pre-clearance guidelines drawn up by Metsäteho Oy (Hakkuutyömaan ennakkoraivaus, 2001; Kärhä et al., 2006) were applied at Stora Enso WSF all along the 21st century. Unlike the testing Tornator guidelines, the pre-clearance guidelines made by Metsäteho did not embody any specific limits for pre-clearance, but only a reference that the undergrowth harmful for harvesting has to be pre-cleared. Metsäteho's pre-clearance guidelines recommended that a circular area (1 m radius) shall be cleared around each merchantable stem and elsewhere the undergrowth harmful for harvesting being higher than 1.5–2.0 m and less than 7 cm of diameter at breast height.

   In the late winter 2013, Stora Enso WSF introduced the Eight-Centimetres-Minimum-Stem-Directive declaring that trees with less than 8 cm diameter at breast height will be undergrowth tree on the marked Stora Enso WSF first-thinning stands, and at Stora Enso WSF this change of minimum stem was updated in the above-mentioned pre-clearance guidelines made by Metsäteho.

3. Forestry Centre Tapio's pre-clearance guidelines. On Stora Enso WSF's first thinnings, where energy wood was cut, Tapio's pre-clearance guidelines based on visibility clearance were used (Äijälä et al., 2010). These guidelines instruct pre-clearance of a circular area (0.5–1.0 m radius) around each merchantable stem to be cut and in intermediate areas of the singular undergrowth trees with stump diameter (d_0) less than 4 cm.

1.3 Aims of survey

Operating on first thinnings with three different pre-clearance guidelines is not an optimal solution for any wood supply organisation. Consequently, a study was started at Stora Enso WSF in June 2013 to sort out the experiences of the applied pre-clearance guidelines for first thinnings and explicitly first thinnings of roundwood.

Upgrading proposals on the applied pre-clearance guidelines were also identified. The main goal was to construct one, clear and functional guideline for pre-clearance of undergrowth on first thinnings enabling a more effective harvesting and supply of first-thinning wood during the future years at Stora Enso WSF.

2. Material and Methods

The survey invented first-thinning experiences learnt by forest machine contractors and their harvester operators at Stora Enso WSF, as well as the harvesting officers at Stora Enso WSF of pre-clearings of first thinnings on all harvested first-thinning areas and especially on cut Tornator's first thinnings during the period of the current year (July 2012 – June 2013).

The survey material was collected by phone interviews in July-September 2013. All Stora Enso WSF's providers of roundwood harvesting services, as well as the during July 2013 contracted, forest machine contractors (N=43) were involved. Totally 41 forest machine contractors responded to the survey. Every contractor was during the interviews asked to appoint two of his harvester operators, who mostly had been cutting on first-thinnings sites in the year 2013. All harvester operators set up on the list (N=88) were contacted by phone. The final survey material of the group of harvester operators consisted of 75 operators.

Besides, every harvesting operation superintendents at Stora Enso WSF (N=54) were contacted by phone and 49 of them interviewed. 18 officer interviews had to be erased from the material consisting of 49 interviews, because some of the harvesting superintendents had a very poor view of pre-clearings and their state. Additionally, all contractor superintendents at Stora Enso WSF (N=6) were interviewed

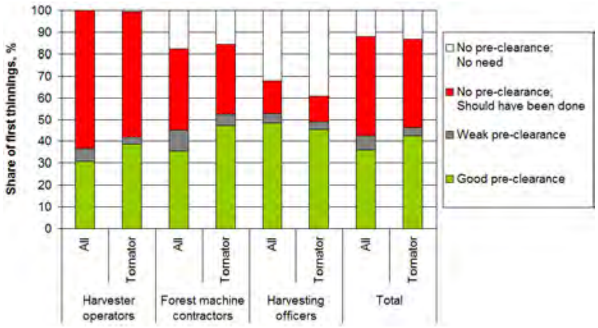

Figure 1. Respondent group estimations of the pre-clearance situation during the current year (July 2012 – June 2013) in all stands, and especially on the Tornator's first thinnings harvested by them.

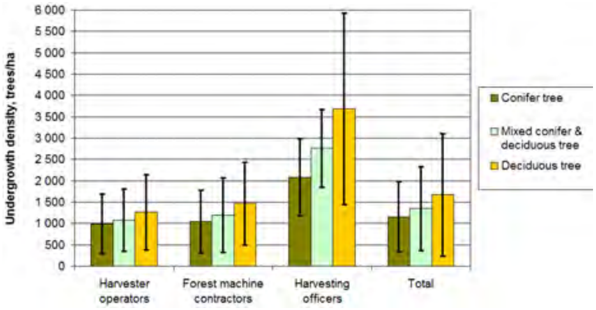

Figure 2. Respondent group opinions on which conifer and deciduous tree undergrowth density begins to hinder the cutting on first thinnings. The bars describe the average and the black lines the standard deviation.

in the survey. Consequently, the final survey material as to the group of harvesting officers consisted of 37 respondents.

The survey material consisted of totally 153 interviews (response rate 80%). Almost half (49%) of the interviewed were harvester operators, more than one fourth (27%) machine contractors, and less than one fourth harvesting officers. The harvester operators had an average experience of 12 years of first-thinning cutting. During the period of July 2012 – June 2013, the harvester operators had cut first-thinning wood, on the average, 11,089 m^3 (sob)/operator, of which volume, an average of 4,873 m^3 was cut on Tornator's first thinnings. 80% of the harvester operators and 73% of the machine contractors had worked on Tornator's first thinnings during the current year.

3. Results

3.1 Present level of pre-clearance of undergrowth

According to the estimates by the interviewees, totally 43% of all first thinnings cut during the current year has been pre-cleared and correspondingly 57% were not (Fig. 1). The respondents considered that the pre-clearings carried out were mostly ably: 36% of the harvesting sites being well pre-cleared. Weakly pre-cleared were 7% of all harvested first thinnings (Fig. 1).

As estimated by the harvester operators, the portion of all pre-cleared first thinnings was 37% of all first thinnings (Fig. 1). The operators claimed that two third of all first-thinning sites were such, which had not been pre-cleared, but should have been. The harvester operators did not recall cutting particularly many uncleared first-thinning sites not having need for pre-clearance during the current year.

Correspondingly, the machine contractors estimated that more than a third of all first thinnings were such, which had not been pre-cleared, but should have been. The harvesting personnel at Stora Enso WSF estimated the share of these sites to less than one fifth (Fig. 1). Summarised the machine contractors' estimations of the pre-clearance situation place themselves between the estimations of the harvester operators and harvesting officers. The pre-clearance situation on Tornator's first thinnings was significantly at the same level as that on all first-thinning stands cut (Fig. 1).

3.2 What is hindering undergrowth?

The interviewees were also asked what kind of undergrowth they consider as harmful for cutting. Their average answers were that:

- when the conifer tree undergrowth density exceeds 1,152 trees/ha and the height 1.42 m, it hinders the cutting,
- when deciduous tree undergrowth density oversteps 1,669 trees/ha and the height 1.86 m, it disturbs the cutting and
- when the mixed conifer and deciduous tree undergrowth density exceeds 1,353 trees/ha and the height 1.62 m, it will cause harm for the cutting work (Figs 2 and 3).

Among the groups of respondents the undergrowth density and height limits hindering for the cutting presented by harvester operators and machine contractors were very closed to each other and significantly lower than the estimations presented by the harvesting officers (Figs 2 and 3): The contractors and operators told, that conifer tree undergrowth begin to be hindering, when the average density is more than one thousand trees per hectare and the height oversteps 1.3–1.4 m. As to deciduous trees, the density and height limits of undergrowth were higher: that is over 1,300–1,500 trees/ha and higher than 1.8 m. The harvesting personnel at Stora Enso WSF considered the average densities of over 2,083 conifer tree undergrowth/ha and more than 3,689 deciduous tree undergrowth/ha as hindering for the cutting. Moreover, the harvesting officers at Stora Enso WSF valued that conifer tree undergrowth of less than 1.7 m height and deciduous tree undergrowth of less than 2.2 m height do not hinder the cutting work (Figs 2 and 3).

3.3 Characteristics of good pre-clearance

Because some respondents stated that some parts of the first thinnings had been poorly pre-cleared during the current year, the interviewees also were inquired about their view on the characteristics of a good pre-clearance. The main statements to this question are listed as follows:

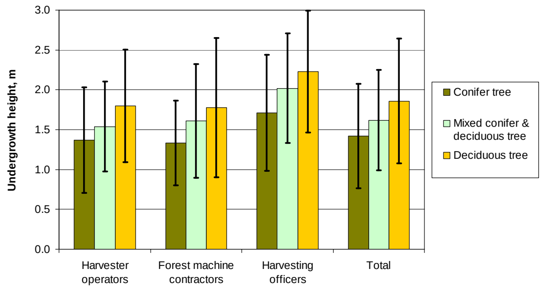

Figure 3. Respondent group opinions on which conifer and deciduous tree undergrowth height begins to hinder the cutting on first thinnings.

1. The trees eligible for harvesting are cleared within a circular area (average radius 1.24 m) and the stumps cut down by sawing (to average less than 10.8 cm). – This implies, that if the first thinning hypothetically had 1,700 trees/ha eligible for harvesting situated evenly spread on the marked stand, and the circular areas (1.24 m radius) are pre-cleared around each harvestable stem, about 80% of the total marked stand will be pre-cleared. As a comparison, should the radius used by pre-clearing the circular area be 1.0 m, then the butt clearance would cover about half of the marked stand area.

2. On intermediate areas the undergrowth higher than 1.96 m is pre-cleared. The majority of the machine contractors and particularly the harvester operators pointed out that a total pre-clearance would be convenient in this case, which means that the undergrowth less than two meters high should not be left uncleared. The contractors and operators commented that the time consumed for pre-clearance easily increases and the clearance gets arduous, when you have to go out and weave in the dense undergrowth with your brush saw to clear only the high (>2 m) undergrowth trees from the intermediate areas.

3. Pre-clearance is, according to its name, carried out in advance, on the average, 9.2 months before harvesting operation, thus enabling the cut undergrowth to be well compressed on the ground. Many operator and contractor accentuated that it is not essential, how many months in advance the clearance is carried out; the main issue is that pre-clearance is done before harvesting. Respectively, the harvesting officers emphasized that pre-clearance has to be done a bit over a year (average 12.6 months) before harvesting.

4. Discussion

4.1 Basic information from survey

The goal of this interview survey was to identify the conceptions among wood harvesting professionals and the present level of pre-clearance of undergrowth on first thinnings and, on the other hand, to research the direction whereto the pre-clearance guidelines should be taken. The project aimed at listening to the “voice of the field” and to compile the basics enabling us to construct one functional guidance for pre-clearance of first-thinning stands at Stora Enso WSF.

Clarified pre-clearance directions were considered important, because it is not possible to apply different pre-clearance guidelines in the forest stands of different groups of forest owners. Likewise the directions for pre-clearance cannot differ depending on whatever – roundwood or energy wood – will be harvested on the first thinnings: The fact is that the undergrowth tree hindering the cutting of roundwood also hinders the felling of energy wood. Additionally, it has to be considered that the same first-thinning stand can, according to market situation, be directed either to separate harvesting of roundwood or energy wood or to integrated harvesting of roundwood and energy wood (cf. Kärhä & Mutikainen, 2008; Kärhä et al., 2011).

The survey gave a good understanding of where the level of the undergrowth limits harmful for cutting are placed according to the views of harvester operators’, machine contractors’ and the harvesting personnel of the wood procurement organisation. The set limits based on conceptions and experiences of the interviewees. The views of harvester operators, being experienced first-thinning operators and having cut huge volumes of timber on first thinnings during the current year, can be considered to base on a very solid ground.

The big differences as to harmful undergrowth limits by cutting, existing between the responding forest machine operators, as well as between the machine contractors and harvesting officers demonstrate, how differently things are encountered. Thus, Kärhä (2006) has emphasized, that different harvester operators have differing tolerance thresholds towards undergrowth: some consider a certain kind of undergrowth as extreme harmful for cutting, when someone else does not see the same undergrowth as especially harmful.

When looking into the defined undergrowth limits affecting the cutting given in this survey, one also has to keep in mind that the limit evaluations of all respondent groups were influenced by those, on first-thinning stands frequently conducted pre-clearance review meetings of marked stands involving exact undergrowth measurements, as well as the active discussion on the subject at Stora Enso WSF in the year 2013.

The undergrowth limits affecting the cutting defined in the survey were, however, not actual pre-clearance limits, because their determination requires consideration of following elements: 1) The declining cutting and forest haulage productivity caused by undergrowth, and its additional cost. 2) The eventually poorer silvicultural result after harvesting and its costs, and finally, 3) at the opposite end of the scale the costs of pre-clearance. For instance, Kärhä (2006) has calculated that with a removal of roundwood of 50 m^3/ha, a stem volume of 80 dm^3 and a average height of spruce undergrowth of 2–3 m, pre-clearance will be a profitable operation for the whole economy whenever the density of spruce undergrowth exceeds 1,400–2,800 stems/ha.

Like Stora Enso WSF, also Metsähallitus (Heikkinen,

2012) and Metsä Group (Lankinen, 2012) have been searching for pre-clearance limits for the first-thinning stands they have harvested. In the survey by Heikkinen (2012), the limits for pre-clearance of spruce undergrowth were 1,200 spruce undergrowth trees/ha and the average height of this undergrowth was 4 m, and 2,200 spruce undergrowth trees/ha with the average height of 3 m. The corresponding pre-clearance limit for deciduous tree undergrowth was 5,000 stems/ha.

4.2 Novel guideline for undergrowth pre-clearance

Based on the carried out survey, a process for constructing new pre-clearance guidelines was launched at Stora Enso WSF in autumn 2013. The interview material collected when surveying had a most important role when drawing up the new guidelines for pre-clearance. As support for the decision-making, profitable pre-clearance limit calculations were made also from the viewpoint of the overall economy (cf. Kärhä, 2006).

After two draft versions of pre-clearance guidelines Stora Enso WSF made a decision on a novel pre-clearance guideline for first thinnings at the end of 2013. The new guideline was applied in 2014. The response received during this not full two years has been good. – One, uniform pre-clearance guideline has boosted our operations on first thinnings: It has more exactly than before directed the pre-clearings to first thinnings obviously having a real need of pre-clearance. Moreover, the quality of the pre-clearings has improved thanks to the unambiguous pre-clearance guideline. All this has had a positive impact on our harvesting productivity and costs of first-thinning wood.

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SLOPE: A 3D forest virtual system to support harvesting operations in mountain areas

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Abstract

Mountain forest management and forest production differ from other industrial management schemes due to; the temporal sequences of vegetative succession which could last years, the remoteness of the forests, limited accessibility and hydro-geological constraints. Forest harvesting in mountain conditions pose a series of organizational and technical problems, since steep terrains and areas are typically served by a relatively poor road network which increases forest operations costs, reducing the produced assortments competitiveness when compared to similar flatlands products. Forestry operations in mountainous areas are rarely performed by harvester or forwarder systems and is the only sector still characterized by manual felling, while extraction of timber or whole trees is performed only in the most evolved cases by cable carriage systems. A higher degree of mechanization in steep terrain conditions, such as a coupling cable crane and processor, can lead to significant improvements, particularly when whole-tree extraction techniques are applied. But their initial setup requires significant time and economical effort, which raises the need of effective planning simulation tools. Nowadays, systems based on 3D representation of geographical information, the so-called virtual globes, are quite common, but the possibility to use these tools as planning and simulation support on the entire forest production has not been completely explored. Through the combination of 3D tree visualization and ecosystem information with management practices and tools a 3D web based system can create realistic visual scenarios for forest management. This paper presents a tool for 3D visualization of forest landscapes, which allows a selection of the most suitable cable crane set-ups and positioning for each forest plot, minimizing or eliminating a time consuming field survey, abridging setup time and overall costs, minimizing the number of required intermediate supports, and maximizing the clearance. Single cable crane lines would also serve as guiding parameters for foresters who are marking the trees to be felled since they will know in advance the direction of timber concentration and extraction.

Keywords

3D visualization, simulation, forest production, cable crane

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1. Introduction

The forest sector has always been very conservative in relation to the new technologies as usually on the field operators tend to be more familiar with manual techniques and simple machines rather than complex and difficult to learn appliance and software. However, as the market has become global and the industrial demand of wood supply has increased, new technology have been slowly adopted to maintain competitive prices and increase harvesting speed and efficiency. Currently, forestry applications are widely adopted in the sector and the majority of them rely on geospatial data for resource management. Recent developments on Unmanned Aerial Vehicles (UAVs), optical systems acquiring multiple-view image data and fast photogrammetric processing algorithms have brought to the market new sources for 3D Digital Surface Models (DSM) of a forest area, while terrestrial laser scanning (TLS) systems can provide a reconstruction of trees shape (e.g. stem taper) within the radius of 10/20 meters from the survey position, supporting low cost, highly portable and rapid measurement of below-canopy 3D forest structure. This data is at the core of the European project SLOPE: Integrated processing and Control Systems for Sustainable Production in Farms and Forests, which aims from a software point of view at the development of a three-dimensional web visual simulation system supporting geo-based realistic modelling and real-time rendering of forest scenes. From this system, new planning tools can be built to support harvesting on steep terrains as part of a more complex multi-disciplinary approach to forest-management planning and decision-making.

Modelling and real-time rendering of high fidelity forest scenes based on real world data is a challenging task in computer graphics and geomatics (Bao et al. 2011) and is a field that has been extensively studied in the past. However, as of today, few researches have been performed on the impact of forest production planning tools over interactive 3D forest models. This paper describes one of the main achievements of the SLOPE project, presenting a web 3D harvesting planning tool specifically developed for mountain environments, which can be used to understand stand succession, landscape transformation, regional planning and to improve decision-making processes and forest management.

After an overview of the decision support tools adopted and experimented in the last decades (Section 2), sections 3 and 4 describe the reconstruction process of a virtual forest model. Section 5 provides an overview of all the simulation and planning tools developed during the projects while section 6 summarizes the achieved results and the planned improvements.

2. State of the art

The history of decision support tools in combination with simulation and optimization techniques in forestry starts in the 70s where some of the first linear-programming software were developed to estimate the forest areas harvesting levels (FAO 2010). In the definition of (McCloy 95), different parts compose a system for forest management: an input interface for data management (editing, update), a database, an analytical engine for statistical and/or numerical analysis, tools for estimation and prediction to be adopted for future developments, a decision-support system and a set of visualization tools. Not all of these elements require an interactive user interface but a forest management system (FIS) should be able to wrap them under the same seamless toolset involving data acquisition and processing, decision support and visualization, thus improving the usability and simplifying their adoption.

FIS involves different information technologies areas where, depending on their technical architecture, data is either stored in a central database or follows a federated approach with retrieval from different remote databases. Due to their spatial context, FIS can be considered extensions of GIS software containing, in addition to geo-referenced data, thematic and non-formatted data with a temporal relation (Wing et 08). One of the main sources of spatial information are remote sensing images. The first aerial photos were taken by analogic cameras with black and white film (Lillesand et al. 00), but nowadays foresters can benefit from new technologies like colour infrared imageries coming from both aerial vehicles and satellites as well as digital image processing techniques. The launch of the satellite Landsat-1 in 1972 started the era of space based remote sensing, with one of the first multispectral camera with 80m resolution, later improved to 30m with the Landsat Thematic Mapper (Lillesand et al. 00). Their light detection and ranging (LIDAR) technology was relatively new with the scanned data constituted by an unstructured set of points in 3D space (point cloud). Compared with conventional data acquisition techniques such as aerial photogrammetry, LIDAR is an active system, works at night, has very high vertical accuracy and resolution per meter and can be used to measure forest canopy heights (Lillesand et al. 00) as well as count and delineate tree stands (Hetemäki 05).

Regarding the decision support, FIS for this purpose appeared in US in the 80s, with a first application for the federal administration and industry of forest. GIS tools were adapted for forest inventory and planning, demonstrating many advantages between the past technology, providing light tables for tracing maps, more clear data visualization with advanced computing calculation (areas) and in early times the ability to constantly update the previously recorded information with additional ones while other management activities, like harvesting and planting were going on. Further integration with enterprise-resource-planning (ERP) systems have been reported in (Hetemäki 05) to manage forest operations while maintaining the documentation required by certification organizations updated. Moreover, they have also been adopted for fire control, road planning and pest management as reported by (Lewis et al. 05).

Regarding 3D visualization, interfaces evolved from simple mapping into sophisticated systems characterized by 3D navigation, interaction and visualization, aspects surveyed in a vast number of research works. Following the "from map to virtual worlds" paradigm, 3D GIS visualize data as a metaphor of the map in 3D (Conti et al. 09). (Thorndyke et al. 82) studied the differences in spatial knowledge acquired from map visualization and exploration. Other surveys stated the importance of real time rendering of terrain and studied new algorithm for this purpose, like multi resolution geometry modelling and multi-resolution textures (Hope 98).

As stated by (Simões et al. 11) , with geospatial information, a user-friendly framework is essential when dealing with mapping applications and the latest generation of 3D interactive applications are the ideal candidates to provide the most user-friendly experience. For a forest landscape planning perspective, understanding spatial patterns and temporal dynamics can take advantage from 3D visualization. With the evolution of computer graphics, the possibility to represent natural environment with interactive photorealistic quality opens new perspective for forestry planners. Finnish researchers highlighted the possibility to use computer-generated images for environmental landscape planning, in particular to understand the visual impact of determined decisions in management procedures. In early forest landscape models, trees were often not represented in their geometrical complexity, but with simple primitives like cones: with the rising of computational power for rendering purposes, challenges of forest rendering were to provide realistic model of forest in real time. Many visualization tools adopted a simple billboard approach, with trees formed by two planar images (Bao et al. 09). Other studies showed programmatic parametric geometrical approaches for representing canopy and tree form, posing great attention to real time performance for average desktop machines and the possibility to use these trees inside an environment reconstructed from 3D digital elevation models (Guo et al. 09). In later years researcher investigated the possibility to create real time better looking 3D forests, creating a new model for lightings inside the forest (Bruneton et al. 12) and new representation of canopy reflectance on steep terrains (Fan et al. 14). The forest 3D visualization is suitable for deploying simulation and modelling of ecological model for environmental evolution (Zyda et al. 97) since with a modelled ecosystem, the environmental planner has easy access to all the data inside an easy to understand visual system.

In these virtual reconstructions, simulation simplifies the understanding of the results of different approaches during the planning phase and the adoption of 3D visualization tools allows the management of a planning problem at different scale levels. At large scale facing problems related to macro landscape design, fire prevention or logistics while at a small scale investigating the nature of the environment and single tree forestry activities like timber harvesting, planting and thinning (Wang et al. 06).

3. The virtual forest model

The project main goal is to represent and render interactive high quality dense forests tree by tree on major web browsers and use this model to support forest production. The input data required for this virtual forest generation includes DTM for terrain representation, forest DSM from UAV surveys, sample plots acquired by TLS and a forest inventory database.

A digital terrain model (DTM) is a regular grid of elevation values on which each point is interpolated from spot height measurement or contour data. It is used to render the terrain and determine the height of the base of tree objects. Digital surface models (DSM) of Figure 1a, IR and RGB image data shown in Figure 1b, are produced by UAV sensor systems during their flight over the forest ,while terrestrial laser scanning acquires cloud of points to reconstruct trees growth. Offline photogrammetric processing can then be used to provide 3D data of the forest and store each tree model in a database containing all its properties.

More in details, the output data at the end of each survey in the SLOPE workflow is the following. Regular grids providing the DTM, point cloud acquired by TLS, the shape information about the trees surveyed by TLS where each tree is represented by a sequence of circles at different height with the centre of the stem and the diameter and the shape information of the tree identified from the UAV data. These four input typologies are the basis for the development of the full 3D forest.

A test site situated in Northern Italy (Lat. 46°14'42.12"N, Lon. 11°19'54.00"E) in the Trentino region has been used for a real data acquisition where five field plots (15m radius each) have been acquired by TLS and DBH (Diameter at breast height), height and specie of each tree was manually measured. Optical image data were acquired in the same period using the UAV system, which consists of a standard and NIR cameras and an integrated navigation system for accurate positioning and altitude determination of the system. Georeferenced orthophotos and DSM with a pixel size of 0.10 m were produced.

By combining these kinds of data, a reproduction of a counterpart of the real forest area in a multiscale visualization has been implemented. Following the virtual globe paradigm, which allows survey area inspection from different resolution and level of details, from the whole world to the single tree accuracy, it is possible to provide a 3D management platform to examine the forest environment from the regional scale to the single tree. The first level of analysis examines the information at the whole forest scale using Earth Observation (EO) data and topographic maps. Satellites images give a wider vision of the survey area, are used to find big patches of trees and in case of multi-spectral or hyper-spectral sensors, can be used to evaluate for instance the health state of the woods. Temporal series of images have been processed in order to evaluate the characteristics of the plot through different indexes: NDRE, which can be directly related to the level of Chlorophyll in the wood and CCCI that can be used as an ancillary measurement to monitor also the Nitrogen and Chlorophyll level.

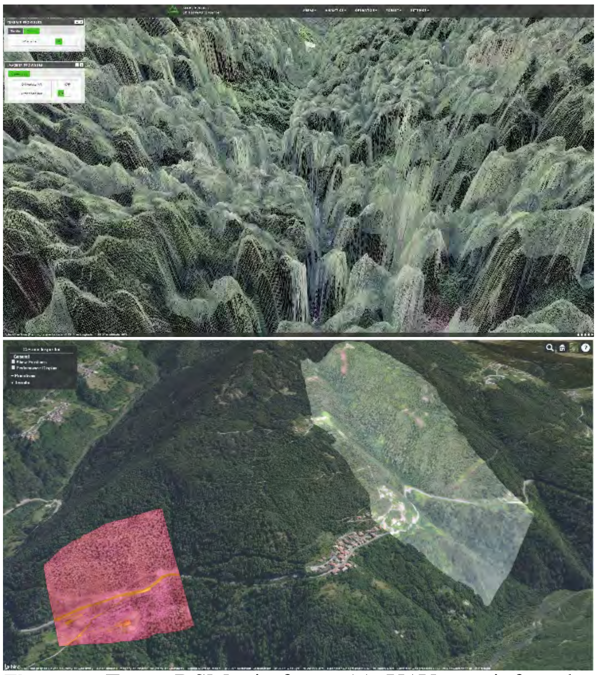

Figure 1. Forest DSM wireframe (a), UAV near infrared (NIR) and orthorectified RGB (b).

To support planning and management of forest resources it is important to consider additional information like cadastral, logistic and environmental data. These data are typically made available as map layers containing the geographical related information and are often freely available as "Open-Data" that can be deployed on a map service after a conversion from their raw data and shown on the 3D web client.

4. From data acquisition to data visualization

The described system is a high-level tool that allows a large scale planning of the forest resources. However, mountain forest management needs a more accurate way to visualize data about vegetation within a smaller scale sufficiently detailed to represent up to a single tree timber. Understanding precisely the economic value of the selected harvesting parcel means optimize the tree felling to areas, which could give the higher profit preserving the silvicultural equilibrium. The first step consist in the acquisition of more resolute spatial information to identify each single tree on the plot. For instance, UAV images give a more accurate smaller scale data of the forest. Through the georeferenced images set it is possible to generate a point cloud densification of the area surveyed and a DSM, in raster geo-referenced image or elevation grid. The elevation grid can reach a resolution of approximately 20 cm representing the DSM of the forest area within the planning tool, recreating the shape of the area and in particular of the digital canopy height model.

The DTM/DSM height-maps data and raster images are exposed respectively as a Tile Mapping Service (TMS) and through an OGC Compliant Web Mapping Service (WMS), which are completely interoperable with any other Geographic visualization service. A key aspect is that we have different level of detail needed in our virtual globe representation for both the orthophotos and the terrain height maps. In particular, for the height maps, the multiscale representation varies from a decimetres scale representation of the surface of the area of interest to the 10 meters scale resolution to represent area in the boundaries of the surveyed site but not involved in planning analysis. The developed system includes a Terrain Tile Map Service that seamlessly exposes maps with different level of details.

The resolution of the digital canopy model obtained by UAV imagery permits, through local maxima algorithm and watershed segmentation to detect single tree and retrieve accurately the number of the trees of that forest parcel (Jakubowski et al. 2013). In this way, due to the georeference of the UAV imagery it is possible to reconstruct the geographical position of the single tree segmented by the aforementioned procedure, and give different identification code to each different tree, correlating this data in the forest visualization model as in the forest inventory database.

To complete the digital reconstruction of the forest the information about stems is needed. The TLS processing can segment from the point cloud the trunks position and size, thus giving an average value of the expected timber volume completed with information like trees number average diameter and the tree density, which is essential to maximize the timber production. These forest parameters have been traditionally estimated on local models for each tree species (e.g. tariff method) which provide a relationship between the measured parameters (i.e. tree DBH, tree height and species) and the target parameters to estimate (i.e. tree volume) but these approaches are not always accurate. Thanks to TLS, it is possible to identify individual trees from the raw scanner point cloud, creating 3D models to accurately recreate an inventory plan of the forest stands. Different TLS samples within a forest allow to infer the main parameters (i.e. tree DBH, and species) for the whole forest. With a combination of this information acquired from the ground with the information derived from UAV data, it is possible to define main geometrical parameters (DBH and height) for the whole forest. The trees are reconstructed through a geometry primitive (cylinder), that reproduces the main morphological characteristics of the tree trunks (height, diameter at different height and quality index) and permit a visual exploration of the plot, to let the user inspect information for each single tree within the three dimensional virtual environment. The conical representation of the tree is functional for the forest planner for a rapid analytics of

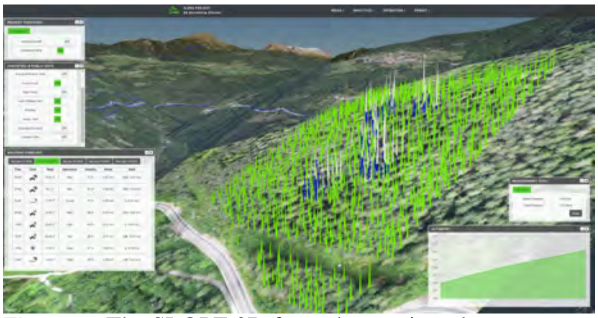

Figure 2. The SLOPE 3D forest harvesting planner interface with weather forecast, satellite imageries, forest rendering and slope analysis.

the economic value of the single stem and augments the decisional support power of the visual virtual environment representation of the forest plot since every tree is mapped inside a data structure representing the whole plot and the parameters for each single tree.

5. The planning tool

In order to achieve a good end-user experience it is essential to provide a smooth and reactive visualization of the forest content with the highest detail possible. This is achievable exploiting the built-in hardware capabilities of modern desktop and mobile computers discrete graphic cards. The so-called hardware acceleration can be used with the adoption of specific standard graphics libraries defining a set of functionalities natively supported by the graphics cards. One of these is OpenGL, a cross-language, multi-platform application programming interface for 2D and 3D graphics widely supported by desktop and mobile hardware. One of the major OpenGL technologies, which has spread in the last years together with is the WebGL technology, which is extensively supported by all the major browsers and platforms.

For this reasons, WebGL together with modern HTML5 web pages have been chosen as the most suitable technology for the interactive visualization of the forest model placed on top of a virtual globe representation of the Earth. The adoption of a virtual globe of the entire Earth allows large scale GIS to small scale point cloud data visualization while the entire Earth coverage, allows parallel visualization of different datasets in different places simplifying the planning and monitoring of wood production.

Among the several WebGL 3D globe alternatives available on the web a highly customized version of the CesiumJS virtual globe, called GeoBrowser3D has been developed. Powered by WebGL graphics and state of the art software technologies, it offers a three-dimensional OGC compliant solution, integrated with computational and visual techniques for an ideal decision making environment. Its main features are the following:

- Support for multi-dimensional GIS and satellite data from different service providers;
- Support of raster data from web mapping and tiling services and vector cartographic data;

Figure 3. The SLOPE forest production workflow.

- Loading and visualization of terrain data from DSM and DTM at multiple resolution;
- Real-time data support using Sensor Observation Service (SOS) standard;
- Support for KML/KMZ Google Earth datasets;
- 3D buildings rendering of large urban areas based on the CityGML standard;
- Planning and collaborative tools like distances and areas measurements, terrain profiling, moving objects tracking and advanced tools for what-if analysis;
- Massive 3D object rendering;
- Support for the open geospatial consortium (OGC) standards: WMS, WFS, OpenLS, etc.;
- Triangulated Irregular Network (TIN) generation and rendering support from multiresolution elevation;

On top of these technologies, a set of new features described in details in the next sections, has been added to the 3D visualization system to simplify the harvesting operation. Each functionality has been specifically tailored to the needs of the actors in charge of the planning and monitoring of the forest production in mountain areas, namely:

- Forest operator: involved directly on field forest operation, like the operation coordinator or the one in charge of the digital surveys
- Forest planner involved in the harvesting decision making process.

These actors are just two among a much higher number that has been recognized (cableway operator, truck operator, harvesting operator, forestry expert, etc.) and has been interviewed to better understand all the use cases and requirements of the SLOPE project workflow of Figure 3.

This workflow, besides the initial forest data collection and reconstruction of the virtual forest model, foresees a planning phase where operators, after the definition of the area to be assessed and marked by foresters, plan the tree felling and extraction. After this phase, which involves the tracking of each tree through RFID tags, trees are processed (cut) and analysed in real time with a highly customized processor head and their properties are stored, tree by tree inside a database for logistic and selling optimization.

5.1 The main interface

As shown in Figure 2, the main interface has three main buttons at the top right corner of the screen to switch between the three working modes that have been identified accordingly with the use cases: analytics, operation and forest. Each mode has its own buttons with floating menus that can be easily moved around the 3D interactive forest model, which covers the main area.

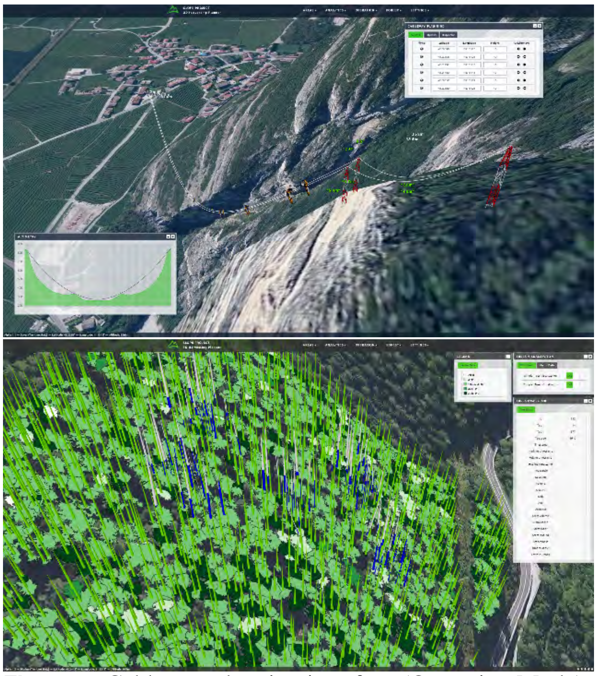

Figure 4. Cableway planning interface (Operation Mode) (a) an tree segmentation and model analysis (Forest Mode) (b).

The analytics mode (Figure 2) provides a set of tools to retrieve geometrical and geophysical information (i.e. slope) about the real estate to be processed. The 3D map can be viewed and inspected with the use of keyboard, mouse and touch gestures and enriched with specific imageries and terrain data (UAVs orthophotos and DSM). It allows viewing a huge amount of trees typical of forest scenario correctly georeferenced thanks to UAV data processing as well as performing terrain analysis, like distance surface estimation and elevation analysis.

The operation mode (Figure 4a), is related to the operational phase, with tools for planning forestry operation for specific days, going from harvesting like felling and processing, to more logistical or general planning ones like assigning resources and machineries. One of the most crucial functionalities on steep terrain is the optimal placement of a cable line to transport logs from the forest to the processing area. This mode enables a what-if analysis where forestry experts can place a cable line, specifying the pillars heights and rope tension visualize the catenary trend of the cable and inspect the covered harvesting area, which depends on the height of the cable from the terrain.

The forest mode (Figure 4b) contains all the tools to

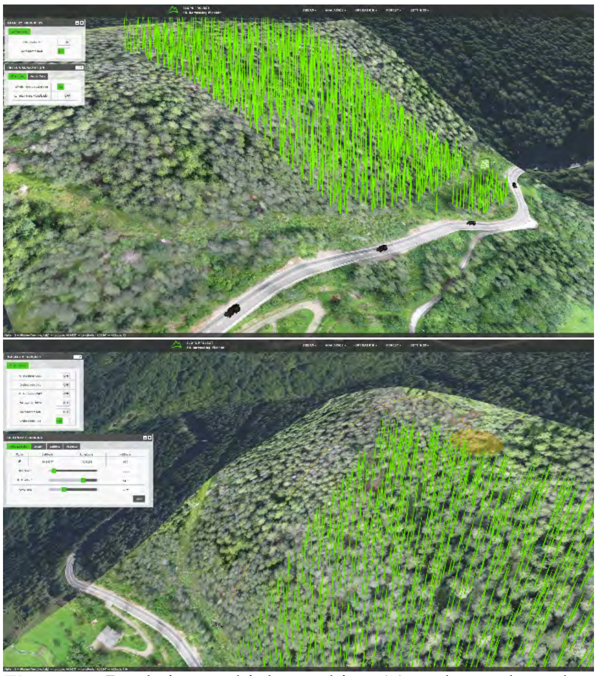

Figure 5. Real-time vehicle tracking (a) and rope launcher simulator (b).

inspect information concerning forest inventory such as tree physical properties (i.e. height, diameter, and species), logs quality, parcels economic value as well as marked and tagged trees within the forest or placed on storage areas. This information can then be used for direct selling and auction of the available wood to sawmill and other customers. In addition to the three main modes, the web viewer provides an authentication service to save and load harvesting plans multilanguage support and a report generation feature to support on the field operations. The following sections provides details on some of the most important features of the operation and forest modes.

5.2 High detail rendering of tree stems

Laser field scan survey could be visualized as point cloud datasets where the space coordinates of each point can be retrieved and translated from the sensor reference system to a geographic one. This project developed a functionality to elaborate the laser scanner output files and convert them into data structures to visualize every point as a geometry inside the virtual environment as simple and complex tree stems. The viewer has been optimized to render in real-time a huge amount of models (Figure 4b). 5.3 Real-time tracking of moving objects for transport monitoring and optimization The slope viewer supports real time monitoring of the position of transport vehicles and the progress of harvesting and processing of the machines (Figure 5a). The vehicle position is retrieved constantly and is represented as a three dimensional moving object within the virtual. In the same way, every machine can be represented as a model, which could be inspected to visualize information about quantity of wood processed, logs harvested and other operations performed on the stems, continuously querying from a database to update the data for work in progress.

5.3 Computer aided cableway planning

Cableway planning in slope areas is often not trivial. Terrain height, forest density, accessibility and machine limitations take a role in the selection of pylons positions, height and number. Usually the setup of a cableway requires 2 days of work and one day for each intermediate pylon that is needed. For this reason, minimizing the number of intermediate pylons is the priority to decrease timings and harvesting costs. With the Slope 3D planning system, shown in Figure 4, it is possible to define the harvesting operation areas for cable yarders and excavators and study in advance the feasible configurations for a cable line. The planning starts by choosing position and height of pylons of the cableway. When the user enables the cableway planning a floating menu is shown and he can directly click on the map to place the first and the following pylons. The map placement can be manual or providing geographical coordinates. Every time the cableway is modified, the system checks the pylon constraints, computes the cable function, checks the cable constraints and calculates the serviceable area. The pylon and cable configurable constraints are:

- Length of the cable between two pylons;
- Angle between previous and next pair of pylons: the cable can turn only a certain amount at each pylon.
- Height of the cable from the ground: the cable cannot be below a certain height from the terrain for proper functioning under load.
- Falling gradient: a minimum negative slope is required to pull the logs.

If all the constraints are respected the system places the new pylon and computes the area serviced by the cableway. The underlying area is based on cable height and terrain characteristics providing a good yet simple estimation of the area serviceable by the cableway, which is roughly assumed as two times the height of the cable line from the terrain in both directions. The cable height evolution between pylons is computed following a catenary function, which describes the curve of a rope hanging from 2 points of a certain length supporting only its weight. Instead of using a fixed length cable based on the distance between the pylons, we calculated the required cable length to reach a certain fixed tensile force. This is what actually happens on the field, cables are tightened to a certain force, roughly 120KN. The catenary itself does not represent the position of the cable under the load of the carriage but it can be considered a good estimate to evaluate the cable behaviour during actual workload. To evaluate the validity of the selected pylon positions the system also calculates a maximum amount by which the cable can lower when under the load of the carriage. The user can dynamically change all the aforementioned parameters and an animation of the carriage can be added to the simulation to be ready for real-time monitoring of the process.

5.4 Rope Launcher simulator

The rope launcher simulator has been developed specifically for an experimental forest industry project that tries to reduce the cable line setup time. The setup procedure requires, among the other things to displace the entire steel cable through the forest following the plan defined with the above tools. Usually, this is a manual process, which requires time and a remarkable human effort. To solve this problem a rope launcher prototype has been designed (Figure 5b) and is going to be tested on the field. This software feature has been implemented to plan transport and positioning of this device as well as to assess the launch range accordingly with the morphology of the terrain. The simulator allows the user to change several parameters like the angle, orientation and speed of the projectiles to see what will be the final trajectory and the landing area.

6. Conclusions and future work

This study presents the visual results of the EU project SLOPE, which aims at the development of a system for the planning and simulation of wood extraction from steep terrains. In particular the development of a forest visual simulation system combining technologies of 3D visualization and GIS through the web. The achievements obtained indicate that the combination of: standard services to provide information, service oriented architecture, new industrial prototypes and WebGL/HTML5 technologies make possible a 3D web based solutions to visualize, manage and simulate forestry data and operations.

The interactive visualization of the forest has been realized using a virtual globe representation that is, as already stated by (Simões et al. 11), the ideal candidate to provide the most user-friendly experience in managing all the different needed information. In this system, it is possible to combine different information coming from several data sources such as digital elevation produced by UAV surveys, terrestrial laser data sets and vector information available form map servers. At the highest level of detail, the simplified geometric models of individual trees are generated on the fly, faithful to the underlying forest data stored in GIS systems. The hybrid representation method for 3D models and digital surface model can provide different representation based on the planning needs of the users. In addition, an implementation of a forest cable yard simulation module has been introduced and verified as being useful for constructing virtual environment for forest harvesting simulation in mountain areas and forest resources management. Finally yet importantly, a new software tool has been added to assist the simulation of an experimental rope launcher that could significantly reduce the cableway deployment time.

After a finalization and optimization of the presented features, the system will be fully integrated with a forest information system acting as a repository of all the production and planning data, as well as the entry point for input data coming from UAV, TLS, Mobile devices and RFID tags. This system will be deeply tested on real pilot scenarios with the participation of all the involve actors.

Acknowledgements

The work presented in this paper has received funding from the EC through the seventh Framework Programme under the Grant Agreement n. 604129 (project “SLOPE – Integrated processing and Control Systems for Sustainable Production in Farms and Forests”). The authors are solely responsible of this work which does not represent the opinion of the EC. The EC is not responsible for any use that might be made of information contained in this paper.

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Assessment of winter harvesting operations in Mediterranean city of Kahramanmaraş, Turkey

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Abstract
Harvesting operations in Turkey are usually conducted within the period from May to October, operations lose their intensity out of this period due to heavy weather and difficult terrain conditions. Winter harvesting operations take place within the period of October to May to provide forest products to the market for whole year and to offer jobs for the logger in winter and to reduce damage on the end product. Besides, performing harvesting operations out of the vegetation period prevents insect-fungus infections, drying, and cracking of harvested timber. However, winter harvesting operations carried out in mountainous regions are very difficult, costly, and time consuming. Thus, winter harvesting operations should be well planned and factors that affect efficiency and cost of the operations should be revealed. In this research, within the concept of winter harvesting operations, tree felling, delimbing and bucking, and debarking activities were studied in Brutian Pine stand in the Mediterranean city of Kahramanmaraş, Turkey. The results indicated that productivities were 15.25 m³/hr, 5.38 m³/hr, and 0.88 m³/hr for tree felling, delimbing and bucking, and debarking activities respectively. It was found that felling time significantly increased as the diameter of the trees increased. The time spend on delimbing, bucking, and debarking activities were reflected by tree diameter and brunch density.

Keywords
winter harvesting, felling, delimbing, bucking, debarking, Brutian pine

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1. Introduction

The demand for wood products has increased in recent decades, this has widened the gap between supply and demand for wood products. In order to prevent this gap, volume loss should be minimized by implementing suitable forest harvesting techniques (Büyüksakallı, 2012). Forest harvesting operations are usually performed between May and October since forest operations can be more difficult in the rest of the year due to severe weather and terrain conditions. The forest harvesting activities conducted between October and May are called winter harvesting operations in Turkey. It has been reported that the amount of annual industrial wood production could potentially increase from 0.7 million m³ to 2.4 million m³ (Erdaş, 2008).

Winter harvesting operation might provide various important benefits and earnings for forest ecosystems. Forest operations are completed before the regeneration period begins, which increases the success of natural regeneration process. Harvesting operations performed on snow surfaces, minimize damages on young regeneration and forest soils (Tunay and Çığ, 1994). The amount of volume loss during harvesting and processing period's decreases since water content within the tree is relatively low in winter season. The physical endurance and quality of forest products extracted during winter season increases (Trzesniowski, 1985). Insect damages on forest products dramatically reduce since harvesting operations are performed in a time period in which insects (especially bark insects) are not active. Forest products are not affected by fungus damage in winter harvesting since effects of fungus are in minimal levels between November and April (Selik, 1988).

By employing forestry workers for harvesting operations during winter season, the workforce is utilized for the whole year. Also the local workforce will be able to spend time on alternative jobs other than forest operations during the summer season (Büyüksakallı, 2012). Since forestry workers encounter difficult work environments during winter harvesting they receive higher salary comparing with the regular work season. The extra payment varies from 20-60% based on work stages (i.e. felling, skidding, forwarding and loading) and tree species. The extra payment for winter harvesting may potentially increase the total timber production costs by about 10%. Thus, this extra cost should be taken into account in determination of sale price of the forest products.

By encouraging winter harvesting operations during the October-May season, the amount of timber production has increased by three times. Since winter harvesting has extra production cost and storage cost, the General Directorate of Forestry has limited winter harvesting operations to productive stands and stands where winter harvesting is more suitable (Erdaş and Acar, 1993). In this study, winter harvesting operations performed in a Mediterranean city of Kahramanmaraş were evaluated considering productivity. Based on this concept, tree felling, delimbing and bucking and debarking activities were analyzed.

2. Material and Methods

2.1 Study Area

The study area was selected from Başkonuş Forest Enterprise Chief (FEC) of Kahramanmaraş Forest Enterprise Directorate in Kahramanmaraş Forest Regional Directorate (Figure 1). The total area of the FEC is 34015 ha in which 18867 ha was covered by forests. The dominant species was Brutian Pine (Pinus brutia.)The stand characteristics of the study area were listed on Table 1. In the field studies, harvesting operations including felling, delimbing and bucking, and debarking were evaluated within two harvesting units (unit number; 235th and 513th) in Başkonuş FEC.

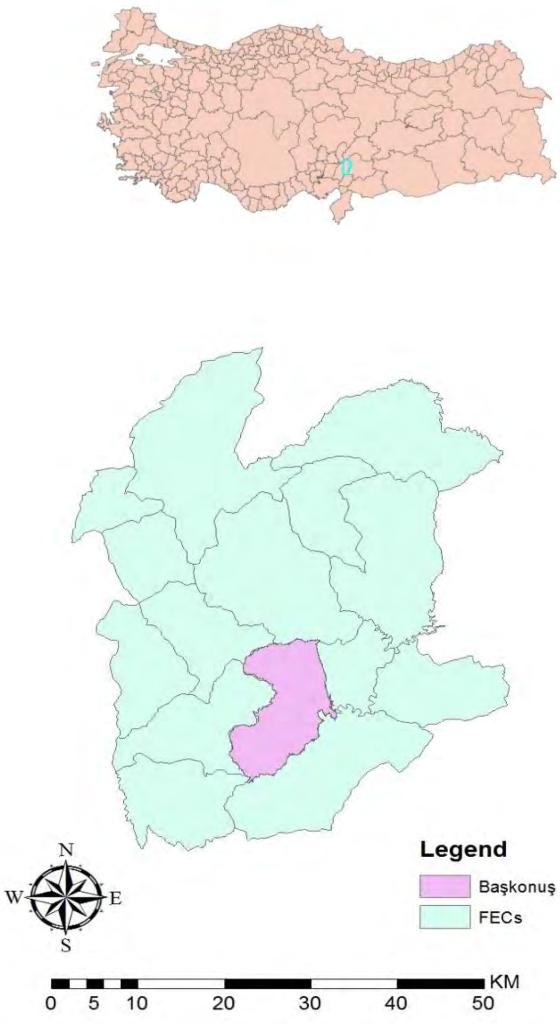

Figure 1. Başkonuş Forest Enterprise Chief (FEC).

Table 1. Stand characteristics.

Unit No	Silvicultural Technique	Elevation	Aspect	Slope (%)
235	Natural Regeneration	800	North East	30
513	Natural Regeneration	920	South West	30

2.2 Time Study

Winter harvesting operations were conducted by a total of 20 loggers who were working in three shifts. The time study data was recorded in tables which also contained information about the study area, operation technique and logging equipment. In order to prevent any bias, data was collected during regular work performance. The operation was followed from a location where work stages could be easily monitored and controlled. The time study was done by using repetition method in which a chronometer was run for each work stage separately. For each operation, the cycle time and work stages data were recorded from randomly selected 30 trees.

During tree felling operation, cycle time begins when felling crew starts moving from the closest road side to stump (Figure 2). The work stages evaluated during time study were listed below:

- General preparation: getting ready before walking into the stump
- Walking: walking from road side to stump
- Preparation: clearing the tree's base and escape routes
- Undercut: undercut to control felling direction
- Cutting: cutting tree from opposite side of undercut
- Felling: starts with felling and ends when tree top hits the ground
- Rooting: cutting roots

After felling the trees, delimbing was done by using chainsaw or axes. Then, trees were measured and bucked at the specified sections. The work stages were:

- Delimbing time: The time spent at the delimbing stage
- Measuring and marking time: The time spend on measuring and marking the trees prior to bucking
- Bucking time: The time spent on bucking the trees and cutting tree tops

After cutting, delimbing, and bucking the trees, debarking work stage was usually applied in Turkey, especially on coniferous trees. The debarking work stage included debarking time (i.e. the time spent on debarking and turning the trees) and delay time (i.e. the time spent during unproductive time period).

Figure 2. Work stages of felling operation.

Table 3. Summary table of felling operation at unit 513.

Variables	Unit	Average	Min.	Max.
Ground slope	%	30	15	45
Walking path slope	%	15	10	20
Walking distance	m	41	10	110
d130 (diameter)	cm	32	20	56
Timber volume	m³	0.731	0.192	2.364
		Time Study Data		
General preparation	min	0.54	0.17	1.17
Walking	min	0.68	0.17	1.83
Preparation	min	0.56	0.25	1.25
Undercut	min	0.85	0.25	2.75
Cutting	min	0.8	0.17	0.25
Felling	min	0.19	0.09	0.3
Rooting	min	0.27	0.17	0.17
Total	min	3.88	9.42	2.07

3. Results and discussion

3.1 Felling Stage

The felling stage of a winter harvesting operation was evaluated using field data collected from two harvesting units (235th and 513th). The results are listed on Table 2 and Table 3. The average productivity for the felling stage was computed based on total cycle time and timber volume. It was found that the average productivity was 19.19 m³/hr and 11.30 m³/hr for unit 235 and 513, respectively. It was found that felling time increases as tree diameter increases. However, increased timber volume results in higher production rate.

Table 2. Summary table of felling operation at unit 235

Variables	Unit	Average	Min.	Max.
Ground slope	%	35	30	60
Walking path slope	%	22.5	15	30
Walking distance	m	42	173	11
d_{130} (diameter)	cm	36	22	58
Timber volume	m³	1.82	0.19	2.76
		Time Study Data		
General preparation	min	0.61	0.17	2.67
Walking	min	1.04	0.27	4.33
Preparation	min	0.72	0.17	2.25
Undercut	min	1.46	0.42	4.75
Cutting	min	1.21	0.33	4.42
Felling	min	0.28	0.08	0.75
Rooting	min	0.38	0.2	1.47
Total	min	5.69	3.05	15.18

The proportion of each work stage as percentage of total cycle time at felling operation was listed on Table 4. It was found that the most time consuming stage at unit 235 and 513 was undercut (25.57%) and cutting stages (20.35%), respectively. The main reason for that was the average tree diameter was higher at unit 235. When considering average time values of the two units, felling (4.69%) was the least time consuming stage, followed by rooting (7.21%) and general preparation (11.99%).

Table 4. Percentage (%) distribution of work stages in felling operation.

Unit No	235	513	Average
General Preparation	10.78	13.2	11.99
Walking	18.34	22.54	20.44
Preparation	12.68	13.81	13.24
Undercut	25.57	18.03	21.8
Cutting	21.18	20.35	20.76
Felling	4.86	4.53	4.69
Rooting	6.6	7.83	7.21

3.2 Delimbing and Bucking Stage

The delimbing and bucking stage of a winter harvesting operation was evaluated for two harvesting units. The results were listed on Table 5 and Table 6. It was found that the average productivity was 5.25 m³/hr and 5.51 m³/hr for unit 235 and 513 respectively.

Table 5. Summary table of delimbing and bucking operation at unit 235.

Variables	Unit	Average	Min.	Max.
Diameter	cm	34	22	46
Timber volume	m³	0.842	0.252	1.573
		Time Study Data		
Delimbing	min	4.98	2.99	9.65
Measuring and marking	min	1.67	1.1	2.3
Bucking	min	2.99	1.8	5.79
Total	min	9.63	6.19	17.74

Table 6. Summary table of delimbing and bucking operation at unit 513.

Variables	Unit	Average	Min.	Max.
Diameter	cm	32	20	56
Timber volume	m³	0.769	0.192	2.364
	Time Study Data			
Delimbing	min	3.46	1.82	8.29
Measuring and marking	min	1.88	1.03	2.92
Bucking	min	3.04	1.6	7.29
Total	min	8.38	4.92	18.5

The proportion of each work stage as percentage of total cycle time is listed on Table 7. It was found that the most time consuming stage at both units was the delimbing stage. Considering average time values of the two units, measuring and marking (23.43%) was the least time consuming stage, followed by bucking (34.60%). The results indicate that the cycle time of delimbing and bucking increases as tree diameter and branch density increases.

Table 7. Percentage distribution of work stages in felling operation.

Unit	Delimbing	Measuring and marking	Bucking
No	time %	time %	time %
235	42.73	24.37	32.9
513	41.23	22.48	36.29
Average	41.98	23.43	34.6

3.3 Debarking Stage

The debarking stage was also evaluated using field data collected from the two harvesting units. The results are listed in Table 8 and Table 9. The average productivities for debarking stage computed based on total cycle time and timber volume were 0.88 m³/hr and 0.87 m³/hr for unit 235 and 513 respectively. Tree size increased the debarking time which lead to a reduction in productivity. Thus, productivity of debarking was slightly higher in unit 235.

Table 8. Summary table of debarking operation at unit 235.

Variables	Unit	Average	Min.	Max.
Timber Volume	m³	0.112	0.04	0.241
	Time Study Data			
Debarking time	min	7.65	2.68	20.83

Table 9. Summary table of debarking operation at unit 513.

Variables	Unit	Average	Min.	Max.
Timber Volume	m³	0.12	0.04	0.204
	Time Study Data			
Debarking time	min	8.24	3.15	16.75

In the field studies it was observed that forestry workers face difficult and risky work environments due to cold weather and frozen ground surfaces. Thus, they should be well trained for winter harvesting operations in order to improve productivity and prevent accidents. Also, workers should be equipped with the necessary protective equipment (special boots, helmet, etc.) and warm clothes.

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Computer vision - context aware aided, cable logging process

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Abstract
Cable logging is one of the major harvesting systems that is commonly used in mountainous areas. Those operations take place in challenging environments, mostly due to difficult accessibility and steep terrain hindering fully automatic harvesting. Cable yarding is a semi manual system that relies on human machine interaction where a major share must be done by forest workers. Our paper presents a method for visual cable logging real time support that can autonomously recognize operational phases within the logging process. This method allows for initializing other computer vision based algorithms for certain operational phases. It also allows for running fully automatic time studies to monitor machine efficiency. A monocular system provides sufficient information that can be analyzed and further expanded for other purposes like safety measures, spatial measurements, productivity studies and autonomous carriage control.

Keywords
computer vision, cable logging, forest operations

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1. Introduction

In forest operations there has been a significant progress in acquisition and utilization of data collected by forest machines. Harvesters provide with a complete set of information needed for detailed productivity reporting. Yet there are numerous forest machines that are lacking sophisticated integrated electronic systems. Cable yarding operations are often based on old systems still actively used in many countries. A standalone system based on signal interpretation from a sensor is a cheap and efficient solution for getting valuable information from the machines that are not self-equipped with any data logging device. Sensor system works independently and evaluates the operation based on visual recognition. Cable yarding operations are executed in a schematic way and despite of being a semi manual system, they follow automated routines. Cable logging has easy to distinguish phase cycles that always follow the same order.

Systems based on visual recognition have the advantage of providing more information than other sensors. Imagery is used for extracting spatio-temporal information as well as camera motion itself. Cameras can also be used to provide with qualitative information or as surveillance tool. Efficient computer vision algorithms can be successfully run on standard PC to produce instant result that ensure that vision systems can be executed in real time.

2. Material and Methods

2.1 Camera system

Cable carriage has an attached camera that is recording the whole yarding operation. It is mounted at the bottom part of the carriage or on the side so that no occlusion from carriage itself is present on recorded images. Lens is oriented towards the surface providing orthogonal view of the forest surface. Camera vertical axis alignes with mainline direction (x axis) that is parallel to carriage side surface (Figure1). We perform field test by acquiring imagery using movie sequence with a standard frame rate. From this sequence, frames are extracted with a desired frequency rate and further processed. In our experiment we use consumer grade action camera Go Pro Hero 3 that is recording movie sequence with a standard frame rate speed 60 FPS. Go Pro camera is precalibrated using standard calibration procedure proposed by (Zhang 1999) with aid of OpenCV camera calibration method.

2.2 Automatic cycle phase detection

In cable logging we distinguish process phases that occur in every turn. These phases are important to be identified since recognition of a specific operation should initialize different algorithm. In our method we want to execute choker setter tracking which is only run at the time when carriage equipped with camera stops at the operational site. When this moment is reached a tracking procedure should start and should end by the time the carriage starts its return motion. In following, the time study method (Huyler and LeDoux 1997) after slight modification we can list the following elements for every cycle (Table 1).

In order to estimate on camera motion we use a fast feature detection method where pixel relocation is indicated by matched frames between two images. First, feature detection is applied to identify and describe features on

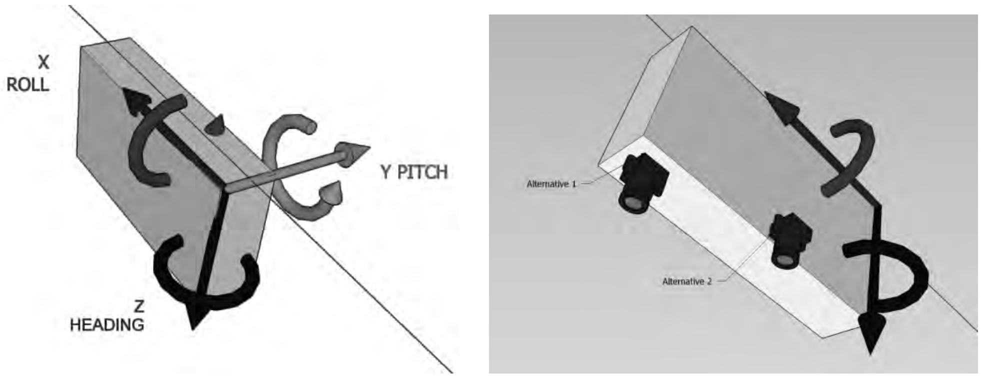

Figure 1. Cable carriage coordinate system and possible location of the camera (2 alternatives).

the images. In our example we will use SURF (Speeded Up Robust Features) and SIFT (Scale Invariant Feature Transformation). From two consecutive images, feature points are obtained. Every image returns Mx64 matrix of M feature vectors, also known as descriptors. Having two sets of extracted features we can get a list of putative matches based on descriptors correspondence. Similarly to the method proposed by (Saeedi, et al. 2014) camera motion is determined by Euclidean distance between the corresponding interest points of two successive frames.

We also use RANdom SAmple Consensus (RANSAC) (Fischler and Bolles 1981) to find inliers, where fitting function is based on homography function that returns perspective transformation H between the source and the destination planes:

$$s_i \begin{bmatrix} x_1 \\ y_i \\ 1 \end{bmatrix} \sim H \begin{bmatrix} x_1 \\ y_i \\ 1 \end{bmatrix} \quad (1)$$

so that the back-projection error:

$$\sum_i (x_i - \frac{h_{11}x_i + h_{12}y_i + h_{13}}{h_{31}x_i + h_{32}y_i + h_{33}})^2 + (y_i - \frac{h_{21}x_i + h_{22}y_i + h_{23}}{h_{31}x_i + h_{32}y_i + h_{33}})^2 \quad (2)$$

is minimized.
Raw output data are representing:

- Median vector orientation (Θ) which is in range from 0 to π.
- Pixel velocity (V) which is a median Euclidean distance for all inlier vectors between two successive frames. V is a 2 dimensional vector with V1 representing x axis pixel distance per frame and V_2 y axis pixel distance per frame.

The above mentioned can successfully be used for interpreting carriage motion with the assumption that carriage rotation and translation is limited. Rotational motion is mostly around X axis (roll), pitch (Y axis) changes due to line slack and there is almost no rotation around Z. Those rotational limits relate to enforcements from mainline. Translational motion is restricted to mainline direction, backwards and forwards which is consistent with X axis of the system. Some translational motion occurs on Z axis due to load suspension and little on Y axis. Vector orientation and pixel velocity can be interpreted initially as "outhaul", "inhaul" and "stop" (Table 2).

In order to assign to a specific phase, we use variable weighting and thus we vote for a different phase. Raw output data, Θ and V_1 are filtered with Kalman filter and then initial classification is done by combining two filtered variables.

Furthermore, based on processed information and other premises, we can specify phase type in detail. When no motion is detected we can classify phase into several other types based on specific criteria. Initial signal returning "stop" phase is converted in the following classes: choking or unloading or can remain unclassified when it does not fill the criteria for the above mentioned. Thus that can be interpreted as operational delay. In addition to phase recognition, every turn is counted. Consecutive turn number is generated always when unloading changes to outhauling.

3. Discussion

The method described above is complementary to currently used sensor platforms. It is designed in the way that implementation should work as real time visual support system. Phase recognition can provide with their duration that can be exploited for productivity monitoring and system efficiency evaluation. However, real time system can be used for further expansion in order to introduce autonomous carriage control and execute different operations depending on current activity.

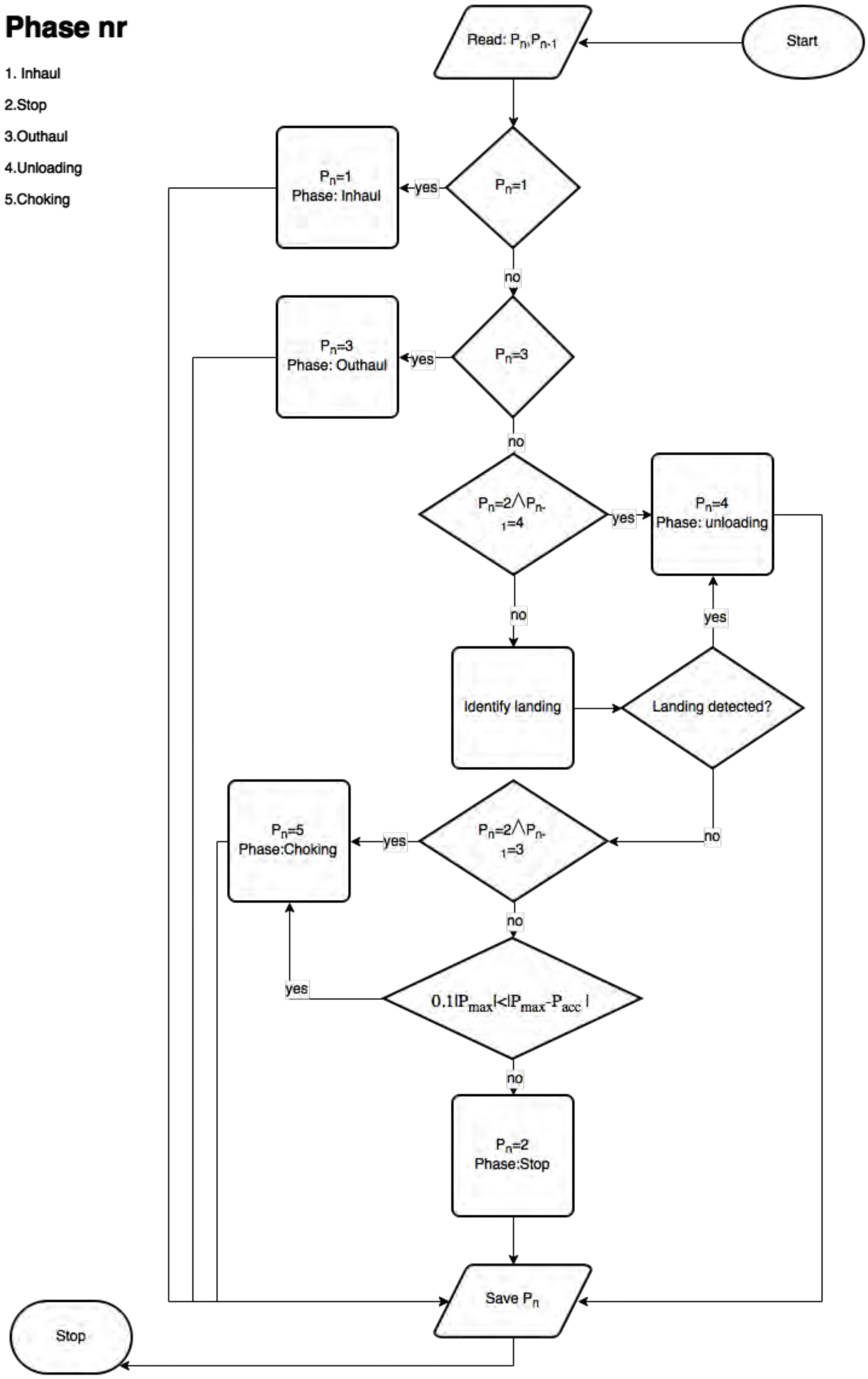

Figure 2. Phase interpretation algorithm flow chart

Table 1. Phases in cycles distinguished for time studies.

Cycle phase	Cycle phase Description
1.Outhaul empty	Begins when the carriage starts to move from the landing out to the destination point and ends when the motion is stopped and the carriage clamps the skyline.
2. Lateral out	Begins when the mainline is lowered toward the choker setter and ends when the setter together with chokers has stopped the forward motion to the load and is ready to hook a turn.
3. Hook-up	Begins at the end of lateral out and ends when the choker setter has completed hooking the chokers and signals to begin yarding.
4. Lateral in	Begins at the end of hook-up and ends when the turn is pulled up to the carriage and the carriage is released.
5. Inhaul	Begins at the end of lateral in and ends when the turn has reached the position on the deck where it can be directly unhooked at the landing.
6. Unhook	Begins at the end of inhaul when the carriage stopped its motion and begins to lower down the load and ends when the chokers have returned to the carriage.
7. Operational delay	All the interruptions that emerge explicitly from yarding process.
8. Mechanical delay	All the pauses caused by machine failures.
9. Other delays	All the breaks which are not related to the yarding process.

Table 2. Interpretation of angular values (Θ) as mean vector orientation and vector lengths V1 as pixel velocity.

Mean vector orientation (Θ)	
value	interpretation
Θ=0	Outhaul
$\Theta = \pi$	Inhaul
$\Theta = \pi/2$	Stop
Pixel distance/frame (V_1)	
value	interpretation
V1>0	Outhaul
V1<-0	Inhaul
V1=0	Stop

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Sensor-based, automated monitoring of fully mechanised harvesting processes – including options for automated process control

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Abstract
Harvesting operations in European forestry are dominated nowadays by machines such as harvesters and forwarders. While data integration of process steps (felling, processing, forwarding) is more or less seamlessly achieved thanks to data standards like StanForD and bridging software products, there is still a major gap when it comes to location-independent monitoring with multivendor capabilities, or even control of these operations. A possible solution is presented here.

Keywords
FOCUS, CAN-bus, automated harvesting monitoring, TimeControl, polterluchs, iFOS

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1. Monitoring aspects

In an EU funded, multinational project (FOCUS – Advances in Forestry Control & Automation systems in Europe) a promising monitoring approach is realised. For this concept a fusion of existing engine respectively machine sensors (1) and independent add-on sensors (2) plus the integration of existing software products (3) is used.

In case of the engine parameters the controller area network (CAN)-bus can provide several data sets, which indicate pretty precise and in a near-to-real-time manner the state of things in the monitored machine. In commercial vehicles, including forestry machines, the network protocol SAE J1939 is widely used for the communication in the CAN-bus. In this case a skidder, model HSM 805HD, was used to show the functionality of such a generalised, vendor independent, monitoring concept. In order to enhance the detail level about the working conditions additional sensors were added into the skidder.

Their signals were included through the HSM central machine controller (CMC) onto the CAN-bus stream. Among these are sensors for measuring the inclination of the machine, the pulling force and the forces at the rear blade.

Access to the data is based on HAFL software (iFOS), where besides these CAN-bus data also further, not CAN-bus based sensors, such as electronic scales or a tyre inflation control systems can be monitored. In one FOCUS test bed situation with the HSM 805HD skidder a GPS was added as a separate sensor in order to localise the operations. A typical exemplary screenshot (Fig. 1) shows the CAN-bus extracted engine revolutions during a test operation as a colour coded line on a map.

Besides these machine-oriented parameters, variables which describe the operational performance, for example the cut volume, the piles of timber etc., are necessary for monitoring forest operations precisely. Here existing external products were used which consequently were integrated into the data stream. TimeControl, a product by Wahlers Forsttechnik GmbH, is used to automatically monitor productivities on harvesters, as it can make use of a link to extract information on produced assortments directly from the internal harvester generated PRD/PRI files. An additional option to enter key parameters manually in user determined time intervals opens this tool to monitor also other, non-harvester based operations. In this case a sky line logging operation in Switzerland was tracked (Fig. 2).

For monitoring the forwarding step another product, polterluchs (again a product by Wahlers ForsttechnikGmbH) is used in order to collect timber pile oriented parameters, such as the number of logs per timber pile. The data get streamed onto the FOCUS architecture.

FOCUS provides also an open architecture, where information as described above, is permanently streamed onto a server during the running operations. This artifice enables a location-independent monitoring for requests coming from locations apart from the processing site. In this case support is given for PC-based but also smart phone-based monitoring requests. Details on the architecture are presented by Mittlböck et al. in a separate FORMEC paper.

2. Control aspects

Finally, based on this permanently available information in a further step an active process control is achieved.

The control idea is based on the fact that in the production chain - from the felling of the trees, over the processing,

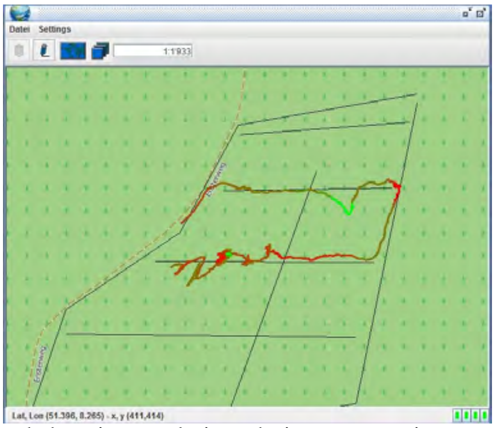

Figure 1. Screen shot iFOS: colour coded engine revolutions during an operation; green color indicates low, red color high engine revolutions, black lines are skid trails; background map from OpenStreetMap.

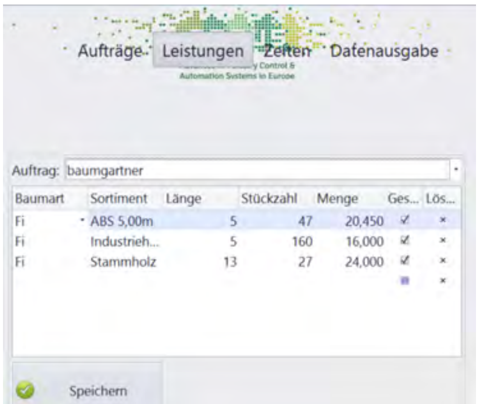

Figure 2. Screenshot Focus Client, while entering productivity figures manually (Wahlers Forsttechnik GmbH).

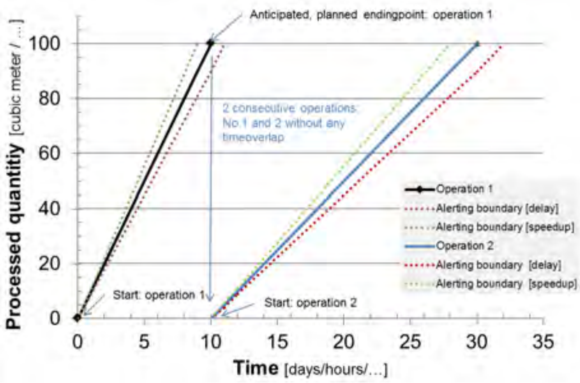

Figure 3. Sequence of two consecutive operational steps.

skidding and forwarding process to the final truck delivery - several separate production steps exist. They all can severally be described by the expected volumes and anticipated operational working times for all these production steps. Such information is based on the experience of the operational managers for the reported, expected production quantities and can be understood as a target time. Due to varying conditions and several reasons it may turn out that the planned target time cannot be met, so that internal reporting limits get triggered (dotted lines in Fig 3). Provided the operator confirms the new adjusted targets, these new target times will get set. This will automatically adjust the starting event of consecutive operational steps (see Fig. 4).

Through the general architecture this information about the process status is instantly available for all partners in the production chain. Except for the (manual) approval for new set targets by the machine operators these control procedures happen automatically in the background. Such an automated and permanent comparison of observed process progress versus the planned progress will help to better speed up cycle times. In case of major deviations alerts are triggered and when necessary further action can be taken by the actors to better match planned process targets.

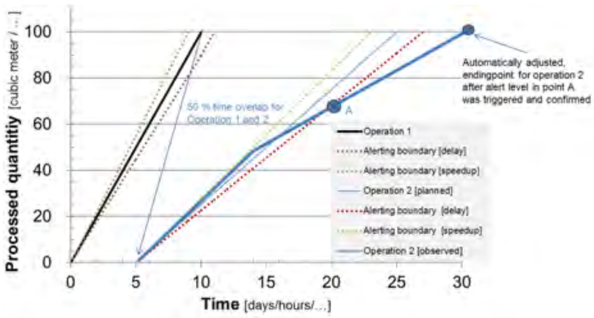

Figure 4. In operation 2 the observed performance (thick dark blue line) results a in a delayed ending point, which may trigger a delayed start for a consecutive operation 3. Notice the 50 percent overlap of operation 1 and 2 versus the sequential approach in Fig. 3.

Topic 4

Harvesting & soil protection

Mounding as method of reforestation of wet and “problematic” forests on organic soils in Latvia

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Abstract
Mounding is a soil scarification method suitable for problematic stand types with low soil bearing capacity, high groundwater levels, and fertile soils, where use of disc trencher might not be efficient. Forest site types *Myrtillosa mel.*, *Myrtillosa turf. mel.* are the most suitable for mounding. These stand types are characteristic of % of Latvia’s forests. The presented study summarizes results of pilot studies of reintroduction of mounding as a the forest soil preparation method in the joint stock company “Latvia State Forests” which manage approximately half of forests in Latvia. Productivity studies and evaluation of quality of soil preparation was done within the scope of the study.

Keywords
scarification, productivity, soil preparation, mounding

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1. Introduction

Mounding is well known in Latvia but in last twenty years very rarely used soil preparation method (Bušs 1932, Katkevičs 1986, Mangalis 2004). Since disk trenchers started to operate in the country, application of mounding rapidly decreased. Fertile and wet forest sites with peat layer of more than 40 cm, such as Myrtillosa was left for natural regeneration more often as other, because it was impossible to prepare soil with disc trenchers due to low soil bearing capacity. Nowadays foresters can use improved planting material promising to reach by 20 % higher increment, better stem quality, resistance to diseases and better adaptation to climate change, and so called “artificial regeneration” of stand coming actual again (Jansons 2008). Excavators are able to move on soft and wet soils, operators of these machines can choose discrete place to prepare soil for a single tree when prepare mounds, inverted humus layer, patch or just scarify the soil (Sutton 1993, Orlander et al. 1998, Saksa 2005).

2. Material and Methods

Mounding trials were done in Eastern part of Latvia, on drained forest sites (*Myrtillosa mel.*, *Myrtillosa turf. mel.*), in spring and autumn in the second year after clear-cut. Soil preparation were done by three different buckets: conventional excavator bucket (110 cm wide), special mounding bucket Karl Oscar (50 cm wide) and specialized bucket MPV-600 (60 cm wide, produced by LSFRI Silava and engineering company Orvi). All three devices were mounted on New Holland E165 excavator. Time studies were done during soil preparation; site characteristic parameters and work elements used for comparison of productivity were: “weather conditions”; “amount of slash on field”; “moving in stand and out”; “moving looking for suitable place to make mound”; “removing of slash or overgrowth before making of mound”, “making of mound”; “compression of mound”, ”other movements with crane”; “non work related operations”. Number and dimensions of mounds, coverage of ground vegetation on mound and seedling surviving were evaluated in sampling plots in each stand in the next autumn after completion of time studies.

3. Results

3.1 Time studies and productivity

During spring the most important factor affecting productivity of mounding was skills of operator, because productivity of work increase constantly during the time studies and did not correlate with equipment used or work conditions. But in autumn there were some, but non-significant, differences between productivity of mounding and bucket used (Figure 1).

Comparison of the work operations shows that proportion between them are approximately the same during the time and the most time consuming operations are crane movement and removal of slash & overgrowth (Figure 2). This result points to importance of leaving clean felling site with piled or extracted harvesting residues before soil preparation (Figure 2).

Average time spent to prepare one mound for trained operator at autumn was 22.9 centiminutes.

3.2 Ecological issues – level of scarification and growth conditions

According to FSC certification rules it is allowed to scarify no more than 30 % of the stand area. Rules of cabinet of ministries No 308 determinate that in case of “artificial regeneration” it is necessary to plant at least 50% of trees and final number of trees should be at least 2000 for spruce

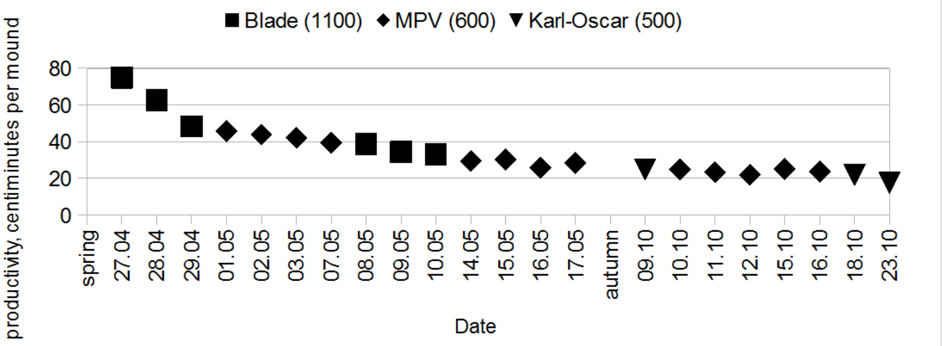

Figure 1. Growth of productivity of mounding during the trials.

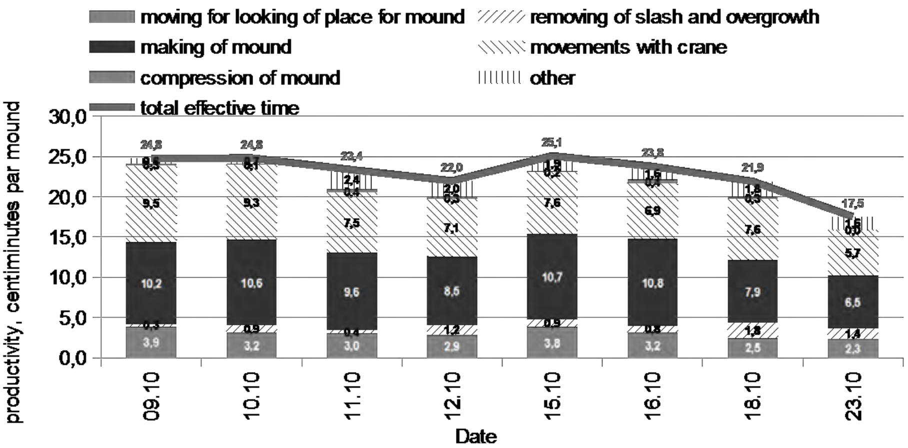

Figure 2. Growth of productivity of mounding during the trials.

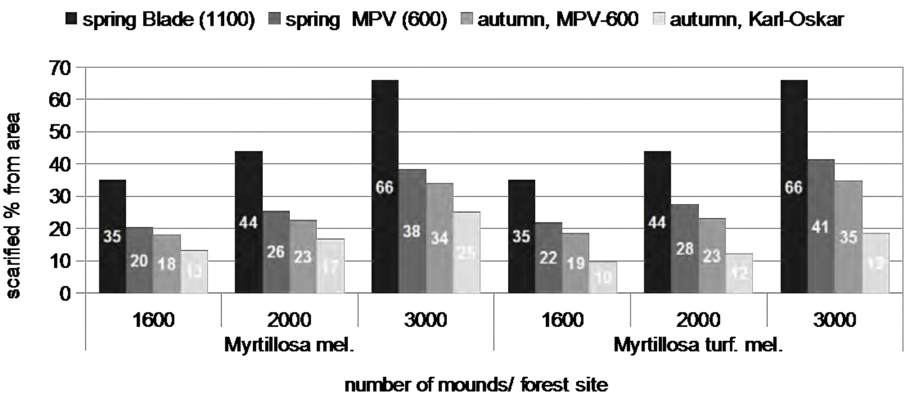

Figure 3. Estimated proportion of scarified area depending from proposed number of planting spots per ha using different buckets.

or 3000 for pine. Figure 3 shows estimated percentage of scarified area depending from required number of planting spots using different mounding devices. For spruce stands preparation of 2000 planting spots wound not exceeds the FSC thresholds for all devices, except the excavator bucket (width 1100mm) but in pine stands only the narrow Karl-Oscar bucket is suitable to prepare 3000 mounds per ha. Wider blade could be used only for reduced number of trees, when it is planned to plant only so called “future trees” considering certain amount of natural ingrowths in the regenerated stand (Figure 3).

In Nordic conditions mounds are free from ground vegetation during two years, but in Latvia the situation is different, because of more fertile soils and climatic conditions, responsible for different balance between grasses, cereals and caulescent plants. In forest site type *Myrtillosa turf. mel.*, vegetation covered only 16-22% of the mounds’ area after the first growing season, but in site type *Myrtillosa mel.* 39-41% of mounds’ area were covered by caulescent vegetation. Percentage of area covered by vegetation was smaller on mounds prepared by wider buckets. In cases, when ground vegetation contained *Juncus sp.* it was necessary to make weed control already in of first growing season on *Myrtillosa mel.* stands.

4. Discussion

Mounding is suitable and ecologically sustainable soil preparation method in artificial forest regeneration for planting up to 2000 trees per ha. Considering soil scarification thresholds and productivity of the operation optimal number of mounds is close 1600 trees per ha. Wider buckets are recommended in fertile site types with more aggressive vegetation, where it is enough to plant target trees considering certain percentage of natural ingrowths. In *Myrtillosa mel.* site type it is necessary to do weed control already during the first growing season.

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Topic 5

Productivity & efficiency

Effectiveness of selection cutting in the Russian Federation

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Abstract
This article is written to demonstrate the effectiveness of selective cutting in the territory of the Russian Federation. The article describes Russian forests and their predominant breeds (dominant stock), further technical process of selective cutting is described, and also the article shows the efficiency of the use of selective cutting in a particular areas in comparison with the final cutting (clear felling system). At the end of the article the economic efficiency of selective cutting and its predominance over the final cutting is summed up.

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Figure 1. Distribution of predominant breeds (dominant stock) on the territory of the Russian Federation.

1. Introduction

Russian forests are mostly boreal (88%), the main forest-forming breed are larch, pine, spruce, cedar, oak, beech, birch, aspen. They occupy about 90% of the territory, covered with forest standing vegetation, including forest-forming coniferous breeds - 68.4% hard-wooded broadleaved - 2.4%, soft-wooded broadleaved - 19.4%. Growing standing larch occupy- 35.8%, pine - 15.6%, spruce - 10.1%, birch-15.0%.

On the territory of the Russian Federation over mature and overmaturity stand forests are dominated, which make up - 42.7%, young growth- 17.2%, middle-aged - 28.5%, ripening breeds - 10.6% of the territory.

About 50% of coniferous species presented by mature and overmaturity stand, however, overmaturity stand forests are located in remote and inaccessible areas. Up to 90% of the forests covering the territory of the Russia Federation are natural, that is, coppice forest, and only 10% have an artificial origin (planted forest). In recent years the practice of selective cutting is widely used, due to a more harmonious exploitation of the forest near mastered logistics routes.

The coniferous forests of the north are overwhelmingly represented by the all-aged growing stock, so for this reason we think that selective cutting is more suitable for their nature and the natural type of growth (forest dynamics).

2. Material and Methods

During using selective cutting in coppice with standard forests, accepted in Russia, permanently preserve the essential elements of the forest, prior and concomitant renewal takes place, the cutting is carried out generally in all-aged coppice.

The selection of trees for felling in Russia is produced according to the economic and silvicultural prerequisites, purposes, methods and technology of selective cutting. Under pressing demand for a particular kind of timber.

In other cases, the standing snag , sick and old growth forests are assigned to be log for the purpose of cultivation and conservation of highly resistant forest stand, strengthen environment-forming and protective functions.

Depending on the economic and environmental factors, the principles of selection of trees for felling, the goals and objectives of growing plants of different composition, we distinguish basically two ways to selective cutting: selection-felling and group-selective.

In this experiment, was chosen technology of selection-felling cuts, in order to determine the optimal number of cutting techniques, to obtain the maximum recruitment of the major domestic breed in the selected areas.

Mainly the technology of selection-felling is used- this cutting wherein defective trees are cut in the first place that is trees with defects of wood, old growth and mature. In the first place these cuttings are done in the forests of major economic importance and in mountain forests.

The use of the selective cutting is closely linked to the economy and the natural features of the forest, for example, there is a promotion of natural regeneration in the capability of spruce forests, since there is an additional source of light,

Figure 2. The principle purpose of the trees for felling in the first reception of the selective cutting.

heat and moisture to the soil under the delimitation of the stand, and as a consequence it increases microbiological processes.

The disadvantage of the selective cutting in our area is the lack of mechanization, that would cause less damage to the forest nature. The main disadvantage is labor costs on the move from tree to tree, finding trees that are selected for felling, the choice of the direction of the rolls and the lack of the forestry roads. Accordingly, there is an increase of the damage of the new growth and growing trees, also there is the probability of the succession of tree species.

The advantage of the selective cutting is the production of the larger and special assortments. Also, the environmental conditions are maintained and improved, the territory is always covered with forest, the regeneration comes naturally. The positive side of the selective cutting is considered to be less damaging for the new growth than the final cutting.

Risks during selective cutting in spruce

- Blowdown. To prevent a possible blowdown in the area, long side of the parcel and logways are oriented in north-south direction at an angle to the prevailing wind rose. In addition, during the cutting is not allowed the formation of large windows in the shelter of the growing stock.
- Reducing the technical qualities of the wood of remaining trees is the second in importance and prevalence of negative factors for the selective cutting in our spruce grove. The Spruce is very sensitive to fraying(mechanical bark damage) of the trunk and the buttress flare damage. Within this framework then there is an infection of the stem rot of healthy trees. This leads to a decrease in the quality of the wood after spruce selective felling , up to the collapse of the growing stock. In order to avoid this factor we conduct a special training session for the fellers for the directional felling, as well as conducting logging operations activities in winter.
- The risk of fungal infections of the leaving part of the stand. The greatest danger in our forests provides the possibility of infection of pine fungus. To prevent this, cutting is carried out in winter on frozen ground and deep snow, to minimize damage to the roots paws, remaining trees during cutting on the logway.

3. Results

3.1 Recruitment

Conducting selective cutting in uneven-aged stands of spruce with a diameter of 8-14 cm, as a general rule, are members of the younger generations, retain the ability to increase the growth and at the underbrush and to form productive spruce stands. Leaving on cutting down trees of the younger age groups helps to preserve forest environment and thus prevents the intensive overgrowing felling of the hardwood.

The stock formed by thinner spruce trees according to the calculations does not exceed 15% of the growing stock of different ages, and the number of trees the thinner spruce is 40%. The costs for the labor and time for the workpiece of the forest thinners while final cutting in spruce grove with the exploitable diameter 8cm, reach 30% or more of the costs for cutting the whole growing stand, and which leads to a significant rise in the cost of harvesting and harvested wood.

3.2 The intensity of felling and volume

The average intensity of the selection of the volume is 55%, including species: spruce - 51%, fir - 58%, birch - 83%.

According to the number of trees the intensity of felling is 34%. In the process of cutting harvested 155 m^3/ha of the commercial timber. Commodity pattern of harvested wood is further shown in Table 1. There is an all-aged growing stock after logging with the forest density of 0.55, volume 137 m^3/ha. The average age of the growing stock revised down to 120 years. Capacity for establishment of underbrush is 75

Commercial efficiency of the two receptions of the selective cutting was higher than in final cutting (clear felling system), even without the necessary expenses for reforestation, for example - the establishment of forest cultures after selective cutting. The selective cutting in our conditions and the area is more advantageous.

Table 1. Commodity pattern of harvested timber, m^3/ha.

Species	Wood commodity					Merchantable material
	large	middle	small	total	Splitwood	
Spruce	30	39	15	84	4	88
Fir	8	13	6	27	2	29
Birch	3	16	3	22	18	40
Total	41	68	24	133	24	157

Table 2. Comparative cost-effectiveness of the continuous cutting.

No	Indicator name	Voluntary-selective felling		Control.
		I felling	II felling	Final Cutting
1	The stock of timber harvested, m^3/ha a) general, b) merchantable	180 157	211 191	321 277
2	The average volume per tree of the timber harvested , m^3	0,68	0,46	0,42
3	The cost of wood harvesting and hauling, rub/m^3	224,5	228,5	224,6
4	Standing sale, rub/m^3	25,2	23,4	23,4
5	The average market price of timber, rub/m^3 (2000 year)	308,0	298,0	299,4
6	Period reduction by a factor of time, years	0	30	0
7	Present value index	-	0,412	-
8	Profits from the sale of 1 m^3 of wood, rub.	58,28	19,01	51,44
9	Profits from the sale of timber from 1 ha, rub	9150,0	3631,6	14301,3
10	Commercial efficiency	0,191		0,180

Surveys conducted after 8 and 13 years after the first session of the selective cutting showed that the percentage of the area of natural attrition does not exceed in the comparison with the natural all-aged spruce stands in the middle of Taiga subzone if the European North.

Successful practical examples of several methods of selective cutting on the spruce stands in the taiga zone are the exceptions rather than the rule. We have developed adistrict, which is exactly the most successful example. The next session of the selective cutting is planned through 20-30 years. Further observations of the state of the abandoned growing stock in parcel will show how our proposed in the Model Forest experience can be distributed in real cutting practices.

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Impact of slope on forwarder load size and productivity

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Abstract
Harvester-forwarder systems are the predominant ground-based harvest system in use in many parts of the world, including Australia. Whereas harvesters can operate on slopes up to 60% (31 degrees), forwarders are restricted to slopes of 45% (24 degrees) due to their high centre of gravity and lower traction. However, there is interest worldwide in increasing the use of mechanised harvesting equipment on steep slopes.
This study compared the cycle times and productivity of the same Valmet 890.3 8 wheel forwarder and operator, on two Australian radiata pine clearfell sites: one site with a slope of less than 10% (Baudin site) and one site with a slope of 21% to 45% (12 to 24 degrees) (Murray site).
The productivity of the forwarder at the mean values of extraction distance (213 m) and load volume (20.8 m^3) pooled across both sites was 79 m^3/Productive Machine Hours excluding delays (PMH_0) at the Baudin site and 68 m^3/PMH_0 at the Murray site. The major factors in the productivity difference were the longer cycle times at the Murray site and the ability of the forwarder at the Baudin site to carry approximately 2 m^3 greater volume of logs per load than when operating at the Murray site as the operator was able to load more logs without risk of the forwarder overturning or the logs sliding off the bunk. Although the forwarder travelled significantly more slowly when operating in the stand at the Murray site (mean loaded travel speed: Murray site 1.44 km/h; Baudin site 5.24 km/h), the impact of this on cycle times was balanced by the significantly faster travel speed of the forwarder on earth tracks at the Murray site (mean loaded travel speed: Murray site 6.57 km/h; Baudin site 5.12 km/h) which made up the majority of the distance travelled in each cycle at the Murray site.

Keywords
forwarder, productivity, slope, load size

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1. Introduction

There has been increasing focus worldwide on using ground-based, mechanised harvesting equipment on steep slopes in order to reduce harvesting costs (Drews et al. 2001) and increase safety (Bell 2002). Specialised steep slope harvesting machines, such as the Valmet “Snake” (Stampfer and Steinmüller 2001), have been developed to work on steeper slopes both in fully ground-based operations and to perform felling, bunching and processing to increase the productivity of cable extraction systems (Acuna et al. 2011). Cable-tethered harvesters and forwarders have also been trialled to allow conventional harvesting machines to operate safely on steeper slopes (Wratschko 2007).

Harvester-forwarder harvesting systems are commonly used in Australian ground-based harvesting operations. Many previous studies have shown that the major determinants of forwarder productivity are extraction distance and load size (e.g. Spinelli et al. 2004, Tiernan et al. 2004, Jirousek et al. 2007, Ghaffariyan et al. 2012, Walsh and Strandgard 2014). Other factors that have been found to impact forwarder productivity include log size (Plamondon and Pitt 2013), log length (Gingras and Favreau 2005), log pile size (Väätäinen et al. 2006), driving speed (Lileng 2007), and slope (Tiernan et al. 2004).

The maximum slope that a harvester-forwarder harvesting system can operate on is generally limited by the forwarder’s capabilities. Tracked self-levelling harvesters can operate on slopes up to 60% (31 degrees) (McEwan et al. 2013) whereas forwarders are restricted to slopes of 45% (24 degrees) due to their high centre of gravity and lower traction (McEwan et al. 2013). The high centre of gravity restricts forwarders to operating up and down slope on steeper slopes and the lack of traction restricts the maximum slope a forwarder can operate on. Traction can be increased by using a forwarder with more wheels and through the use of traction aids, such as band tracks (McEwan et al. 2013).

Although operation on steep slopes is known to affect forwarder productivity, there has been little research in this area. The objective of this paper was to determine whether a forwarder operating on a site with slopes of 21% to 45% (12 to 24 degrees) had significantly different productivity and load size compared with the same forwarder operating on a site with a maximum slope <10% (6 degrees).

2. Methodology

The study was conducted at two mature clearfell Pinus radiata plantations in south-west Western Australia (Table 1). The Baudin trial site was located in a 32-year-old P. radiata plantation, on a flat, sandy soil near Busselton. The Baudin study results formed part of a study by Ghaffariyan et al. (2015).The Murray trial site was located in a 32-year-old P. radiata plantation, on a deep red loam soil near Dwellingup with slopes of 21% to 45% (12 to 24 degrees). The same mechanised cut-to-length harvesting system with the same operators was used to perform the harvest at both sites. Trees were felled and processed infield by a harvester with a Cat541 tracked base, equipped with a Rosin RD977 harvesting head. Logs were extracted to roadside log landings using an eight-wheel Valmet 890.3 forwarder. When operating at the Murray site, the forwarder had band tracks fitted on the rear wheels.

Table 1. Site description.

Site attribute	Baudin*	Murray
Surface area (ha)	2.3	2.2
Mean DBH (cm)	42.1	35.3
Mean tree height (m)	29.7	25
Mean merchantable tree volume (m^3)	1.53	1.3
Merchantable stocking (trees/ha)	251	286
Standing merchantable volume (GMt/ha)	385	360
Slope range (%)	0 - 10	21 - 45

**Results from the two treatments in the Ghaffariyan et al. (2015) trial were combined in the current study.*

The Baudin study was conducted on the 6th and 7th of August 2013. Intermittent rainfall during the trial did not appear to have an impact on the performance of the forwarder. The Murray trial was conducted on the 15th and 16th of January 2014 in hot, sunny conditions with dry ground.

At the Baudin site, the majority of the distance travelled in each forwarder cycle took place within the stand, whereas at the Murray site the majority of the distance travelled in each forwarder cycle took place on a formed earth surface road. Forwarding was performed uphill at the Murray site.

During the Murray trial, the activities of the forwarder were recorded using a digital video recorder. From the video recordings, forwarder cycle times were captured using TimerPro software (www.acsco.com) and load sizes were estimated by counting logs during unloading. During the Baudin trial, forwarder activities and load sizes were captured using a handheld computer. A Multidat onboard computer (Brown et al. 2002) equipped with a GPS was installed in the forwarder at both sites. At both sites, forwarder travel distances and speeds were determined from the GPS data. Delays were excluded from cycle times at both sites.

In this study, only forwarder cycles where the product collected was Laminated Veneer Lumber (LVL) logs (Murray site) or sawlogs (Baudin site) were compared because mean log sizes for these products were similar (0.46 m^3 for LVL logs and 0.43 m^3 for sawlogs) (green density was assumed to be 1000 kg/m^3 (Chan et al. 2010)) and because these products accounted for the majority of the merchantable volume at the respective trial sites.

The impact of slope on forwarder performance at the Murray site was examined by regressing cycle time against extraction distance (the distance from where the first log was loaded to the point where unloading commenced) and slope and productivity against extraction distance and slope.

The large differences in extraction distances between the two sites could potentially have masked the impact of other factors on forwarder productivity. In order to remove this effect, regression coefficients were compared using dummy variables.

Linear regressions of forwarder productivity (m^3Productive Machine Hour delay free (PMH_0)) against extraction distance (m) and cycle time (min) against extraction distance (m) were compared between sites using dummy variables. Load sizes (m^3) and number of logs per load were compared between sites using t-tests. Forwarder speed empty and loaded, in the stand and on the track were also compared between sites using t-tests. All comparisons were made at $p<0.05$.

3. Results

At the Murray site, 15 forwarder cycles were studied and 34 cycles were studied at the Baudin site. Slope was not a significant variable in the regressions of cycle time against extraction distance and slope and productivity against extraction distance and slope.

Forwarder productivity m^3/PMH_0) plotted against extraction distance (m) at each site is shown in Figure 1. The slopes of the linear regressions fitted to each dataset were not significantly different, however, the intercepts were significantly different (Table 2). The forwarder productivity at the pooled mean extraction distance (213 m) and pooled mean load volume (20.8 m^3) was 79 m^3/PMH_0 at the Baudin site and 68 m^3/PMH_0 at the Murray site.

Forwarder cycle time (min) plotted against extraction distance (m) at each site is shown in Figure 2. The coefficients of the linear regressions fitted to each dataset were not significantly different (Table 3).

Mean load volume and number of logs per load at the Baudin study site (21.3 m^3 and 49.6 logs) were both significantly greater than at the Murray study site (19.4 m^3 and 43.4 logs). The forwarder speed was significantly higher at the Baudin site than at the Murray site when operating in the stand (loaded and unloaded) and significantly slower at the Baudin site than at the Murray site when operating on the track (loaded and unloaded - Table 4).

4. Discussion

Forwarder cycle time in the current study was found to be primarily dependent on extraction distance at both sites, as has been shown in numerous previous studies (e.g. Spinelli

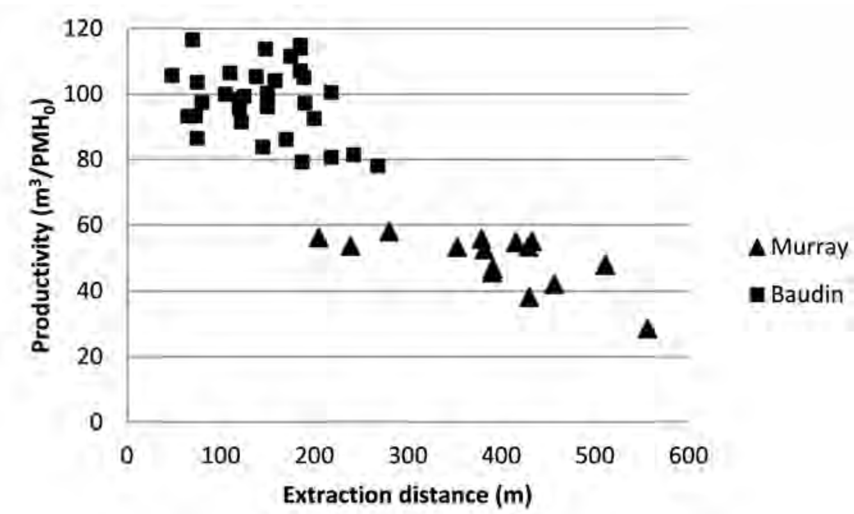

Figure 1. Forwarder productivity m^3/PMH_0) plotted against extraction distance (m) at the Murray and Baudin sites.

Table 2. Regression models of forwarder productivity against extraction distance at the Murray and Baudin sites.

Site	Model	R^2 adjusted
Murray	Productivity = 72.0 - 0.0578 x Extraction distance	40.9
Baudin	Productivity = 106 - 0.0546 x Extraction distance	5.2

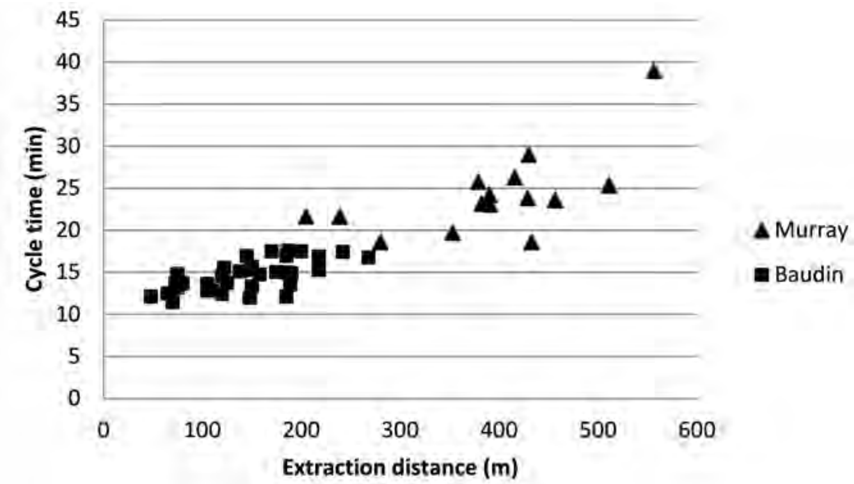

Figure 2. Forwarder cycle time (min) plotted against extraction distance (m) at the Murray and Baudin sites.

Table 3. Regression models of forwarder cycle time against extraction distance at the Murray and Baudin sites.

Site	Model	R^2 adjusted
Murray	Cycle time = 11.0 + 0.0339 x Extraction distance	36.2
Baudin	Cycle time = 11.4 + 0.0223 x Extraction distance	41.9

Table 4. Forwarder speed (km/h) empty and loaded, in the stand and on the track.

Site	Empty travel speed		Loaded travel speed	
	In stand	On track	In stand	On track
Baudin	4.02*	3.61*	5.24*	5.12*
Murray	2.64*	6.74*	1.44*	6.57*

** Significant difference between travel speeds at each site.*

et al. 2004, Tiernan et al. 2004, Jirousek et al. 2007, Ghaffariyan et al. 2012, Walsh and Strandgard 2014). The finding that the coefficients of the regressions between cycle time and extraction distance at each site were not significantly different suggests that operating on the slope at the Murray site did not have a major impact on the forwarder cycle time, which is supported by the finding that slope was not a significant variable in the regression of cycle time against extraction distance and slope. However, the comparisons of travel speed showed that the forwarder at the Murray site was significantly slower when operating within the stand and significantly faster when operating on the track compared with its speeds at the Baudin site. This suggests that operating on the slope in the stand was having a significant impact on the forwarder speed at the Murray site, but the faster 'on track' speed balanced the slower 'in stand' speed for the full cycle.

The forwarder was fitted with band tracks on the rear wheels at the Murray site. Stankic et al. (2011) found that fitting band tracks reduced the forwarder speed when operating in the stand or on the track. This concurs with the current study findings for travel speeds in the stand, but the opposite was found when the forwarder was travelling on tracks. However, it is possible that the shorter track travel distances at the Baudin site did not allow the forwarder to achieve the 'on track' travel speeds noted at the Murray site.

Forwarder productivity at the Baudin site was greater than that at the Murray site. The shorter cycle times at the Baudin site were a major cause of this difference in productivity. However, the finding that there were no significant differences between the slopes of the regression between productivity and extraction distance at each site and that the intercepts were significantly different, in conjunction with the significantly higher mean load volumes at the Baudin site suggested that the greater productivity at the Baudin site was also the result of the greater mean log volumes and log numbers transported per cycle at that site. The forwarder operator stated to the researchers after the trial that he loaded fewer logs on the forwarder bunk when operating on steeper slopes because of the increased potential for rollovers and for logs to slip off the load. The potential danger of rollover or log loss may be greater than that suggested by the mean slope along the forwarder's extraction tracks. Visser and Berkett (2015) observed that the actual slope experienced by a harvesting machine can be much greater than the mean slope angle because of small-scale terrain changes. This effect was noted during the study at the Murray site when the forwarder traversed a track through the stand running across the slope which considerably increased the slope experienced by the forwarder and slowed its operation at this point.

5. Conclusion

The forwarder was less productive when operating at the Murray site because of the longer cycle times than at the Baudin site and because the load volumes were significantly smaller at the Murray site. The smaller load volumes at the Murray site were the result of the forwarder operator transporting significantly fewer logs per cycle to reduce the chances of rollover and logs slipping from the load when operating on steeper slopes. The forwarder also travelled significantly more slowly in the stand at the Murray site than at the Baudin site but the impact of this was masked in the cycle time by the forwarder's significantly faster speed when travelling empty and loaded on the track at the Murray site which made up the majority of each cycle at this site.

Acknowledgements

The researchers would like to thank the Western Australian Forest Products Commission and the Plantation Logging Company (harvesting contractors), without whose assistance this research trial would not have been possible.

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Economic analysis of a Eucalyptus globulus stocking and harvesting trial in Western Australia

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Abstract
The impact of management of plantation stocking density on individual tree size can affect final harvest costs and productivity. This paper examined the economic profitability of four stocking (thinning) treatments applied to a Eucalyptus globulus forest stand in Western Australia. Eighteen sample plots were laid out randomly in the plantation and were thinned to waste 3.2 years after establishment to nominal stockings of 1000 (UTH), 700, 500 and 400 stems per hectare. The economic analysis showed that at their theoretical optimal rotation age, all thinning treatments resulted in a lower Land Expectation Value (LEV) and net financial loss over the full rotation when compared to the unthinned control (UTH) stocking treatment. Positive impacts on individual tree growth and form and associated reductions in harvesting costs did not compensate for overall losses in per hectare yield.

Keywords
E. globulus, stocking density, harvesting productivity and cost, thinning, Australia

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1. Introduction

In Australia almost 1,000,000 ha of eucalypt plantations (over 50% of which is Eucalyptus globulus) have been established, primarily since 1990 and principally as a source of pulpwood (Gavran 2014). The majority of these plantations have been planted at a stocking density of approximately 1000 - 1250 stems per ha with early weed control and fertiliser application and a target rotation length of ten years.

Manipulation of plantation stocking density through initial stocking and, to a lesser extent, thinning is a key silvicultural tool used by plantation managers to achieve their objectives. Studies across a broad range of both coniferous (e.g. Pinus radiata (Sutton 1968), and hardwood, e.g. E. nitens (Neilsen and Gerrand 1999), E. grandis (Schönau 1974), species have found that increasing initial stocking density increases total wood volume per hectare and decreases mean tree volume and diameter, although the effect of stocking density on tree traits tends to reduce with increasing age (Mead 2005).

The impact of manipulating plantation stocking density on individual tree size can affect final harvest costs and productivity as numerous studies have shown tree size to be a major driver of harvesting costs and productivity (e.g. Acuna and Kellogg 2009; Strandgard et al. 2013). However, harvest cost impacts need to be considered in the context of the total costs and returns for a rotation. Tong et al. (2005), in a simulation of the impact of pre-commercial thinning on final harvest costs and returns from Pinus banksiana stands found that the additional costs associated with thinning were more than offset by the lower final harvest costs resulting from larger and fewer trees.

The present study investigated the effect of different stocking densities on standing tree and harvesting traits in an E. globulus stand in Western Australia (WA). Specifically the study aimed to (i) quantify the effect of stocking density on standing tree traits including over bark diameter at breast height (DBHOB), tree height, tree volume, and tree form traits (branches and forks); (ii) quantify the effect of stocking density on harvesting traits including machine hourly productivity and cost per cubic metre; (iii) conduct an economic analysis and determine optimal rotation ages of different stocking densities assuming a E. globulus plantation with infinite rotations, (iv) conducting a sensitivity analysis to determine the factors with the greatest incidence on LEV.

2. Material and Methods

2.1 Stocking and harvesting trial

The stocking trial was established on a Western Australian Plantation Resources (WAPRES) property near Greenbushes, Western Australia (33°48’45.9"S, 116°04’38.7"E).

The study site was planted with bluegum (Eucalyptus globulus) at 1000 stems per hectare (sph) (spaced 5.0m between rows and 1.9m between trees) in early July 1999 and a stocking trial was subsequently established on the site in September 2002 (3.2 years after establishment) to assess the impact of stocking density on tree growth and stand production. Post-planting chemical weed control was undertaken at four months and at one year after planting.

Eighteen sample plots were laid out randomly in the plantation. Fifteen plots were thinned to waste, to 700, 500 or 400 sph. Stockings “1000” (control unthinned, hereafter named "UTH") and "700" were replicated three times whereas treatments "500" and "400" were replicated six times (completely randomized design). In the thinning-to-waste treatments ("700", "500", and "400") at age 3.2, trees of poorer form (resulting mainly from parrot damage) were removed as a priority. Note that the spacing treatment at age 3.2 did not completely eliminate forking in the treated stands as some further forking (including parrot damage) occurred after treatment.

The harvesting trial occurred during final felling of the site in January 2009 (9.5 years after establishment). Harvesting was carried out using a tracked excavator-based Cat 322L harvester equipped with a 20-inch Waratah HTH620 head (Figure 1) and operated by an experienced operator. Terrain on the study site was firm and even, and slopes ranged from flat to a gentle side slope (average 6°). Product specification focused on the production of 5.2m logs to a minimum small-end diameter of 50mm.

Harvester cycle elements were measured on a tree-by-tree basis during harvesting of all 18 plots. Each treatment plot measured 35m long x 30m (six rows) wide and the operator worked along strips comprised of three rows at a time. All work elements for each tree, plot and treatment were accurately timed and manually recorded at the time of felling. Work elements included brushing or clearing, felling, moving, processing, stacking or bunching, and travel time. Every tree in the treatment plots was measured for diameter at breast height (DBHOB) and height prior to harvest and assessed to determine the expected impact of three major form criteria (branchiness, forking and sweep) on harvester productivity using a 2-class coding system (Class 1: no anticipated impact of form factor on harvesting/processing productivity, Class 2: possible or expected impact of form factor on harvesting/processing productivity).

2.2 Yield and harvest productivity modellingl

Trees in measurement plots were measured for DBHOB, tree height, and survival on six occasions during the trial period (age 3.2, 3.4, 4.3, 5.4, 7.6, and 9.5 years). Plot and treatment results obtained included: mean DBHOB, basal area, volume, mean tree height, stocking and survival. The volume increment was used to develop a yield model which in turn was used to generate mean annual increment (MAI) curves from ages 5 to 12 (i.e. beyond the actual harvest age) and conduct the economic analysis on the four stocking treatments based on projected data.

A general harvesting productivity model was developed from the data collected during the time and motion study. A stepwise regression procedure was used for that purpose, starting from a maximal model including all the independent variables: "thinning treatment" (indicator), "tree size" (continuous), "branchiness" (binary), and forking (binary). Then, variables with no statistically significant effect ($p>0.05$) were excluded one by one from the model. To homogenize the variance of the dependent variable to improve fit, both productivity and tree size were transformed to their natural logarithm. In addition, an ANOVA test was run on plot level data collected at the time of harvest to test statistical significant differences between stocking treatments for the variates DBHOB, tree height, basal area, and harvest productivity. A Shapiro-Wilk normality test and an equal variance test were performed at a significance level of 0.05, and pairwise multiple comparisons between treatments were performed using the Holm-Sidak test.

2.3 Economic analysis

The financially optimal stocking alternative was determined by calculating the Land Expectation Value (LEV) for each alternative and selecting the one that maximized LEV. LEV is the present value per unit area of the projected costs and revenues from an infinite series of identical even-age forest rotations, starting initially from bare land (Chang 1984, Cordes 2013). It is the primary approach for assessing and selecting management options for even-aged stands when the objective is to maximize the financial return from growing timber. In its simplest formulation, LEV calculation assumes that each rotation is of equal length, the sequence of events within each rotation is the same, and the net revenue associated with each event within the rotation is the same for all rotations.

The mathematical formulation to calculate LEV is presented in equation 1. The four basic types of costs and revenues associated with most even-aged forest rotations are 1) an establishment cost, 2) a final net revenue, 3) annual costs, and 4) miscellaneous intermediate costs or revenues that occur in the middle of the rotation.

The LEV calculated for each thinning (stocking) alternative uses the following input values that approximate the real values at the time of the study (all costs are expressed in Australian dollars). Establishment cost (year 0), annual land leasing cost, and thinning cost (year 3.2) were estimated at 1450 \$ per ha, 500 \$ per ha, and 400 \$ per ha, respectively. Harvesting costs per \$ m^{-3}were calculated from the results obtained with the productivity model developed in the study, and assuming an hourly cost of 220 \$ per PMH, while transport cost was estimated at 10 \$ m^{-3}. A mill gate price of 75 \$ $m^{-3}$was used to determine the revenue per unit area, and a 7% interest rate was used for the analysis.

For each stocking treatment, the theoretical rotation age that maximized LEV was calculated using Excel's Solver and a sensitivity analysis was conducted on a few key parameters to determine their impact on LEV and rotation age. These included establishment cost, annual leasing cost, thinning cost, yield per unit area, harvest productivity, mill gate price, and interest rate. In addition, supplementary tornado charts were built to compare the relative importance of these parameters and assess their impact on LEV.

3. Results and discussion

3.1 Tree and stand factors at time of harvest

Table 1 summarizes the tree growth and stand production for trees within stocking treatments at the time of harvest (age 9.5). It is evident that the spacing treatment at age 3.2 had a significant impact on tree growth. Average over bark diameter at breast height (DBHOB) increased by 45% when moving from the control UTH stocking (1000 sph) down to 400 sph, and average tree height increased by 19%. De-

Figure 1. Tracked excavator-based harvester used in the trial.

$$LEV = \frac{[-E + \sum_{t=1}^{R-1} \frac{I_t}{(1+r)^t} + \frac{A[(1+r)^R - 1]}{r(1+r)^R} + \frac{PY}{(1+r)^R} + \frac{HY}{(1+r)^R}](1+r)^R}{(1+r)^R - 1} \quad (1)$$

LEV = *Land Expectation Value per unit area*
R = *the length of a rotation (in years),*
E = *the stand establishment cost per unit area,*
A = *the annual land leasing cost per unit area*
It = *the thinning-to-waste cost per unit area occurring after plantation establishment and before the final harvest,*
Y = *the expected yield of pulplogs* (m^3) *per unit area at the final rotation,*
P = *the mill gate price of pulplogs per* m^3,
H = *the harvesting and transportation cost per* m^3, *and*
r = *the real interest rate.*

spite the increased tree growth in the spaced plots, overall stand production (in tonnes per hectare) was less than that in the control plots at time of harvest. Average final merchantable yield at the 400, 500 and 700 stocking densities was consistently about 7% - 8% less than UTH.

As the spacing treatment at age 3.2 targeted stems of poor form, it had a significant impact on overall stand form within the different stockings (Table 1). In the control UTH stocking treatment, 38% of the stems had major forks compared with only 23% in the 500 and 400. Just a few Class-2 sweep and branchiness trees were observed in the study and therefore they were left out from the analysis.

The ANOVA test revealed statistically significant differences between stocking treatments for the variates DBHOB, tree height, and tree volume (p-values = <0.001, 0.034, and <0.001, respectively). Table 2 shows the results of the pairwise multiple comparison procedure for the variates DBHOB, Tree height, and Tree volume, and Figure 2 shows a combined histogram/box plot chart for the variate Tree volume, which had the biggest effect on harvest productivity.

With the exception of stockings 700 and UTH, multiple comparisons for variates DBHOB and Tree volume were statistically significant between stockings. The only comparison that was found to be statistically significant for the variate Tree height was that between stocking 400 and UTH. In comparison to stockings 500 and 400, a greater number of trees in stockings UTH and 700 were concentrated on the lower part of the tree volume range. According to Figure 2, 75% of the trees have a tree volume greater than 0.11, 0.18, 0.23, and 0.32 m^3, in stockings UTH, 700, 500, and 400, respectively.

3.2 Yield and MAI curves

Figure 3 shows standing volume curves for the stocking treatments from age 5 and projected to age 12. Across this age range, the volume per ha of the unthinned treatment (UTH) was 9.7%, 10.4%, and 17.9% greater than that of stockings 700, 500, 400, respectively. The volume per ha of stocking 400 equalled that of stockings 500 and 700 at around age 11, and of stocking UTH at around age 12. There was little difference between the volume per ha of stockings 700 and 500 from ages 5 to 12. A similar trend occurs with MAI values. The MAI of stocking 400 increased at a greater rate than that of the other treatments until year 10.5 when it equalled those of treatments 700 and 500. It equalled the MAI of the UTH stocking at about age 12. Maximum MAI values (biological rotation age) were reached at ages 9.5, 10.0, 9.6, and 11.3, for stocking treatments UTH, 700, 500, and 400, respectively (Figure 4).

3.3 Harvest productivity study and modelling

A total of 1048 trees (cycles) were timed for the harvester-processor. The mean time per tree associated with each work element in a full cycle is presented in Table 3. As expected, processing and felling were the most time consuming work elements, on average accounting for 78.% and 16.3% of the total cycle time, respectively.

The lowest mean cycle time was obtained for the 700 sph treatment, mainly due to a reduced processing time. Results shows that both processing and felling time were high with a stocking of 1000 sph, and drop when stocking was reduced to 700 or 500 sph, and increase again when the stocking was further reduced to 400 sph. This was mainly caused by the increased fork proportion and tree size. Also, moving time increased at lower stockings as the harvester-processor had to travel longer distances to reach each tree to be harvested. The harvester-processor's productivity regression model including coefficients and statistically significant variables (P <0.05) selected with the stepwise procedure (tree volume and forking) is presented in Equation (2); the corresponding productivity equation is presented in Equation (3). Regression model's adjusted R^2 was 0.85; the variables Tree Volume and Forking explained 78% and 7% of the variation in productivity, respectively.

The surface chart in Figure 5 presents productivity values for various combinations of tree volume (ranging from 0.1 $m^3$to 1.3 m^3) and fork proportions (ranging from 0-100%). Mean productivity values for the stockings UTH, 700, 500, and 400 at the rotation age (9.5 years) were 25.9, 22.8, 18.3, and 14.5 m^3/PMH_0. It is evident from the figure that the impact of forks on productivity becomes more prominent as tree volume increases. In addition, with a lower proportion of forks, productivity fluctuates at higher rates across the tree volume range.

3.4 LEV by stocking treatment

LEV values peaked at ages 9.6, 10.0, 9.8, and 10.8 (theoretical optimal rotation ages), for stocking treatments UTH, 700, 500, and 400, respectively (Figure 6). In all the cases, theoretical optimal rotation ages exceeded the rotation length for the trial (age 9.5). A substantially lower LEV was found for stocking 700 mainly owing to a lower harvesting productivity (higher harvesting cost per m^3) compared to stocking treatments 500 and 400, and a lower revenue in comparison to the UTH treatment.

At their theoretical optimal rotation ages, yields per ha reached 202.2 m^3 (LEV = 799.8 $/ha), 195.7 m^3 (LEV = 58.8 $/ha), 190.2 m^3 (LEV = 458.8 $/ha), and 207.7 m^3 (LEV = 542.8 $/ha), for stockings UTH, 700, 500, and 400, respectively. Thus, in comparison to stocking UTH, a net loss of 3.6 $/t, 1.54 $/t, and 1.3 $/t, was obtained for stockings 700, 500, and 400, respectively. To match the LEV of the UTH stocking, the yield per ha of stocking treatment 700, 500, and 400, would need to increase to 207.4 m^3/ha (6.0%), 195.4 m^3/ha (2.7%), and 212.9 m^3/ha (2.5%), respectively.

3.5 Sensitivity analysis on LEV

The tornado chart in Figure 7 presents the sensitivity analysis results for a number of factors (and their corresponding lowest and highest ranges) impacting LEV. Only results for stocking treatment 400 are presented, however the trend is very similar for the remaining stocking treatments. Mill gate price and yield per ha are the factors with the highest impact on LEV. Unfavourable conditions - including higher thinning costs, establishment costs, and leasing costs, as well as lower yields per ha, harvesting productivities and lower

Table 1. Tree and stand factors at time of harvest

Tree and stand factors	Target stocking (trees/ha)			
	UTH	700	500	400
Number of treatment plots	3	3	6	6
Actual merchantable stocking (trees per ha)	978	637	489	393
Mean tree diameter (DBHOB), mm	174	205	226	253
Mean tree height, m	20	21.4	22.2	23.7
Mean standing tree volume, m^3/tree	0.233	0.286	0.366	0.464
Stem form (Forking), % of trees				
Class 1	62	62	77	77
Class 2	38	38	23	23
Merchantable yield, tonnes/ha*	194.6	179.9	178.1	180.2
Differential		-8%	-8%	-7%

** A 1:1 tonne to volume conversion ratio was used.*

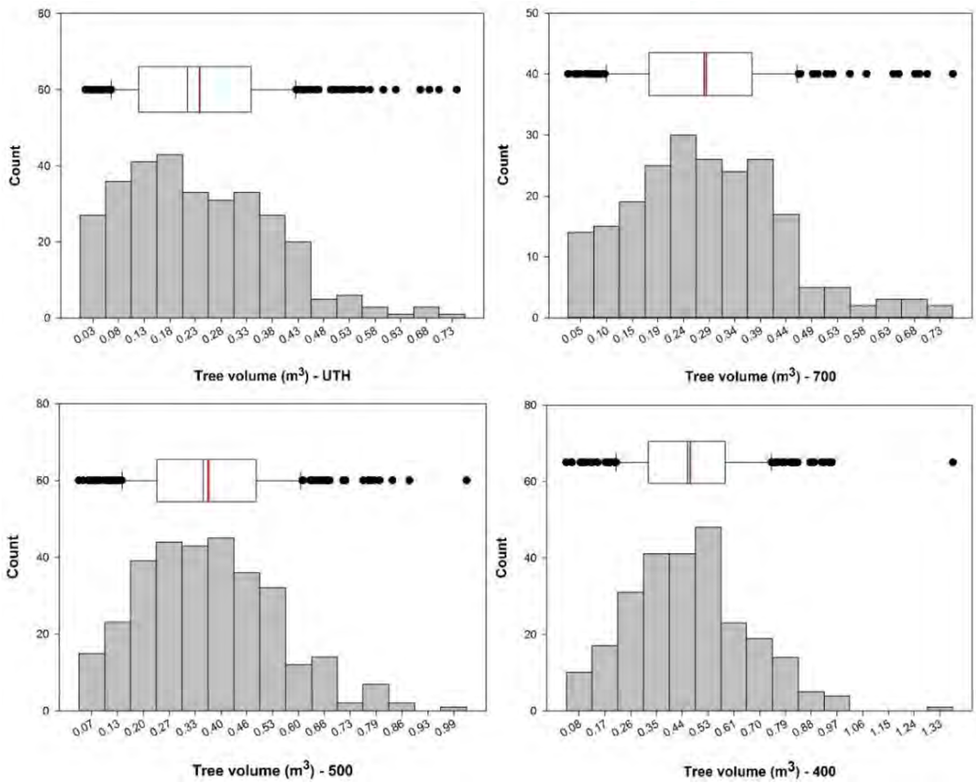

Figure 2. Combined histogram/box-plot charts for variate “Tree volume” by stocking treatment. The vertical red line in the box plot corresponds to the mean value.

Table 2. Pairwise multiple comparison between stocking treatments

Comparison	Variate		
	DBHOB p-value	**Tree height** p-value	**Tree volume** p-value
400 vs UTH	<0.001	0.034	<0.001
500 vs UTH	0.003	0.287	0.005
400 vs 700	0.004	0.248	0.032
400 vs 500	0.039	0.364	0.045
700 vs UTH	0.069	0.506	0.163

p-values >0.05 indicate no statistically significant difference between stocking treatments.

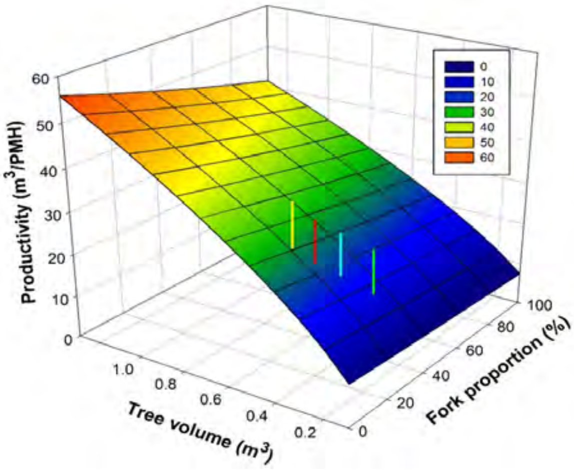

Figure 5. Harvesting productivity as a function of tree volume and fork proportion. Vertical bars show the mean productivity by stocking (yellow: 400, red: 500, cyan: 700, green: UTH)

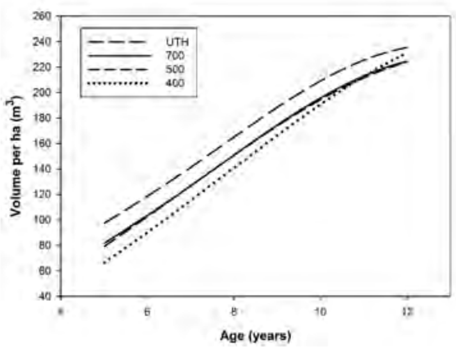

Figure 3. Standing volume curves by stocking treatment

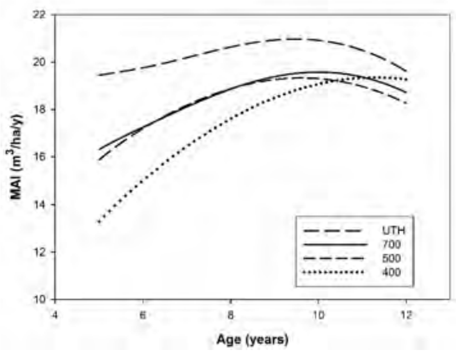

Figure 4. Standing volume curves by stocking treatment

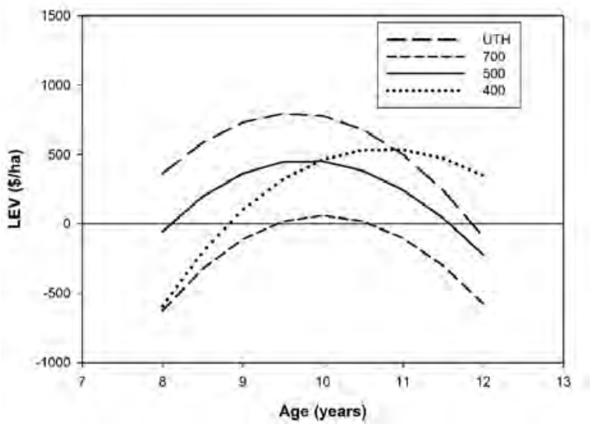

Figure 6. Land expectation values by stocking treatment

Table 3. Summary of harvester-processor time study. Mean time per cycle in seconds and share of element time in total cycle time.

	UTH		700		500		400	
Work Element	s	%	s	%	s	%	s	%
Felling	16.1	17.6	14.4	16.9	14.3	14.8	15.7	15.8
Processing	71.3	78.1	66.5	78.2	77.3	79.9	77.8	78.2
Brushing or cleaning	0.8	0.8	0.12	0.1	0.26	0.3	0.2	0.2
Moving	3	3.3	3.8	4.5	4.7	4.9	5.6	5.6
Travelling	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	**91.4**	**100**	**85**	**100**	**96.8**	**100**	**99.5**	**100**

Felling	Begins when crane begins to engage the tree and ends when processing commences
Processing	Debarking, delimbing, and bucking (i.e., cross-cutting) of logs
Brushing or cleaning	Removal or movement of slash, undergrowth, or unmerchantable trees
Moving	Not associated with felling and processing, harvester moving within a pass (3 harvested rows per pass)
Travelling	Movement between passes or bays

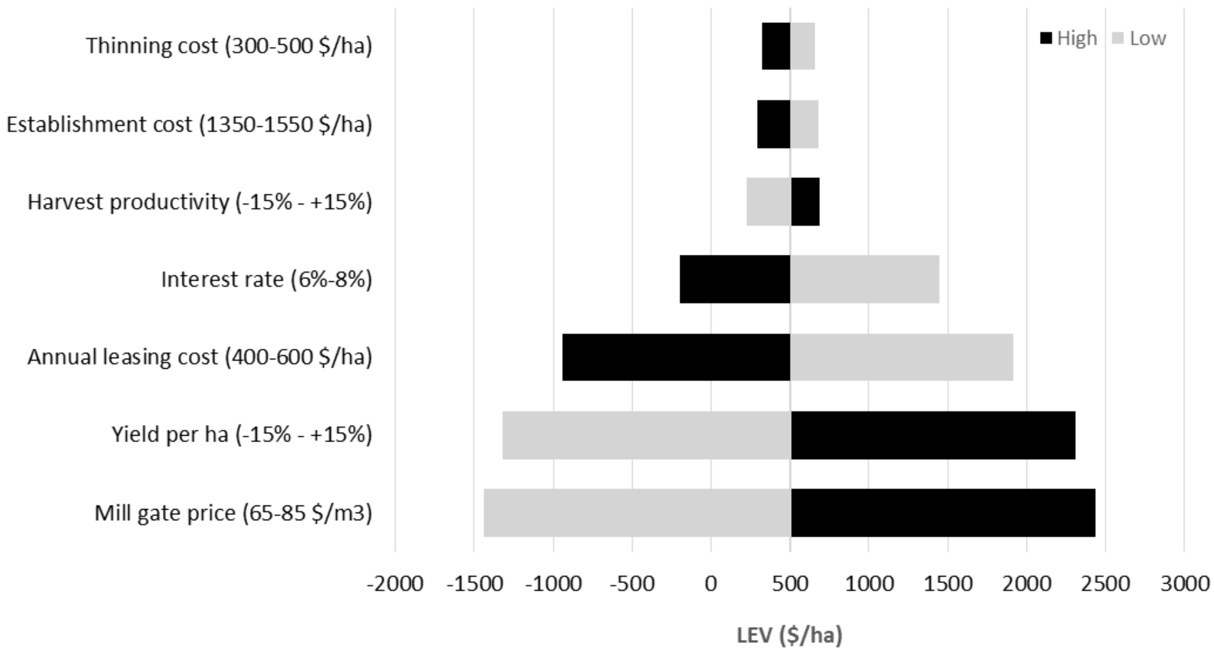

Figure 7. Tornado chart showing the effect different factors on LEV (Stocking 400). Values in parenthesis depicts the lowest and highest range evaluated for each factor.

mill gate prices – impact LEV negatively and postpone the optimal rotation age. Likewise, as expected, a higher interest rate results in an earlier rotation age (11.0 and 10.6 years for an interest rate of 6% and 8%, respectively).

4. Conclusions

This paper has presented an economic analysis of a Eucalyptus globulus stocking and harvesting trial in Western Australia. The impact of the manipulation of plantation stocking density on individual tree size can affect final harvest costs and productivity as numerous studies have shown tree size to be a major driver of harvesting costs and productivity. However, harvest cost impacts need to be considered in the context of the total costs and returns for a rotation.

The results of this analysis showed that increased average diameter up to 45% and height up to 19% when moving from standard 1000 stocking (UTH) down to 400 stocking. Increased tree volume and removal of poorly formed stems during thinning increased harvester productivity by up to 66% when moving from standard 1000 stocking down to 400 stocking. Although not presented in the paper, a preliminary analysis indicates that this could reduce direct harvesting costs by up to 40%.

In the 400 sph stocking treatment, mean tree volume was double that of the UTH treatment at time of harvest. However, final stand yield of the thinned stands at harvest time was less than that of the standard UTH stocking. The economic analysis showed that at their theoretical optimal rotation age, all thinning treatments resulted in a lower Land Expectation Value (LEV) and net financial loss over the full rotation when compared to the control (UTH) stocking treatment. Positive impacts on individual tree growth and form and associated reductions in harvesting costs did not compensate for overall losses in per hectare yield.

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The propose of performance standards for forwarders

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Abstract
The standards for forwarders were carried out following the; performance class of the machine, group of stem volumes, forwarding distance and the type of felling. The standards do not define the species from which the 2 - 6 m long assortments are produced. An average performance of the forwarder with the performance up to 60 kW ranges from 2.0 m³/h to 4.2 m³/h depending on the volume of the felled species and the forwarding distance, without taking into account the type of felling. For the performance class of forwarders over 60 kW the machine performance ranges from 7.1 m³/h to 20.0 m³/h based on the same above mentioned factors. Work performance is comprised of; unit time, batch and shift time for necessary breaks (inclusion coefficient of batch and unit time for the work of forwarder amounts to 1.25 and the inclusion coefficient of the time necessary for relaxation to 1.06). Electronic normative calculation is possible on the website: http://vnhu.forestoffice.eu/

Keywords
forwarder, standards, performance

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1. Introduction

The share of harvester technology has the second highest representation in the Czech Republic (CR). The harvesters were deployed in the CR in 2013 for processing 4.7 mil. m3 of timber, i.e. a 30% share of annual harvested timber volume; the share also copies a share from processed volume at State Forests, State Enterprise, i.e. 31% (Ministry of Agriculture, 2014). With regard to rapid development of the technology connected with high machinery performance, responsible time planning of harvest works is necessary by work contractor or service supplier. These organizations must provide a year-round schedule of harvesting works and preparation of work place in response to supplier-consumer relations.

Meeting the facts and the possibility of their realization are the main objectives of this project carry out the analysis of operative time consumption of forwarders which constitutes the main component of work shift and the propose work performance standards for low, medium and high-performance forwarders.

2. Material and Methods

The objective is a proposal of time norm expressed directly by time (standard hours). The norm expresses the size of a standard consumption of time needed for work operation depending on woody species, mean volume of logged stem, forwarding distance and performance class of forwarders. The methodology of work is summarized in the following point:

- The analysis of production process
  - Parallel work operation of the forwarder
  - Non-operative batch and shift times
- Mathematics-statistical analysis of time consumption for forwarders
  - Mathematics-statistical analysis of time consumption for work operation during forwarding
  - Regression and correlation analysis of forwarder time consumption dependence on the stem volume of the logged woody species and forwarding distance
- Forwarder work day record
- Total time for forwarding work operation
- Proposed time normatives and establishing performance standards

The methodological procedure is described in detail in Dvořák et al. 2011.

3. Results

The proposed performance standards and normatives of time consumption for timber forwarding using forwarders are carried out from the work records based on the work contents analysis of the logging-transport and work shift operation. The proposed standards are valid for common production conditions which can be ensured at the workplace following standard technological (e.g. Uusitalo 2010, Dvorak et al. 2011, Persson 2011, Persson 2013) and work procedures established by the laws of the CR and corresponding regulations, company's internal and organization regulations and rules about safety and health protection for logging and forwarding operations (Law No. 262/2006 Coll, Government regulation No. 28/2002 Coll).

Appropriate values of performance standards express a vital time consumption of the operators qualified for the performance of quality work.

The analysis of production process, the mathematics-statistical analysis of time consumption for forwarders, the forwarder work day record and the total time for forwarding work operation are published e.g. in Slamka-Radocha (2010), Dvorak et al. (2011).

3.1 The proposal of performance standards for forwarders

It is valid for logging in standard work conditions. Circumstances which have a considerable impact on the change of standard time consumption are mentioned in Part II where there are also given particular per cent normatives of performance standards modification.

In this part there are described individual work operations which create one work cycle of the forwarder with the mention of limit points which strictly define an initial movement which commences the operation.

Part I.: Classification, contents and application of performance standards and normatives

1 Performance standards are classified for the wood forwarding as follows

11 based on a performance class of a forwarder

111 classification according to the engine performance for low-performance machines to 60kW including medium and high-performance machines over 60 kW

12 based on an average volume of felled stems in cubic meters without bark

121 for forwarders of all performance classes: to 0.09, 0.10 – 0.14, 0.15 – 0.19, 0.20 – 0.29, 0.30 – 0.49, 0.50 – 0.69, 0.70 – 0.99, over 0.99.

13 based on a forwarding distance from the stand to the roadside landing in meters

131 for forwarders of all performance classes: to 100, 100 – 200, 201 – 300, 301 – 400, 401 – 500, 501 – 600, 601 – 700, 701 – 800, 801 – 900, 901 – 1000, for every other 100 m.

2 Performance standards contain

21 total normative time, calculated from the time of unit work with the inclusion of batch work, shift work and times for necessary breaks.

22 batch work time (tab. 1) contains time necessary for handling and studying work orders for work unit, time for preparation with the workplace (work unit), time for technical service of the workplace (work units).

23 time for shift work (tab. 2) contains time for work preparation and termination, time for standard machine maintenance, time for minor machine repairs (e.g. hydraulic system and so on), time for securing the machine and workplace after the termination of work.

24 time of unit work (tab. 3) contains times for work operation segments which correspond with the contents of the normatives in the following classification

25 Time for breaks at work (T2) and time for relaxation is used for regular interruption of work so that working hours lasting 8,5 h include 30 min for breaks, as stated by Law No. 262/2006 Coll., Labour Code. Breaks serve for the worker's relaxation. During the breaks the worker is not obliged to perform any other auxiliary or additional works necessary for the running of the following cycle without useless interruptions.

Table 1. Batch work time.

Type of work time	Work contents	Initial limit point	Final limit point
B101	Preparation and termination of work on a work unit (travel to the work unit, familiarization with the work unit and its patrol, safety measures, stack preparation and so on)	Moment of initiation of particular batch work	Moment of terminating particular batch work
B102	Technical service of the workplace (production units) – e.g. treatment of damaged woody species		

Table 2. Time for shift work.

Type of work time	**Work contents**	**Initial limit point**	**Final limit point**
C101	Shift work orders (accepting the order, dialogue with a TEW concerning technical-organizational questions)	Moment of initiating an appropriate shift time	Moment of terminating an appropriate shift time
C102	Preparation work at the beginning of the shift and termination of work at the end of the shift		
C103	Common daily maintenance of the machine following the machine's manual*)		
C104	Minor, common machine repair not exceeding 30 min of the shift time		

*)*the standards do not include non-standard maintenance of the machine and standard maintenance carried out in longer time periods than in daily periods.*

Table 3. Time of unit work.

Type of work time	Work contents	Initial limit point	Final limit point
A101	Ride of the machine without load from the roadside landing to the production unit (departure of the forwarder from the roadside landing; arrival at the production unit)	The start of the empty forwarder.	Stopping he forwarder for loading the first assortments on the forwarding trail or clearing.
A102	Creating the load (Lifting the hydro-manipulator from storage position to work position after arriving at the stand or clearing; necessary maneuvering in order to place the machine in a suitable position for assortment loading; assortment loading; the preparation of the machine for travel in order to load the storage area or depart for the roadside landing, or landing; the machine travel to the stand; positioning the hydor-manipulator to transport position for loading the storage area if possible and the departure for the roadside landing, or landing)	Stopping the forwarder for loading the first assortments on the forwarding trail or clearing.	The start of the loaded forwarder from the stand or clearing to the landing (of the production unit).
A103	Ride of the machine with load from the production unit to the roadside landing including maneuvering the forwarder to a suitable position for off-loading the timber using the hydraulic boom to the landing.	The start of loaded forwarder from the stand or clearing to the landing (of production unit).	Stopping the machine at the roadside landing (landing).
A104	Off-loading the timber at the roadside landing (handling the hydro-manipulator for loading; necessary end-trimming and assortment distribution at the landing; storing the hydro-manipulator to transport position).	Stopping the machine at the roadside landing (landing).	The start of an empty forwarder.

3 Main work requirements

31 Work quality

No damage to surrounding standing trees, protection of young cultures and natural seeding. No damage to forest roads with the risk of subsequent erosion. Storing and undersettig assortments at the landing in order to prevent their landslide and prepare them for forwarding from the roadside landing without any other necessary tasks.

32 Forwarded raw material

- Assortments produced by harvester
- Asortments produced manually for forwarding by a low-performance forwarder

The volume of the felled stem is taken over from the operation system of the harvester which processes the raw material. As regards motor-manual production, the volume of the felled stem is calculated as a share of the produced raw material and a number of processed stems. It is given in cubic meters without bark.

33 Work tools and basic equipment of workers

- forwarder
- work protective aids following valid regulations
- equipment for common maintenance of the machine

34 Organization of the workplace

Work organization is modified by internal technological regulations

35 Work operation of the forwarder

The operator is required to observe the orders from the manual for machine operation produced by the machine's manufacturer.

36 Work safety and hygiene

Work safety and hygiene follows:

- Law No. 262/2006 Coll., Labour Code,
- Government regulation No. 28/2002 Coll., which states the manner of work organization and work procedures which the employer must provide for the work in the forest and workplaces of similar character,
- Other corresponding regulations and internal directives.

4 The applicaton of performance standards and normatives

41 Performance standards and time normatives for timber forwarding by forwarders are used according to

- performance class of the forwarder (paragraph 11)
- mean volume of the felled stems (paragraph 12)
- forwarding distance (paragraph 13)

It is valid for logging in standard work conditions. Circumstances which have a considerable impact on the change of standard time consumption are mentioned in Part II where there are also given particular per cent normatives of performance standards modification.

42 Indicating performance standards by numerical registration numbers

is done in the following order: Registration number of the standard (line) / indication number (column)

Part II.: Per cent modifications of performance standards
Per cent modifications of performance standards express deviations from normal work conditions that have a significant impact on the time consumption.

1.	In work facilitation, which causes the time consumption reduction, the standards and normatives of time are reduced as follows:		
	11	when facilitating the work	
	111	if there is no decks facing or logs sorting carried out while stacking the timber to the landing	up to about 10%
2	If the work becomes more difficult due to the impact of worse than usual average work conditions, which result in the increase in time consumption; the standards and normatives of time are modified with respect to the real influence as follows:		
	21	under the influence of terrain conditions the total standard increases as follows:	
	211	- when working on the slope with the inclination over 20%	up to about 10%
	212	– when working on the slope with the inclination over 20% with rope anchoring	up to about 8%
	213	– when working on the slope with the inclination over 20%, if the slope is slippery	up to about 12%
	214	– when working on conditionally bearable/ muddy terrain	up to about 8%
	215	– when working in an articulated terrain; in the terrain with obstacles (stones, hollows), which do not break the condition of pasability, however, they make the mobility of the machine more difficult	up to about 5%
	216	– when working in stands with weedy undergrowth over 1.5 m tall	up to about 3%
	217	– when working with the protection of undesirable natural seeding and advance growth	up to about 5%
	22	when being affected by climatic conditions the total time standard increases	
	221	– when working in snow layer above 40 cm	up to about 10%
	23	when affected by the type of felling or special logging requirements the total time standard increases	
	231	- with tending intensity to 20% (mild thinning)	up to about 10%
	232	- when felling in dense stands with difficult maneuverability with the harvester, hydraulic crane and the cutting head	up to about 2%
	233	- when forwarding timber after motor-manual production or disseminated timber after random felling	up to about 10%

Part III.: Tables of time performance standards and normatives for forwarding
A. Performance standards for low-performance forwarders to 60 kW (tab. 4)

Table 4. Performance standards classified according to the selected production factors.

Work field: Logging activity **Type of work:** Forwarding		**Work device:** Low-performance forwarders **to 60 kW** including (Mean size of the load – N = 3,1 m^3)							
Number of workers: 1									
Tree species:		Coniferous and deciduous – fresh and dry							
Forwarded timber:		Assortments 2 – 6 m							
Type of felling		Pre-felling							
					Final felling				
Volume of mean felled stem (m^3)		to 0.09	0.10 – 0.14	0.15 – 0.19	0.20 – 0.29	0.30 – 0.49	0.50 – 0.69	0.70 – 0,99	above 0.99
Forwarding distance (m)	**Registration number of the standard**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
		Time consumption (Sh/m^3)							
to 100	**4001**	0.27	0.27	0.27	0.26	0.26	0.25	0.24	0.24
100 – 200	**4002**	0.30	0.29	0.29	0.29	0.28	0.28	0.27	0.26
201 – 300	**4003**	0.32	0.32	0.32	0.31	0.31	0.30	0.29	0.29
301 – 400	**4004**	0.34	0.34	0.34	0.34	0.33	0.32	0.31	0.31
401 – 500	**4005**	0.37	0.37	0.36	0.36	0.36	0.35	0.34	0.33
501 – 600	**4006**	0.39	0.39	0.39	0.38	0.38	0.37	0.36	0.36
601 – 700	**4007**	0.42	0.41	0.41	0.41	0.40	0.40	0.39	0.38
701 – 800	**4008**	0.44	0.44	0.44	0.43	0.43	0.42	0.41	0.41
801 – 900	**4009**	0.46	0.46	0.46	0.46	0.45	0.44	0.44	0.43
901 – 1000	**4010**	0.49	0.49	0.48	0.48	0.48	0.47	0.46	0.45
For other 100 m	**4011**	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

B. Performance standards for medium and high-performance forwarders above 60 k.

Table 5. Performance standards classified according to the selected production factors.

Work field: Logging activity **Type of work:** Forwarding		**Work field:** Medium and high-performance forwarders **above 60 kW** (Mean size of the load – N = 12,1 m^3)							
Number of workers: 1									
Tree species:		Coniferous and deciduous – fresh and dry							
Forwarded timber:		Assortments 2 – 6 m							
Type of felling		Pre-felling							
				Final felling					
Volume of mean felled stem (m^3)		to 0.09	0.10 – 0.14	0.15 – 0.19	0.20 – 0.29	0.30 – 0.49	0.50 – 0.69	0.70 – 0.99	above 0.99
Forwarding distance (m)	**Registration number of the standard**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
		Time consumption (Sh/m^3)							
to 100	**5001**	0.09	0.08	0.08	0.08	0.07	0.06	0.06	0.05
100 – 200	**5002**	0.09	0.09	0.09	0.08	0.08	0.07	0.06	0.05
201 – 300	**5003**	0.10	0.09	0.09	0.09	0.08	0.08	0.07	0.06
301 – 400	**5004**	0.10	0.10	0.10	0.10	0.09	0.08	0.07	0.07
401 – 500	**5005**	0.11	0.11	0.10	0.10	0.10	0.09	0.08	0.07
501 – 600	**5006**	0.11	0.11	0.11	0.11	0.10	0.09	0.08	0.08
601 – 700	**5007**	0.12	0.12	0.12	0.11	0.11	0.10	0.09	0.08
701 – 800	**5008**	0.13	0.12	0.12	0.12	0.11	0.10	0.09	0.09
801 – 900	**5009**	0.13	0.13	0.13	0.12	0.12	0.11	0.10	0.09
901 – 1000	**5010**	0.14	0.13	0.13	0.13	0.12	0.12	0.11	0.10
For other 100 m	**5011**	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005

C. Additional standards and normatives.

Table 6. Additional standards and normatives.

Work activity	Number of the standard	Time consumption (Sh)
Ride on public roads and paved forest roads to the workplace or from the workplace (per 1 km)	4030	0.08
Ride on soft forest roads to the workplace and from the workplace (per 1 km)	4031	0.1
Chain assembly	4032	0.5
Chain removal	4033	0.3
Track assembly	4034	0.5
Track removal	4035	0.3
Loading, off-loading and machine preparation for transport	4036	0.3
Planned maintenance A	4039	8.5
The second or another half-hour of repair at the workplace (30 min of repairs are included in the standard shift time)	4040	0.5

4. Conclusions

Assortment logging method, today connected with harvester technology, is the second most frequently used tehnology in the CR with repsect to the range and volume of logged timber. High performance of the work carried out by harvesters and forwarders during a shift is connected with high technical-organizational requirements for providing maximum workload of the technology and minimal delays. For the purposes of work planning in particular, performance standards were proposed by the present project.

The standards for forwarders were carried out following a performance class of the machine, group of stem volumes, forwarding distance and the type of felling. The standards do not define the species from which 2 - 6 m long assortments are produced. Statistical analysis confirms the difference in the time consumption of unit time between pre-felling and felling, however, only with regard to the fact that pre-felling is connected with forwarding timber from stands with lower stem volume of logged tree species and vice versa. For low-performance machines with an average load volume 3.1 m³, statistical significance between types of felling in stem volume groups 3 and 4 can be rejected. For machines with the performance over 60 kW and with an average capacity of storage area 12.1 m³ the same condition counts as for the groups of stem volumes 2 and 4. The statistical analysis does not confirm any impact of different assortment length on work performance.

An average performance of the forwarder with the performance to 60 kW ranges from 2.0 m³/h to 4.2 m³/h following the volume of the felled species and forwarding distance without taking into account the type of felling. For performance class of the forwarder over 60 kW the machine performance ranges from 7.1 m³/h to 20.0 m³/h based on the same above mentioned factors. Work performance comprises unit time, batch and shift time for necessary breaks (inclusion coefficient of batch and unit time for the work of forwarder amounts to 1.25 and the inclusion coefficient of the time necessary for relaxation to 1.06).

Performance standards classified according to the selected production factors can be modified using per cent modifications following other production factors or extended by additional normatives.

Acknowledgements

Supported by the National Agency for Agricultural Research Czech Republic, Project No. QJ1520005 Optimization of cut-to-length logging and grading of harvester processed timber and proposed control procedures of timber volume measurements accuracy with the objective to enhance the production function of forests and maintain stand stability with respect to harmful agents.

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Selection of debarking technique for pine logs in cut-to-length harvesting method

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Abstract
In Turkish forestry, annual timber production has reached a total of 15 million m³ per annum, 2/3 of which is supplied from coniferous trees. The industrial logs obtained from coniferous trees are required to have the bark peeled for various reasons. Motor-manual cut-to-length (CTL) harvesting methods are commonly used for felling, delimbing, debarking, and cross-cutting of trees at the stump site. Debarking operations can be done by; axe/hatchet, log spade, or a chainsaw mounted debarking apparatus (log debarker). Depending on the preferred technique, the debarking activity time commonly takes 50-80% of the total harvesting time. In terms of time saving and cost reduction of harvesting processes, the loggers and managers can be faced with the issue of which method is the best for debarking logs. The study aims to develop a selection methodology for determining the appropriate debarking technique for pine logs at the stump site. Hence, Analytic Hierarchy Process (AHP), one of the most popular multi-criteria decision making methods, was used to compare the alternative techniques so that it could be; technically appropriate, economically viable, ecologically non-degrading, and socially acceptable. In this methodology criteria and indicator set was used to achieve qualitative assessment for the selection of debarking techniques. The most appropriate technique could be chosen according to both hypothetical forest conditions based on experimental data and real (in-situ) conditions based on observational data.

Keywords
debarking, log debarker, axe, log spade, technology selection, AHP, brutian pine

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1. Introduction

Motor-manual cut-to-length (CTL) harvesting is commonly applied in forest operations in Turkey, based on the use of chainsaw for felling, delimbing, and crosscutting trees. Debarking is also carried out manually by sharpened hand tools, axe and/or spud or motor-manually by chainsaw mounted bark peeling attachment (log debarker/LD) at the stump site. The debarking is the process of elimination bark from stem on a falling tree.

The rule, aim, and functions of debarking are to remove bark for increase wood quality, to keep the wood losses to save raw material (Baroth, 2005), to reduce the weight of the log by providing quickly dry, to minimize the coefficient of friction on the ground (wood can lose own weight quickly dried up, the rate of 35 to 40%, by debarking), to facilitate the process of transport along skidding and hauling distances, to prevent damage caused by insects and protect the health of forest, to reduce storage defects, to contribute to the needs of organic matter in the forest by leaving bark residues, to reduce eradication of bark debris by way of facilitating wood manipulation (Gürtan, 1969; Grammel, 1988; Engür, 1996, Eker et al., 2011). Therefore, debarking is presumably the most considerable activity and it is a technical necessity especially for coniferous tree species operated with CTL harvesting, in Turkey.

Debarking is operated with various methods and techniques such that: (1) Manuel methods with hand tools (axe, debarking spade, debarking knife, and debarking spud), (2) Mechanical methods with debarking machines, (3) Chemical matters, and (4) Water pressure and friction techniques. Additionally, chainsaw mounted log debarker (LD) is being motor-manually used for peeling bark of coniferous in Turkey, as well (Eker, 2004, Eker et al., 2011). Some modified small-scale technology is also developed like that pneumatic debarking spade with manual orientated used in peeling of broad leaved tree species.

However, annual wood production is approximately 15 million cubic meter, 25% of which is supplied by brutian pine (*Pinus brutia* Ten.) trees. This ratio means that approximately 15 million timber logs are handled and debarked by a few bark peeling techniques at the stump site in every year. Depending on the preferred technique, debarking activity time commonly covers 50-80% of the total harvesting time for one unit production. In terms of time saving and cost reduction of harvesting process, the loggers and managers can be faced with the issue of which one is the most appropriate technology for debarking of the logs. Justification of the study is focused on that the determination of appropriateness of the technology for the debarking of felled trees is a key task to be addressed to ensure the future compatibility of the harvesting process in supporting sustainable development.

The intention of the study is to specify useful and systematic method of assessment for selection of appropriate log debarking technology considering technical, economic, social, and environmental aspects. The study aims to develop a criterion and indicator set for appropriateness analysis of debarking techniques for pine logs at the stump site, to compare and to assess different debarking techniques primarily along the criteria and indicators, and to highlight important parts of multi criteria decision-making (MCDM) process with Analytic Hierarchy Process (AHP) when selecting debarking methods and equipment.

2. Material and Methods

This study was focused on the three different (stump site) debarking techniques for felled pine log within CTL harvesting method and the comparison methodology of the techniques to choice the best one. Tools of the debarking techniques were chainsaw mounted log debarking apparatus (log debarker) (Figure 1a, b), axe (Figure 2a, b), and log spade (Figure 3a, b). The system boundary was mentioned in Table 1 for the techniques.

Table 1. System boundaries of alternative debarking techniques.

System No	Main Tool	Component
System-I	Chainsaw mounted log debarker	1 Operator + 1 co-worker + 1 chainsaw + 1 debarker head
System-II	Axe	1 Worker + 1 co-worker + 1 axe
System-III	Spade	1 Worker + 1 co-worker + 1 log spade

The study material, data and information used in study, was based on the technical properties, working techniques and conditions, terms of use, productivity values, costs, advantage-disadvantage, etc. of the debarking techniques. Data required for the comparison of debarking technique, obtained from previous researches, literature, guidebook, application reports, field survey, and unstructured interview performed with forest workers/operators. In order to make a decision on the selection for the most appropriate debarking technique, ranking, weighting- sum method, and Analytic Hierarchy Process/AHP (Saaty, 1980) were used in multi-criteria decision making concept. All tabulation, ranking, and AHP analysis were achieved by using of MS Excell spreadsheets.

Definition of the appropriateness for debarking of brutian pine log produced from clear-cutting and thinning operations was realized by technology selection methodology developed by Eker (2004). First of all, the criteria and indicators set were developed to determine the appropriateness of a technique or method, or system according to main criteria and indicators of sustainable forestry. In this study, the appropriateness criteria and sub-criteria were summarized in below.

The most appropriate debarking technique should be; technically possible, economically feasible, environmentally sound (ccologically balanced), institutionally acceptable, socially agreeable, biodiversity respectful, silviculturally acceptable, locally controlled, cost effective, labor intensive, reasonably flexible, reliable, knowledge rich, etc. The criteria were degraded into 4 main criteria so that they can be quantifiable, comparable, and ratable to facilitate decision making process. These criteria were technical, economic, ecological/environmental, and social criterion, each of which was divided into indicators represented the main criterion (Table 2). Afterwards, well-known AHP methodology was used in rating, scaling and prioritizing of the indicators and criteria.

However, to prevent mistakes and to fortify consistency of decision maker or decision making process, a multi-stage sequential methodology was developed and applied in this study for choosing the best technique. The process included that were:

Step 1: It was determined the priority value of the main criteria by pairwise comparison method. This step was repeated for indicator set in each criterion.

Step 2: Each alternative technique or system was symbolized by "levelling strategy" with respect to indicators. The levelling strategy was based on a levelling scale represented by letter character from low, medium to low, medium, moderate to high, and to high.

Step 3: With the support from the first and second step, a gradation value was appointed to each alternative respect to each indicator. The grading scale consisted of numerical ranking values from 1 (the worst) to 9 (the best).

Step 4: Original AHP method was used in the comparison between alternatives respect to each indicator, by means of pairwise comparison. However, to constitute pairwise comparison matrix, in this step, the modified relative appropriateness value (for eigenvector) was produced by converting classic relative importance values (Table 3). To solve the comparison matrices, "the best method" (Eker, 2004) was used in processes.

Step 5: The priority vector of the each indicator set was multiplied by relative appropriateness value and acquired the total weighted eigenvector for each alternative respect to indicators.

Step 6: Step 5 was repeated for each criterion, thus; the weighted eigenvector was obtained for rating alternatives and selection of the best alternative. This was solution of the decision matrix.

3. Results

The priority vector achieved by comparing of technical, economic, environmental, and social criteria, for the selection of the best debarking technique, in the scale of brutian pine tree, was summarized in Table 4. According to Table 4, the technical criterion has the top level priority as the usual manner.

The relative value vector (eigenvector) for each alternative debarking technique was computed respect to each indicator. Then, the eigenvector of each indicator was mul-

(a) (b)

Figure 1. a) Chainsaw mounted log debarker, b) Debarking with log debarker (P: M.Eker).

(a) (b)

Figure 2. a) Axe for log debarking, b) Debarking with axe (P: M.Eker).

(a) (b)

Figure 3. a) Log spade and profiles, b) Log debarking with log spade (P: D. Özer).

Table 2. Criteria and indicators set for AHP decision matrices.

Criteria/C	Economical/C_1	Environmental/C_2	Social/C_3	Technical/C_4
Indicators/I	Operational costs	Soil compaction	Employment capacity	Reliability
	Fixed costs	Erosion	Opportunities	Access to resource
	Capital investment	Nutrient losses	Dependency to rules	Availability
	Productivity	Hydrological cycle	Hygiene	Locally controllable
	Profitability	Water quality	Health and safety	Reasonably flexible
	Energy requirement	Waste matter	Training requirement	Cleanliness
		Emission	Regional development	Work and product quality
		Biological diversity	Work load	Precision requirement
		Forest health		Planning requirement
				Dependency to conditions

Table 3. Converted gradation scale for quantitative comparison of alternatives.

Intensity of importance in AHP methodology		Appropriateness grading scale	
Rating	**Definition**	**Definition**	**Rating**
1	Equal	Equally appropriate	1
3	Somewhat more	Somewhat more appropriate	3
5	Much more	Much more appropriate	5
7	Very much more	Very much more appropriate	7
9	Absolutely more	The most appropriate	9
2, 4, 6, 8	Intermediate	Intermediate appropriateness	2, 4, 6, 8

Table 4. Pairwise comparison matrix of the criteria with respect to the goal.

Criteria	Technical	Economic	Environmental	Social	Priorities
Technical	1	1	7	5	0.431
Economic	1	1	5	7	0.399
Environmental	1/7	1/5	1	1/3	0.059
Social	1/5	1/7	3	1	0.111

Lmax= 4.124, CI=0.041, CR=0.042

tiplied by priority vector, and the weighted eigenvector was obtained, respectively (Table 6, 7, 8, 9).

Table 5. Priority vector for the indicators with respect to economic criterion.

Indicators for Economic Criterion	Priorities
Operational costs	0.219
Fixed costs	0.273
Capital investment	0.277
Productivity	0.109
Profitability	0.085
Energy requirement	0.036

Lmax= 6.645, CI=0.129, CR=0.097

When the relative value vector of each alternative respect to main criteria was added, the final priority vector and decision support values could be achieved by multi criteria decision making procedure (Table 10). According to Table 10, it was determined that debarking with axe (manual technology) was the most appropriate technique, as technically feasible, economically viable, environmentally sound, and socially acceptable, for debarking of pine logs within CTL harvesting system.

In the same way, the priorities vector of the indicator set within each group of the criterion was calculated, as well. In table 5, it was given example of priority vector for the indicators in economic criterion.

4. Discussion

Debarking operations within CTL harvesting process covers a significant time to supply unit cubic meter wood raw material. The calculation procedure of the unit cost per cubic meter is based on standard working time and unit expenditure. Currently, salary or costing of debarking activity is not readily separate from the cutting process. Therefore, it is

Table 6. Combined comparison matrix of the alternatives with respect to indicators of economic criterion.

Economic Criterion Indicators and Alternatives	Log Debarker	Axe	Spade
Operational Cost	0.096	0.619	0.284
Fixed Cost	0.066	0.623	0.311
Capital Investment	0.057	0.649	0.295
Productivity	0.724	0.083	0.193
Profitability	0.142	0.525	0.334
Energy Requirement	0.066	0.311	0.623
Total Eigenvector	0.189	0.470	0.342
Weighted Total Eigenvector	0.146	0.557*	0.297

* Example of the most appropriate debarking technique respect to economic consideration

Table 7. Combined comparison matrix of the alternatives with respect to indicators of environmental criterion.

Environmental Criterion Indicators and Alternatives	Log Debarker	Axe	Spade
Soil Compaction	0.214	0.429	0.357
Erosion	0.142	0.525	0.334
Nutrient Losses	0.631	0.299	0.07
Hydrological Cycle	0.648	0.23	0.122
Water Quality	0.106	0.26	0.633
Waste matter	0.052	0.316	0.632
Emission	0.053	0.474	0.474
Biological Diversity	0.07	0.58	0.35
Forest Health	0.074	0.283	0.643
Total Eigenvector	0.232	0.351	0.417
Weighted Total Eigenvector	0.248	0.355	0.397

Table 8. Combined comparison matrix of the alternatives with respect to indicators of social criterion.

Social Criterion Indicators and Alternatives	Log Debarker	Axe	Spade
Employment Capacity	0.052	0.592	0.356
Opportunities	0.633	0.26	0.106
Dependency to Legislation	0.118	0.501	0.38
Hygene	0.057	0.295	0.649
Occupational Health and Safety	0.083	0.193	0.724
Training Requirement	0.088	0.669	0.243
Regional Development	0.088	0.669	0.243
Work load	0.088	0.243	0.669
Total Eigenvector	0.150	0.395	0.452
Weighted Total Eigenvector	0.089	0.374	0.506

Table 9. Combined comparison matrix of the alternatives with respect to indicators of technical criterion.

Technical Criterion Indicators and Alternatives	Log Debarker	Axe	Spade
Reliability	0.111	0.588	0.301
Access to Resource	0.064	0.669	0.267
Availability	0.723	0.216	0.061
Locally Controllable	0.106	0.633	0.26
Reasonably Flexible	0.106	0.633	0.26
Cleanliness	0.057	0.295	0.649
Work and Product Quality	0.104	0.231	0.665
Precision Requirement	0.623	0.239	0.138
Planning Requirement	0.074	0.643	0.283
Dependency to Conditions	0.071	0.748	0.18
Total Eigenvector	0.204	0.490	0.307
Weighted Total Eigenvector	0.271	0.387	0.254

Table 10. Decision matrix and solution respect to multi-criteria by using of AHP.

Criteria	Technical	Economic	Environmental	Social	Total Eigenvector	Final Priority
Priorities	0.431	0.399	0.059	0.111		
Log Debarker	0.271	0.146	0.089	0.089	0.188	0.200
Axe	0.387	0.554	0.355	0.374	0.374	0.451*
Spade	0.254	0.299	0.397	0.506	0.506	0.308

** The most appropriate debarking technique respect to all criteria* possible to reduce the debarking time with the selection of right or best debarking technique.

In this study, debarking with axe was obtained the most appropriate debarking technique with multi criteria decision process. These results originated from general information of each alternative, but not site specific or stand level. If the comparison between these alternative techniques was performed with stand level and state-based, then it was possible to reach different results. However, in the decision process which debarking technique is more suitable, the recommendation can be taken into consideration in below:

- If there is inadequate labor force, intensive work, need to time, thin barked trees, abundance chainsaw, etc, then chainsaw mounted log debarker can be suitable for the situation. Furthermore, if any problem on payment or cost calculation process, both log debarker (for thin barked logs) and axe (for thick barked logs) can be used with together.
- If the harvesting time is in the spring and/or within vegetation period, and thinning or tending operations are to be performed, and there are thin barked logs, then log spud can be available for the time savings and cost reduction, and product quality as well.

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Performance evaluation of artificial neural networks for modeling winching time of a Timber Jack 450 C

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Abstract
Estimating forest equipment production is an important part of cost management in forestry, which results in a reduction of operations expenses. In other words, the high cost of investment in forest harvesting, is a good reason for forest engineering research and time modeling. This paper applied one of the Artificial intelligence subsets, called the Artificial Neural Networks (ANNs), to predict winching time of a Timber jack 450C wheeled skidder in the Neka Choob forests. In order to collect winching data, continuous time study methods were used. While measuring the time winching, factors affecting winching time (such as slope, distance, number and volume at every winching cycle) were also measured. Two neural networks type-Radial Basis Function and Multi-Layer Perceptron- were used to develop winching time model by artificial neural networks. In addition, to compare the accuracy of ANN and mathematical model, a regression method was developed. Results showed that RBF network provided results that are more accurate at estimating winching net time than the MLP neural networks. Distance to the center of the skid trail in both networks was the most important variable. The results showed that the model developed by neural networks are more precise than the linear regression method.

Keywords
forest exploitation, time study, artificial intelligence, winching, multi-layer perceptron, radial basis function

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1. Introduction

Ground skidding system is the most prevalent harvesting system in the Hyrcanian zone for forest policy makers and managers (Sarikhani 2008), because of; the high primary cost of related machinery systems, voluminous diameters of timber, huge crown of broad-leaved species and steep terrain. Primary transportation of wood is a sensitive and expensive process in forest harvesting, which briefly, consists of winching and transformation of timbers from cutting site to the roadside. Nowadays because of harvesting mechanization, the determination of the efficiency of machinery, with regard to decrease the cost of harvesting is known by everyone in advance. In other words, high cost (price) of investing in forest harvesting is a good reason for engineering investigations and modeling the skidding time. Whenever the production of forest products is to be measure or predicted, mensuration techniques must be developed and adapted to suit the particular circumstances (Özçelik, Diamantopoulou et al. 2010). Various sampling methods can reduce the cost but this is only acceptable if the reliability of estimates does not suffer (Wiant, Wood et al. 1996).

The aim of this study was to compare data from a monitored winching operation with the outputs of models used to predict the time of winching during ground-based logging operations. Multiple linear and non-linear regression is the most common way for creating models to estimate winching time (Ratkowsky and Giles 1990). The methods tested are based on regression, fuzzy logic, and neural networks and all use independent variables that are easy to measure such as Distance (winching distance) and slope (winching slope), to predict the time of winching. The application of artificial intelligence (AI) in forest and natural resources management started with the development of expert systems for problem solving and decision-making (Coulson, Folse et al. 1987). Artificial Neural Networks have also begun to emerge as an alternative approach for modeling nonlinear and complex phenomena in forest science (McRoberts, Schmoldt et al. 1991, Gimblett and Ball 1995, Lek, Delacoste et al. 1996, Atkinson and Tatnall 1997). Artificial neural networks are a subset of artificial intelligence techniques, with structure and function similar to a brain that it has components that called nodes or neurons (Strobl and Forte 2007). The range today is used in solving many problems; assessment, optimization, prediction, diagnosis and control are common. Usually a neural network is made of three-layers: input, hidden and output (Wu 1994). Hidden layer, the so-called black box of neural network, is the main processing part of the neural network and can include multiple layers and various neurons. Artificial neural networks are based on the assumptions (Fausett 1994) that; a) information processing occurs at many simple elements (neurons or nodes), b) signals are passed between elements over connection links, c) each link has an associate weight and d) each element applies an activation function to its net input to determine its output signal. One of the most commonly and useful neural networks in natural resource management, is the feed forward neural network with back propagation algorithm (MLP network) (Rumelhart, McClelland et al. 1986). Another one of the most important types of neural networks is radial basis function (RBF). This network due to variety of applications, has become one of the most famous neural networks and is most important competitor in multi-layer perceptron.

A number of researchers have investigated the applicability of ANN models to diverse natural resources and engineering modeling applications. For example, ANN models have been used to predict; forest cover type from cartographic variables such as aspect, altitude (Blackard and Dean 1999), forest age using TM images (Jensen, Qiu et al. 1999), pine bark volume (Diamantopoulou 2005), wind throw risks (Hanewinkel, Zhou et al. 2004), tree felling times (Karaman and Çalışkan 2009) and landslide susceptibility (Lee, Ryu et al. 2006, Yilmaz and Akay 2008). Comparisons between MLP and RBF neural networks and regression analysis were made of on the basis of precision of trunk volume estimates (Bayati and Najafi, 2013). In this study we compare two neural network models, multi-layer perceptron (MLP) and radial basis function (RBF), on the basis of their predicted winching time during log skidding operations in NEKA CHOOB Co forests.

ANNs are becoming popular at least partially because they do not require assumptions about the forms of underlying distributions (Gurney, 1997).

2. Material and Methods

2.1 Study Site

The study was conducted in a 29 ha of compartment 329 in NEKA CHOOB Co Forests (36° 30'-36° 31' N, 53° 31'-53° 32' E) in northern Iran on northwestern-facing slopes of 0-30% (average of 15%), at altitudes of 730-780 m. The study area is dominated by natural forests, dominated by deciduous tree species including; Fagus orientalis, Carpinus betulus, and Alnus subcordata. The forest management method used is mixed un-even aged high forest with single tree and group selection harvests. Harvested trees were felled, limbed, and bucked with chainsaws (Stihl model NS 880 with a 75 cm long bar) into 5-15 m long logs and yarded with a wheeled cable skidder (Timber-Jack 450 C) to roadside landings. The number and volume of trees per hectare, for the entire parcel (29 ha) was 193 and 372.9 m^3 respectively.

2.2 Field Data Collection

Continuous time study methods were applied to evaluate the performance of skidder (a Timber Jack 450C), which are a precise method for scientific investigations in operation research. In this method, the project is first divided to its components and then the time of each winching cycle element measured. The different elements of one cycle winching time are; releasing the winch, choker setting and winching. In the process of providing field data, we tried to take samples from all combinations of sampling space. Simultaneously the factors affecting on time and hourly production of the machine (e.g. winching slope, winching distance, number of logs and volume of load) was investigated.

2.3 Designing Neural Network Model

Samples with known inputs were consecutively fed into the network and responses taken from were compared with known outputs. During the learning process, this comparison propagated at the rear of the network. As a result, the connection weights among layers changed so that the difference between predicted value and target decreased again as located in the acceptable domain. As the training process goes forth, the given responses in the network will be increasingly more accurate. Distance from the center of bole to center of skidding trail (D), winching trail slope (SW), bole volume at every winching turn (V) and number of bole at every turn winching (NB); were network inputs in winching operation (Fig) and variable the time of winching process in each operation was considered separately as the network output. The Neural network toolbox of MATLAB (ver. 7.7) which has a graphical user interface for design, implementation, visualization, and simulation was used for the modeling process. MLP and RBF networks were adopted for skidding time modeling (Fig 1 & 2).

Simultaneously with network training, errors between real data and predicting values were minimized and the training process moved to stability. In order to select the number of layers and neurons for evaluating different typologies, the increasing method was used. By implementing this method, when network trap in local optimum, new neurons are gradually added and the optimum size of network obtained. About 60% of data was used for training the network with different topologies and BR training algorithm. Training data feed to the network through the training process and network was adjusted according to its error. About 20% of data was used as validation data and the rest was used for testing the model. The validation data was utilized to control the power of network generalization and to stop the training in order to prevent over fitting. Testing data has no effect on training and provides an independent measure of network performance during and after the training [1]. In order to comparing results of ANNs with regression analysis, stepwise regression analysis was developed using SPSS 21 software (Norusis 1999).

Network performance evaluated by sum of square error RMSE, % RMSE, % Bias and coefficient R^2 between output and inputs (Laar 1991). When RMSE minimized and R^2 is more than 0.8, the model can be assessed as a very good model.

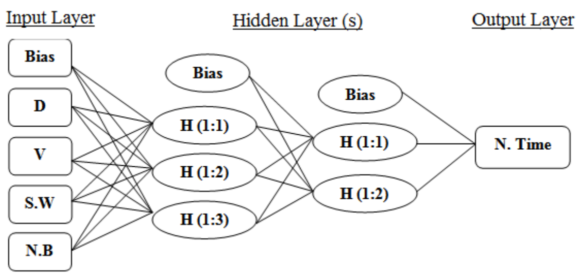

Figure 1. MLP neural network structure.

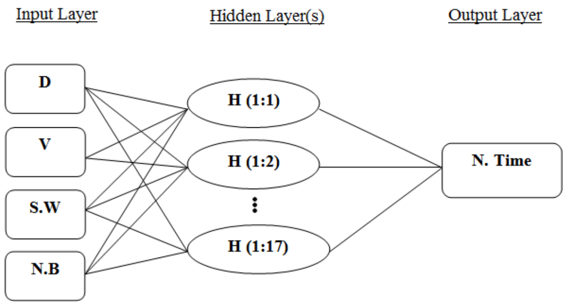

Figure 2. RBF neural network structure.

3. Results

Results of correlation analysis showed that there was significant positive correlation between stem volume and other variables, (p-value < 0.01) (Table 1).

Table 1. Correlation between variables.

Variable	Winching Time
W Distance	0.8
W Slope	0.04
Volume	0.44
Number of Logs	0.42

***Correlation is significant at the 0.01 level*

$$T = 0.265 + 0.032D + 0.074V \quad (1)$$

Figures 3 to 5, show the results of models in prediction winching time during training step.

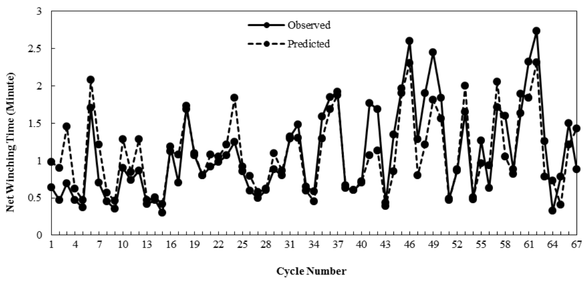

Figure 3. Predicted winching time in training step using regression analysis.

The model created by stepwise regression analysis in function of winching distance (D) and loading volume (V) variables with 0.72 R^2.

About 20% of data (17 cycles) used for testing models, that these results showed in (Table 3) and (Figs 6-8). In addition, these results indicated that RBF have better result compared to other models.

Sensitivity analysis showed that in neural network MLP, distance of bole from center of skidding route (D) (100%) and the number of log per cycle (N.B) (28%) and in neural network RBF, distance of bole from center of skidding route (D) (100%) and number of log per cycle (NB) (42.7%),

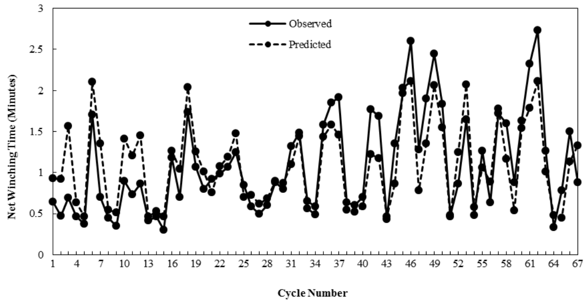

Figure 4. Predicted winching time in training step using MLP.

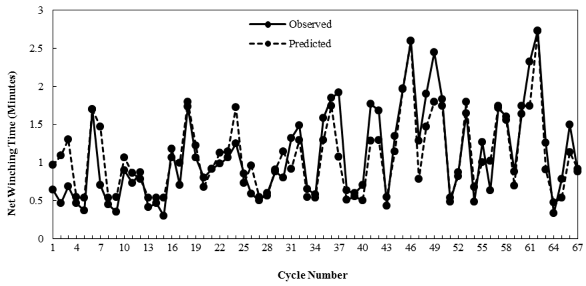

Figure 5. Predicted winching time in training step using RBF.

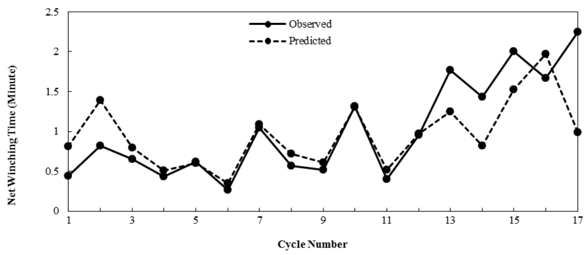

Figure 6. Predicted winching time in testing step using regression analysis.

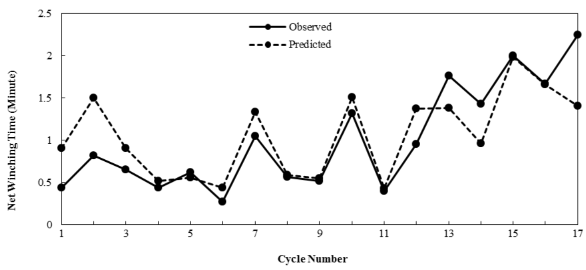

Figure 7. Predicted winching time in testing step using MLP.

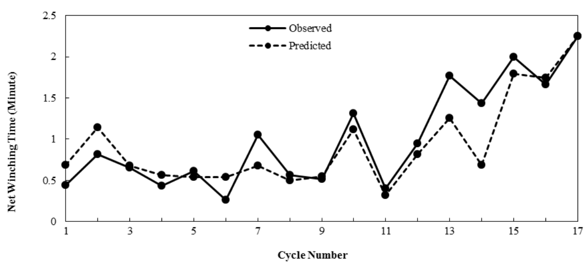

Figure 8. Predicted winching time in testing step using RBF.

Table 2. Performance criteria results in training step.

Method	Composition	Activation Function Input Layer	Activation Function Output Layer	R^2	RMSE	% RMSE	% Bias
Regression	T= 0.265+0.032D+0.074V	-	-	0.72	0.33	30.08	-9.38
MLP	4-3-2-1	TanHyp	Identity	0.93	0.29	26.83	-7.55
RBF	4-17-1	Softmax	Identity	0.94	0.23	21.49	-6.63

Table 3. Performance criteria results in testing step.

Method	R^2	RMSE	% RMSE	% Bias
Regression	0.83	0.43	42.32	-9.83
MLP	0.91	0.36	35.44	-8.39
RBF	0.93	0.28	27.84	-2.77

Table 4. Independent variable importance.

Network	Variable	Importance	Normalized Importance
MLP	Distance	0.419	100.00%
	S.W	0.128	30.50%
	V	0.336	80.10%
	N.B	0.117	28%
RBF	Distance	0.406	100.00%
	S.W	0.219	53.90%
	V	0.201	49.50%
	N.B	0.174	42.70%

The comparison of precision two neural networks in predicting winching time showed that, the RBF neural network with one hidden layer and 17 neurons in this layer with activation function (Softmax and Identity), compared to MLP neural network with two hidden layers and 3 neurons in the first layer and 2 neurons in the second hidden layer and activation function (TanHyp and Identity); has more precision and less error in both training and testing steps; also these models have better results compared to regression analysis in training step (Table 2).

4. Discussion

In this research, we represented models for predicting the time of winching by skidder Timber Jack 450C. The ANN technique introduced in this study has the ability to overcome problems in forest data, such as non-linear relationships, heteroskedasticity, multi-Collinearity, outliers and noise, appears promising as an alternative to the traditional regression models. Furthermore, there is no need for the modeler to guess the form of the fitting function, as is needed for regression modeling. Furthermore, this approach is sufficiently general and has great potential for application for many ecosystem-modeling problems. Even though acceptable result has been obtained in this manner, it is necessary to use other networks in modeling of physical objects, such as Cascade Forward Back Propagation and different learning algorithm like LM, BGF and CGF to derive the best model. The nature of the problem determines which neural network or learning algorithm to use. Generally, in the modeling of physical objects such as winching operations, for the reason that unknown factors may affect the damage, and these mutual effects in the most cases would cause the creation of nonlinear space, its modeling will be very critical and with error.

The results of this research can be useful as environmental criteria for future researchers to evaluate current logging systems in hilly terrains, and to choose the best alternative and develop a decision support system for logging planning in this area. Finally, considering the fact that this study was carried out on a small-scale in order to evaluate the performance of artificial neural networks in one of the most common activities in the forest, it is recommended that further studies using this technique in the field to do more comparisons created with this technique.

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Cutting productivity of windfalls in Finland

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Abstract
During the 2000's several powerful storms caused disastrous damage in Finnish forests. There were no studies of windfall salvaging after big storms in Finland. Therefore, a time study of the cutting productivity of windfalls was conducted. The comparative time-study data was collected in December 2013 after the Eino and Seija storms. When cutting windfalls from clear felling operations, the stem processing time was on average 4–15 s/stem higher than cutting normal standing trees. When cutting windfall stems with a volume of 300–1,500 dm^3 the stem processing time increased on average by 14–36% compared to cutting normal standing trees. Furthermore, the moving and miscellaneous times in cutting windfalls were higher than operating at non-windfall sites. Consequently, cutting productivity of windfalls was on average 20–35% lower than cutting standing trees of clear cuttings with a stem size of 300–1,500 dm^3 in the study.

Keywords
clear cuttings, salvaging, storms, windfalls, wood harvesting

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1. Introduction

During the 2000's, there have been several big storms in Finland. The powerful storms have caused disastrous damage for forests: For instance, at the end of 2001 the Pyry and Janika storms felt approximately 7.3 million m^3 (solid over bark, sob) of forests in Finland (Ihalainen & Ahola, 2003). In summer 2010 the Asta, Veera, Lahja and Sylvi storms felt in total 8.1 million m^3 sob of wood (Asta, Veera, 2010). Furthermore, the Tapani and Hannu storms in the late 2011 felt 3.5 million m^3 sob of wood. After that, the Eino, Oskari and Seija storms altogether at the end of 2013 felt 3.0 million m^3 sob of forests in Finland. It is forecasted that the damages caused by big storms for forest stands will be increasing in the future in Finland because of climate change (e.g. Gregow, 2013).

In Finland, the Law of Warding Forest Damages (Laki metsätuhojen, 2013) obliges a forest landowner to harvest windfalls from her/his forest stand. If windfall trees are left forests, harmful insect pests attack windfalls and furthermore close standing, living trees (e.g. Viiri et al., 2011). Salvaging of windfall trees is certainly much more difficult compared to harvesting trees from normal forest stand with standing trees. Forest machine entrepreneurs underline that harvesting costs of windfalls are typically 30–70% higher than those of stems from normal, standing tree loggings (Jaakkola, 2012a). According to the survey of the Trade Association of Finnish Forestry and Earth Moving Contractors, the most commonly used paying method of windfall salvaging for a forest machine entrepreneur is to add a so called additional storm charge to the normal wood harvesting fee. Jaakkola (2012b) reported that in 2012 the average additional storm charge percentage was 37% in Finland.

Many comprehensive windfall salvaging studies have been reported internationally in the 21st century (Hagauer, 2001; Dvořák, 2010; Magagnotti et al., 2013; Szewczyk et al., 2014; Talbot et al., 2014). Besides, some Swedish research reports (Bergkvist, 2005; Sondell, 2006) have shared windfall salvaging experiences of the enormous Gudrun storm. Unfortunately, there were no studies of windfall salvaging after big storms in Finland. Therefore, a time study of cutting productivity of windfalls in final-felling stands was conducted at Stora Enso Wood Supply Finland.

2. Material and Methods

The time-study data was collected in Eastern Finland in December 2013 after the Eino and Seija storms (Fig. 1). There were three harvesters (a John Deere 1270D/H414, Logset 8H/TH 75X, and Ponsse Ergo/H73), as well as three harvester operators in the study. The same harvesters/operators cut also normal standing trees of clear cuttings. Hence, the study was a comparative time study (cf. Harstela, 1991). All operators were well-skilled at final fellings with the working experience of more than ten years. Each operator had cut also a lot of windfalls after the Asta storm in 2010.

There were nine time-study stands in the research. The stands were divided into 23 time-study plots according to a cutting method used (thinning vs. clear cutting). The STM files of harvesters were collected from each study

Figure 1. A view from the cabin of the John Deere 1270D harvester cutting windfalls on the plot of number 16 in the time study. Photo: Tuomas Anttonen.

stand. The cutting work was recorded on video, and the time study was carried out by analyzing the video material by a new tool developed by Ari Laurén (Niemistö et al., 2012). The tool was developed using Microsoft Visual Basic language in Excel software. In the analysis tool, a video clip is browsed in an Excel sheet and the work element boundaries are determined by the researcher during browsing. By using the time signature in the video clip, the start and end times of each work element are recorded together with the code of the work element. The video clip can be viewed quickly, forwarded and rewound or viewed in slow motion when needed. The record for each work element can be double-checked and edited afterwards using the recorded time signature in the video clip.

The total data was 1,751 windfall and normal standing stems. From the windfall study plots, in total 1,160 stems were cut of which 938 stems were harvested from clear-cutting plots and 222 stems from thinning plots. From the standing tree study plots, a total of 591 stems were cut. The majority of the stems processed was Norway spruce (*Picea abies* (L.) Karst.). 16% of the harvested stems were Scots pine (*Pinus sylvestris* L.) and 4% of the stems were birch.

The damage type was attached for all stems processed in the time study: 1) Standing tree (normal standing stem in stand), 2) Felled whole tree with stump (windfall stem on the ground; no separate butt and top sections), 3) Hang-up whole tree (standing tree had lodged a felling whole stem in the question), 4) Felled broken tree with separate butt and top sections, 5) Broken tree section (felled broken tree with separate either butt section or top section; in other words, the butt and top sections of windfalls could not be combined for one stem in the time study), and 6) Felled whole tree without stump (as the earlier damage type 2 but the stumps of these felled trees had been cut by a lumberjack beforehand salvage cutting operation). Figure 2 presents the number of stems processed by damage type, by operator, and by cutting method in the study.

The work cycle (i.e. all the work elements for processing one stem) was divided into 22 time elements in the time study. For modeling, the time elements were aggregated for the following main time consumption elements of productive cutting work:

- Moving time
- Stem processing time (i.e. boom-out, felling, delimbing & cross-cutting, and boom-in (cf. Fig. 4))
- Miscellaneous times (i.e. planning of work, clearing of undergrowth, sorting of industrial roundwood poles, and removing of logging residues).

When modeling the moving times and determining the average miscellaneous time consumption, all stems processed in the study were used. Correspondingly, when calculating the stem processing functions for each operator with windfalls in clear cuttings, the damage types 2–5 were included in the modeling process. Respectively, when modeling the stem processing with the standing trees at clear-cutting sites, only the standing trees (i.e. the damage type 1) of normal clear-cutting plots were utilized. Thus, the final study material for stem processing modeling was 1,088 trees. The stem processing time was modeled by applying non-linear (NLIN) regression analysis with the stem volume and windfall dummy (0 = normal clear cutting with a standing tree [damage type 1]; 1 = windfall tree in clear-cutting stand [damage types 2–5]) as the independent variables. The stem processing functions for the windfall thinning wood were not determined because there were only a few thinning stems for the operators 1 and 3 in the study (cf. Fig. 2).

3. Results

3.1 Time consumption

Moving time was dependent on the total density of stems cut. The total density of removal was between 284–708 stems/ha (average 422 stems/ha) on the clear-cutting plots of windfalls and 371–712 stems/ha (average 459 stems/ha) on the normal clear-cutting plots. The moving time per processed stem decreased when the density of removal increased. When the total density of stems processed was 450 stems/ha, the moving time was 11.8 s/stem in windfall cutting and 5.4 s/stem in standing (i.e. non-windfall) tree cutting (Fig. 3). Consequently, the moving time consumption was 120% higher on the windfall plots than on the non-windfall plots with a density of 450 stems/ha in the study.

With all operators, the time element of boom-out – including harvester head getting a good grip in handling stem – took significantly more time of the total stem processing time with windfalls than operating with the stems of normal clear cuttings. On average, the boom-out phase used 10.1 percentage points more time in windfall clear cuttings than in normal clear cuttings (Fig. 4).

The stem processing functions for each operator were computed. When cutting windfalls of clear cuttings, the stem processing time by operator was, on the average, 4.0–14.8 s/stem higher than cutting normal standing trees (Fig. 5). When cutting windfall stems with a volume of 300–1,500 dm^3 the stem processing time increased, on the average, 14–36% compared to cutting normal standing trees (Fig. 6). With the operator 1 the stem processing time multiplied most (24–58%) and with the operator 2 the increase

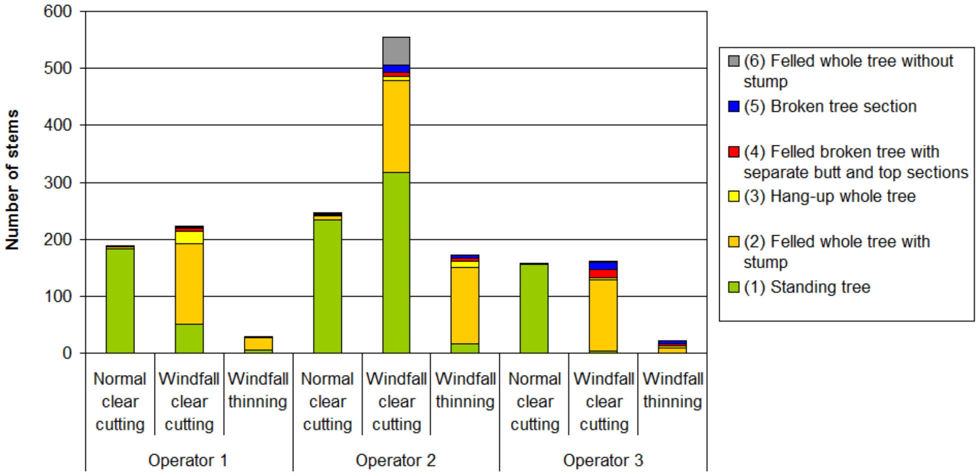

Figure 2. The number of stems by damage type, by operator, and by cutting method in the time study.

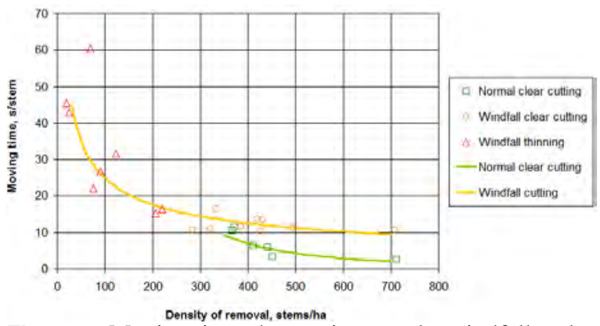

Figure 3. Moving time observations on the windfall and non-windfall time-study plots and the calculated moving time consumption functions.

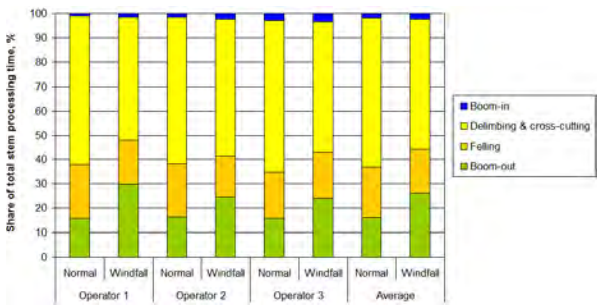

Figure 4. The distributions of total stem processing time by operator and on the average in normal (with standing trees) and windfall clear cuttings in the study. 1,088 trees of stem processing modeling as a data (cf. Fig. 5).

was the smallest, only 7–16% with a stem size of 300–1,500 dm^3 (Fig. 6).

Miscellaneous time with cutting windfall stems was, on the average, 3.7 s/stem and with normal standing trees, on the average, 1.5 s/stem. Hence, miscellaneous time in cutting windfalls was 147% higher than operating with the standing trees.

3.2 Productivity

To sum up, cutting productivity of windfalls was, on the average, 20–35% lower than cutting standing trees of clear cuttings with a stem size of 300–1,500 dm^3 in the study (Fig. 7). There was a significant variation between the operators in relative cutting productivities: with the operator 2 cutting productivity in windfall clear cuttings was 16–29% lower and with the operator 1 even 25–42% lower than at normal clear-cutting sites in the study (Fig. 7).

4. Discussion

In the research, the total data was 1,751 windfall and normal standing stems, and the final study material for stem processing modeling was 1,088 clear-cutting trees. The size of the material was relatively large comparing to the study material of earlier clear-cutting studies during the 2000's in Finland (e.g. Nurminen et al., 2006). Furthermore, there were also the bigger (>1.5 m^3) trees in the study data.

The results indicated that the average cutting productivity with windfalls is 20–35% lower than with the normal standing stems of clear cuttings. The research results produced new information about the effect of storm damage on the cutting productivity. Forest haulage of logs cut in the study was not researched. It can be assumed that there is no significant difference between the forwarding productivity of timber at windfall and normal clear-cutting sites.

When looking into the study results it must be paid attention to that the study data was collected from only three harvesters, which operated three drivers. Besides, the damages caused by the Eino and Seija storms were not very harmful ones. That is to say there were not much broken trees but mostly felled whole trees with stump on the ground

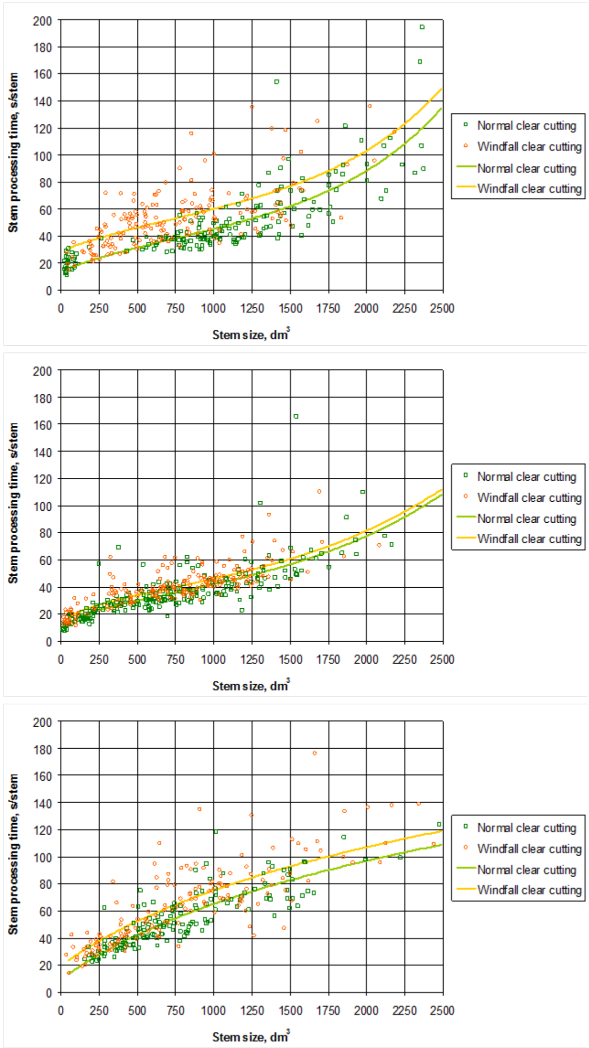

Figure 5. Stem processing time curves as a function of stem size by operator in normal and windfall clear cuttings. Top: the operator 1 and bottom: the operator 3.

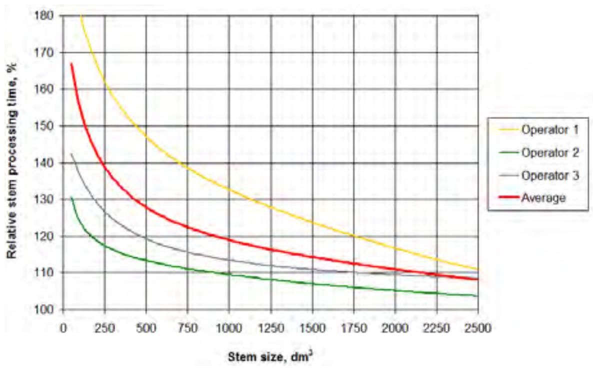

Figure 6. The relative stem processing time in windfall clear cutting by operator and on the average as a function of stem volume in the study. Relative stem processing time 100 = stem processing time in normal clear cutting.

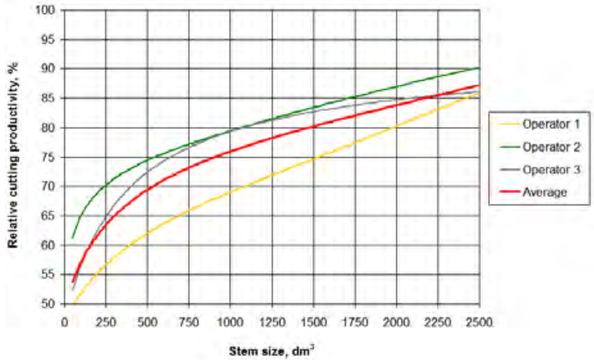

Figure 7. The relative cutting productivity in windfall clear cutting as a function of stem volume by operator and on the average. Productivity 100 = cutting productivity in normal clear cutting. Density of removal was 450 stems/ha in the calculation.

on time-study plots (cf. Figs 1 and 2). Nevertheless, these kinds of storm damages (i.e. felled whole stems with stump) are typical ones in Finland.

Numerous forest work studies have been carried out to analyze the effect of harvester operators (Ovaskainen et al., 2004; Ovaskainen et al., 2006; Palander et al., 2012), and many studies have emphasized that there is a significant correlation between the working experience and skills of operator and his/her productivity in forest machine work. For instance, Sirén (1998), Kärhä et al. (2004) and Ovaskainen (2009) have shown that the differences between operators may be as great as 35–40%. Therefore, more time studies with more operators are needed both in different windfall and normal clear cuttings in the future in Finland.

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Topic 6

Bioenergy & Wood chip supply chains

Profitability of drying wood chips integrated into fuelwood supply

J. Raitila[1]*, V.-P. Heiskanen[2]

Abstract
Moisture affects the profitability of supplying wood chips and the economy of running a heating plant. Most fuelwood is seasoned outdoors, therefore drying depends on the weather, and the desired moisture level of wood cannot always be achieved. To get rid of weather dependency, wood chips can easily be dried in driers connected to a heating plant. For most of the year small and medium-sized heating plants have significant excess heating capacity that could be used to dry fuelwood. This study aimed to present the possibilities and analyse the profitability of drying wood chips in warm air dryers as part of a fuel supply chain. The investment in and running costs of a dryer determine how feasible such a drying method is as part of the wood fuel supply chain. The profitability of drying increases significantly if the heating enterprise can increase its sales because of a higher boiler output. Thus warm air drying of fuelwood can quite easily be made profitable if there is the potential to expand the heat clientele.

Keywords
bioenergy, moisture, fuelwood, drying, biomass heating

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1. Introduction

The most important quality factor of fuelwood is moisture [1]. In order to increase the calorific value of fuelwood, wood has to be dried. Besides this, most boilers and combustion devices cannot combust wet wood efficiently. Traditionally, fuelwood is seasoned in outdoor storages until the desired moisture level has been achieved. These storages, often simple stockpiles at a landing, also serve as a buffer for high fuel demand in winter.

In most cases, fuelwood supply follows the same principles. First the trees are felled, delimbed and forwarded to a landing where they are stacked for storage or transported to a specific storage site such as a wood yard or terminal. Then they are seasoned long enough to ensure the desired moisture level. Finally, after six to twelve months, storage wood stacks are chipped and wood chips are transported to a heating or power plant for energy generation. Some suppliers may chip semi-dried logs and store these chips at the plant. Naturally, variations of these supply chains and methods occur depending on harvesting circumstances such as the terrain and machines as well as types of fuelwood to be harvested. For example, in the Nordic countries logging residues and whole trees are used much more extensively than in Central and Southern Europe. [2]

Although the most common contemporary supply methods of fuelwood originate from experience and good practices, they all have some significant weaknesses with regard to quality management. Outdoor seasoning is always very weather-dependent and therefore only estimates can be provided for moisture. Because of constantly changing drying conditions, moisture of delivered wood chips inevitably fluctuates. In a rainy year wood fuel may never reach the desired moisture level and the end user therefore has to combust wet wood. If overly wet wood is used, the efficiency of a boiler decreases, the likelihood of malfunctions increase, and the highest output cannot be reached. In addition, much more fuel is needed to produce the needed amount of energy [3].

Another challenge of seasoning wood outdoors is related to general storage management and costs. The larger the end user, the more wood has to be stored in advance in order to meet high demand in winter. This may make storage management complicated as wood stacks are usually distributed at many landings far away from the heating plant. In any case, keeping large amounts of wood in storage for a long time is costly, and it involves a risk of losing some value of stored wood because of a decrease in quality or material losses, such as through natural biodegrading [4] [5].

One possible way of drying wood chips is with a warm air dryer built next to a heating plant. Small and medium-sized heating plants have significant excess heating capacity most of the year. Their utilisation rate is less than 50% on average [6]. Only during a couple of winter months do they work close to their full capacity [7]. Therefore, fuelwood dryers could use this excess capacity to dry wood chips to be used in these heating plants. The benefits of combusting dry wood chips (20-30% MC) are undisputable: boilers would work more efficiently, there would be fewer malfunctions of the system, boiler output would be higher, less additional fuel is needed and fewer wood chips are needed [8].

This study aimed to show the possibilities and analyse the profitability of drying wood chips in warm air dryers as part of a fuel supply chain.

2. Material and Methods

In order to evaluate benefits of drying wood chips for the whole supply chain of fuelwood, the costs of wood supply for chosen cases and possible drying costs were first calculated. Drying costs were estimated with an Excel-based calculation model, created in the Development of new or improved logistics for lignocellulosic biomass harvest, storage and transport project (INFRES). Finally, profitability was evaluated by calculating the costs of drying and comparing them with the benefits from more economical heat production with drier wood chips.

2.1 Studied supply chains

The pricing of different phases of supply chains can be done in many ways, depending on contracts. Often the first parts in the chain, such as logging, forwarding, chipping and transportation are priced based on volume or weight. On the other hand, sometimes the end user may only want to pay for delivered wood chips based on their heating value. In practice, there are many more supply and pricing combinations, depending on each case [9] [10].

To make comparison easier, the supply costs of wood chips per produced energy (€/MWh) were calculated based predominantly on volumes or the calorific value of delivered wood chips. The costs used in this exercise are from recent studies and entrepreneur interviews [11] [12]. Two virtual supply chain models typically used in rural areas in Finland were chosen to provide wood chips for two heating plants producing either 1,500 MWh or 5,000 MWh of heating energy annually. Fuelwood consisted of whole trees in both cases.

In the first supply model, a contractor model, the wood supplier or the end user directly buys fuelwood from a roadside storage. Subcontractors are used for chipping and transportation. Harvesting costs are included in the roadside price of stacked fuelwood because drying takes place after harvesting and therefore harvesting costs do not change. In the second supply model, a single supplier takes care of the whole supply chain and delivers wood chips directly to the plant. No matter the model, a truck-mounted mobile chipper and a chip truck with a load space of 120 m³ are used to supply for the bigger plant. Correspondingly, a tractor-powered chipper and an agricultural tractor with a 20 m³ trailer are used to supply the smaller plant.

Plant 1, Energy production 5,000 MWh/a:
The following assumptions and costs were used in supply chain calculations for the contractor model:

- Roadside price of whole trees: 12 €/MWh
- Chipping costs: 3.6 €/loose m³
- Transportation costs: 3.6 €/km
- Combustion efficiency of boiler: 78-88%, depending on wood chip moisture (55-20%)
- Costs caused by heating system malfunction: 120 € per maintenance visit
- Costs caused by extra heating oil used for heating: 14,000 €/year, depending on wood chip moisture (55-20%)

Bigger plants usually pay for the heating value of wood chips which is measured at the plant. Therefore, euros per heating value (€/MWh) was used to measure the cost of wood chip raw material. The degree of moisture in wood chips directly affects combustion efficiency and the wood chip volumes needed for energy production through chipping and transportation costs. It should also be noted that when wet chips (>47% MC) are transported, the full capacity of a chip truck cannot be used if the total weight of the vehicle is limited to 60 tons [13]. In the single-supplier model, the cost calculation is simpler because the supplier is paid for delivered wood chips for their heating value. Therefore, the following costs were used:

- Delivered wood chips: 20 €/MWh
- Combustion efficiency of boiler: 78-88%, depending on wood chip moisture (55-20%)
- Costs caused by heating system malfunction: 120 € per maintenance visit
- Costs caused by extra heating oil used for heating: 14,000 €/year, depending on wood chip moisture (55-20%)

Plant 2, Energy production 1,500 MWh/a:
The following assumptions and costs were used in the supply chain calculations for the contractor model:

- Roadside price for whole trees: 25 €/solid m³
- Chipping costs: 4.5 €/loose m³
- Transportation costs: 2 €/loose m³
- Combustion efficiency of boiler: 78-88%, depending on wood chip moisture (55-20%)
- Costs caused by heating system malfunction: 120 € per maintenance visit
- Costs caused by extra heating oil used for heating: 5,200 €/year, depending on wood chip moisture (55-20%)

In the single-supplier model, the corresponding costs were:

- Delivered wood chips: 20 €/MWh
- Combustion efficiency of boiler: 78-88%, depending on wood chip moisture (55-20%)
- Costs caused by heating system malfunction: 120 € per maintenance visit

- Costs caused by extra heating oil used for heating: 5,200 €/year, depending on wood chip moisture (55-20%)

It is important to note that in this supply situation costs for wood, chipping and transportation are purposely based on volumes because smaller plants find it easier to have just one way to measure and pay for different costs. If different phases of the supply chain are paid for in volume, the cost difference for delivered wood chips between the contractor and single-supplier models becomes significantly higher, the wetter the raw material is. This is natural because for the same amount of wood, less heating energy is delivered.

2.2 Drying costs and profitability evaluation

In order to understand some of the physics of drying and how to size a fuelwood dryer, an Excel-based calculator was created in the INFRES project [14]. The model was also validated and drying demonstrated in the project. Drying costs used in this article were calculated with the model.

Plant 2 (1,500 MWh/a) was chosen as a case study to evaluate the profitability of drying wood chips at a heating plant, because the tested and demonstrated freight container dryer has enough drying capacity to dry all the wood chips used annually at that plant. For the annual amount of wood chips combusted at Plant 1, a much bigger dryer would be needed. Profitability was evaluated by calculating the costs of drying and comparing them with the benefits from more economical heat production with drier wood chips containing only 20% moisture. A drying example was calculated for a 25 m³ fuelwood dryer for 55% and 45% wood chips with the following parameters:

- Annual volume of dried wood chips: 2,100 loose m³
- Annual heating energy used for drying, calculated with the drying model: 374 MWh (55% moisture) and 225 MWh (45% moisture)
- Heating costs for drying: 40 €/MWh including fuel, capital and running costs of the heating plant or 24 €/MWh without any other costs but those for fuel
- Investment cost of dryer: 35,000 € according to a Finnish manufacturer [15]
- Electricity and maintenance costs: 1,300 €/year
- Pay-off period: 10 years
- Interest rate: 5%

Two different costs for drying heat were chosen, depending on whether the capital and running costs of the heating plant should be included. There is a basis for both arguments. If drying heat is purchased from a heat enterprise, even if this enterprise owns both the plant and the dryer, it is natural to include all real costs of heat production in the heat price unless capital and running costs are covered in some other way. On the other hand, the heat enterprise may consider capital and running costs to be covered by heat supply contracts. Therefore, drying wood chips only increases annual fuel costs. In practice, the higher drying heat price should be applied when both investments, the plant and dryer, are made at the same time and are considered as one unit. The lower price can be considered when the heat enterprise already has enough customers for its normal heating business but still has boiler capacity for drying.

When drying costs were compared with lower heating energy production costs, the following benefits were taken into consideration: fewer wood chips are needed, transportation and chipping costs are lower, boiler efficiency increases, fewer malfunctions occur, and less additional fuel is needed.

The profitability of drying and drying investment was evaluated by using the net present value method [16]. Net present values of costs and benefits for a ten-year pay-off period were calculated for both contractor and single-supplier supply chains, using Plant 2 as the end user. Because dry wood chips cannot be stored outdoors, an additional storage investment (35,000 €) was also included in the calculations.

3. Results and discussion

3.1 Supply costs of wood chips

Figures 1 and 2 illustrate the costs of wood chip supply to the chosen heating plants for produced heating energy in relation to the moisture content of delivered wood chips to the moisture content of delivered wood chips.

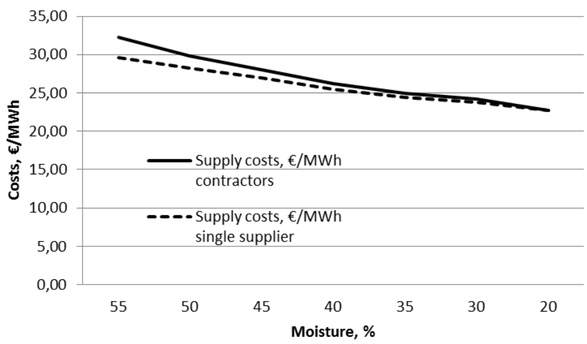

Figure 1. Supply costs of wood chips for 5,000 MWh energy production in the single-supplier and contractor models.

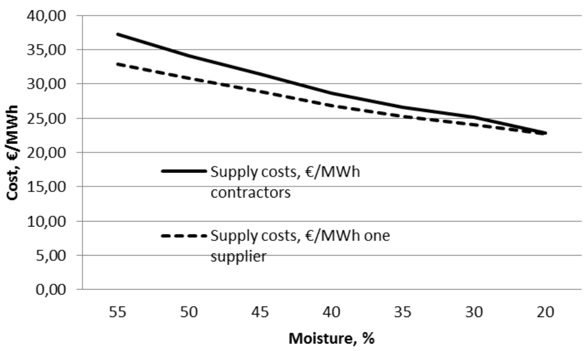

Figure 2. Supply costs of wood chips for 1,500 MWh energy production in the single-supplier and contractor models.

These calculation examples show how moisture affects the costs of supplying heating plants with wood chips. Cost differences increase the more supply costs are based on volumes. The total cost difference also shows how much more the end user could pay for drier wood chips for the same amount of produced heating energy. In other words, the cost difference could be used for drying, whether it be natural or artificial.

3.2 Profitability of drying wood chips at a heating plant

In the chosen case, the drying costs were 9.3 €/loose m³ for 55% wood chips if drying heat costs were 40 €/MWh, and 6.5 €/loose m³ if drying heat costs were 24 €/MWh. The corresponding costs for 45% wood chips were 7.0 €/loose m³ and 4.8 €/loose m³.

In the single-supplier model, investments would only be profitable if drying heat is lower (24 €/MWh) and fresh wood is dried without any pre-seasoning. On the other hand, drying investments would be profitable in most contractor cases. This is natural because in the contractor model, most of the supply costs of wood chips are based on volumes, and therefore drying reduces the supply costs of fuelwood more than in supply chains that charge for work units mainly based on the heating value of wood (Table 1).

In the previous comparisons, it is assumed that the annual heat sales remain unchanged despite increased heat production capacity due to better fuel. The profitability of drying increases considerably if the heating enterprise can increase its sales because of a higher boiler output.

Let us assume that each year, Plant 2 dries the drier's maximum capacity of 2,500 loose m³ of wood chips instead of the 2,100 loose m³ needed in order to provide energy for annual heat sales of 1,500 MWh. Then the plant could sell 300 MWh more heating energy. This would increase annual gross revenues by 18,000 € if customers pay 60 €/MWh for heat. This annual increase in revenues makes the drying investment profitable in all options (Table 2).

In the least profitable option (single-supplier, 40 €/MWh for drying heat and storage), gross revenues should increase by 9,000 € annually in order to make the drying investment profitable. In practice, this requires drying another 200 loose m³ of wood chips and using half of the increased boiler output. Correspondingly, in the contractor model, drying only 50 loose m³ of chips, thus increasing revenues by 3,000 €, would guarantee the profitability of the investment.

The calculated examples show that drying wood chips in a warm air dryer can very well be a feasible option for small and medium-sized heating enterprises, particularly if such a heating plant can increase annual heat sales because of the increased heating output of the system.

4. Discussion

Boilers of small and medium-sized heating plants are sized to meet high energy output needs in winter, but the maximum capacity is usually required only for three to six weeks a year [17]. Therefore, these plants could be used to dry their own wood chips. According to a recent questionnaire study, more than half of the heat entrepreneurs in Central Finland are interested in drying wood chips or log wood at their heating plants [18].

The investment and running costs of a dryer determine how feasible such a drying method is as part of the wood fuel supply chain. Compared to the heating plant investment, suitable dryers can only be acquired at less than 10% of the plant investment. Because dry wood chips cannot be stored in the open, a storage shelter should be provided.

As total investments can be quite modest, the running costs of the dryer play the biggest part in the profitability of drying fuelwood. The most crucial cost factor is the cost of heating drying air. If the heating plant is built as a separate project, and capital, maintenance and running costs are covered by a normal heating business, extra heat for drying can be obtained at the cost of the fuel required for drying. On the other hand, if both the plant and dryer are constructed in the same project, it might also be necessary to include at least some of the capital costs of the plant in the drying cost.

The pricing of different phases of supply chains can be carried out in many ways, depending on contracts. Often the first parts in the chain, such as logging, forwarding, chipping and transportation, are priced for volume or weight [19]. On the other hand, sometimes the end user may only wish to pay for delivered wood chips based on their heating value. In reality, many more trade and pricing practices exist, depending on countries, companies and volumes of business. In any case, the moisture of delivered fuelwood has a greater effect on the profitability of the whole heating energy supply the more work phases are priced for volumes.

Warm air drying was studied in connection with two common Finnish supply chains models: the contractor and the single-supplier models. In the single-supplier model, investments would only be profitable if drying heat costs 24 €/MWh and fresh wood is dried without any pre-seasoning. On the other hand, with the same heat cost, drying investments would be profitable in most contractor cases. This is natural because, in the contractor model, most supply costs of wood chips were based on volumes.

The profitability of drying increases significantly if the heating enterprise can increase its sales because of a higher boiler output. If half of the increased boiler output due to better fuel can be used for heat sales, all the investment options studied would be profitable, even if a heat cost of 40 €/MWh for drying is applied. Thus warm air drying of fuelwood can quite easily be made profitable if there is potential to expand the clientele for heating.

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Table 1. Profitability of the dryer investment in selected supply cases. Figures indicate the difference between costs and benefits in net present values (NPV) over the ten-year investment period.

	Drying heat 40 €/MWh		Drying heat 24 €/MWh		Drying heat 40 €/MWh + storage		Drying heat 24 €/MWh + storage	
Initial moisture of wood chips	Contractor model	One supplier	Contractor model	One supplier	Contractor model	One supplier	Contractor model	One supplier
55%	14,792	-36,170	60,196	9,234	-775	-51,738	46,683	-6,334
45%	-8,159	-37,222	19,407	-9,655	-23,727	-52,789	5,894	-25,223

Table 2. Profitability of the dryer investment in chosen supply cases if an extra 300 MWh of energy can be sold. Figures indicate the difference between costs and benefits in net present values (NPV) over the ten-year investment period.

	Drying heat 40 €/MWh		Drying heat 24 €/MWh		Drying heat 40 €/MWh + storage		Drying heat 24 €/MWh + storage	
Initial moisture of wood chips	Contractor model	One supplier	Contractor model	One supplier	Contractor model	One supplier	Contractor model	One supplier
55%	162,462	101,792	216,514	155,845	146,894	63,779	203,001	140,277
45%	135,139	100,541	167,956	133,358	119,571	61,724	154,443	117,790

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How drum design can affect chipper performance

N. Magagnotti[1,2]*, R. Spinelli[1,2], E. Cavallo[3], L. Eliasson[4], A. Facello[3]

Abstract
Chipping is an essential element in the energy supply chain and mobile chippers are very popular because they can work directly in the forest or at the roadside landing. Due to space constrain, drum chippers are dominating forest biomass operations. Drum chipper are less efficient then disc chipper but they are also less sensitive to feedstock quality. Drum chippers come in two main design types: closed drum with full-length knives and open drum with staggered narrow knives.
The goal of this study was to analyse the specific effect of these design types on productivity, fuel consumption and product quality, using different raw material types. For this purpose, two commercial chipper models with almost identical characteristic were selected to represent the alternative drum designs. Both machines were fed with two different feedstock types: chestnut logs and chestnut branches. The study included 12 repetitions per combination of drum design, feedstock type and knife condition (new or worn out) for a total of 2 x 2 x 2 x 12 = 96 repetitions. Both chippers were attached to the same instrumented tractor, and all product obtained from each chipping bout was blown into big bags and weighed with a load cell attached to a forklift. The study showed that the closed drum design was better suited to handle branch material, compared to the open drum design, especially when knives were dull. Under these conditions, productivity was higher, fuel consumption lower and chip quality better for the closed drum design. No significant differences between the two designs were found when processing logs or when the knives were new. In general, the performance of both designs was significantly affected by feedstock type and knife wear.

Keywords
biomass, forestry, productivity, fuel, wood

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Extended Abstract

Due to a booming renewable energy market, chips demand has grown in the past decades and it is likely to grow even faster in the coming years. Chipping is an essential element in the energy supply chain and mobile chippers are very popular because they can work directly in the forest or at the roadside landing. Due to space constraints, drum chippers are dominating forest biomass operations. Drum chipper are less efficient then disc chippers but they are also less sensitive to feedstock quality. Drum chippers come in two main design types: closed drum with full-length knives and open drum with staggered narrow knives. The goal of this study was to analyze the specific effect of these design types on productivity, fuel consumption and product quality, using different raw material types. For this purpose, two commercial chipper models with almost identical characteristic were selected to represent the alternative drum designs. A Pezzolato PTH 700/660 represented the closed drum type and a Mus-max Terminator 7, the open drum model (Figure 1 and Table 1).

Both machines were fed with two different feedstock types: chestnut logs and chestnut branches. Both materials were fresh. The study included 12 repetitions per combination of drum design, feedstock type and knife condition (new or worn out) for a total of 2 x 2 x 2 x 12 = 96 repetitions. Each repetition consisted of a grapple load of material corresponding to ca. 200 kg for logs and ca. 100 for branches.

Feedstock types were fed to each machine in a random sequence. Both chippers were attached to the same instrumented tractor, and all product obtained from each chipping bout was blown into big bags and weighed with a load cell attached to a forklift. Effective time consumption was measured on the power consumption graphs, rather than by timing the actual work. A sample was collected from each repetition for determining moisture content and particle size distribution. Mean values indicated that drum chipper was more productive than the open drum model (Table 2). When shifting from logs to branches, there was an increase in time consumption: 30% for the closed drum model and 80% for the open drum design, regardless of the knives condition.

Fuel and energy consumption had the same trend for both machines: they increased when the knives were worn and when branches replaced logs as feedstock.

Power use was higher for the closed drum chipper compared to the open drum model, for all feedstock and knife status. For both machines power use decreased when branches

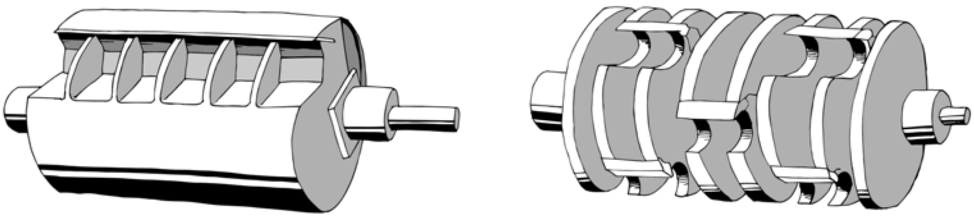

Figure 1. Closed drum (left) and open drum (right).

Table 1. Technical characteristic of the two chipper.

	Unit	Pezzolato PTH 700/660	Mus-Max Terminator 7
Drum diameter	mm	660	600
Drum width	mm	640	600
Weight	kg	840	750
Drum speed	rpm	790	750
Screen	mm	80x80	80x80
Knives	n	2	8
Cut length	mm	20	20
Infeed width	mm	600	600
Infeed height	mm	500	500

Table 2. Average time, power, fuel and energy consumption per dry ton by drum design, knife status and feedstock type.

Drum	Knives	Material	Time $s\ t^{-1}$	Power kW	Fuel $l\ t^{-1}$	Energy $MJ\ t^{-1}$
Closed	New	Logs	385.3^{D}	65.9^{A}	2.3^{D}	25.2^{D}
Closed	New	Branches	454.7^{DCB}	57.1^{B}	2.3^{D}	24.6^{D}
Closed	Worn	Logs	461.7^{DCB}	70.7^{A}	2.9^{CD}	32.5^{CD}
Closed	Worn	Branches	644.3^{DCB}	71.6^{A}	4.1^{B}	46.1^{B}
Open	New	Logs	420.2^{DC}	56.7^{B}	2.2^{D}	23.6^{D}
Open	New	Branches	772.6^{B}	41.7^{C}	3.0^{CBD}	30.9^{CD}
Open	Worn	Logs	759.1^{BC}	56.2^{B}	3.9^{CB}	41.5^{CB}
Open	Worn	Branches	1371.6^{A}	46.2^{C}	5.8^{A}	59.9^{A}

Different letters in the same column indicate that the difference between the values is statistically significant at the 5% level, according to the Tukey hsd test.

replaced logs. For branches, both drum model and knife condition had a significant effect on particle size distribution: the proportion of oversize was higher for the open drum design than for the closed drum design. Drum design had no effect on the chips quality obtained from logs. For logs, there was an interaction between particle size distribution and knife condition: new blades produced smaller quantity of chips in the 63-100 mm fraction, compared to worn blades.

In general, the performance of both designs was significantly affected by feedstock type and knife wear. The closed drum design was better suited to handle branch material, compared to the open drum design. These results can be relevant to technology choice. Operators planning to work large quantity of branch material are better off with a closed drum chipper. When the main feedstock is logs, drum configuration is not an issue. At a strategic level, one can relate the potential of each drum model to the expected use of different feedstock type and to the final users.

Acknowledgements

This study was funded by the EU, through the 7th Framework Program (311881) and within the scope of the INFRES Project.

Use of synthetic rope in the extraction of stems and whole-trees in a Radiata pine thinning on steep terrain in the north of Spain

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Abstract
Over recent years there has been increasing interest in the harvesting of forest biomass destined for energy production. However, there are a number of limitations with respect to the efficiency and profitability of such exploitations and these have implications for the future development of the sector.
One of the main challenges is the limited productivity of these activities, which is due principally to the low density of the material and the steep slopes characterizing the majority of forestry exploitations in regions such as Asturias (Northwest Spain). Against this background, this study aims to evaluate and improve the harvesting system through the use of synthetic cable in the extraction of stems and whole trees in thinnings of Pinus radiata in steep stands, with slopes greater than 45%.
Two work systems were evaluated through time study methodology: 1. Stem harvesting, with chipping at plant and 2. Harvesting of whole trees, with chipping at roadside. The productivities and costs of every stage were calculated. The productivity for each extraction stage (for stem and whole tree harvesting) using a tractor and synthetic cable were found to be 1.40 and 1.79 oven dry tonnes/SMH respectively, and the costs for the respective green material were 72.15 € and 77.71 € per oven dry tonne. In addition, the quality of the wood chips resulting from each system was analyzed, including moisture and ash content, granulometry and gross calorific value.

Keywords
forest biomass, thinning, stems, whole tree, steep terrain, synthetic rope, time study

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1. Introduction

The main goals of European and Spanish energy policies are: security of supply, environmental sustainability and economic competitiveness. In that sense, the Spanish government has incorporated the EU's objectives (minimum quota of 20 per cent of energy from renewable sources in the gross final energy consumption) in its Plan of Renewable Energies (PER, 2011).

The use of forest biomass has great potential to achieve these goals, taking into account that at present its contribution is estimated at about 5,545,287 green tonnes, accounting for only 30 per cent of the potential available forest biomass (including forest residues of final cuttings and whole-trees from thinnings) (PER, 2011).

Silvicultural treatments (thinnings and prunings) are essential for the proper management of stands and to obtain high value end-products in final fellings. In many cases though they are not performed due to lack of financial incentive because of the low market prices of the small trees removed. The use of biomass has opened a new funding possibility for this type of treatment, raising the interest of forest owners and companies in carrying out these treatments.

However, mechanization in the collection and removal of biomass (or the correct adaptation of existing technology) is one of the keys to the development of this area, since this type of residues has a problem of harvesting cost due to the lack of integration of timber and biomass supply chains (which could be rectified using new logistics and mechanization means) and also because its production is seasonal, which creates supply difficulties for the potential final consumer in power plants (Tolosana et al., 2010).

This is especially important in difficult conditions as is the case in Northern Spain with its steep terrain, small harvesting areas and deficient forest road networks. In such areas, the relatively low profit margins make the careful planning and evaluation of harvesting systems essential, seeking to improvement productivity and reduce costs. Moreover, it is important to improve the conditions for workers, which are especially hard in these areas.

Taking into account the above, the replacement of traditional steel cable by synthetic rope produces an improvement in working conditions, ergonomics and productivities (Pilkerton et al., 2001, 2003, 2004; Spong, 2007, Magagnotti and Spinelli, 2012). Furthermore, its use reduces environmental impact, causing less damage on the stand and soil (Spong, 2007; Golsse, 1996; Lapointe, 2000; Hartter et al., 2006). For the evaluation of harvesting systems, time studies allow the evaluation of productivity and cost, the detection of bottlenecks, causes of delays, etc, in order to asses and improve the productivity of the system. The overall objective of this study was to determine and analyse the productivity and cost of two harvesting systems to obtain biomass in pine thinnings, using a synthetic rope to skid stems or whole trees, and chipping at roadside or at the plant.

2. Material and Methods

2.1 Productivity and cost study

The study was conducted during a thinning operation of a radiate pine stand of a total of 30.53 ha. A forest inventory was performed to measure the dasometric characteristics of the stand. The volume per hectare was 233.96 m^3/ha and mean stocking was 1,591 trees/ha. A first semi-systematic thinning was executed in summer 2013, removing one of every four rows and making a low intensity thinning in the remaining rows. A total of 423 trees/ha (26.6%) were removed leaving a final stocking of 1,168 trees/ha. Table 1 shows the main data for the study area.

Table 1:

Table 1. Main dasometric variables.

	Avg.	Min.	Max.
dbh (cm)	17.4	8.05	25.25
treeheigth (m)	13.88	10.9	18.4
volume per tree (m^3)	0.1598	0.0507	0.3152

A synthetic rope (high density polyethylene), replacing the usual steel cable, was used in the skidding of both stems and whole trees. The synthetic rope has a lower weight, greater flexibility and the same strength as the same diameter of steel cable. In order to improve the productivity and reduce the workload of operatives, several chokers and sliders (Figure 1) were attached to the main line allowing the extraction of multiple stems or whole trees in the same cycle, thereby reducing the number and distance of worker displacements in the thinning area.

Figure 1. Detail of use of chokers and sliders for skidding of multiple stems.

Two harvesting systems were evaluated:

- System 1 "Chipping at plant": Logs were transported to the plant for chipping. The stages evaluated were the following: manual felling with Stihl 362 chainsaw, skidding stems to road with Same Explorer 90 CV tractor, wood preparation (Doosan Solar 55V mini excavator and chainsaw), hauling to landing with Valtra 8400 tractor with Guerra RTH-8000 trailer, transport with Man 19-362 truck (payload of 24 tonnes) and chipping at plant with Pezzolatto PTH 900/660 chipper mounted on Dingo AD6-24 forwarder. A total of 60 hours and 40 minutes were recorded in the different stages. In this system the biomass removed was 28.65 oven dry tonnes per hectare (odt/ha).
- System 2 "Chipping at roadside". Whole trees were chipped at the roadside, and the chips transported to the plant. The stages evaluated were: manual felling with Stihl 362 chainsaw, skidding whole trees to road with Same Explorer 90 CV tractor and synthetic rope, chipping at roadside (Pezzolatto PTH 900/660), hauling chips with Same Laser 150 tractor with a 25 m^3 trailer and unloading onto the ground and transport to plant with Volvo 480 truck with walking floor trailer of 90 m^3. A total of 51 hours and 29 minutes were recorded in the time study. In this harvesting system, the biomass removed was 39.17odt/ha.

The products obtained in each harvesting system (chips or logs) were transported to a pellet plant 34 km away. Table 2 presents the duration of timings of each stage.

Table 2. Duration of time studies of each stage in both systems (hh:mm:ss).

Stage	Chipping at plant	Chipping at roadside
Manual felling	17:48:27	09:14:50
Skidding	12:55:33	16:15:40
Wood preparation	11:48:52	-
Forwarding logs/chips	08:56:22	09:58:25
Transport to plant	07:32:09	06:39:54
Chipping	01:39:30	09:20:28

To evaluate the work systems, two 0.8 ha plots with similar characteristics were established in a 16-year-old stand, and a band painted on each tree to indicate which diametric class it belonged to (Figure 2) so as to be able to note this variable during the timing of manual felling and skidding. In the inventory, diameter at breast height of every tree and a sample of total heights were measured.

Each work cycle was divided into work elements and to avoid later mistakes, the work elements were clearly and concisely defined, setting the start and finish points.

For the productivity analysis, a detailed time study was performed, recording the exact time elapsed in every work element. Work sampling (fixed interval 1 minute) was used in the stages where the work cycle was not clearly defined (chipping) or with simultaneous tasks (wood preparation). In addition, certain parameters known to have a large influence on cycle time were also recorded (diameter of indi-

Figure 2. Marking trees to fell with different colour bands according to diameter class.

vidual tree, skidding distance, etc.) as well as observations related with each cycle.

Data acquisition was conducted using the specific time study software UMT® (LAUBRASS Inc., 2007). The time spent in each work element of the forwarder task was recorded on a Trimble Nomad handheld computer. The timing data were reviewed to eliminate errors and outliers (Olsen et al., 1998) and then, time study data and additional data (influential parameters) were combined into a single data set using proc SQL from SAS/STAT® (SAS Institute Inc., 2004), and grouped by cycle number.

Productivity for each machine was estimated per hour by dividing the number of tonnes of biomass extracted (odt), by total hour (SMH, Scheduled Machine Hour) and per productive hour (PMH, Productive Machine Hour).

For cost calculations, fixed and variable costs were calculated (Miyata, 1980; FAO, 1992) using data provided by the forestry company.

2.2 Wood Fuel Quality

Several properties of the two types of biomass (stem and whole tree chips) were measured: moisture content, particle size classification, bulk density, ash content and gross calorific value, following the specific UNE-EN ISO standards for this kind of wood fuel. For this evaluation, several samples were taken from different pile positions to obtain homogeneous and representative samples. These samples were transported to the lab in hermetic plastic bags.

3. Results

3.1 Productivity and cost analysis

For Manual Felling, Figure 3 shows the comparison between mean time consumption in the main work elements in both systems. Mean cycle time was longer in system 1 (4 minutes and 4 seconds vs. 1 minute and 37 seconds) because in this harvesting system this stage included felling and removing the branches and top of felled trees. The utilization rate was low in both systems (68.4% and 60.38% respectively in system 1 and 2) due to weather conditions (higher temperatures and humidity) and harvesting conditions (steep terrain and tall gorse) that forced workers to frequently rest, drink, etc. Individual volume of felled tree and stem/total aboveground biomass were taken into account to calculate productivity in cubic meters and oven dry tonnes per productive and schedule machine hour (PMH and SMH).

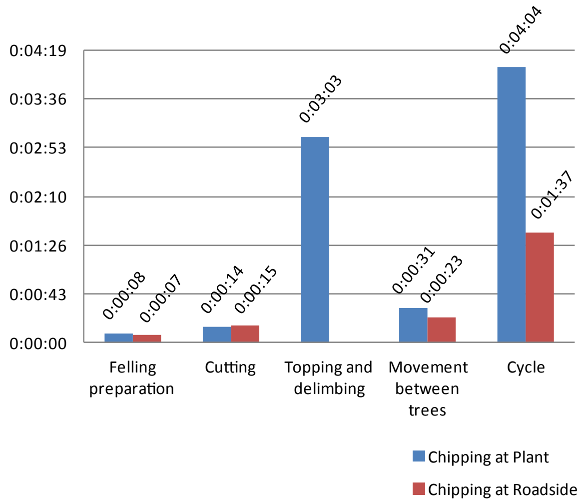

Figure 3. Average time consumption (hh:mm:ss) in main work elements of manual felling.

In the case of skidding, stems or whole trees (according to the system) were skidded from stump area to the roadside with synthetic rope and multiple chokers. In system 1 the driver and another worker made the stem hook up and in systems 2 the work team comprised the driver and two operators. The utilization rate was 79.4% and 87% in system 1 and 2 respectively. Although these values are not low, approximately 70% of non-productive time was consumed in rest and personal needs due to the climatic and harvesting conditions cited above, hence this stage could be more productive when there are more favorable conditions. In every cycle an average of 2.6 stems (system 1) and 2.3 whole-trees (system 2) were extracted per cycle. Release, hooking and unhooking times were heavily influenced by the difficulty of the displacements of workers due to dense understory and the large amount of branches on the ground after the felling phase.

In the stage of wood preparation of stems in system 1, two machines worked simultaneously: a mini-excavator and a chainsaw. The mini-excavator took the stems to the roadside and held them to make it easier for the chainsaw operator to cut them, and then the excavator stacked the logs. As would be expected, the number of interferences between the two machines was high.

In system 2, whole trees were chipped at roadside with Pezzolato PTH 900/660 chipper, which unloaded over the tractor trailer. The utilization rate was low (61.22%) due to

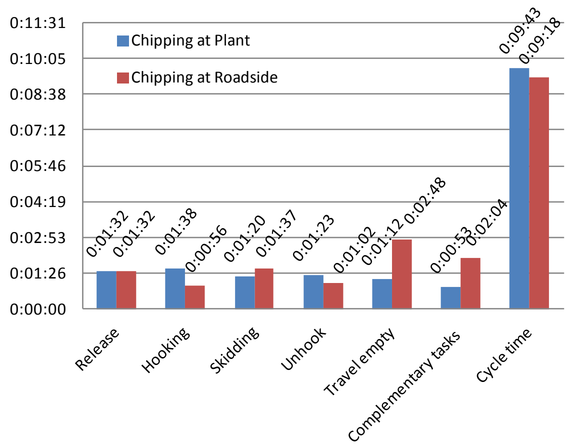

Figure 4. Average time consumption (hh:mm:ss) in main work elements of skidding.

interferences with the hauling tractor.

In the forwarding stage, logs or chips were hauled to landing (a distance of 1,200 and 1,700 m in system 1 and 2 respectively). The average cycle times were 1 hour and 16 minutes for system 1 and 1 hour and 55 minutes for system 2.

Transport road to plant (34 km) was performed by a Man 19-362 truck in system 1 (with a mean cycle time of 3 hours and 46 minutes). In system 2, a Volvo 480 truck with walking floor trailer of 90 m^3 transported chips to the plant, with an average cycle time of 3 hours and 20 minutes.

Chipping at plant was performed by a Pezzolato PTH 900/660 chipper. Table 3 shows the results of productivities and costs of the different stages in both systems. The hourly costs (€/SMH) were calculated with data provide by the forestry company and for transport and chip loading the costs were given directly by the transport company.

3.2 Wood Fuel Quality

The results of quality control are shown in Table 4.

4. Discussion

4.1 Productivity and cost

The productivities of manual felling and skidding were influenced by weather conditions and the dense understory, so they would be higher under more usual conditions, and consequently, total harvesting cost would decrease. As expected, manual felling in system 2 is more productive because there is no topping and delimbing of trees. In skidding, productivities are similar but it is necessary to take into account that in system 2 the driver was helped by two workers, whereas in system 1 only one extra worker was needed. In cases where it is feasible, one alternative to improve felling and skidding is increasing mechanization by using a harvester or a feller-buncher (Kärhä et al., 2005).

Chipping at plant was more productive than chipping at roadside, due specifically to the interferences between the chipper and the hauling tractor in the latter. Some studies have estimated an increasing of 30% in productivity through chipping at plant (Laitila, 2008, Antilla et al, 2011).

Table 3. Productivities and costs of system 1 (Chipping at plant) and 2 (Chipping at roadside).

	Productivity (odt/h)	Costs (€/odt)
Chipping at plant		
Manual felling	1.17	9.18
Skidding	1.4	18.11
Wood preparation	2.01	11.26
Forwarding logs	2.52	12.42
Transport to plant	2.55	13.64
Chipping at plant	10.11	7.53
Sum		72.15
Chipping at roadside		
Manual felling	4.31	2.49
Skidding	1.79	19.04
Chipping whole tree	2.53	30.11
Forwarding whole trees	2.35	13.4
Loading chips		1.81
Transport to plant	4.33	10.85
Sum		77.71

In this study, system 1 (stems) was found to be profitable (taking into account the standing timber price and current market price of chips), although the benefit was very low. System 2 (whole trees) was not cost effective, but taking into account the increased amount of wood fuel harvested per unit area in this type of system (Kofman and Kent, 2009), the barrier of profitability can be overcome by improving logistics between phases, or chipping at landing when the size of the landing size permits this.

4.2 Wood fuel quality

The two harvesting systems produced chips of high quality, i.e. classified as meeting the standard UNE-EN ISO 17225, Parts 1 and 4. If the chips are classified according to part 4 of the Standard (which has stricter requirements), they belong to class B1. They cannot be classified in the higher category because of their moisture content.

In the case of whole tree (system 2), the quantity of needles in the final material to be chipped decreased during storage, hence the low percentage of ash content and the similar characteristics of both types of chips. It is therefore advisable not to chip immediately after felling of whole trees in order to reduce moisture content and achieve needle fall, with consequent improvement in chip quality (Kofman and Kent, 2009). In addition, nutrient extraction is reduced given that needles can account for between 70-80% of the nutrients of a tree.

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Table 4. Wood fuel quality parameters evaluated in the study.

	Chips from whole-trees		Chips from stems	
	Results	Classification ISO 17225-1	Results	Classification ISO 17225-1
Moisture content (%)	46.7	M50	48.59	M50
Bulk density	304.85	BD300	327.77	BD300
Dimensions	P31S	P31S	P31S	P31S
Fines	F10	F10	F10	F10
Ash (%)	0.8	A1.0	0.4	A0.5
Gross Calorific Value (MJ/kg)	20.54		20.06	
Classification (ISO 17225-4)	B1		B1	

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Evaluation of the Flowcut prototype head designed for early, biomass dense, thinnings

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Abstract
The Flowcut felling head is designed for continuous cutting and accumulation of small diameter trees. Felling and accumulation in a corridor is only interrupted by piling the trees when the accumulation capacity of the head is fully utilized. Theoretical studies has shown that this working method has the potential to at least double the performance in early, biomass dense, thinning. This study is a first in-field test of the Flowcut felling head and the main objective was to evaluate the heads functionality and performance and discuss further developments. Results show that the Flowcut felling head indicates a potential to increase harvester performance in early dense thinnings. The principle for cutting and accumulation was operational but there are areas that call for improvement.

Keywords
pre-commercial thinning, fuel wood, first thinning, time studies, felling head, bioenergy

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1. Introduction

The greatest potential for improving harvesting productivity in early thinning is to decrease the time needed for cutting and handling each tree. This can be done by accumulating felled trees in the felling head and handling many trees per work cycle. Multi tree handling gets more important the denser stands are and especially if the trees are small (Peters 1991, Belbo 2011). Simulations show that intermittently continuous cutting and accumulation may, at least, double harvester performance in dense young stands if combined with boom-corridor thinning systems between strip roads (Winsauer 1984, Bergström 2009). The new Flowcut felling head has been designed and built for continuous cutting and accumulation of small diameter trees, in order to utilize the performance potential. This study is a first in-field test of the Flowcut felling head and the main objective was to evaluate the head's functionality and performance in early thinning and discuss further developments of it.

2. Material and Methods

The test was performed close to Åsbro, Sweden (59°29'N, 15°3'E) in June 2015 in five test plots. The plots sizes were of 59 to 76 m long strip-road sections with a width corresponding to the crane reach. Stand data (tree species, tree height and diameter) were registered in four randomly placed 50 m² circular sample plots in each strip road section (Table 1). After logging, the same sample plots were re-measured and tree diameter and species was registered. This was combined with measuring of length and width of each boom-corridor to enable calculation of thinning intensity. Along each boom-corridor, the number of dropped trees and the number of damaged residual trees were registered. The damages were divided into two groups, those caused by bashing and those caused by the saw chain.

The felling was done using a Valmet 911.4 harvester with an 11 meter crane, maneuvered by the operator that had been involved in the early testing of the felling head. The operator made between one and three boom-corridors on each side of the machine every 3-4 meters. Continuous time studies of predefined work elements were done to estimate harvester performance. The material from each boom-corridor was placed in a separate pile and weighed using a boom tip scale (Intermercato XW 70 BS) mounted on a forwarder. A total of six biomass samples were taken from different trees sizes to determine moisture content. The samples were oven dried at 104°C until constant weight was reached.

The harvester performance was calculated as tonnes (t) dry matter (DM) harvested per efficient work hour (E_0h) and as number of stems harvested per E_0h. Note that the times measured are efficient times on rather small and strait plots so they are an underestimation of the long term efficient work times. The results are presented as averages from each strip road section.

Additional measures of the maximum possible speed the head was able to cut and accumulate trees in a continuous movement was made. The test were performed in four strips of 5.2-7.9 m in length each containing 2-3 trees "equally" spaced from each other in a straight line. Measurements of time started from an idle position of the head, at least 1 m to first tree to be cut, and ended approximately 1 m after the last tree was cut.

Table 1. Initial stand data.

Plot	1	2	3	4	5
Stems per hectare	7700	6150	7700	9600	12250
Average diameter at breast height (mm)	34	36	28	26	41
Distribution of species (%) (pine/spruce/other)	57/0/43	61/1/38	56/2/42	74/3/21	81/0/19

Table 2. Harvesting performance.

Plot	1	2	3	4	5
Per crane cycle					
Time (s)	34	32	29	31	28
Stems (n)	6.15	5.69	4.77	4.72	4.12
Removal					
Dry tonnes harvested per hectare	4.57	5.35	6.99	6.06	6.41
Average tree weight (kg DM*stem^{-1})	2.5	2.9	3.8	3.8	5.7

3. Results and discussion

Between 173 and 246 trees were harvested in each plot, which was completed in 39-48 crane cycles. The cutting accounted for roughly 50 percent of the total efficient time, with decreasing portion as the tree size increased and number of trees per crane cycle decreased. The harvested trees were small which resulted in fast handling per tree but low overall performance (Table 2, Figure 1).

A separate test of revealed that the Flowcut head could continuously cut and accumulate trees at crane speeds up to 0.6-1.0 m/s.

The post-harvest inventory recorded between 50 and 180 damaged stems per hectare or 1.1-3.5 percent of the total number of remaining stems. A majority of the damage were caused by either the saw chain when trees had not been fully cut through or when the head had pushed over and partly up-rooted trees. 99 trees that were cut were dropped and never put into the piles. This is equivalent to roughly one tenth of the total number of trees cut.

4. Discussion and conclusions

Conclusions concerning the performance of the head during the study has to be based partly on observations made by the study personnel during the study. The performed evaluation of a prototype Flowcut felling head do indicate a potential to increase harvester performance in early dense thinnings. The principle for cutting and accumulation was operational but there are areas that call for improvement, which is to be expected as neither working technique nor the head itself has reached a mature stage.

The Flowcut head can cut and accumulate trees during a continuing movement in boom-corridors and bunch the trees at road-side. However the felling head does not reach its full potential as 1) the cutting was not fast enough for the boom speeds used by the operator resulting in incompletely severed and up-rooted trees, and 2) that manual decisions are needed throughout the accumulation work which in combination with improper sequencing of the accumulator arms increases the risk for dropped trees. The balance

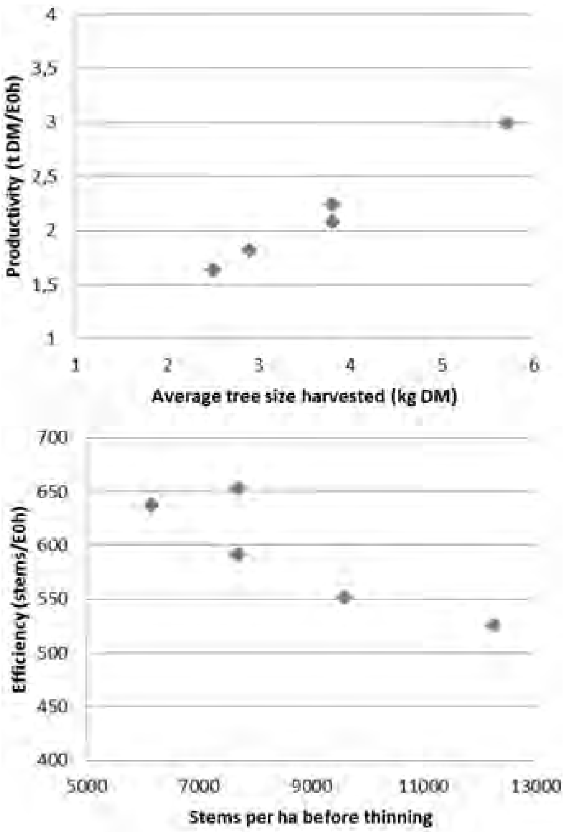

Figure 1. Performance as tonnes DM (upper) and harvested stems per hour (lower) for the Flowcut head in early biomass dense thinning.

between boom speed and shearing speed may be improved as the operator gets more familiar working with the felling head but replacing the saw bar with a disc may improve shearing speed and improve the cutting performance. In Bergström et al. (2007) a head movement speed of 1.0 m/s when harvesting trees corridor-wise gave an 2 to 3-fold productivity increase in comparison to selective cutting in pre-commercial thinning stands. However, in Bergström et al. (2007) the speed was kept constant regardless of number of trees handled and position of the head and in practice it is likely that the average speed will decrease

The felling head could be improved by an increased automation of accumulation, i.e. less or no need for operator control, and trimming of the sequences for the holding arms. And maybe also by replacing the saw bar with a circular saw disc, which may enable higher security of cutting.

The overall impression is however that the head has potential to reach expected levels of efficiency, but based on this first test it is too early to estimate its expected productivity, when fully developed, or in in different stand conditions.

Acknowledgements

The ESS-programme (Efficient Forest Fuel Systems) which is funded by the Swedish energy authority and the Swedish forest sector, Skogssällskapet and Sveaskog are gratefully acknowledged for their support.

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Productivity and cost of harvesting short-rotation birch stands on cut-away peatlands in northern Finland

P. Jylhä[1], D. Bergström[2]*

Abstract
Downy birch has shown potential for fairly high biomass production (3–4 oven-dry tonnes (ODt) per ha per year) on cutaway peatlands, with only minor investments. There is however a lack in knowledge of the operational cost for harvesting these stands. The objective was therefore to construct time consumption models for clear-cutting and forwarding of downy birch biomass from naturally afforested, unthinned downy birch dominated thickets. In the clear-cutting of 17 time-study plots which covered a vast range of tree size characteristics, an accumulating felling head equipped with a circular saw disc (Bracke C16) with a high cutting efficiency was used and subsequent forwarding was done using a modified medium-sized forwarder. Cutting productivity reached 3–11 ODt per effective hour (E_0h), and it was highly dependent on stand characteristics. At a distance of 300 m, for example, forwarding productivity was 6.7–10.4 ODt/E_0h. Our study shows that biomass 1) can be harvested by clear-cutting from young downy birch thickets in a cost-efficient way and 2) provides prediction models for cutting and hauling work to be used in e.g. cost analysis.

Keywords
clear-cutting, forwarding, bioenergy, whole trees, profitability, short-rotation production

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1. Introduction

Marginal lands show potential for increasing energy biomass reserves. The study of Jylhä et al. (2015) indicated that intensive production of downy birch could be profitable without subsidies in former peat production areas in northern Finland with a rotation exceeding 20 years. Dense downy birch (Betula pubescens) stands can be established at low cost in these sites, where they can reach a mean annual biomass production exceeding three oven-dry tonnes (ODt) per hectare. Harvesters designed for industrial roundwood are inefficient or too costly in small-diameter and dense stands, while the cutting capacity of modified agricultural harvesters limits their use in natural thickets. We constructed time consumption models for whole-tree-cutting and forwarding of whole trees from unthinned, mixed downy birch thickets. These models were used for calculating the cost of forest chip production.

2. Material and Methods

In cutting, a six-wheeled Valmet 911.3 harvester, equipped with the Bracke C16.b accumulating biomass felling head was used. Whole trees were forwarded with a modified Ponsse Buffalo S16 forwarder. Time studies were performed in unthinned, naturally afforested mixed downy birch stands 14–29 years in age. Biomass recovery varied between 40 and 173 ODt/ha, and stand density was 5,200–160,000 trees/ha. Mean height of the trees (Hba) varied between 5 and 15 m and mean breast-height diameter (DBHba) between 3 and 14 cm (both figures are means weighed by basal area). Biomass recoveries were derived from crane scale measurement and moisture contents of whole-trees. The other stand parameters are based on pre-harvesting stand measurements.

The calculations of hourly productivities of cutting and forwarding were based on the time consumption models. The unit costs of forest chip production were calculated as described in Jylhä et al. (2015). However, hourly costs of the machinery involved in forest chip production were updated to the level prevailed in May 2015.

3. Results and discussion

Cutting productivity varied from 3 to 11ODt/E_0h, depending on stand characteristics. Increase of Hba from 4 cm to 12 cm increased cutting efficiency ca. 3.5-fold (Fig. 1). Cutting productivity was 20–40% higher than assumed in the profitability calculations of Jylhä et al. (2015). An average size of a full forwarder load was 4.0 ODt. In stands with a mean height of 10 m (DBHba $\approx$ 8 cm, removal $\approx$ 80 ODt/ha), for example, forwarding efficiency was ca. 7 ODt/E_0h at distance of 300 m. Achieved forwarding productivity exceeded the assumption of Jylhä et al. (2015) by 10–30%.

4. Conclusions

Our study shows that biomass can be harvested from dense downy birch thickets in cost-efficient way by clear-cuts. The

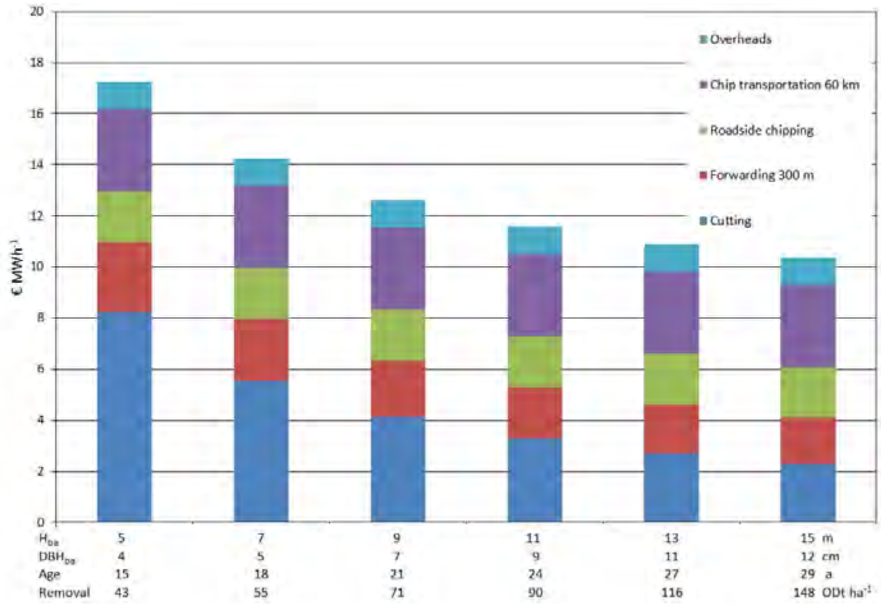

Figure 1. The total costs of forest chip production from biomass harvested from unthinned downy birch dominated stands. A moisture content of 40% was assumed for the chips.

results indicate that the profitability calculations of Jylhä et al. (2015) are sound in terms of harvesting costs and finding in present study indicate that the operational cost could be some 10-20% lower than assumed their study. The data used for modelling the time consumption of cutting and forwarding originates from unthinned thickets, where stand parameters were strongly intercorrelated. The models are suitable for calculating the efficiency of harvesting small-diameter whole trees from coppiced stands. However, the models are not applicable to thinned stands.

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Effects of harvested tree size and density of undergrowth on the operational efficiency of a bundle-harvester system in early fuel wood thinnings

D. Bergström[1]*, F. Di Fulvio[2], Y. Nuutinen[3]

Abstract
The objective of the study was to improve the knowledge of the effects of harvested tree size and density of undergrowth on the operational efficiency of a bundle-harvester in early fuel wood thinnings in the Nordics. There were no significant differences between treatments (clearing vs. no clearing) in the harvested and remaining stands' properties or in operational efficiency. The productivity was on average 3.1 OD t/PMH_0(6.6 fresh t/PM0H; 15.1 bundles/PMH_0) and was modeled by using the harvested stem volume as a single independent variable. The study provides complementary knowledge to earlier studies of the system's performance, especially for harvesting <30 dm³ stems. The productivity of the bundle-harvester was limited by the cutting efficiency and could probably be significantly increased by using a felling and bunching head that could cut and accumulate trees during continuous boom movements.

Keywords
pre-commercial thinning, productivity, Scots pine, bioenergy

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1. Introduction

Small diameter trees in young dense forests are already harvested in the Nordic countries to produce fuels for heat and power generation, and the harvested volumes are expected to increase as demand for high quality residual biomasses for biorefining will rise (Bergström & Matisons 2014). Bergström and Di Fulvio (2014a) theoretically show the use of bundle-harvesting systems for young dense thinnings could significantly reduce supply costs compared to conventional tree-part handling systems in thinning forests.

A third version of the Fixteri bundle-harvester system was launched in 2013, with reported increases in efficiency (time/bundle) of 90-160%, providing productivities of 9.7-13.8 m^3 solid /$PMH_{15}$when thinning Scots pine-dominated stands, compared to previous prototype models (Björheden & Nuutinen 2014). The solid volumes of the produced bundles range from 0.3 to 0.5 m^3 (Jylhä & Laitila 2007) and their use increases forwarders' and trucks' payloads by ca 50%, respectively, in comparison to handling loose materials (Laitila et al. 2009). However, the system's productivity has not been extensively studied in stands with an average harvested tree volume below 30 dm³, in which there may be significant proportions of disturbing under-growth trees that may reduce cutting productivities (cf. Kärhä 2006, Jonsson 2015), and hence cost efficiency.

The objective of the study presented here was to evaluate effects of harvested tree size and density of undergrowth on the operational efficiency of the third prototype of the bundle-harvester in early fuel wood thinnings.

2. Material and Methods

In total 26 units were marked out for harvesting with an average area of 1215 m², covering a total area of 3.2 ha. Ten of the 26 units were pre-cleaned, by cutting undergrowth trees of $\leq$ 2.5 cm diameter at breast height (DBH). The study site was located in Holmsund (N 63°43', E 20°25'), near the coast of northern Sweden, in a 30-35 year-old stand containing mostly Scots pine (Pinus sylvestris L.), Norway spruce (Picea abies (L.) Karst.) and birch (Betula spp.). The ground generally had good bearing capacity, the surface had no obstacles, the slope was slight and it was classified as 2.1.1 according to Berg´s (1992) terrain classification.

The machine system studied was a harwarder equipped with a felling crane and a bundling unit capable of bucking the cut trees and bundling them into 2.6 m long cylinders with ca. 60-70 cm diameters. The base machine was an 8-wheeled Logman 811FC harwarder (Logman, Oy) and was equipped with a 10 m reach Logfit FT100 crane (Logfit AB). The crane was equipped with a Nisula 280E+ (Nisula Forest Oy) accumulating felling head with max cutting diameter of 28 cm. The bundling unit was a Fixteri FX15a machine (mass ca. 6,500 kg, width 240 cm, length 410 cm, height 280 cm; www.fixteri.fi). During harvest, whole trees are cut, accumulated and fed to the bundling unit for processing. The bundling process is automated with possibilities for the operator to control the process. The felling, feeding, dropping and weighing work can be performed simultaneously with the bundling process. The thinning was carried out selectively from below along strip road systems, with broadleaves prioritized for removal and targeting a residual density of at least 1200-1500 future crop trees/ha.

The time study was conducted between the 5^{th} and 14^{th} of May 2014, and the total duration of the monitored work was 29.40 PMH_{15}. The work time consumption was continuously recorded. At the same time, the machine computer created a dataset for each unit containing information on the weight for each bundle and ejecting time. After the time study, the DBH and species of all trees, and numbers of undergrowth trees, were recorded again in the inventory transects. The remaining stands' properties and the time consumed (sec/tree) when harvesting not pre-cleared and pre-cleared units were compared by analysis of variance (ANOVA). Correlation analysis was applied to evaluate correlations between independent variables using Pearson´s correlation test. Analysis of covariance (ANCOVA) was used for analyzing the combined effects of treatments and independent variables on the productivity. Regression analysis was used for testing possible significant predictors of the bundles' mass (OD kg/bundle). A P-level of 5% was used as a threshold for statistical significance.

3. Results

There were no significant differences in properties between units that were cleaned and not cleaned prior to thinning, in either harvested (e.g. tree volume, tree height and density) or remaining stands (e.g. basal area, stand density, stem volume, height, damage and strip road spacing). A prediction model with OD t/bundle as a dependent variable and proportion of birch trees in the bundle as an independent variable was obtained (Eq. 1).

On average 4.1 trees/crane cycle were harvested and there were no between-treatment differences in this respect. On average each crane cycle took 44.6 sec and 5.5 crane cycles were required to produce a bundle. The number of crane cycles required per bundle was highly correlated to the average harvested tree size ($R=-0.775$; $P<0.001$). The time consumption per bundle was modeled as a function of the time consumption per crane cycle (Eq. 2)

The productivity reached on average 3.1 OD t/PMH_0(Fig. 1). The independent variable harvested stem volume (dm³) provided the highest predictive power, and hence was used as a single covariate in the ANCOVA analysis. All combinations of other independent variables gave less good predictions and/or were biased by multicollinearity. On average 15.1 bundles/PMH_0were produced and the stem volume provided slightly better productivity predictions, in terms of bundles/PMH_0than in terms of OD mass.

During the total field trial period (98.5 PMH_{15}) the system consumed 15.87 MWh of diesel fuel and produced 1392.36 MWh of biofuel, corresponding to an average energy efficiency of 172 MJ/OD t (187 MJ/OD t in PMH_{15}time). On average a bundle had a fresh weight of 454 kg, corresponding to 0.96 MWh, and fuel consumption averaged 15.1 l/PMH_0(16.4 l/PMH_{15}).

4. Discussion

Unexpectedly, the density of undergrowth trees did not significantly affect the efficiency of the cutting work, as found in previous studies (e.g. Kärhä 2006, Jonsson 2015). A possible explanation is that the cutting work in the present study was performed with an accumulating felling head equipped with shearing knives that is less sensitive to disturbing undergrowth during cutting than the accumulating harvester heads used in the cited studies. The productivity recorded in the present study was 23% and 9% lower than values recorded by Björheden and Nuutinen (2014), for harvesting trees of 27 dm³ and 44 dm³, respectively, when the same bundle-harvester system was used for thinning pine-dominated stands during winter (Fig. 2). However, in their study the intensity of thinning was much higher (the density of remaining trees after thinning was much lower) which render higher cutting efficiency and probably is the main explanation to the big difference.

It should be noted that biomass losses during the bundling process lead to proportional losses in productivity, and are probably correlated to the sizes of cut trees, and ratios of conifers to broadleaves. On average the tree sections lost 7.1-10.1% of mass during the bundling process and by visual inspection, this mass consisted mainly of fine branches and needles. Whether the losses due to bundling should be minimized or set at certain levels is a question of prioritizing productivity or nutrient removal and fuel quality. However, the magnitude of losses due to compression/bundling should be controlled, regardless of the technology and system used, to optimize the balance between productivity and losses in accordance with stand conditions and economic goals.

The overall productivity for the whole trial time is very similar to values obtained from the time study, corroborating the robustness of the models obtained from the time study units. However, users should be aware of the limited numbers of operators and stand types that the models are based upon. The operational fuel consumption during the field trial period is consistent with earlier measurements under somewhat different conditions (Jylhä 2011), indicating that the system consumes ca. 16 l diesel/PMH_{15}.

The study was conducted in forest sites with good bearing capacity, low roughness and limited slopes. Due to the system's high mass it could potentially be limited by difficult soil conditions, thus further studies are also needed to assess effects of soil properties on its operational efficiency. The machine's center of gravity was not measured, but it is likely to be higher than for a standard harvester, due to the addition of the bundling unit. This might also restrict the machine's operational maneuverability on slopes somewhat, and warrants investigation.

5. Conclusions

The study provides information about the system's performance that complements earlier findings, especially when handling relatively small trees, and the recorded productivity is consistent with previous reports. The system's time consumption per bundle was not affected by either tree size or the mixture of tree species harvested, but the mass of

$$Bundle\ mass\ (ODt/bundle) = 190.27 + 0.249(birch, \%\ no.\ of\ trees\ cut) \quad (1)$$

R^2(adj)= 12.02%, P= 0.046

$$Time/bundle\ (min) = -1.95 + 0.136(time/crane\ cycle, sec) \quad (2)$$

R^2(adj)= 60.4%, P= <0.001

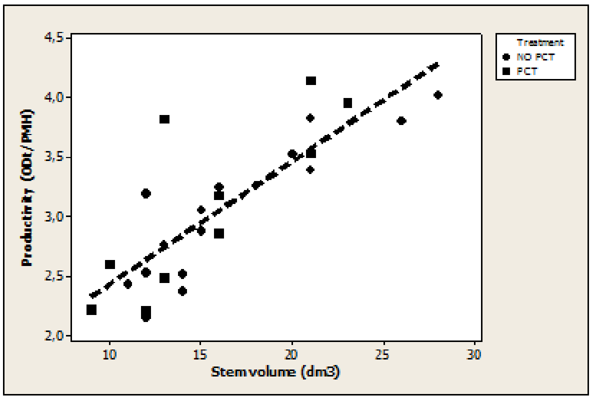

Figure 1. Productivity of the bundle-harvester system as a function of average size of harvested tree.

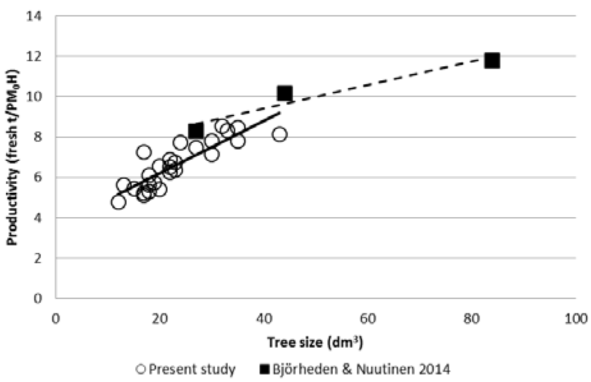

Figure 2. Productivity as a function of harvested tree size (stem + branch volume) recorded in the present study and according to findings by Björheden and Nuutinen (2014).

the bundles was positively correlated with the proportion of birch trees cut. The bundling unit's maximum efficiency was not reached during the trial, but estimates indicate that it could be significantly (perhaps up to 100%) higher. However, to reach such efficiency the system would have to be equipped with a felling and bunching head that can cut trees during continuous boom movements. In the near future it should be equipped with a head with higher cutting efficiency, e.g. the Bracke C16 head, and its productivity, maneuverability and quality of bundles should be further investigated in various forest conditions.

Acknowledgements

A complete report of this study was submitted for review in June 2015 to the Croatian Journal of Forest Engineering. The research leading to these results has received funding from the European Union Seventh Framework Program (FP7/2012-2015) [grant agreement no. 311881] and the SKM project funded, inter alia, by the Swedish Energy Agency.

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Impact of number of stems retained per stool on harvester productivity and fuel consumption in Eucalyptus globulus second rotation coppiced plantations in south west Western Australia

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Abstract
Regeneration of eucalypt plantations from coppice is increasingly being used in Australia to reduce re-establishment costs. Coppiced plantations are thinned to one to three stems per stool or left unthinned. However, little is known about the impact of differing stem numbers per stool on harvester productivity and fuel consumption.
Study objectives were to compare the productivity and fuel consumption of a single grip harvester harvesting one stem per stool, two stems per stool and all stems retained per stool. The study was performed with a Hyundai 210LC-9 excavator base with a SP 591LX harvesting head, in a 10.5 year old, second rotation coppiced Eucalyptus globulus stand in south-west Western Australia, being clearfelled for pulp logs. Time and piece counts, cycle and elemental times were recorded for the harvester in each treatment.
Stem size was the major factor influencing harvester productivity (20.8 m^3/productive machine hour without delays (PMH_0), 11.8 m^3/PMH_0 and 8.6 m^3/PMH_0 in the single stem, two stem and unthinned treatments, respectively).
Significant differences were found between treatments for the move/position and felling time elements. However, these differences did not significantly affect harvester cycle times, because the processing time element made up at least 65% of the harvester cycle time in each treatment.
The fuel consumption data collection period was too short to draw many conclusions. However, greater harvester fuel use per PMH_0 when operating in the single stem treatment may have been caused by the fewer stems per hectare (sph) and larger trees in this treatment increasing the harvester's workload, and the lower fuel use per m^3 in this treatment may have reflected the significantly greater harvester productivity.

Keywords
harvester, coppice, productivity, stems per ha, Eucalyptus globulus

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1. Introduction

Australia has over 950,000 ha of eucalypt plantations, of which 521,000 ha is Eucalyptus globulus Labill (Gavran 2015). These plantations are typically grown on a nominal ten year rotation to produce export wood chips for pulp production. E. globulus readily regenerates from the stump (referred to as coppice) when harvested (Blake 1983) and many plantation managers in Australia and overseas routinely regenerate E. globulus plantations using the coppicing method, largely because it avoids much of the costs associated with replanting, with estimated savings of AUD$ 1000/ha (Whittock et al. 2004). In Australia, eucalypt coppice stands are typically thinned to one to two stems per stool within two years of resprouting, but may be left unthinned (Archibald 2002). Although replanting can be a more expensive option, it allows plantation managers to take advantage of genetic improvements that could improve growth rates and dry matter yield (Whittock et al. 2004). In addition, stools may fail to resprout (Whittock et al. 2003) which can leave areas of a regenerated stand understocked or unstocked.

Eucalypt coppice stands in Australia are harvested by either whole tree harvesting (WTH) systems that extract whole trees to roadside for infield chipping, or by cut to length harvesting (CTL) systems that extract debarked logs only. The main disadvantage of WTH systems is the reduction in site nutrients from removing the bark, and with evergreen species such as eucalypts, the crown and leaves (Jenkins 2013). Compared to other fully mechanised harvesting methods, the cut-to-length (CTL) method is generally regarded as a more environmentally friendly, versatile and safe method that provides end products of more consistent and higher quality than mechanised full tree and tree length methods (Kellogg and Bettinger 1994).

There are very few published studies of single-grip harvester productivity using CTL harvesting in coppiced eucalypt plantations. Coppice stands differ from planted stands as they can have multiple stems per stool. Increasing the number of stems per stool decreases their mean diameter (Poynton 1965) but does not significantly affect total site volume production (Poynton 1981). While Suchomel et al. (2011) found that the number of stems per stump in oak coppice did not affect harvester productivity, decreasing the mean stem diameter is likely to reduce harvester productivity, as many previous studies of planted stands have shown (e.g. Kellogg and Bettinger 1994, Purfürst and Erler 2011, Ramantswana et al. 2013, Strandgard et al. in press).

The objectives of this study were to compare the productivity and fuel consumption of a single-grip harvester conducting CTL harvesting in an E. globulus coppice stand where the coppice had been thinned to a single stem per stool, thinned to two stems per stool or left unthinned.

2. Methodology

The trial was conducted in a 10.5 year old E. globulus plantation being clearfelled to produce pulp logs, which was located approximately 9 km south of Bridgetown (lat. -34.049829; lon. 116.105264) in south-west Western Australia. The first rotation of planted trees at the site was established at a nominal stocking of 1200 sph. It was clearfelled in 2004 and two years later 67.1ha was thinned to a single stem per stool, 3.5 ha thinned to two stems per stool and 6.4 ha left unthinned. Thinning was done to waste and the residual material was left in the stand. Stem form was very good in all treatments (<1% defective trees).

The trial was conducted in December 2014 in dry, sunny conditions. The harvest trial was performed using a Hyundai 210LC-9 excavator base (4051 engine hours) with an SP 591LX harvesting head. The harvester operator had over 15 years of experience operating harvesters. During the trial, each stem was felled, debarked and processed into nominally 4.6 m logs by the harvester at the stump and stacked for transport by a forwarder to roadside.

The productivity of the harvester operating in each treatment was estimated using time and piece (T&P) counts. Two T&P counts were conducted in the single stem and two stem treatments and four in the unthinned treatment. Each T&P count was conducted for 2 hours. All delays were excluded from the observation time. Harvester productivity was estimated by first multiplying the number of stems cut during each T&P count by the mean stem volume (calculated from a 0.03 ha inventory plot established in the area harvested during the T&P count using a single tree volume model supplied by the plantation owner) to estimate the total volume cut (m^3) during the T&P count. This volume was then divided by the observation time (hours) to derive harvester productivity (m^3/Productive Machine Hour excluding delays (PMH_0)).

Video recordings of the harvester operating in each treatment were used to calculate cycle times and elemental times (defined in Table 2) for approximately 100 stems in each treatment. A cycle was defined by the harvester activities associated with an individual stem. Cycle times and elemental times were compared between treatments using an ANOVA ($p<0.05$). Elemental times for brushing/clearing, stacking/bunching and delays were excluded from cycle times and the analysis as their mean times were less than one second for each treatment.

At the end of each day, the harvester fuel tank was filled to the same level and the litres added was recorded. Harvester fuel consumption (l/PMH_0) was estimated by dividing the number of litres used each day by the total productive machine hours for that day. The fuel consumption to harvest and process each cubic metre of wood (l/m^3) was then calculated by dividing the mean hourly fuel consumption in each treatment by the harvester productivity for that treatment.

3. Results

Harvester productivity in each treatment estimated from T&P counts and from the Australian general harvester productivity model (Strandgard et al. in press) based on the mean stem volume in each treatment and the percentage difference between each productivity estimate are shown in Table 3.

Estimated harvester productivity (m^3/PMH_0) in each treatment estimated using time and piece counts and the Australian general harvester productivity model (Strandgard et al. in press)

Harvester mean elemental and cycle times for each treatment are shown in Table 4. The mean Move/position time for the two stem treatment was significantly less than that for the other treatments. The mean Felling time for the single stem treatment was significantly less than that for the unthinned treatment, whereas the time for the two stems treatment was not significantly different from the other two treatments. The Processing and cycle times for the single stem treatment were significantly greater than those for the other treatments.

Harvester fuel consumption (l/PMH_0 and l/m^3) in each of the treatments is shown in Table 5.

4. Discussion

Harvester productivity was found to be strongly related to the mean stem size in each treatment, which concurs with the findings of numerous previous trials (e.g. Kellogg and Bettinger 1994, Purfürst and Erler 2011, Ramantswana et al. 2013, Strandgard et al. in press), though these trials were overwhelmingly conducted in planted stands. However, Ramantswana et al. (2013) also found that tree size was the most significant factor explaining harvester productivity in a eucalypt coppice harvesting trial in South Africa. The productivity of the harvester in each treatment was greater than that predicted by the Australian general harvester productivity model (Strandgard et al. in press) for the mean tree volume in each treatment. However, the general model aims to predict the performance of a harvester

Table 1. Stem and stand characteristics at time of harvest.

Characteristic	Treatment		
	Single stem	Two stems	Unthinned
Mean stem number per stool	1	1.5	3.1
Stems per hectare	848	1200	2745
Stools per hectare	848	800	864
Mean stem DBHOB (mm)	167	127	105
Mean stem height (m)	20.4	15.7	15
Mean stem volume (m^3)	0.21	0.09	0.06
Volume per hectare (m^3/ha)	175	107	174

Table 2. Time element definitions.

Time element	Definition
Moving/positioning	Starts when tracks begin to move or when boom begins its swing towards next tree. Ends when felling commences.
Felling	Starts when head clamps onto tree. Ends when feed rollers are activated.
Processing	Starts when feed rollers are activated. Debarking, delimbing and cross-cutting of tree. Ends when felling boom begins to swing to next tree or tracks begin to move.
Brushing/Clearing	Any interruption to other elements to remove unmerchantable trees or clear processing debris.
Stacking/Bunching	Starts when the boom commences a swing to retrieve, move or ‘stack’ any processed logs. Ends when the boom moves to perform some other activity
Delay	Any interruption to previous elements.

Table 3. Estimated harvester productivity (m^3/PMH_0) in each treatment estimated using time and piece counts and the Australian general harvester productivity model (Strandgard et al. in press)

Estimate source	Treatment		
	Single stem	Two stems	Unthinned
T&P counts	20.8	11.8	8.6
General productivity model	17.7	9.7	7.5
% difference	17.5	21.6	14.7

Table 4. Harvester mean elemental times and cycle times for each treatment (seconds). Treatments sharing a letter were not significantly different.

Treatment	Move / position	Felling	Processing	Cycle time
Single stem	5.3a	3.6a	23.1a	32.1a
Two stems	4.6b	3.7ab	15.2b	23.5b
Unthinned	5.3a	4.2b	16.0b	24.8b

Table 5. Harvester fuel consumption (l/PMH_0 and l/m^3)

Treatment	Harvester fuel consumption l/PMH_0	l/m3
Single stem	32.4	1.6
Two stems	27.1	2.3
Unthinned	28	3.3

operated by an “average” operator under “average” conditions. Purfürst and Erler (2011) found that, after tree size, operator performance was the next most important factor in explaining harvester productivity. Although not tested, the performance of the operator in the current trial was believed to be above average. In addition, the operator spent very little time (<1 second per cycle) on non-harvesting activities and delays during the trial. Tree form can also have a significant impact on harvester performance (Suchomel et al. 2011, Ramantswana et al. 2013). In the current trial, the proportion of trees with defects that affected the harvester performance in all treatments (<1%) was very low compared to that observed in by Hamilton et al. (2015) in a nearby E. globulus plantation trial (9.5% forking and 2.7% branching defects).

Coppice characteristics may also have affected the harvester’s performance. Retaining multiple stems per stool increased the sph in the current trial relative to the single stem treatment. This was likely to explain the significantly quicker moving/positioning time in the two stem treatment compared with the single stem treatment. However, the moving/positioning time in the unthinned treatment, which had the greatest sph in the trial, was not significantly different from that of the single stem treatment. This was likely to be the result of the additional time required in the unthinned treatment for the operator to position the head on many stools to grasp and fell all the stems simultaneously which counteracted the reduction in moving time from the greater sph. Similarly, the slowest mean felling time, which was recorded for the unthinned treatment, was caused by the operator having to move some stems to a clearer area prior to processing. However, the differences between treatments in moving/positioning and felling times did not have a significant effect on cycle times because the processing time element made up at least 65% of the harvester cycle time in each of the treatments.

Fuel consumption per productive machine hour was at the upper end of the range expected for a tracked harvester (FPInnovations 2009). Most previous fuel consumption trials have been conducted on wheeled harvesters, which use considerably less fuel than a similarly sized tracked harvester (FPInnovations 2009). Given the short time over which fuel consumption data was collected, it is hard to draw general conclusions about harvester fuel consumption related to the coppice treatments. However, the finding that the harvester used more fuel per PMH_0 when operating in the single stem treatment than in the other two treatments, suggests that the lower sph and larger individual stems in the single stem treatment would be likely to increase the harvester workload. The lower fuel use per m^3 in this treatment is likely to be the result of the increased productivity associated with the larger stems.

5. Conclusion

In the comparison of harvester productivity between single stem, two stem and unthinned treatments, mean stem size was found to be the major driver of harvester productivity, as has been found in many previous trials of planted stands. Significant differences in the mean move/position and felling time elements between the treatments did not affect the mean cycle times for each treatment because processing time accounted for at least 65% of the total cycle time in each of the treatments.

The period of fuel consumption data collection was too short to draw many conclusions. However, the greater harvester fuel use per PMH_0 when operating in the single stem treatment may have been the result of the lower sph and larger trees in this treatment increasing the harvester’s workload, and the lower fuel use per m^3 in this treatment may have reflected the significantly greater harvester productivity in this treatment.

6. Acknowledgements

The authors would like to thank the plantation owners, Australian Bluegum Plantations, WAPRES and the harvesting contractor Wilsons Logging for their assistance in this trial.

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Determining the effects of felling method and season of year on coppice regeneration

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Abstract
There is increasing interest in plantations with the objective of producing biomass for energy and fuel. These types of plantations are called Short Rotation Woody Crops (SRWC). Popular SRWC species are Eucalypt (Eucalyptus spp.), Cottonwood (Populus deltoids) and Black Willow (Salix spp.). These species have in common; strong growth rates, the ability to coppice and rotations of 2-10 years. SRWC have generated interest for many forest products companies and timber producers and although they might help with the supply for the expected growth on the bioenergy and biofuels market, there are still several concerns about the best way to harvest them while maximizing their ability to coppice. SRWC have elevated establishment and maintenance costs if compared to other type of plantations, but due the coppicing ability, the same plantation may be harvested up to 5 times without the need of establishing a new one. Study plots were installed at several locations in Florida, Mississippi and Arkansas, and were cut with a chainsaw and a shear head during summer and winter, to determine the effects of felling method and season on coppice regeneration. Thus, plots were divided in 4 treatments: shear-winter, saw-winter, shear-summer and saw-summer. Harvesting eucalypt and cottonwood trees during winter resulted in better survival rates than harvesting during summer; however, there was no effect of felling method on coppice regeneration. Finally, no statistically significant difference was found on coppice regeneration of black willow when harvesting during winter or summer with a chainsaw or a shear head.

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1. Introduction

The increasing necessity of finding new alternatives to produce fuel and energy has never been so evident in the United States. Issues like the increasing population, dependence on foreign oil, and the declining availability of fossil fuels have made renewable energy sources, such as biomass, become a plausible and promising option to address these issues. Moreover, researchers and politicians have developed some ideas, where a major part of the nation's energy needs will be sourced from renewable fuels (25x'25 Alliance). Several states in the U.S. are joining alliances to replace 25% of their fuel consumption by some type of clean energy. As a result, a great amount of biomass will be required to produce clean energy and accomplish the goals. A considerable amount of that biomass will be allocated to woody biomass from harvest and forest products mill residues, but also from new plantations intended to supply new biofuel and bioenergy mills.

Recently, several companies and institutions have ventured into the short rotation woody crops (SRWC) supply system. According to the U.S. Department of Energy (2011), a SRWC is an intensively-managed plantation of a fast-growing tree species that produces large amount of biomass over a short period of time, usually less than 10 years, that can be shortened to as little as 3 years when coppiced, depending on the species and production method. The characteristics that define the SRWC are the ability to coppice, rotations between 2 and 10 years, and an impressive fast growth. It is also important to highlight that SRWC generally have very high costs. Tuskan (1998) specifies that SRWC involve appropriate site selection, use of improved clonal planting, extensive weed control, fertilization as required, pest control, and efficient harvesting and post-harvest processing. For this reason, to maximize the utilization of the plantation through the coppicing ability is fundamental. The coppicing ability is the ability that a tree has to regenerated new stems from the stump, after the harvest is performed. Popular SRWC species are Cottonwood (Populus deltoids), Black Willow (Salix spp.), and Eucalypt (Eucalyptus spp). The United States Department of Energy (2011) states that poplar, southern pine, willow, and eucalypt, are the most likely woody energy crop species to be developed for bioenergy production today.

Although the establishment of SRWC plantations is becoming popular in the SE region, the biofuel and bioenergy markets are not yet completely developed. In countries and regions where a bioenergy market is already established, the development and use of machinery specialized to harvest SRWC is very common. However, in the U.S. the absence of a solid bioenergy market has discouraged the development of a system specialized in harvesting SRWC plantations, thus making the investment on a foreign machine not feasible. The utilization of smaller equipment, with low capital and maintenance cost, such as a skid steer with a shear head, may be a temporary option, while specialized machinery is being developed. However, this equipment may cause damage to the stump's structure and bark, which could cause possible effects on coppice regeneration.

On the other hand, little is known about the optimal harvest scheduling in SRWC in the Southeast. The effect of the season of the harvest has always been a subject of interest. Theories state that harvesting during summer could damage the stump, preventing coppice, and thus limiting the harvest to the winter season.

It is evident that further research in SRWC harvesting techniques and machinery is needed. This study will compare the effects of harvesting SRWC plantations in the Southeast region with a small shear-head and with a chainsaw (simulating a circular saw-head), and also examine the potential difference in coppice response between harvesting during winter and summer seasons.

2. Material and Methods

Six sites (Table 1) were selected to determine the effect of the felling method and the season of year on coppice regeneration. Three sites located in Florida were planted with Eucalypt (two with clonal E. urograndis and one with E. grandis from seedlings). Two sites, in Arkansas and Mississippi, were planted with clonal Cottonwood (Populus deltoides), and one in Mississippi was planted with clonal Black Willow (Salix spp.).

Two felling methods were compared to determine the different effects they may have on coppice regeneration. They were a small shear-head, attached to a skid steer, and a chainsaw (to simulate the effect of a circular saw-head). The harvests took place at each study site in two different seasons of year: summer and winter. A randomized block design was the experimental design used to install the treatments at each study site, which were composed by a study plot divided into four treatments: summer/saw harvest, summer/shear harvest, winter/saw harvest, and winter/shear harvest. The study plots in all sites were 0,5 hectares in size.

2.1 Harvesting Methodology

The layout or design of the plantations was fundamental to the selection of the harvesting treatment. The ideal methodology was the completely randomized design, randomly cutting each tree, and controlling the effect of extraneous variables. However, due to physical and spatial limitations, and to facilitate the felling operation, it was not possible to implement the random design. As a consequence, alternating the felling equipment between rows, harvesting one row with the chainsaw and the adjacent row with the shear-head was the selected experimental design. At the Evans and Lykes study sites, alternating the felling equipment was not possible due the layout of the plantation; consequently, instead of alternating the equipment every row, it was alternated every 5 rows, thus creating blocks of 5 rows for each equipment.

After completion of the harvest at each site, an evaluation of damage caused to the stump and stump bark was performed. Five bark damage classes were specified, each representing the percentage of the bark of the stump that resulted damaged: 0 (0%), 1 (1-25%), 2 (26-50%), 3 (51-75%), and 4 (>75%). The types of harvest damage observed on stumps were: barber chair, missing chunk(s), fiber pull, split, and shattered stump. Different from the bark damage, the harvest damage was caused to the structural part of the stump, or to the wood, and not to the exterior part. Additionally, the diameter of the stump's cut surface (DGL) was measured for each stump, to account for the effect that diameter may have on the coppice regeneration.

2.2 Coppice Evaluation

The field evaluation of the coppice response occurred 5 months after the winter harvest and 6 months after the summer harvest. For the coppice evaluation, each stump was individually analyzed. If the stump presented regeneration of new sprouts, it was recorded as a live stump. However, if it had no new stems it was recorded as a "dead" stump. The number of new stems regenerated was counted at each stump.

2.3 Data Analysis

The Generalized Linear Mixed Model (GLMM) analysis was used to compare the coppicing response of the stumps and to determine the effects that the independent variables (felling equipment, harvest season, and bark and stump damage) have on the dependent variable (coppice response), which was classified as the coppicing ability (or stump survival) and the number of new stems regenerated per stump. Additionally, stumps' DGL and skidder damage (when existing) were considered, since they could be related to coppicing ability of the cut trees.

Although each stump was individually evaluated, due the experimental design, the harvesting methodology, and the layout of the study plots, a random effect of rows nested into plot was accounted for the Evans and Lykes sites, while a random effect of rows was accounted for all the other sites. As a consequence, plots (for Evans and Lykes) and rows (for the other sites) were considered as the experimental unit, and not the stump. Each study site was individually analyzed, with the utilization of a full model (Table 2).

3. Results and Discussions

After the coppice evaluation, it was decided that, due to technical issues Bates and Lykes study sites would not be included on the analysis. Also, although the effect of season on coppice regeneration was calculated for all study sites, and the results are reported, the experimental design of the plots was not the ideal. Hence, it can be inferred that the results presented for the effects of season on coppice regeneration can be suggested but not considered definitive. The significance of factors were determined at $\alpha = 0.05$. Additionally, an ANOVA was performed for each model to determine their significance, at $\alpha = 0.05$.

3.1 Effects of felling method and season on eucalypt coppice regeneration

At Evans site, a significant season effect was observed (p-value: 0.00398), in which 96% of the trees felled during winter regenerated coppice, while only 79% of the trees

Table 1. Description of the sites harvested during the project.

Site	Location	Species	Age at harvest	DBH (cm)	Plantation spacing (trees/ha)	Trees Felled
Evans	Florida	*E. urograndis*	2	12,2	1.820	828
Bates	Florida	*E. urograndis*	2	11,7	3.205	867
Lykes	Florida	*E. grandis*	8	18,8	Unknown	105
Estes	Arkansas	*P. deltoides*	3	4,3	Unknown	803
Admire – C	Mississippi	*P. deltoides*	5	11,9	4.300	301
Admire – W	Mississippi	*S. nigra*	5	7,6	4.300	583

felled during summer regenerated new sprouts (Figure 1). No significant difference was observed between felling with the shear head or chainsaw.

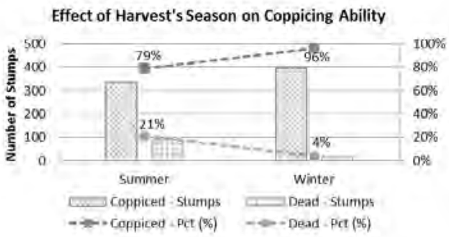

Figure 1. Effect of season on stump survival of eucalypt harvested at Evans.

3.2 Other factors affecting coppice regeneration of eucalypt

Higher damage on the bark of the stump resulted statistically significant (p-value: 0,00419), negatively affecting the ability to coppice of eucalypt at Evans site. In total, 55 trees felled were classified under the bark damage class 0 and 52 (95%) of those trees successfully regenerated coppice; on the other hand, 151 of trees felled were classified under the bark damage class 4 and only 125 (83%) of those trees were successful in regenerating coppice.

The number of sprouts regenerated per stump resulted significantly affected by the DGL at the Evans site (p-value: 7.42-7). Stumps with larger diameters generally regenerated a larger number of sprouts (Figure 2). Smaller stumps, with DGL range between 0 – 5 centimeters, regenerated an average of 3 sprouts per stump, and larger stumps, with DGL on the range between 20 – 25 centimeters, averaged 6.7 sprouts per stump regenerated.

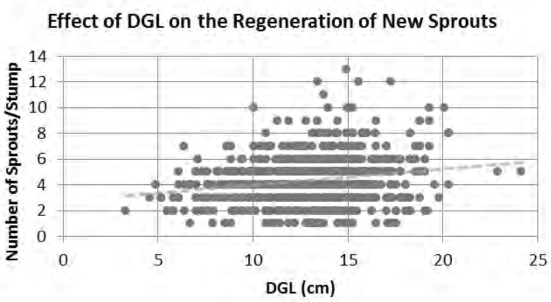

Figure 2. Scatter plot of the effect of DGL on the number of sprouts per stump on Evans.

3.3 Effects of felling method and season on cottonwood coppice regeneration

The season variable was the only significant variable on the stumps' survival at the Estes site (p-value: 0,000372), where 98% of trees harvested during the winter were successful in regenerating coppice, while only 49% of trees harvested during summer regenerated coppice (Figure 3).

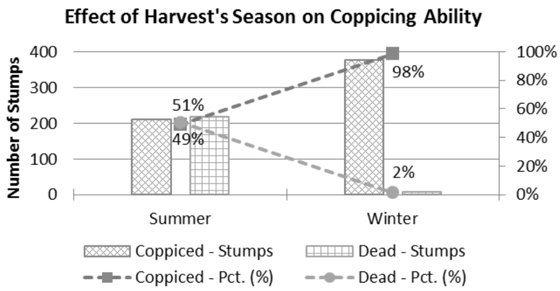

Figure 3. Effect of harvest season on the survival of cottonwood stumps at Estes.

On the other hand, the felling equipment had a significant effect on the number of new sprouts per stump of felled cottonwood at the Admire site (p-value: 0.0350). On average, stumps cut with the shear head regenerated 5,7 sprouts, while stumps cut with the chainsaw regenerated 4,7 sprouts.

3.4 Other factors affecting coppice regeneration of cottonwood

The DGL of the stumps had a significant effect on the stump survival of trees cut at Admire. Stumps with larger DGL showed better survival rates than the stumps with a smaller DGL.

The DGL of the stumps also had a significant effect on the number of new sprouts, both in the Admire (p-value: 0,0001) and Estes (p-value: 0,0001) study sites. At the Admire study site, it was observed that stumps with a larger DGL regenerated more sprouts, when compared to stumps with a smaller DGL (Figure 4). On average, stumps with lower DGL regenerated 2,7 sprouts, while the stumps with larger DGL regenerated an average of 8,5 sprouts. The results were similar at Estes, where stumps with a smaller DGL regenerated less sprouts than stumps with a larger DGL. On average, the stumps with DGL between 0 and 5 centimeters regenerated 1,4 sprouts, while the stumps with larger DGL regenerated up to 12,6 sprouts.

Table 2. Models used to determine the felling techniques on coppice regeneration.

Site	#	Model	
Evans	1	$CR = \frac{FM}{S} + Dam + FM : Dam + DGL + HD + SD + (1\vert\frac{Plot}{Row})$	(1)
Evans	2	$NS = \frac{FM}{S} + Dam + FM : Dam + DGL + HD + SD + (1\vert\frac{Plot}{Row})$	(2)
Lykes	3	$CR = FM + Dam + FM : Dam + DGL + HD + SD + (1\vert\frac{Plot}{Row})$	(3)
Lykes	4	$NS = FM + Dam + FM : Dam + DGL + HD + SD + (1\vert\frac{Plot}{Row})$	(4)
Estes	5	$CR = \frac{FM}{S} + Dam + FM : Dam + DGL + HD + (1\vert\frac{Plot}{Row})$	(5)
Estes	6	$NS = \frac{FM}{S} + Dam + FM : Dam + DGL + HD + (1\vert\frac{Plot}{Row})$	(6)
Admire	7	$CR = FM/S + Dam + FM : Dam + DGL + HD + (1\vert\frac{Plot}{Row})$	(7)
Admire	8	$NS = FM/S + Dam + FM : Dam + DGL + HD + (1\vert\frac{Plot}{Row})$	(8)

CR	*Coppice regeneration*
S	*Season (winter and summer)*
FM	*Felling Method (shear and chainsaw)*
Dam	*Bark Damage Class*
DGL	*Diameter at Ground Level (cm)*
HD	*Harvest Damage Type*
SD	*Skidder Damage*
NS	*Number of New Sprouts*
:	*Interaction between*

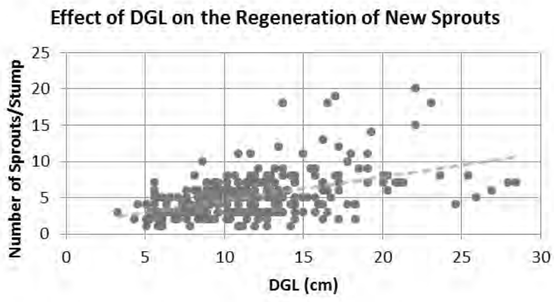

Figure 4. Scatter plot for the effect of the stump DGL on the number of new sprouts per stump at Admire.

3.5 Effect of felling method and harvest season on coppice regeneration of black willow

It was observed that the average number of sprouts regenerated per stump was higher when the harvest was performed during summer than when performed during winter (p-value: 0,0001). Stumps cut during summer averaged 6,2 sprouts per stump while stumps cut during winter average 4,5 sprouts per stump.

3.6 Other factors affecting coppice regeneration of black willow

The DGL was determined to have an effect on the coppice regeneration of black willow, both in the stump survival (p-value: 0,0188) and in the number of sprouts regenerated per stump (p-value: 0,0001). Stumps with the smallest DGL had lower survival rates when compared to stumps with larger DGL. The DGL of the black willow stumps also had a significant effect on the number of new sprouts per stump. A positive linear relation was observed between the DGL and the number of sprouts per stump, where stumps with larger DGL, generally regenerated a larger number of sprouts.

4. Discussion

The key outcome of this study was to determine if the felling equipment and the season of year could have an impact on the coppicing ability of the stumps of eucalypt, cottonwood and black willow; however, additional variables were present at the time of the harvest and could not be left out, broadening the scope of the study. It has been proved with many tree species that factors as species, tree diameter, bark damage, and harvest damage may have impacts on the regeneration of coppice (De Souza et al., 1991; Ducrey and Turrel, 1992; Hytonen, 1994, 1996, 2001; Simões et al., 1972; Strong and Zavitovski, 1983).

4.1 Effect of harvest season on coppice regeneration

Eucalypt and cottonwood trees presented better survival rates when the harvest was performed during winter. This pattern was expected to be observed on cottonwood and black willow trees, which are deciduous genera, however it was not expected on the eucalypt, since it is an evergreen genus without a clear dormancy phase, capable of producing sprouts when felled at any time of the year (Ceulemans et al., 1996). The lower survival rate observed on the cottonwood harvested during summer may be explained with the fact that the carbohydrate reserve on the root system is lower after the onset of shoot growth during the first part of the growing season (Ceulemans et al., 1996; Strong and Zavitovski, 1983). On the other hand, the higher survival rate observed on the eucalypt harvested during winter may be explained with the fact that the period of rain in south Florida occurs during summer, and although eucalypt is an evergreen species, it may store higher levels of carbohydrates during the drought period, maximizing the regeneration of coppice if harvest occurs during winter.

Although harvest season did not affected the survival of black willow stumps, a significant effect was observed on the number of sprouts per stump. Stumps cut during summer season regenerated, on average, more sprouts than stumps cut during winter. This pattern was not expected, however it seems to match the results of other studies (Steinbeck, 1978; Hytönen, 1994). According to Hytönen, 1996, the reasons for differences in coppicing due to timing of the cutting are not fully understood, since the number of sprouts regenerated varies, presenting better results either during summer or winter.

4.2 Effect of the felling method on coppice regeneration

There were no differences observed on stump survival of eucalypt, cottonwood nor black willow when harvesting with a shear head or a chainsaw, which was expected, since previous and similar studies showed similar results (Simões et al. 1972; Hytönen, 1994; Crist et al., 1983). However, the effect observed on the number of sprouts regenerated per stump on the cottonwood site Admire, proved that stumps cut with the shear head regenerated, on average, more sprouts than stumps cut with the chainsaw, which also coincided with Hytönen (1994) results, where leaving a rougher cutting surface resulted in higher number of sprouts regenerated. Nonetheless, in this project, the DGL of sheared stumps resulted slightly larger than the sawed stumps, which can also explain the higher average number of sprouts.

4.3 Other factors affecting coppice regeneration

It was observed that DGL had a positive linear relationship with the average number of sprouts regenerated in all sites. Stumps with larger DGL averaged more sprouts than sprouts with smaller DGL. This result was expected, since the stumps with larger DGL, theoretically, have more buds on their surface, which can develop to form new stems to replace the material removed or damaged during the harvest.

The DGL also showed significance on the survival of black willow and cottonwood stumps at the Admire study site. In this case, stumps with larger DGL presented better survival than the smaller stumps. A result that sounds pertinent, since stumps with larger DGL probably have a larger root system, which can capture higher amount of nutrients and water, suppressing the growth or regeneration of new sprouts by the stumps with smaller DGL.

It was also noted that bark damage caused a significant effect on the survival of eucalypt stumps at Evans site. A negative linear relationship was observed, where the more severe the bark damage to the stump was, the lower the survival rate resulted. This is probably because the axillary buds that regenerate sprouts in eucalypt trees are located under the bark, and damaging the bark may damage or expose those buds, affecting the coppice regeneration (Ceulemans et al. 1996; Opie et al., 1984).

5. Conclusions

Despite analyzing the effects of season on coppice, operational harvesting restrictions affected the experimental design. For this reason, the results presented should not be considered as definitive, and further research is recommended to determine the effect of season on coppice regeneration.

5.1 Stump Survival

The results showed a season effect on the eucalypt and cottonwood trees, restricting the harvest of these species to the winter season. Nonetheless, it was not fully understood why the seasonality was observed on the eucalypt. Perhaps the precipitation may be the answer, but further research and study is recommended to determine the best harvesting schedule of eucalypt in South Florida. Additionally, the coppice regeneration of eucalypt in a different region of the United States, with a precipitation regime evenly distributed through the year, may not result affected during any season, since, as already mentioned, it is an evergreen specie and could regenerate coppice regardless of the season.

The utilization of the shear head attached to a skid steer proved to be a good option while waiting for the development of machinery specialized on harvesting SRWC. Since no difference was found on coppice regeneration between harvesting with a chainsaw and a shear head, the use a shear head (which results in lower capital and maintenance costs) instead of a circular saw feller-buncher or a chainsaw (which imply higher danger and lower productivity) is highly recommended.

5.2 Number of sprouts per stump

Although the number of sprouts regenerated per stump was studied, it is very important to deepen the study on the importance of this factor. It was found that depending on the species, the number of sprouts per stump was affected by DGL, felling method, and harvest season. However, the DGL of the stump was consistent in showing statistically significant effect on the number of sprouts for all the species. In all cases, stumps with larger DGL regenerated more sprouts per stump, which is pertinent due the higher number of shoot buds present on larger stumps.

Nonetheless, the importance of the number of sprouts regenerated per stump is not yet clear. There is no certainty about the benefits of having several sprouts per stump, instead of having a unique sprout. Perhaps having a single sprout regenerated per stump may be more desirable, depending on the goal of implementing a coppice plantation. In addition, there is knowledge of occurrence of self-pruning after a determined time after the harvest, in which the coppiced stumps will automatically eliminate the smaller stems, maintaining only the dominants or one single main stem.

In conclusion, the season effect observed on the stump survival of eucalypt and cottonwood may imply an economic impact on the SRWC supply, restricting the harvest to the winter harvest. However, the utilization of the shear head can be recommended as a possible felling method to harvest SRWC, since it does not have an effect on the survival of the stumps; which could reduce the costs of actual harvests operations used at SRWC plantations.

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Wood harvesting and processing of non-standard wood to chips for bioenergy

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Abstract

The objective of this paper is to study the effect of using chips from non-standard wood for energy purposes in Bulgaria. There are good market conditions for wood chip: both for the use in the country and for export. In this examined.

Technologies for the utilization of non-standard wood (residues from logging included), were investigated by using a mobile chipper for wood chipping at the cutting areas. For this purpose, the following chippers were used; “Vermeer BC 1500”, “Schliesing 220 MX”, “Caravaggi”, “Droeppelmann”, “Vandaele-TV250”, “Skorpion 500 RB”, “Pezzolato PTH 480/660” etc, with a productivity from 10 to 18 solid m³/day. The chopping of entire stems of poplar and black locust plantations with big machines at station conditions was more easily performed.

Usually, before chipping, big lots of woody biomass of volumes up to 150 tons were prepared. “JENZ HEM 581”, “Doppstadt DH 608” or “Eschlbock biber 80” chippers were used and the productivity achieved by them reached 70 tons/day, not covering their full working capacity. Over the last years, the production of chips in Bulgaria varied from 4,000 to 10,000 tons per year, with a tendency to increase.

Taking into account the prices of the supply ex-customer, and the quality of the chips produced from wood for boards in factories and the chips produced in forest, the differences were established between the former and the latter ones. The prices were 50-60 €/t for chips produced in factory conditions and 30-40 €/t for chips produced in forests from residues after cuttings.

The consumable and the technical characteristics of the wood chips produced from non-standard timber are given. The measurements and the calculations were made in accordance with the approved standards for solid biofuels. The results showed the significant energy potential of the wood chips produced from waste wood biomass. Comparing the wood chips produced in factory conditions to the other ones produced in forest, it became evident that the former ones covered the requirements, while the latter ones showed evidence of higher deviations from the standard and had a higher moisture and ash content at burning; for that reason, in some cases the wood chips produced in forest need additional chipping and drying at stations.

In relation to this investigation, an assessment was made on the possibility for the increase of non-standard wood harvesting and its use for energy purposes and utilization for chips production.

Keywords

woody biomass, forest residues, wood chips, chips supply, production cost

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1. Introduction

In the recent years, with the exception of the severe crisis in 2009, the analysis of the wood market has shown a relatively steady balance among the consumers of wood designated to be processed into secondary products, the local population which uses the above said raw material for heating, and the export. The unrealized quantities of the stored harvested wood, reported in the last years, have resulted disparagingly low; and, moreover, a lack of a well-developed energetic segment of woody biomass has been found out.

The energetic chips are most often sold by the ton and their caloricity depends to the greatest extent on their moisture. Though, when they are supplied, as it is used to do in firewood supply, it is much easier to control their volume. The tree species and the fraction size are also very important for chips. The firms dealing with chips production in our country consider that the most serious problem therein is the transportation cost. The chips are too voluminous, of a low specific weight (density). That is unprofitable in transportation via terra, at a distance of more than 100-150 km. For the above said reason, the use of the chips for burning is suitable for a local use: i.e., at short distances. The wood chips are the fuel of the future. In our country, compared to the other ones, that market is still undeveloped; though, some good practices have been promoted there, in the recent years. Wood chip heating is predominantly applicable in houses where people are still used to burn wood for heating. Down to the present day, the population of Bulgaria uses mainly wood for heating. It is a pity, indeed, that wood chips are burnt in low energy-efficient facilities (which efficiency factor is no more than 50-60%). If such low energy-efficient facilities are replaced by high energy-efficient ones, the quantity of the used fuel, i.e., wood, could be reduced twice or so. The greatest potential has been found out in the public sector: schools, hospitals, kindergartens.

According to Kanzian et al. (2009), the use of the harvesting residues can only be recommended for large plants because of the poor fuel quality. In that case, residues would be chipped at or near the landing, piled and transported by self-loading trucks, at a price between 8.4 and 9.1 EUR/m³, in the bulk state. In order to meet the increasing demand and to ensure a continuous supply, especially during the winter and spring seasons, it is necessary to optimize the supply chain by including storage terminals. However, both the use of the terminals and the increased demand lead to higher logistical costs. For example, if the total volume is handled via terminals, the average supply costs, storage included, will increase by 26%. Such a higher demand increases the costs by 24%.

Roadside chipping has become increasingly popular also in Europe, including the Nordic Countries (Stampfer and Kanzian, 2006, Tahvanainen and Anttila, 2011). There are also Marchi et al. (2011) who express the same opinion: according to them, the roadside chipping was over four times more productive than the terrain chipping, and it allowed reducing harvesting cost by one third. The transport of chips directly from the roadside landing to the final conversion plant is a cost effective alternative, especially with larger object volumes and longer distances (Belbo and Talbot, 2014). The point of comminution largely determines the efficacy of supply systems (Björheden, 2008).

According to Moskalik and Ostolska (2011), the decisive factors for determining the changes in productivity, are tree-stand conditions and concentration and the manner of raw material placement. Other important factors which can also influence the productivity and the environmental balance of chipping are the knives conditions and the raw material (Natia et al., 2011).

There is also the distance of the chips transportation to the consumers, which plays an important part to a great extent. According to Ghaffariyan et al. (2014), longer transport distances and lower truck payloads resulted in a higher transport cost per unit of delivered chips. In addition, the highest supply chain costs occur when moisture content range between 20% and 30%. The transport of chips directly from roadside landing to the final conversion plant is a cost effective alternative, especially with larger object volumes and longer distances (Belbo and Talbot, 2014). When it is necessary to make a decision on transport vehicles type and number, the site conditions in forest should be taken into account, and, particularly, the road width and the curve ratings (Schulmeyer and Hüttl, 2014), considering the fact that if the haulage distance is of 145 km, the fuel consumption will increase by 86% (eighty six percentages) above that value which is reported in recovery directly from the landing (Johnson et al., 2012).

In fact, storing is necessary because of the fact that the annual cycle of demand and supply do not follow each other. Simultaneously, the storing affects the quality of the forest biomass designated for forest wood chips production. In fact, the energy content depends on the material moisture content and on the type and the form of the forest biomass (Cavalli and Grigolato, 2008). A very important moment of chips storage is their drying. The artificial drying of wood chips by using a surplus heat is an alternative when there is a demand for supply of chips with low moisture when more heat is released during the combustion, lower emissions are produced and a better efficiency of the fuel boiler is achieved (Nordhagen, 2010).

2. Material and Methods

10 samples of wood chips from all over the country were analyzed in this study. Each one was taken when different technologies were implemented for the purpose, different tree species (designated for wood) and chippers were used in different forest exploitation conditions.

Prominence was given to the combustion properties and the technical characteristics of the wood chips from non-standard wood. The wood chips size, the total moisture and ash content, the heat of burning, the volume density, the bark content were determined, as well as the content of the chemical elements as following: nitrogen, phosphorus, calcium and magnesium.

Non-standard wood in logging comprises forest residues after conducting sanitary cuttings, renewable ones, thinning and others. Non-standard wood after wood working includes wood slabs, off-cuts, slices and others.

Forest residues are such parts of tree, which ones are considered residues left after logging: branches, leaves (needles), non-standard wood and wood brush. The greatest part of them remains underutilized, due to their specificity.

The residues are raw materials characterized by a high content of moisture, comparatively high ash content and a very low density. According to some data excerpted from literature sources, the moisture content of the energetic chips from fresh wood could reach 40-50 %, depending on the season, the habitat, the tree species etc. Besides, the bulk density of such chips varies from 80 to 400 kg/m³, depending on the species of the tree, moisture and that part of the tree, which is utilized for chips production. For that reason, such chips are un-remunerative for transportation in a raw state.

By using appropriate technologies for collecting, cutting, chipping, transporting and storing, these residues can be utilized as a remunerative energetic raw material. The control of the combustion process depends mainly on the chips moisture level.

The measurements and the calculations have been made in conformity with the standards in force for solid biofuels.

Moisture content, volume density, ash content, caloric value, energetic density are important factors which should be taken into consideration in combustion plants, transportation, determination of combustion resources size, as well as in biofuels purchase and sale.

In regard to fluctuations in chips quality, such fluctuations could be considered a challenge for the combustion plants, as they reflect on the boiler efficiency. Boilers can be better used if wood quality is previously known and specified. And it is quite possible to be achieved by analyzing and controlling the parameters.

The average size of each one of the analyzed samples from residues is of a length from 1,7 to 4,6 cm; the length depends on the kind of the machines, the used raw material and the setting of the knives. Knives number and sharpness are also important factors reflecting on the chips size.

The heat of combustion, measured by MJ/kg, when absolutely dry materials are burnt, has been determined according to J.19P STANDARD, by an adiabatic calorimeter of electrical ignition, KL-3 type, and a standard bomb calorimeter. Each sample of biomass has been previously disintegrated by a laboratory disintegrator to chips. The sieved 0.35 mm fraction is used for the determination of the heat of combustion and there is also the moisture content in chips, which has to be reported in the final calculation.

The volume density of the samples has been determined in weight where 1 dm³ of biomass is weighed and the reported value is recalculated depending on the analyzed moisture.

Ash and moisture contents are detected by using the standard methods while chemical elements are detected by applying the spectrocalorimetric, flame-photometric and other methods. As regard to the ash content, it has been detected by using a muffle furnace, at a temperature up to 550°C.

3. Results and discussion

In the European Union, the increase in logging will have been expected to reach more than 20%, residues included, by 2020, mainly depending on the economic growth and the political decisions. The greatest changes are expected to occur in the Baltic States and the Countries of the Southeastern Europe (Asikainen et al., 2008).

In Bulgaria, the energetic chips from non-standard wood are the most suitable type of additional fuel for a centralized heat supply, cogeneration and local heating systems. In the recent years, the energetic chips have been used in the UE States, too: in heating systems for domestic purposes, with the power of 20 - 100 kW. Similar systems for heating of residential buildings have also been developed and produced in our country.

The energetic chips are most often sold by the ton and their caloricity depends to the greatest extent on their moisture. Though, when they are supplied, as it is used to do in fire wood supply, it is much easier to control their volume. The tree species and the fraction size become as important for chips, as they are for wood. In principle, the energetic chips produced in our country are specified in Bulgarian State Standard EN 14961-4:2011: Solid biofuels. Specification and types of fuel. Part 4., where general requirements are given for wood chips designated for non- industrial needs. The method for qualifying, which is applied to the energetic wood chips, is based on the Austrian Standard ÖNORM M 7 133 and German Standard DIN 66 165.

In regard to the energetic purposes and in a more concrete case of the woody biomass utilization, it can be confirmed that future includes the wood chips use and the burning: the wood chips are the fuel of the future. It is a fact that sufficient quantities of woody biomass suitable for chips production are available in Bulgaria (s. Table 1). That market has been still undeveloped in our country, in comparison with other ones, regardless of good practices which have been carried out in the recent years. That type of heating is mostly applicable in houses where people still use to store firewood.

In principle, taking into consideration the fact that the average age of the forests in our country is 53 years and, in a year, there are averagely about 55-65% of the assortment structure of the wood (obtained from the tree species), fit to be used for energetic purposes, in the last 3 years, the average percentage of the obtained wood, 63% approximately, has been considered fit for energetic purposes, as it is evident in Table 1, following below.

Table 1. Distribution of the harvested wood in Bulgaria: its total quantity and the quantities considered fit for energetic purposes, during the period 2012-2014 (m³).

Year	Small size wood, firewood and brush wood	Total quantity of harvested wood
2012	4,344,617	6,840,753
2013	4,265,272	6,795,534
2014	3,910,382	6,190,957

In the last several years, the forest residues size has been maintained relatively constant: 18-20% of the standing wood. At the moment, stumps, bark and some of the other residues left after cutting are neither being collected nor used as energetic sources (in most of the cases, stumps remain unused inside the cutting areas, for economic and ecologic reasons). The average annual volume of the branches and brush wood, collected and utilized in the last 10 years, is 50 thousand cubic meters, varying from 30 to 80 thousand cubic meters; in wood from deciduous trees, brush wood dominates. It is obvious that few quantities only of forest residues are being used now, due to the fact that collecting such small-size wood is not economically efficient. In the terrain infrastructural and other conditions existing in Bulgaria, the technology for the harvesting and utilization of such kind of wood would include chopping of branches and brush wood into chips in forest itself, at a point as closer as possible to the cutting area, where a forest road access is available.

The size of the forest logging residues after different kinds of cuttings, of the waste after woodworking and the energetic equivalent of the above said residues and waste are indicated in Table 2.

Note: There are some 10-15% of the indicated wood quantities after wood harvesting, which could be assimilated by using the existing technologies; t.o.e./p.y. – tons of oil equivalent per year.

In regard to non-standard wood as logging waste, in Bulgaria, the production of chips from the above mentioned residues includes manual labor and low-productive

Table 2. Quantities of woody biomass from non-standard wood fit for processing into chips for bioenergy in Bulgaria.

Year	forest logging residues, sanitary cuttings, a part of thinnings etc.		slabs, off-cuts, slices and others	
	solid m³	**t.o.e./p.y.**	**solid m³**	**t.o.e./p.y.**
2015	1,400,000	289,000	80,000	36,870
2020	1,530,000	330,600	95,000	43,780

machines for residues collection and haulage. There are contemporaneous technologies (still, not fully used in our country) for utilization and processing of logging residues into chips, as following: 1) forest residues packages supplied ex consumer; 2) chips production in forest. The former technology requires the use of a specialized machine for wood residues (branches and tops) packaging. Such a machine is equipped with a manipulator and a specific packing device. The most serious disadvantage of such machines is their high price. There is also a positive aspect which should be recognized of that technology: that there is no need of using other specialized machines, as the packages of residues can be transported by using more simplified haulage means. The latter technology requires residues collection after cutting and their transportation to the chippers.

Chips harvesting in forest consists of residues collection in the cutting area, transportation to a storage site or to a upper landing in forest and chipping by a chipper. It is obvious that in limbing and bucking of the trees in proximity to a haulage road or a upper landing, a higher effect will be obtained. The produced chips are transported by trailers or specialized trucks. The chips production in the cutting area has a low productivity, due to the fact that few quantities only of logging residues are spread throughout the territory of the cutting area and the chipper needs much time to move forward. Technologies for assimilation of the branches after logging by chipping them in the cutting area with mobile chippers have been put into operation in Bulgaria (Fig. 1a).

“Vermeer BC 1500”, „Schliesing 220 MX”, „Caravaggi”, „Droeppelmann”, Vandaele-TV250”, „Skorpion 500 RB”, „Pezzolato PTH 480/660” and other chippers have been used for that purpose. On even and slightly hilly terrains, the logging residues (from which the previously mentioned samples have been taken and analyzed) have been obtained most often after logging in forest and limbing of branches by chain saws in the cutting areas. The mobile chippers are moved through the cutting area with the trailers attached to a tractor or trucks adapted for chips transportation. Assortments have been obtained earlier, and their setting in order among the cultures depends on the roads disposition. There is another way to collect and chip residues when they are obtained in the mountain areas, instead. Such residues are piled there, in proximity to roads, to be subsequently chipped by a chipper.

It is easier to collect poplar sprouts and black locusta ones when half-stems or non-standard sections and branches are harvested and transported (s. Fig. 1b). Usually, big plies are prepared which volume is of 150 - 200 t before chipping. „JENZ HEM 581”, “Doppstadt DH 608” and „Eschlbock biber 80” chippers are used for that purpose, which productivity is of 70 - 180 tons daily. The problem is that in such cases their working capacity cannot be covered to a sufficient extent.

The waste mass remaining after woodworking is also a significant source of a raw material for energetic chips production (s. Fig. 1c). In the process of timber working in the woodworking and upholstery plants, there are different kinds of waste and in many cases such waste products can be used for energetic purposes. In squared timber production, the quantity of waste is of 28-46%. There is a comparatively low output in veneer production: 38-48%, which depends on the raw material harvesting. In all the rest woodworking processes the quantity of waste is from 7% to 23%. It is important to optimize the chain from the source to the final consumer in order to keep on the woody biomass as a competitive and profitable source of energy.

Complete studies have been conducted for the determination of the combustion properties of the above mentioned technologies applicable to chips production in the course of our experiments (s. Table 3). The results have shown that the wood chips from residual woody biomass have a sufficient energetic potential. By increasing bark and leaves mixes the heat of burning decreases while the ash content rises up to exceed the standard from 2,5 to 3,5 times, and the energetic chips are placed into A2 Class reaching the ash content of more than 1% of the fuel weight. The heat of burning of wood chips from logging residues is lower than that one of the waste after woodworking. In fact, the energetic content depends on the moisture of the material and the type and form of the raw material obtained from the forests.

When a comparison is made between the wood chips produced in factory conditions and those ones produced in forests, it becomes evident that the former chips cover the requirements while the latter ones show a larger deviation from the standard, having a higher moisture and ash content in burning. For that reason, additional chipping and drying of the raw material should be performed in stationary conditions.

In conformity with this study, an evaluation was made on the possibility for the increase and utilization of the non-standard wood in form of chips, suitable for energetic purposes.

In the course of the examination conducted on the combustion properties of the chips produced by us, in different combustion plants, it has been established that the advantages of the chips obtained from branches, as solid fuel, are: the low energetic density of 0.5 MWh/m³ the low price. The control of the burning process depends mainly on the density level. Chips of low moisture (up to 30% WB) require an average control level of the burning process and a boiler for moderately wet fuels. Chips of high moisture (over 35%

Table 3. Qualitative characteristics of wood chips produced in forest, designated for bio-energy from non standard wood.

Indices	Unit	ÖNORM M7133, DIN 66 165 and BDS EN 14 961-4:2011 Standards	Brushwood from solid wood from deciduous species	Logging residues in oak stands and cut undergrowth	Firewood from non-standard wood in oak stands	Logging residues in locust culture	Logging residues in Quercus cerris coppice stands	Residues after wood-working of coniferous wood	Parts of stems, trees, branches, technological wood	Wood designated for technological conversion (processing) (unfit)	Firewood from non-standard wood and stem part	Parts of stems, trees, branches and other residues
1. Total moisture (at the moment of studying)	%	<30	19	29	24	21	20	24	13	12	14	26
2. Ash	%	0.5-3	5.2	3.6	3.1	4.9	4.2	4.7	1.1	0.9	3	3
3. Heat from burning (of absolutely dry material)	MJ/kg	6-20	12.6	14.3	16.7	14.8	15.5	17.9	19.9	21.2	20.1	19.9
4. Bulk density	kg/m³	150-400	150	225	243	198	199	269	225	210	261	135
5. Wood	%		73.3	77.1	92.04	76.77	80.8	69.03	99.31	93.53	90.28	86.2
6. Bark	%		26.7	22.9	7.96	23.23	19.2	30.97	0.69	6.47	9.72	13.8
7. Nitrogen	%		0.45	0.55	0.45	0.7	0.5	0.34	0.14	0.2	0.31	0.14
8. Phosphorus	%		0.06	0.07	0.06	0.09	0.06	0.04	0.06	0.05	0.27	0.21
9. Potassium	%		0.13	0.13	0.12	0.06	0.14	0.11	0.04	0.05	0.25	0.5
10. Calcium	%		0.72	0.64	1.41	2.02	0.59	0.17	0.22	0.27	0.78	0.64
11. Magnesium	%		0.1	0.13	0.15	0.11	0.1	0.07	0.06	0.07	0.15	0.09
12. Type of the chipper			„Schliesing 220 MX”	„Schliesing 220 MX”	Pezzolato PTH 1000/1000	“Vandaele-TV 250” „Skorpion 500 RB”	„Skorpion 500 RB” “Vandaele-TV 250”	“Lindana TP660 PHM”	„Eschlbock biber 80”	„Pezzolato PTH 480/660”	“Heizohack-HM6-300VM”	„JENZ HEM 581”
13. Tree species			oak. beech. cerris and others	oak. cerris	oak(80%) and cerris(20%)	acacia	cerris(80%). hawthorn and hornbeam(20%)	black and white pine	spruce	white and black pine	beech	poplar

Note: The studied samples have been got from different firms producing chips from non-standard forest wood in Bulgaria. BDS EN 14 961-4:2011 - The Bulgarian Institute for Standardization is the national executive body for standardization in the Republic of Bulgaria

Figure 1. Chips harvesting for bio-energy from non-standard wood: a) forest logging residues; b) parts of stems, trees, branches and others, and c) waste wood after woodworking.

WB) require a high control level of the burning process and a boiler for wet fuels. The economically motivated use of such chips is for average-size and large-size heating, steam and cogeneration plants (from 1 MW to 50 MW).

Besides, the inverse proportion between the energetic value and the water content should also be taken into account. The difference between the chips obtained from different kinds of wood (soft and hard) is mainly in their density and their energetic value, respectively. Regardless of the various types of the existing forests where various forestry systems could be used, the bare cuttings on comparatively small areas are considered the most appropriate for a complex wood utilization. Such kinds of cuttings can be applied to intensive poplar cultures and to locust and lime tree ones, to a certain extent. As a result of such cuttings, coppice plantations are obtained, of an increased number of rotations.

As for Bulgaria, the most prospective technologies for processing of residues and converting them into chips, - which some countries have been already applying, - are the following ones: a) chips production from wood residues by using mobile chippers and chips supply by specialized trailers and trucks to customers; and b) supply of packaged logging residues in packs (bales) from forest to customers and a subsequent production of chips. Another problem is when some of the above indicated technologies require additional operations as bolts of materials and others, in such cases, it will be necessary to use other machines, too. So, it should also be taken into consideration a possibility for chips production from residues, by bolts of coarser parts of the trees. But the transportation machine shall not depend on such additional operations. That is why the operations of cutting and collecting of the residues shall be performed separately, with a difference in time.

It leaves still a lot to be desired regard to chips production and supply in our country. The main problems are: 1) about where and when wood could be chopped, where and how it should be stored and hot it could be offered and supplied, as well as 2) about the introduction of such machinery which would be fit for use in our conditions. Terrain chipping of wood in the cutting areas or its roadside chipping would be the best solutions. As for machinery for chipping, there are a great variety of tractor driven chippers which, more seldom, are equipped with an autonomous motor installed on trailer or truck, being usually equipped with a crane for delivering of materials. The low intensity of cuttings in our country and the small-size assortments obtained from them require the use of such chippers which driving power is up to 50-60 kW. There are also electrically driven drum chippers for chipping of waste materials (residues) from the sawmill production.

As a result of the different technologies used for the production of the examined chips, a necessity of optimization was established, which consisted of a preliminary preparation by piling the residues, converting them into chips by chipping and transporting the chips to the final consumer. Any nonobservance of the logging technology reflects on the chain for the biomass utilization; the production of such wood residues which are to be processed in piles, drops on; and, for that reason, the chipper performing the operations shall be moved all the time, but it will lead to a significant rise of the operating costs.

According to the firms which have been dealing with chips obtaining in our country, a serious problem in chips production is the transportation cost when unsuitable means of transport are used. Taking into account the prices of supply ex customer and the quality of the chips produced from wood, for boards, in factory, and the chips produced in forest, the differences were established between the former and the latter ones. The prices were 50-60 €/t for chips produced in factory conditions and 30-40 €/t for chips produced in forests from residues after cuttings.

Two types of energy production from biomass shall be distinguished: for the utilization of the residual biomass in industry and for the electric and thermal energy supply to the population. In regard to the former type of energy, there is experience accumulated in Bulgaria in using and exploiting such kinds of plants in enterprises working with large quantities of residual biomass which, if is not utilized, shall be disposed in specific conditions, because of its easy inflammability. Such types of plants are the boilers for thermal energy production from biomass in the large-scale producers of cellulose and paper as Sviloza in the town of Svishtov (88 MWth) and Mondi in the town of Stamboliyski (35 MWth), along with the installed two turbo generators of 6 MWe and 4 MWe, or totally 10 MWe.

In Bulgaria, the sector of the electric and thermal energy from forest wood biomass for final consumption by the population has been still making its first steps. According to the data reported by ESO, i.e. Bulgaria‘ s Electricity System

Operator, there are 1,571 MWh electric energy produced from biomass (0.003% of the total produced electric energy). Thus, in practice, the electric energy production from biomass hardly participate in the energetic mix. Up to now, 5 plants only for electric energy production from biomass have been put into operation: 10 MWe in Mondi Factory in the town of Stamboiyski, 5 MWe – a plant located in the town of Etropole, which is not working now, 1.5 MWe – in the town of Dospat, 1 MWe – in the town of Montana and 0.5 MWe in the town of Blagoevgrad; but some of the above indicated plants do not work permanently. There are also three stations for thermal energy production from biomass, for the needs of the local population only: in the town of Bansko – 10 MWth, in the town of Ihtiman – 3 MWth, and in the town of Haskovo – 2 MWth. The main generating facility in the heating plant for all the three stations is one bolier only for pyrolysis burning of wood chips.

A simplified analysis of the conditions in Bulgaria has shown that a newly installed power for electric energy production of 5 MW needs of about 80-100 thousand cubic meters of wood in a year. In order to provide a profitable production, the above said quantities of wood should be obtained, in practice, within a range of 50 km approximately, 100 km at the maximum, because of the high value of the transportation costs. In that regard, the construction of large-scale plants for electric energy production is accompanied by two main risks, and, precisely: work with a higher value raw material, as in such cases it is necessary to use woody biomass transported even from farther areas, and a doubt if it could be possible to utilize, to a full extent, the thermal energy from the cogeneration. It would be better if the power stations using woody biomass produced simultaneously both thermal and electric energy (it is the so called high efficient cogeneration production). The total efficiency (thermal and electric) can reach 70%. The general inference is that the wood chips from non-standard wood produced in Bulgaria have the advantages as following: such wood chips are produced from a cheap and predominantly residual woody biomass; they do not require high production costs; their caloricity is good, analogical to that one of the low quality wood pellets; they could be utilized in high efficient facilities for warm water production for heating thus giving a possibility for cutting down the costs for heating; they are considered an ecological fuel releasing low emissions of greenhouse gases in burning, hence, reducing of the environmental pollution; they are a cheap type of fuel as their specific price is lower than that one of the conventional types of fuels; a type of fuel which has very good possibilities for storage, conservation, transportation and regulation of the combustion process.

4. Conclusion

1. In regard to wood chips quality: it is their purity which is considered determining for the non-standard wood chips quality, the reduced bark content included; that can be achieved by sieving the chopped biomass. Another important feature is their moisture. The low moisture content below 15% means that the combustion characteristics of the chips are comparable to the pellets and eco-briquettes ones (i.e. no less than 16,5 MJ/kg), at a significantly lower price of the energetic chips. Sieved chips of moisture between 20-30% (13,3 MJ/kg) are the most often used for a combustion process of a good quality and lead to a regular burning in the boilers for biomass. Yet, chips are wood residues.

2. In regard to raw material quantity: a lower chips production for energetic purposes is mainly due to the great number of small-scale firms dealing with wood harvesting, the low degree of mechanization and workers‘ qualification, the scarcely developed road network on the forest territories and the low percentage of the forests use and the reduced implementation of the forestry plans.

3. In regard to woody biomass plants construction: the problem of the supplies reliability and the raw material logistics is of a particular importance and can be considered a real challenge, due to the reasons as following below:

   - There are only few large-scale wood processing enterprises which are able to supply a sufficiently large quantity of wood residues; moreover, in some cases, if such enterprises produce wood boards, for example, they play the part of competitors using and buying residuals left after wood processing.
   - Regardless of the fact that by adopting the Law on Forests, an opportunity has been given for a conclusion of long-term contracts for wood supply with the State and the Municipal Forest Enterprises, that same opportunity has not been well developed, yet.
   - Using residual wood only, mainly consisting of branches and wood brush, and not firewood, such kinds of raw materials are too largely spread: in small surface cutting areas characterized by a low quantitative concentration of row material and a difficult access to them, due to missing roads and other reasons.
   - It is necessary to set up regional networks of logistics centers in the country, in order to provide for a reliable and steady process. The principal activity of such a center is to guarantee a relationship between the sellers of round wood and the consumers of wood processed (converted) into the form of wood chips for energy production. The availability of such logistics centers will be of a very significant importance for the small-scale power stations.

By the moment, there are the available several thermoelectric power stations which cover to a significant extent the conditions for the thermal energy remunerability and utilization, and if some reconstructions are made in the technology of non-standard wood chips burning, the existing thermoelectric power stations would be able to ensure a sustainable utilization of the chips for cogeneration of energy.

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Developing biomass supply systems for forested marginal land in Sweden

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Abstract
The demand for small-diameter trees is expected to increase with the development of a bio-based society. Forested marginal land can provide significant amounts of small-diameter trees, estimated to be 5-10 TWh/year in Sweden. Typical marginal land in northern Sweden was inventoried, the productivity of the forestry machinery used on the land measured, and the cost of wood fuel delivery using different supply systems calculated. Of the systems studied, the most cost-effective used a bundler-harvester in combination with a conventional forwarder (or alternatively a farm tractor), a timber truck for transportation of bundles, and comminution at the factory. However, the size and condition of marginal sites can differ widely, so flexible systems are required to maintain high levels of efficiency. Further development and integration of harvesting marginal land with conventional forest land could decrease the delivery costs of small-diameter trees.

Keywords
wood fuel, overgrown farmland, small-diameter tree, early thinning, bundler-harvester

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1. Introduction

Logging residues (tops and branches) represent the main raw material (53%) for the production of wood chips from primary forest biomass in Sweden (ca. 20 TWh), followed by roundwood (34%), small-diameter (undelimbed) trees (12%) and stumps (1%) (Statistics Sweden, 2014). The demand for small-diameter trees is expected to increase with the development of a bio-based society, as the use of by-products from traditional forest industries and logging residues is close to the maximum in relation to their availability. Small-diameter trees provide higher quality wood chips than logging residues (with lower ash contents because of their higher stemwood contents).

Biomass-dense thinning forests (non-commercially thinned stands) are considered to be the main source of small-diameter trees in Sweden, with estimated harvest potentials of at least 2.7-4.3 M oven-dry (OD) tonnes (t) per year according to Routa et al. (2013) and Fernandez-Lacruz et al. (2015). The two main industries that acquire small-diameter trees from thinnings are pulp mills and energy plants, the former using delimbed stemwood for pulp production and the latter using undelimbed whole trees (and roundwood that does not meet the forest industry's quality requirements) for generating heat and/or electricity. Forested marginal land, including overgrown farmland (e.g. arable land and pasture), edges of fields, roadsides (Iwarsson-Wide et al., 2013), railways and power line corridors, can provide significant amounts of small-diameter trees, estimated to be 5-10 TWh/year in Sweden (Emanuelsson et al., 2014). These stands are often similar to biomass-dense thinning forests (heterogeneous and small tree sizes, high stock densities, etc.) and could therefore be harvested using similar techniques, for example harvesters with accumulating felling/harvester heads. However, in contrast to energy thinnings on conventional forest land, where the aim is to optimize the future production of high-value roundwood, the biomass on marginal land can be clear-cut (in some cases regularly, e.g. every 10-20 years) or thinned very intensely, which can result in larger volumes and higher productivity. The land may need to be cleared for safety reasons, for example along power line corridors, or with the intention of planting a more productive forest on overgrown farmland, or thinned strongly, for example for sheep farming or other agricultural uses. These stands are often easily accessible from existing road networks, but they can be scattered in the landscape and their size may be too small to be economically viable. However, if the land does need to be cleared, biomass extraction can provide the opportunity to at least reduce maintenance costs. As shown by Iwarsson-Wide (2009), Fernandez-Lacruz et al. (2013), Bergström et al. (2015) and Jylhä et al. (2015), the most appropriate technology and working methods need to be identified for each situation.

High harvesting costs and long transportation distances to the end users (e.g. energy plants, pulp mills or future bio-refineries) represent the major barriers to achieving high levels of cost efficiency when extracting biomass from marginal land, as for many biomass-dense, non-commercially-thinned forests in Sweden. Nevertheless, there is potential for cost reduction by integrating the harvesting of marginal land with conventional forestry and by using innovative harvesting technologies and alternative systems to extract the biomass. The aim of this study was therefore to 1) characterize typical marginal land in northern Sweden, 2) study the productivity of the conventional and innovative machine systems being used on this land and 3) compare the cost of wood fuel delivery using different supply systems.

2. Material and Methods

2.1 Inventory

The inventory was performed between October 2013 and August 2014 in nine different study areas within a range of 50 km around Umeå (northern Sweden). Four types of predominantly marginal land were found (Table 1): overgrown farmland (arable land and pasture, 38.2 ha in total), edges of arable land (3.4 ha in total, sometimes in the form of drainage ditches), industrial sites (peri-urban areas, about 1.5 ha) and forested roadsides (1.5 ha).

The stands were systematically inventoried, laying down circular plots (stand A, radius= 3 m) or transects of variable width and length (stands B, C and D, width=2, 3 and 4 m, respectively). In each plot/transect, diameter at breast height (DBH) and the species of all trees with DBH $\geq$ 1 cm were recorded. Trees with DBH <1 cm were just counted. Tree height (and DBH) of each tree species was measured from a sample of at least 20 trees in each stand. Terrain conditions were assessed using the method described by Berg (1992), including bearing capacity (G), roughness (Y) and slope (L). For calculating the standing volume (m^3/ha) and biomass density (OD t/ha), volume and biomass functions from the Swedish literature were used. In stands A, B and C, the biomass was actually harvested and scaled (in the field with an axle load scale system and a scale in the forwarder's crane, and at the power plant), so the harvested area was measured with a global positioning system (GPS) to calculate biomass density (OD t/ha).

The GYL of the studied stands showed a good ground structure (Y=1), meaning that there were few or no obstacles (stones, blocks, pits, etc.) to driving over the terrain, and a flat or slight slope (L=1). The bearing capacity in stands B and C (G=3 on a scale from 1 to 5) meant that machines should not be driven during periods of high ground moisture (e.g. during periods of heavy rain in the autumn, but especially when the snow and ground frost were melting during the spring). Winter, normally characterized by ground frost and packed snow, provided the best conditions for driving, followed by summer and early autumn, when the ground could be very dry. Such driving conditions can be expected on most farmland normally associated with a fine soil texture and weak structure.

2.2 Harvesting systems

The productivity of two machine systems (referred to as Logmax and Fixteri) (Table 2) was measured in stands B and C (Table 1). In stand B (overgrown edges, using Logmax), the harvester worked from the adjacent arable land, extending the crane perpendicular to the driving direction and cutting all trees in a swath 3-8 m wide (average 5.7 m). The edges and drainage ditches around the estate were cleared of vegetation overshadowing or hindering the water from draining. In stand C (overgrown arable land) all biomass was clear-cut using the bundler-harvester (Fixteri) system.

The total work time including delays < 15 min (reported as scheduled machine hours, SMH) was recorded with an Allegro Field PC® with SDI software. The productive work time was defined as SMH excluding delays and referred to as productive machine hours (PMH). Time studies were performed as continuous time studies, as the work elements were of sufficient length to be recorded individually with precision. In order to allow comparisons between the Fixteri and Logmax systems, an equivalent productivity of Logmax, assuming it worked on the same stand (C) as Fixteri, was calculated. This was done using a conversion factor following the same proportions as the harvester productivity in a previous study (Bergström and Di Fulvio, 2014a), as a function of the stem volume of stands B and C (Table 1).

In the field study, when forwarding biomass from stand C, a full load contained about 40 bundles, because of the flexible loading bunk of the forwarder (Komatsu 865). However, in order to allow comparisons with a farm tractor (equipped with a timber trailer with a loading crane), the efficiency of the forwarder was modelled assuming the flexible bunk was not used. Therefore a full load only contained 22 bundles, as if working a first thinning. The bundles produced were on average 233 OD kg (46% moisture content, MC), 2.6 m in length and 60-70 cm in diameter. The efficiency of the farm tractor was derived from the forwarder, assuming a 35% longer time for loading and unloading (calculated from the study of Gullberg, 1997).

The efficiencies of the forestry machinery used included a 10% delay time, while a delay of 5% was assumed for the farm tractor. The hourly costs were based on analytical calculations from a previous study (Bergström and Di Fulvio, 2014b). Conversion from Swedish crowns (SEK) to Euros (€) assumed an exchange rate of 9.5 SEK/€. Forestry machinery was considered to cost 211 € per machine and relocation, while the farm tractor was assumed to drive itself during 1h, with a relocation cost of 55 €.

2.3 Comminution and road transport systems

The efficiency of two systems for comminution and three systems for delivery of biomass was measured for a variety of field studies on marginal land and conventional forest land (dense thinning stands) and expanded using data from the literature (Table 3). The efficiencies for the chipper included a 10% delay time, and an 8-min delay per load for the trucks.

A. Transportation of loose rough-delimbed tree sections to the factory in a truck and comminution at the factory with a semi-stationary chipper (Doppstadt DH-910). This chipper required another truck and a crane (Epsilon Q170L) for relocation and feed-in.

B. Transportation of bundles to the factory with a conventional timber truck and comminution at the factory with the same type of semi-stationary chipper as in A.

C. Chipping of rough-delimbed tree sections at the roadside (tree sections stacked in windrows) by a forwarder-

Table 1. Stand characteristics of representative marginal land in study areas around Umeå.

Stand	**A**	**B**	**C**	**D**
Type of marginal land	Overgrown industrial site	Overgrown edges of arable land	Overgrown arable land	Overgrown roadside
Location	*Ersmarksberget*	*Ersmark*	*Norrbyn*	*Trollberget*
Harvested area (ha)	0.15	0.35	1.13	1.5
Typical stand size (ha)	1	0.5	4	Up to road length
Density (all trees/ha)	16 446	20 105	4 341	2 450
Density (DBH ≥3 cm trees/ha)	7 604	8 916	2 079	1 217
DBH[1] (cm)	7	10.6	14.9	14.9
Height[1] (m)	8.4	8.7	12.9	11.1
Stem volume[2] (dm^3)	23	54	140	128
Biomass (OD t/ha)	52.5	97	70.6	38.2
Volume[3] (m^3/ha)	123	199	134	91
Basal area (m^2/ha)	26	46	19	11
Species (A:B:S:W:P)[4]	100:0:0:0:0	10:49:32:4:5	20:73:6:0:1	0:41:0:0:59
Forwarding distance (m), average	206	196	180	0
Driving conditions (GYL)	2.1.1.	3.1.1.	3.1.1.	1.1.1.

[1] *Average, basal-area weighted.*
[2] *Volume over bark above the stump to the top, excluding branches and needles, basal-area weighted.*
[3] *Volume of whole-tree (stem and branches inc. needles).*
A conversion factor (m^3 solid/OD t) derived from the inventory data was used.
[4] *Tree species (%): A=grey alder (Alnus incana), B=birch (Betula spp.), S=Norway spruce (Picea abies), W=willow (Salix spp.), P=Scots pine (Pinus sylvestris).*

Table 2. Properties of base machines for harvesting and forwarding.

System	**Logmax**	**Fixteri**
Harvester	EcoLog 560D with AHH[1] Log Max 5000D (modified knifes, rough-delimbing)	Fixteri FX15a bundler on harwarder Logman 811FC with AFH[2] Nisula 285E+
Efficiency (SMH/OD t)	0.1382	0.1687
Hourly cost (€/SMH)	113.5	144.3
Forwarder (medium-size)		
Assortment	Rough-delimbed tree sections	Bundles
Efficiency[3] (SMH/OD t)	y=0.0003x+0.1118	y=0.0002x+0.0602
Full load (OD t)	3.3	5.1
Hourly cost (€/SMH)	78.5	78.5
Farm tractor with timber trailer (medium-size)		
Assortment	Rough-delimbed tree sections	Bundles
Efficiency[3] (SMH/OD t)	y=0.0003x+0.1398	y=0.0002x+0.0738
Full load (OD t)	3.3	5.1
Hourly cost (€/SMH)	55.4	55.4

[1] *Accumulating harvester head.*
[2] *Accumulating felling head.*
[3] *Terrain driving distance (m), one way.*

mounted chipper (Bruks 805 CT on Komatsu 860.4) equipped with a self-dumping chip bin of 20 m³. Chips were dumped on the floor and a chip-truck (Volvo FH13) with a crane (Epsilon M110LS97) and bucket halves (HSP Gripen 055, about 1.5 m³) loaded and delivered the chips to the factory (with a container and trailer of 122 m³ total size).

2.4 System analyses

The cost of each harvesting system, using a medium-size forwarder, or alternatively a farm tractor with a timber trailer, was calculated for working on overgrown arable land (stand C, size of 4 ha and 70.6 OD t/ha, Table 1). The total delivery cost was calculated as a function of the distance to the factory, considering harvesting costs and each combination of system for comminution and transportation (Table 3). Calculations assumed a terrain driving distance of 300 m (one way) for the forwarder and the farm tractor, and 50 m (one way) for the forwarder-mounted chipper. The trucking cost was calculated using the method described in the literature (Bergström and Di Fulvio, 2014b). A gross calorific value of 20.5 MJ/OD kg and an MC of 50% for the delivered biomass were assumed, which equalled to a net calorific value of 4.65 MWh/OD t.

Three wood chip prices at the factory gate were considered: low (11 €/MWh $\approx$ 49 €/OD t), medium (15 €/MWh $\approx$ 69 €/OD t) and high (19 €/MWh $\approx$ 88 €/OD t). In order to allow comparisons, the calculated delivery cost for uncomminuted assortments, i.e. bundles and tree sections, already included the cost of chipping at the factory. For example, given a price of 19 €/MWh for wood chips at the gate, the real price paid for the uncomminuted bundles and tree sections should discount the cost of chipping, resulting in a price of ca. 15 €/MWh. However, the calculations included this cost on the "supply side", so that comparisons could be made easily. Analyses also considered a margin of 5 €/OD t (ca. 1 €/MWh), which could represent, for example, the net profit at the roadside for the forest owner for each OD t of biomass sold (the profit after discounting the harvesting costs from the stumpage price).

3. Results

The results in Fig. 1 show higher costs for the Fixteri compared with the Logmax system when using a conventional forwarder. Even though forwarding was more efficient for bundles than rough-delimbed tree sections (ca. 72% more efficient at a distance of 300 m), the higher (26%) hourly cost assumed for the bundler-harvester, compared with the harvester alone, explained the results. If, instead, a farm tractor was used for distances >275 m, the Fixteri system became a more cost-efficient option than the Logmax with a conventional forwarder. The Logmax system in combination with a farm tractor yielded the lowest costs regardless of driving distance.

The results in Fig. 2 show that using a forwarder, the delivery of rough-delimbed tree sections with loose transportation in trucks and chipping at the factory (system A) yielded the greatest costs for distances > 60 km. For shorter distances, chipping at the forest roadside and delivery with chip-trucks (system C) became the most expensive system. However, if the bundler-harvester system (Fixteri) was used in combination with a forwarder and a timber truck, and bundles were chipped at the factory (system B), the delivery costs could be decreased by 7% or 5%, compared with systems A and C, respectively, at a distance of 100 km. Overall, for distances > 20 km and using a conventional forwarder, the bundle-harvester in combination with a timber truck for transportation of bundles and chipping at the factory (system B) was the most cost-effective system. The delivery cost could be reduced by a further 4-5% if more cost-effective machines were used for terrain driving, such as a farm tractor with a timber trailer. Thus, the Fixteri system was the most cost-efficient system for distances > 35 km.

4. Discussion

As shown in Fig. 3, the price paid for the biomass at the factory has a huge effect on the profitability of the supply chains. Assuming a relatively high price for wood chips at the factory gate (19 €/MWh $\approx$ 88 €/OD t), the three alternatives considered (tree sections chipped at the factory, tree sections chipped at the roadside and bundles chipped at the factory) were all profitable with a large margin. Using a conventional forest forwarder and taking into account a margin of 5 €/OD t, the results suggested that tree sections chipped at the factory could be delivered profitably over distances of up to 190 km, while tree sections chipped at the roadside and bundles chipped at the factory could cover distances > 200 km. However, considering a medium price (15 €/MWh $\approx$ 69 €/OD t) and the same margin, the break-even distances decreased to 70, 73 and 104 km, respectively.

The results show that if the bundle-harvester (Fixteri) system is used in combination with a farm tractor, road transportation with timber trucks and comminution at the factory, the level of profit can remain high even if the given wood fuel prices fall. However, the lowest red line illustrates the fact that if the price of the wood chips at the factory gate decreases too much, it is not viable to remove the wood fuel from the forest. Low prices can therefore put at risk wood fuel supply chains that have required many years to set up. Although the analyses show that the use of farm tractors with timber trailers can reduce costs because of their low operational cost, this is based on assumptions taken from the literature, which therefore need to be verified in the field. The use of the bundle-harvester on farmland or other sites with reduced bearing capacity can be limited during some periods of the year because of the heavy weight of this system (ca. 23.5 tonnes in total).

The delivery of wood fuel from the studied marginal land on average presented lower costs than the equivalent biomass harvesting of a dense first thinning. This was because of the higher concentration of biomass and the method used (i.e. clear-cutting), but also because the tree size was relatively large (DBH 14.9 cm and stem volume 140 dm³), being a more typical size for pulpwood than energy-wood. Even though the harvesting technologies used in marginal

Table 3. Properties of base machines for comminution and transportation to the factory.

System	A		B	C	
	Chipper (inc. truck)	Truck for rough-delimbed tree sections	Timber truck for bundles	Chipper (inc. forwarder)[1]	Chip-truck
Efficiency	y=0.0411 SMH/OD t	y=1.0149 SMH/load	y=1.1505 SMH/load	y=0.0003x+0.0954 SMH/OD t	y=0.9943 SMH/load
Full load (OD t)	-	13.8	20	3.4	19
Cost (€/SMH)	315.8	36.4	35.6	163.2	52.1
Other costs	842 €/relocation	18.7 €/load 1.1/km	17.8 €/load 0.9 €/km	316 €/relocation	23.7 €/load 1.0/km

[1] *In the modelled efficiency, x=terrain driving distance (m), one way, from the windrow where the tree sections were stacked to the place where the chips were dumped (normally roadside or landing).*

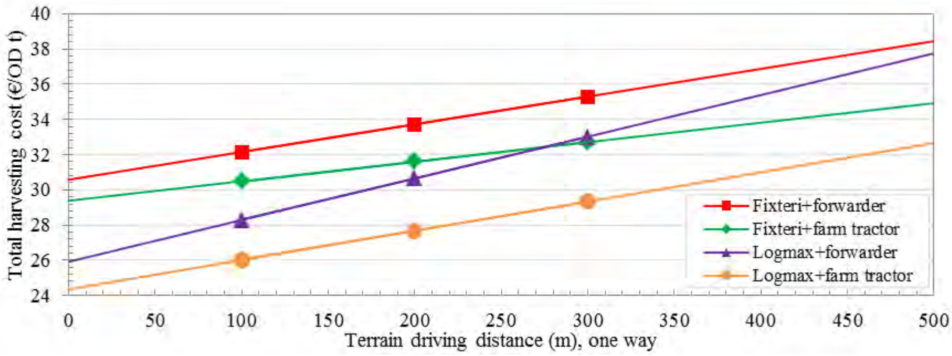

Figure 1. Total harvesting cost (harvester and forwarder, inc. machine relocation costs) on overgrown arable land, as a function of terrain driving distance (one way).

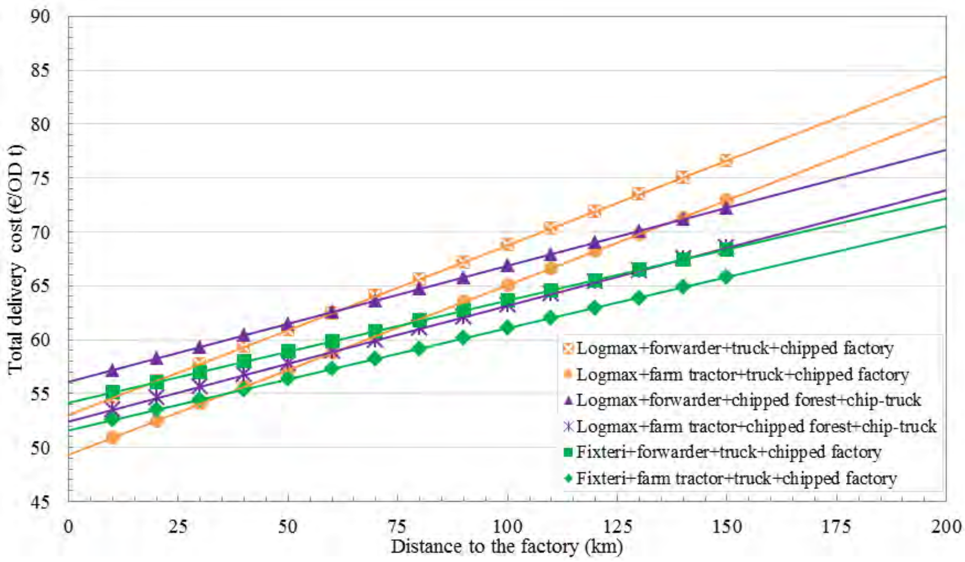

Figure 2. Total delivery cost as a function of the distance to the factory (km).

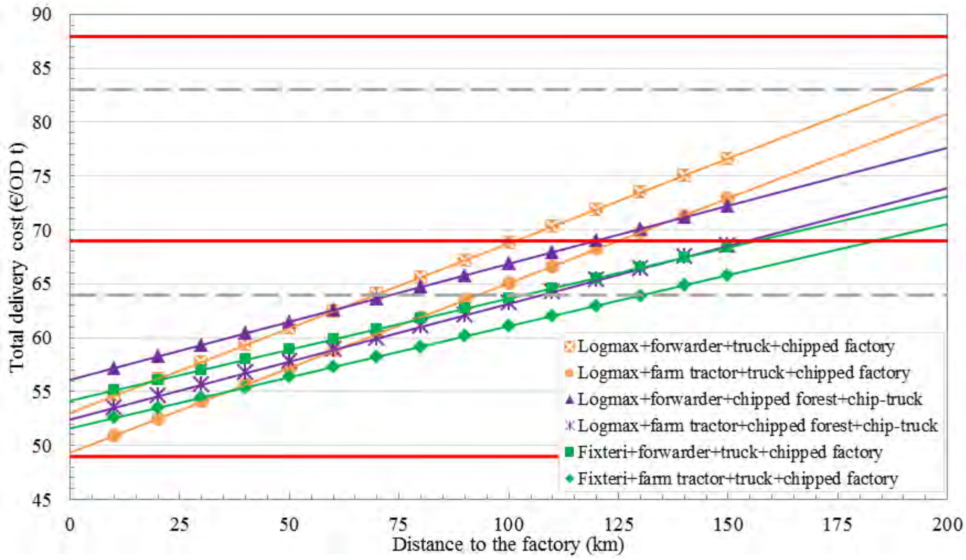

Figure 3. Total delivery cost as a function of the distance to the factory (km). The horizontal red lines indicate the price paid for wood chips at the factory gate, i.e. break-even distances at which the delivery cost equals the income: low price=11 €/MWh (≈49 €/OD t), medium=15 €/MWh (≈69 €/OD t) and high=19 €/MWh (≈88 €/OD t). The grey lines represent the real income from delivering the biomass, considering a margin of 5 €/OD t.

land can be similar to those used in conventional forestry, the harvesting costs can be expected to be higher in marginal land with smaller tree sizes, smaller harvesting sites and longer terrain driving distances (narrow and long sites, such as edges of arable land). As conditions can vary greatly from site to site, it is difficult to generalize for all harvests from marginal land.

The use of rough-delimbing and bundling increased the efficiency of transportation. Even though the harvesting may become more expensive, savings are made during transportation and comminution at the factory (or terminal) by large-scale chippers, rather than forwarder-mounted chippers at the forest roadside. The transportation of bundles can be integrated with the transportation of roundwood using the same timber trucks. Handling bundles is also easier than handling tree sections or logging residues, making comminution more effective. The costs can be further decreased if large farm tractors equipped with timber trailers are used instead of forwarders, because of the lower operational cost. Further development and integration of harvesting marginal land with conventional forest land can decrease the delivery costs of small-diameter trees.

5. Acknowledgements

The authors gratefully acknowledge the financial support of the Swedish Energy Agency (Energimyndigheten) for funding the research project SKM: Skog, Klimat och Miljö (Forest, Climate and Environment), and Fonden för skogsvetenskaplig forskning for funding our participation in the 48th International Symposium on Forestry Mechanization.

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Main innovation types of forest biomass supply chains

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Abstract
The aim of this study was to determine how process innovations can be applied in forest biomass supply chains by reducing costs to add value, compared to traditional supply chains. This work is the summary and comparison of publications. Innovation can be recommended once the added value advantages are justified and sufficient. The process innovation of forest biomass supply chains contains several possibilities. There is a need to identify which processes should be renewed incrementally or completely. The main innovation types determined by the case articles are divided into; incremental, radical and network innovation. Achieving cost reduction was possible by innovating the traditional forest biomass supply chain processes in a novel way. There were cost reduction variances between the alternative case studies and the types of innovation. For the case of network innovation however, presenting the co-operation of an entire supply chain by linking forest management and logistics together in process innovation provided the highest cost reduction. The study method could be used for analysing stumpage price in a more reliable way as a part of the entire supply chains for forest biomass

Keywords
innovation, strategy, supply chains, forest management, forest biomass

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1. Introduction

1.1 Background

The development of the forest biomass value chain should be seen as integrating the roundwood and energy wood supply chains (Björheden 2000). On the other hand, the overall value chains of forest biomass have not been studied much. Improvements in the productivity of biomass production, harvesting and transport systems are clearly the key to enhancing the bioenergy share of total energy production (Gan and Smith 2006). The overall cost reduction potential is estimated to be up to 25%, mainly due to better technology, improved harvesting techniques and optimised long-distance transportation (Hogan et al. 2010). However, Windisch et al. (2013) has presented even higher cost reduction potentials (20-39%) by reengineering business process of forest biomass supply chain relative to the currently applied business process.

A large number of studies have been carried out concerning forest fuel systems. The most important stakeholders in the forest biomass supply chain are 1. forest owners, 2. logistic actors and 3. the plant as a final user of forest biomass material. However, studies are usually separated to research the perspective of either forest owners, logistics actors or final users. In recent years, research focus of forest biomass supply chains has concentrated on the overall logistics system or a part of the system, e.g. logging, harvesting, chipping or transportation. Few studies can be found from overall supply chain systems of forest biomass for energy. Unless the overall aspects included in the analysis of forest biomass supply chains, the forest management alternatives and reliable stumpage price estimates in analysis have been missing.

The forest biomass supply chain has been improved and developed by many innovations that have decreased the costs to a reasonable level for achieving the materials used for energy purposes. Small-diameter energy wood procurement has been an interesting topic of research and innovation for a long time. While integrated methods for harvesting energy wood and commercial timber have evolved, the high costs compared to those from logging residues have still hindered large-scale utilisation without subsidies (Jylhä 2011; Routa et al. 2013). In spite of the high cost, the largest share (3.7 million m^3, total 7.5 million m^3) of forest-based chips used in Finland came from small-diameter wood in 2014 (Ylitalo 2015). Scots pine represents the largest additional source of small-diameter energy wood (2.5–5.0 million m^3) in Finland (Anttila et al. 2013). It must be noted that the accumulation potential is dependent on the measurement specifications. For comparison, pine pulp wood is the most harvested and used timber assortment in Finland, with a utilisation of 15.3 million m^3 in 2014, which represents 48% of the total pulp wood (31.9 million m^3) and 27% of the total timber use (61.5 million m^3) (Luke 2015).

1.2 Definition of innovation

"An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (Oslo manual 2005). Innovation is defined as a dynamic process in which technologies replace the old with "creative destruction" either through "radical" innovations creating major revolutionary changes or "incremental" innovations continuously advancing the process of change. Innovation is the only way to sustain a company's competitive advantage in the long run (Schumpeter 1934; Rumelt 1984). Current innovation research has underlined the meaning of learning and spreading know-how instead of theoretic-technical innovations. Co-operative networking can be seen as one of the main innovation process themes nowadays, but far more detailed research needs to be conducted in the form of case studies (Pittaway et al. 2004).

Improving the productivity as process innovation is the way for a company and its network to achieve a cost advantage over its competitors through the cost reduction. The main goal is to increase added value to the final customer in the long-term while enabling more profit to the company and its network in the short-term.

1.3 Aim of the study

The aim of this study is to enhance the knowledge concerning the innovation types and possible cost reduction for developing cost-efficient supply chains of small-diameter wood. The research question of this work is: "What kind of innovation type can achieve the largest cost reduction of the supply chain of small diameter wood?"

The main interest is to define the innovation types that can be used for the process innovation concentrating on small-diameter wood supply chains in case studies. New innovative supply chain processes are described in this work as a way to decrease delivery costs over traditional ones. The traditional supply chain means the current system, which has taken the main position of the supply chain process in the market. In this work, traditional supply chains are presented as a current dominant technology or process of supply chains of small diameter wood.

2. Material and Methods

2.1 Supply chain cost

The work is a summary and comparison of recent case studies for the small-diameter wood supply chain either to industrial or energy use. The study results concluded in the articles were divided into the main innovation types (incremental, radical and network innovation) which are presented as a conclusion for comparing forest biomass supply chain cases (Karttunen 2015). Some additional supply chain costs have been included to the original studies to maintain comparability between the case studies. Following earlier studies were used in the case studies (Table 1).

The main cost results were presented as units of €/m^3. The main material difference between the traditional industrial pulp wood and innovative supply chains of energy wood use was the difference of moisture content. The basic tree density for Scots pine in this study was set at 400 kg/m^3 (Lindblad and Verkasalo 2001). The average moisture content for small-diameter delimbed energy wood was set at 35% (to be 615 kg/m^3), whole tree bundling 45% (to be 727 kg/m^3) and industrial pulp wood 55% (to be 889 kg/m^3).

Table 1. Table 1. Cost data based mainly on the early studies. Figures reported in the table for first traditional supply chain and then innovative supply chain. Reference numbers: 1: Alavarvi & Ovaskainen 2013, 2: Petty & Kärhä 2014, 3: Laitila & Väätäinen 2011, 4: Nuutinen & Björheden 2014, 5: Kärhä et al. 2009, 6: Laitila et al. 2009, 7: Karttunen & Laitila, 2015, 8: New estimate or simulation.

Case	1	2	3
Stumpage price	1/1,8	1/1,8	7/7
Procurement cost	1/1	1/1	1/1
Logging cost	2/2	2/4	7/7
Forwarding cost	2/2	2/5,6	7/7
Long-distance transportation cost	8/3	3/3	3/3
Chipping cost	3/3	3/3	3/3
Terminal cost	3/3	3/3	3/3
Feed-in transport cost	3/3	3/3	3/3

The difference of top diameter between delimbed energy wood logging and industrial pulp wood exists. Following cases were presented:

1. Case: Traditional single tree cutting vs. innovative multi-tree cutting of small-diameter wood "Incremental innovation"

   Multi-tree cutting system have developed incrementally starting from the cutting head of multifunctional forest machine based on single tree cut-to-length system. Supply chain process of small diameter wood after cutting is the same in comparison. Though, innovative supply chain of multi-tree cutting produced delimbed energy wood, which was dried at roadside. Traditional supply chain was based on single tree cutting of pulp wood which was transported fresh to the end-use facility. This case study productivity and main costs based on published article (Petty & Kärhä 2014). Stumpage price was tested to vary between 10 and 12 €/m^3 in innovative case.

2. Case : Traditional multi-tree cutting vs. innovative bundling system of small-diameter wood "Radical innovation"

   Bundling system of small-diameter wood can be considered as radical innovation. Bundling system "Fixteri" has been studied and developed in Finland in recent years (Jylhä & Laitila 2007, Kärhä et al. 2009, Nuutinen & Björheden 2013). The productivity of early prototype has been studied as follows; Fixteri I achieving 2.6–3.7 m^3/hE$_0$ (tree size 31–40 dm^3) (Laitila & Jylhä 2007) and Fixteri II having 4.6–5.1 m^3/hE$_0$ in same conditions. The newest prototype Fixteri FX15a has achieved the productivity of 9.7–11.9 m^3/hE$_0$ (tree size 28–44 dm^3) in the latest studies (Nuutinen & Björheden 2013). This case study is based on the productivity of latest bundling prototype (Nuutinen & Björheden 2013) and it was compared to traditional multi-tree cutting (Alavarvi & Ovaskainen

2013). Cost parameters based on the published report with some fixed extra costs included (Alavarvi & Ovaskainen 2013). The stumpage price was tested to vary between 8 and 12 €/m^3 in innovative case.

3. Case: Traditional vs. innovative forest management and supply chain of small-diameter wood "Network innovation"

   The idea of network innovation in forest technology is to combine forest management simulation with harvesting and supply chain management together to measure the entire supply chain costs (Karttunen 2015). It can be used as decision making tool to find out the most cost-efficient methods from several alternatives based either forest stand condition, harvesting method or supply chain solution. The study method gives reliable possibilities to estimate the needed stumpage price for forest owner and cost reduction potential from the entire supply chain of alternative case studies.

2.2 Cost reduction

Cost reduction (%) between the traditional and innovative cases were presented as a summary. Following equation was used:

$$Costreduction\,(\%) = \frac{Cost_T - Cost_I}{Cost_T}100 \qquad (1)$$

$Cost_T$: Cost of traditional supply chain (€/unit)
$Cost_I$: Cost of innovative supply chain (€/unit)

3. Results

3.1 The total supply chain cost

The total cost of supply chains varied between 46.4 and 50.7 €/m^3 for traditional supply chains and between 44.1 and 46.8 €/m^3 for innovative supply chains (Figure 1). The stumpage price estimates (7.2–14.8 €/m^3, 16–29%) and logging cost (10.8–15.3 €/m^3, 23–31%) presented the largest part of the total costs. The total cost of supply chains showed that innovative supply chains achieved lower costs than traditional ones in all cases (Figure 2).

3.2 Cost reduction potential

The average cost reduction of incremental innovation was the lowest (4.9%), but had the potential for near 10% if the stumpage price was estimated lower (Figure 3). Radical innovation presented the middle level in terms of average cost reduction (6.8%), but had the potential for near 15% if the stumpage price was estimated lower. Network innovation case presented the highest average cost reduction (10.6%) and had cost reduction potential for near 15%.

4. Conclusion

Innovation is a key factor for a company and its network strategy management to achieve competitive advantage. The aim of innovation is to replace traditional dominant technologies or processes in a new way, which enables more

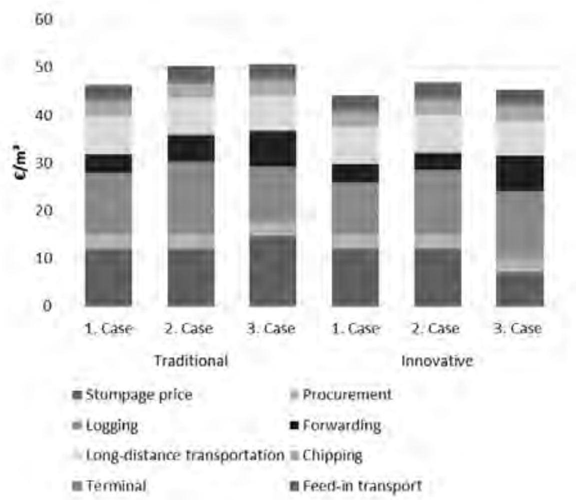

Figure 1. Total costs of small diameter supply chains consist of many cost parts. Innovative cases were 1.Case: Incremental, 2. Case: Radical, and 3. Case: Network innovation.

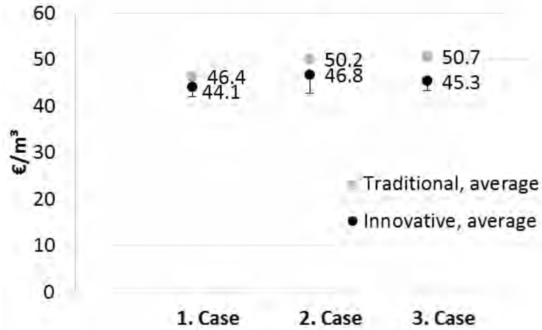

Figure 2. The total costs of main innovation type cases (€/m^3).

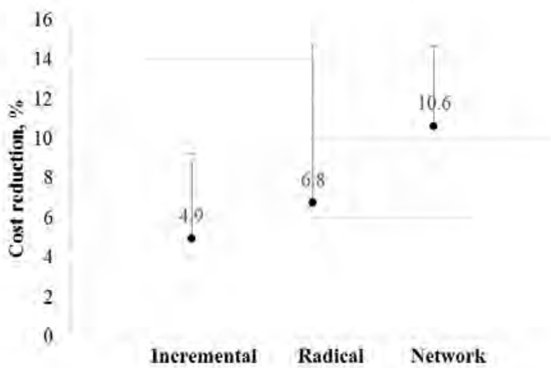

Figure 3. Cost reduction (%) associated with the main innovation types. The cost reduction potential based on lower stumpage price estimates in incremental innovation (from 12 to 10 €/m^3), radical innovation (12 to 8 €/m^3) and in network innovation the reliable stumpage price estimates were already included in the study method.

advantages to the company, its network or customer. Several innovation cases were determined in this work and those were divided into incremental, radical and network innovation types. It was possible to achieve the advantage as a cost reduction by innovating traditional forest biomass supply chain processes in a novel way. The most interesting finding of this study is the importance of stumpage prices in the total cost and cost reduction potential of alternative small-diameter wood supply chain case studies.

The case of network innovation, combining forest management simulation with logistics analysis together as process innovation provided the highest cost reduction. The stumpage prices are normally excluded from the total cost analysis. In cases of network innovation the stumpage prices were included in the study method to analyse forest management and more reliable energy wood stumpage prices as wholeness. It is important to find out cost-efficient energy wood supply chains to increase the use of renewable forest based energy.

The innovation study cases exhibited a great amount of variances between each other. The chosen scale is an important aspect in the comparisons, and the chosen scenarios are another. In this work, the traditional and innovation cases of the most promising scenarios were chosen as the reference scenario. The innovation scenario was compared either to the traditional option of the same scenario or to the traditional baseline scenario of the entire study.

The incremental innovative case study presented the supply chain costs for multi-tree cutting method of delimbed energy wood compared it to the single tree cutting of industrial pulp wood. The case study showed that innovating cutting technology and processes incrementally, the cost of first thinning can be decreased compared the traditional supply chain. However, an incremental innovative strategy is not always enough to maintain competitiveness (Karttunen 2015) and the reason why the other innovation possibilities must be studied.

The radical innovation case study based on the bundling system of small-diameter wood from first thinning and compared it to traditional multi-tree handling used for industrial wood. The case studies (Nuutinen & Björheden 2014, AlaVarvi & Ovaskainen 2013) showed that it was possible to achieve cost reduction. Unless the productivity of the latest bundling system has increased dramatically, the cost difference compared to multi-tree cutting seems to be low when the entire supply chain costs are included. Studies of Laitila & Väätäinen (2013) presented even higher productivities for multi-tree handling (average 12.8 m^3/hE_0) than here presented bundling system. Cutting productivity is normally increasing when size of trees grow, which has influence on cost-efficiency too. It would be important to choose the correct supply chain method for the correct stand in practice. To make sure comparability between the study cases, it would be important to choose the most suitable alternatives. Bundling system could have been compared with single tree cutting in this study. Anyway, there is always business risk in using new radical technology like bundling system where supply chain process must be changed. However, the idea of this case study was to show how lower stumpage price estimates can produce higher cost reduction potential. Lower stumpage price could be justified because of larger removal of whole trees compared to industrial wood.

In network innovation the multi-tree cutting from denser forest stands was compared with traditional forest stand density. Network innovation indicates a combination of forest management and supply chain processes to find out cost-effectiveness for the entire supply chain. It showed that denser forest stands could be more cost-efficient for multi-tree cutting of delimbed energy wood than operating traditional industrial pulp wood from the stand of normal density.

The methods presented in this work could be mainly applied in forest biomass supply chain concerning the development and utilizing of small-diameter wood from first thinnings. All in all, the study method of forest management simulations to achieve more reliable stumpage prices could also be included in the analysis of the other cases to analyse the entire cost reduction potential of forest resources for either energy or industrial purposes. The comparability in the innovation types and case studies of forest biomass supply chains should be paid more attention in the future studies.

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Quality and productivity in comminution of small-diameter tree bundles

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Abstract
Bundling small-diameter trees from thinnings has become a viable technology with the development of the Fixteri harvester-bundler. Several studies have measured the productivity of the machine itself, however, bundles themselves also influence the supply chain. A study was conducted to investigate the quality and productivity of five different chippers and one grinder when comminuting bundles produced of small-diameter trees. The productivity varied considerably between the machines, 1:2.3 being the observed relation between lowest and highest performance of machines. Productivity when comminuting bundles was higher than normally found in literature for unbundled (loose) material. The quality of the produced fuel chips varied between machines, due to particle size. The average size of the chips varied between 5 and 20 mm, with distribution of particle size between 0<3.15-63<100 mm. The study indicated that productivity and quality of fuel chips are dependent on machine type. Further investigations should examine different machine systems in designed experiments where e.g. several assortments and operational environments are included.

Keywords
fuel wood, early thinnings, whole-tree bundles, fixteri, comminution

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1. Introduction

Comminution is the process in which material, forest raw material in our case, is reduced into a desired particle size, such as solid wood fuel chips. The quality of fuel chips is highly dependent on both technology and raw material utilized (Eriksson et al. 2013). Two technologies are primarily used in comminution of forest raw material: those that cut the wood (chippers) and those that crush wood (impact with blunt tools) (Eriksson et al. 2013). Bundling whole-trees from early thinnings is one important assortment within Nordic supply chains for bioenergy. Findings of recent studies (Ala-Varvi and Ovaskainen 2013, Bergström et al. 2015, Nuutinen and Björheden 2016) indicate that bundling small-diameter trees from thinnings has become a viable technology with the development of the Fixteri harvester-bundler. The competitiveness of the machine concept is highly dependent on wood chip prices, as well as characteristics of the stand. However, features of the bundles also influence e.g. forwarding, storage and comminution. Bergström and Di Fulvio (2014) show that bundle systems can significantly reduce supply cost (via terrain and road transportation) for early thinnings in comparison to traditional systems were loose materials are handled. Similarly, Kärhä et al. (2009) found that the forwarding costs of whole trees were more than double when compared to whole tree bundles. Ala-Varvi and Ovaskainen (2013) found the total cost of the wood chip supply chain of whole-tree bundling (46.7 €/m³) to be lower compared to undelimbed trees (50.2 €/m³) if the average volume of removed trees was less than 85 dm³.

If whole tree bundles are processed for energy purposes they are comminuted at terminals or industry before being fed into a boiler. Acceptable, or good quality wood chips vary depending on boiler technology and the feeding mechanism. By other words, each power plant has its own characteristic quality requirements when utilizing forest chips for energy purposes. Generally, a more uniform size is preferable as it makes it is easier to control the burning process. However, the market for machine systems for comminution provides a great variation in technologies, which allow for variations in fuel chip qualities.

1.1 Objectives

The aim of this case study was to measure the quality of chips produced from small diameter whole-tree bundles. Two main comminution methods, chipping and grinding, were tested. Six different machines were studied, five chippers and one grinder (Table 1). The particle size distribution, moisture content, bulk density of the chips produced from bundles and the productivity of comminution work for each machine were studied.

2. Material and Methods

The study was carried out in late winter (March 2014) in Central Finland in the municipality of Padasjoki.

Comminuted bundles were produced from small-diameter whole-trees using the Fixteri FX15a small-tree bundler (Fixteri 2015) in May 2013. The produced bundles are typically 2.6 m long with a diameter of 60-70 cm and contain approximately 0.6 m³ solid. Bundles are tied by means of plastic netting (Bergström et al. 2015, Nuutinen and Björheden 2016). After cutting, bundles were hauled to roadside and stored for approximately 2 months prior to transportation to the study site terminal where the study was conducted. Bundles were produced in first thinning stands from whole-trees by volume of ¼ Scots pine (Pinus sylvestris L.), ¼ Norway spruce (Picea abies (L.) Karst.), ¼ Downy birch (Betula pubescens), and ¼ Black alder (Alnus glutinosa). The size of the whole-trees included in bundles varied in the range of 15 – 35 dm³ and 5 – 13 cm at breast height diameter (dbh) with a corresponding average size of 25 dm³ and 9 cm dbh. Approximately 1,000 m³ of bundles, 5 m in height were stored at the study terminal for 6 months between August 2013 and March 2014.

Each studied machine for comminution was tested on the same day and location. During the experiments the weather was clear and only a small amount of snow was covering the bundle storage. In storage, bundles were loaded in a crisscross system (bundle layers were crossed) to enhance air circulation throughout the pile. The A, B, C and E machine types were placed with infeed opening perpendicular to the pile surface, while machine types D and F were situated parallel to the pile. The volume of the comminuted chips of the six experiments (machine-runs) totaled 327.4 m³ loose (128.4 tonnes). Immediately after comminution, test loads of the produced chips were transported to the power plant of Keljonlahti in Jyväskylä, Finland.

2.1 Sampling and analysis of fuel chips

This study followed the SFS- EN ISO 17225-1 standard which determines the fuel quality classes and specifications for solid biofuels of raw and processed materials originating from a) forestry and arboriculture; b) agriculture and horticulture; and c) aquaculture (ISOb 2015). Under SFS- EN ISO 17225-1 the particle size analysis was conducted according to SFS- EN ISO 15149-1 standard, bulk density was defined by the SFS- EN ISO 15103 standard and moisture content was determined using the SFS- EN ISO 14774-2 standard (Alakangas and Impola 2014). Particle analysis results of the six machine types are listed as Type A, B, C, D, E and F to ensure impartiality.

During comminution experiments, the upper surfaces of the ready chip loads were not adjusted horizontally and for that reason the degree of filling of the load space was visually assessed before transport to the power plant. At the plant, each load was measured with a certified weight scale: filled and empty load weights were recorded. For the analysis of the chips, three 50 dm³ chip samples were systematically collected from different points of each load immediately after loading. The sub samples of each load were packed in a plastic sample bag to prevent evaporation of water. In the laboratory analysis, the sub samples of each load were combined. Sampling was performed by a certified environmental sampling specialist (Ismo Tiihonen), whom had several years of work experience.

Particle size analysis

A sieve with circular holes following sieve sizes 3.15 mm, 8 mm, 16 mm, 31.5 mm, 45 mm, 62 mm and 100 mm was utilized. The chip sample for the analysis meet the standard minimum 8 dm³. The chip samples were sieved for 15 min. Prior to sieving, samples were air dried to moisture content under 20%. Sample were sieved horizontally across the sieve holes into digressive diameter classes. Finally, the particles of each sieve size were weighed to an accuracy of 0.1 g. The particle size distribution of chips in SFS-EN ISO 17225-1 standard is determined by the means of proportions of different fractions (Alakangas 2012, Alakangas and Impola 2014). According to analyzed particle size distribution (Figure 1), comminuted forest chips were divided into particle size classes (Table 2). The numerical values of main fraction P refer to the particle sizes at least 60 w-% (weight %) passing through the mentioned round hole sieve size. The fine fraction F means the proportion of particle sizes below 3.15 mm. The coarse fraction is the proportion of maximum length of particles. For example P16, F25 means that the total weight-% of sieves 3.15-16 mm is at least 60%, the coarse fraction of over 31.5w% is maximum 6w-% and the proportion of fines fraction (<3.15 mm) is maximum 25

2.2 Implementation of time study

The time study was conducted by video recording of the work performance of the studied machines. The operation time was recorded using continuous timing method. In the time study, each machine comminuted one load, which took 15 to 30 minutes of effective working time. The analysis of video material was carried out using the Excel software based time study application developed at Natural Resources Institute Finland (Luke) by Ari Lauren. From the video, the work elements of the operation time of each studied machine were determined. The durations and proportions of the work elements were also analyzed.

The division of work elements followed the studies of the CBI 5800 grinder conducted by Eliasson et al. (2012) and Nuutinen et al. (2014):

- Swinging the boom towards a bundle stack (crane out)
- Grasping the grapple bunch
- Transferring the grapple bunch to the chipper/grinder (crane in)
- Feeding the grapple bunch into the chipper/grinder
- Additional feeding of the bundles
- Chipping/Grinding
- Arrangement of the bundle stack
- Delays (interruption)

The recorded work elements excluding delays were included to the effective working time (E_0h). To ensure the comparability of the results of the time study, the effective

Table 1. Technical information of the studied machines.

Machine model	Engine power (kW)	Diameter of drum (mm)	Number of blades	Dimension of infeed (mm)	Dimension of sieves (mm)	Load space vol. (m³)
A	Volvo, 562	1300	2	1090x 700	100, comb	54
B	Volvo, 525	860	10	1000x 600	80x80	50
C	Mercedes Benz, 468	1040	24	1200x 820	80x80	94
D	Cummins, 400	1440	4		80x120	55
E	Cummins, 496	900	2	1000x 720	120, comb	94
F*	Own, $\leq$ 330	-	-	-	-	97

*Machine type F may be equipped with various engine options up to 330 kW, chipper knife set up when producing wood fuel, diameter capacity of 610 mm, and 610x1524 mm mill opening.
[1]Measured volume loaded onto either trailer or trucks

hourly productivity (E_0h) of chipping was presented as per whole-tree chips' loose (l-m³) volume, green mass (t) and dry mass (t). Working time distribution and productivity results of chippers follow the particle analysis results in listing the machines as type A, B, C, D and E.

3. Results

3.1 Chip qualities

Rough chips with a diameter over 100 mm were not found in any samples (Figure1). The proportion of chips with diameter 63 < 100 mm comminuted by machine types F and A were 7 and 3.7%, while for other machines this fraction was not found. Particles of 45 < 63 mm were produced only by F and A machine types with proportions of 6 and 6.1%. With other machines, proportions were minor, in the range of 0.2 - 2.6%.

Machine type B had the smallest proportion of chips between 16 < 45 mm (12.9%), while type C had the largest (61.4%). Other machines varied between 25.8 - 40.3%. With dimensions of 3.15 < 16 mm, machine types E and B held the highest proportion of chips (60.4 and 52.9%), while other studied machines ranged from 30.6 to 47.4%. The chips comminuted by the type E machine (Table 2, Figure 1) had the smallest dimension of particle size class P16. By other words, 60.4% of the dry mass of the chips produced was in the diameter range of 3.15 < 16 mm. Machine type F, had the largest particle size dimension P45S meaning that 67.5% was in the diameter range of 3.15 < 45 mm and length of maximum particles was below 200 mm. The chips produced by machine type B had the largest proportion of fine fractions, at 33.7%, whereas chips produced by type C included the lowest share (5.4%) (Table 2). The chips comminuted by A, D and E machine types (Figure 2) were the most homogenous. The proportions of their main fractions P31S, P31S and P16 accounted for 66.8, 80.1 and 60.4% (Table 2, Figure 1). The chips produced by C and B machine types were more heterogeneous. Hence, 46.6% of machine type C chips were in the diameter range of 16 < 31.5 mm and for chips produced by type B, the proportion of fines with a diameter < 3.15 mm was 33.7%

(Figure 1). The moisture content of the produced chips of the studied machines varied between 51.9 and 59.9%. The dry bulk density (109 kg/m³) of chips produced by machine type F was lowest of all machines, while the densities of chips produced by other machines varied from 158 to 178 kg/m³ (Table 2). The chips from machine type B had the smallest mean particle size of 5.79 mm, followed by machine type E at 10.93 mm (Table 2, Figure 2). The proportion of chips produced from machine type B below 8 mm in diameter was 63.6%, while the proportion produced from machine type E between 8 < 31.5 mm in diameter was 61.8% (Figure 1). The mean chip size of 20.64 mm of machine type C was the largest and displayed a proportion of chips within 16 < 31.5 mm that was 46.6% (Table 2, Figure 1).The cumulative proportion of chips for A, B, C, D, E and F machine types in the diameter range of 3.15 < 16 mm were 49.8, 86.7, 36, 60.9, 74 and 58.3%. In the diameter range of 3.15 < 31.5 mm 79, 95.1, 82.6, 93.6, 98 and 76.4%, respectively (Figure 2). The proportion of chips of all machines over 31.5 mm in diameter varied from 2 – 23.6%.

3.2 Productivity

The productivity of chipping of the studied five chippers based on loose volume forest chips was in range of 179-402 m³/E_0h. Respectively, the productivity based on green mass varied from 74.4-148.3 t/E_0h and productivity based on dry mass from 29.8-71.3 t/E_0h. The averages of productivities of the single chippers based on loose volume, green mass and dry mass were 309 m³/E_0h, 113.7 t/E_0h and 52.2 t/E_0h (Figure 3).

On average, the most time consuming work elements were: Swinging the boom towards a bundle stack (crane out), Transferring the grapple bunch to the chipper (crane in) and Feeding the grapple bunch into the chipper with the proportions of 25, 28.4 and 26.2% (Figure 3). The average weight of grapple bunches of the A, B, C, D and E machine types was 428, 456, 447, 595 and 405 kg. Average grapple bunch weight of all chippers was 466 kg.

4. Discussion

Our study analyzed moisture content and particle size distribution of small diameter whole tree bundles comminuted by six different machines. Of the chips comminuted, moisture content was very high (52-60%) and did not fulfill the minimum requirement of the power plant. The high moisture

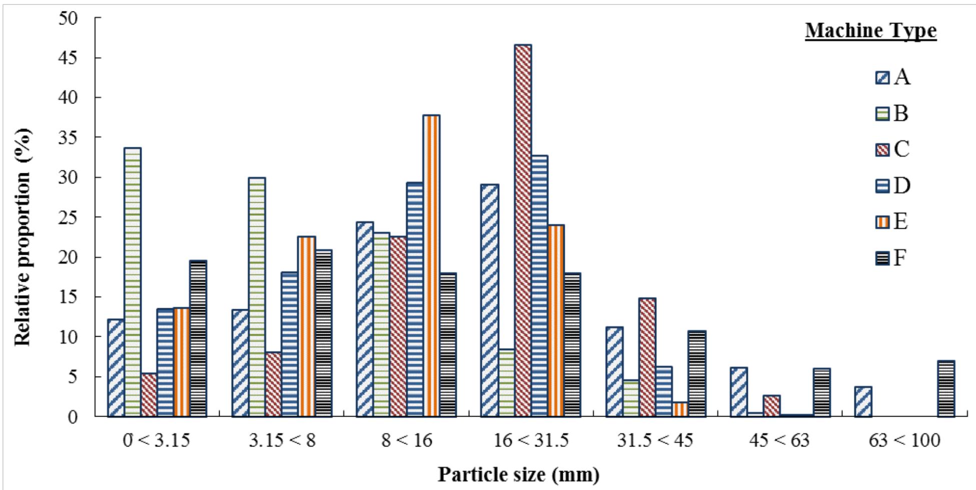

Figure 1. Figure 1. Particle size distribution of chips comminuted.

Table 2. Particle size classes for chips comminuted for studied machines by SFS-EN ISO 17225-1, mean particle size, moisture content, moist and dry bulk density.

Machine type	Main fraction class (w-%)	Fine fraction class (w-%)	Mean particle size50%(mm)	Moisture content (w-%)	Moist bulk density after chipping (kg/m³)	Dry bulk density (kg/m³)
A	P31S (66.8)	F15 (12.2)	16.08	51.9	371	178
B	P31S (61.3)	F30+(33.7)	5.79	59.9	417	167
C	P31S (77.2)	F10 (5.4)	20.64	54.7	353	160
D	P31S (80.1)	F15 (13.5)	13.02	51.9	369	177
E	P16 (60.4)	F15 (13.6)	10.93	55	351	158
F	P456 (67.5)	F20 (19.5)	12.3	58	259	109

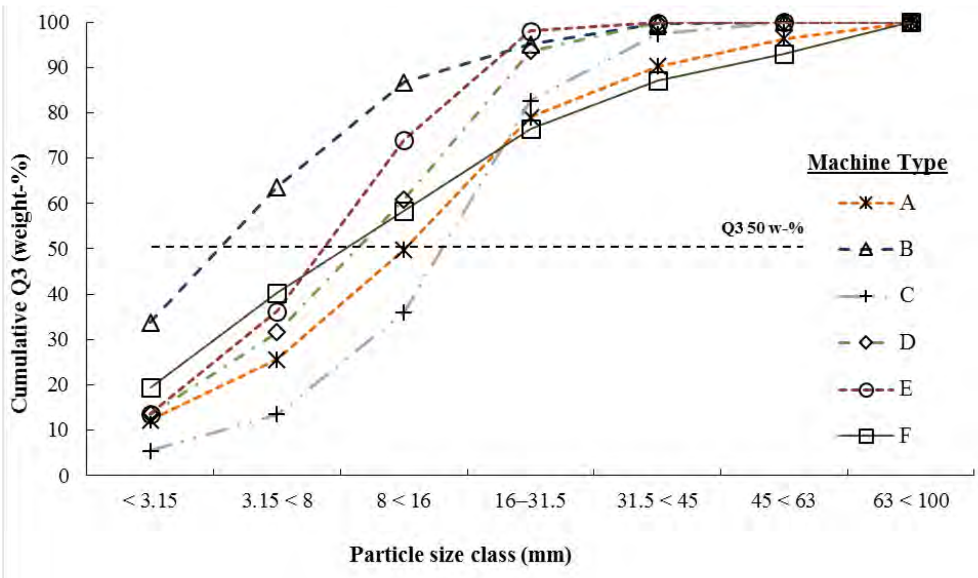

Figure 2. Cumulative particle size distribution.

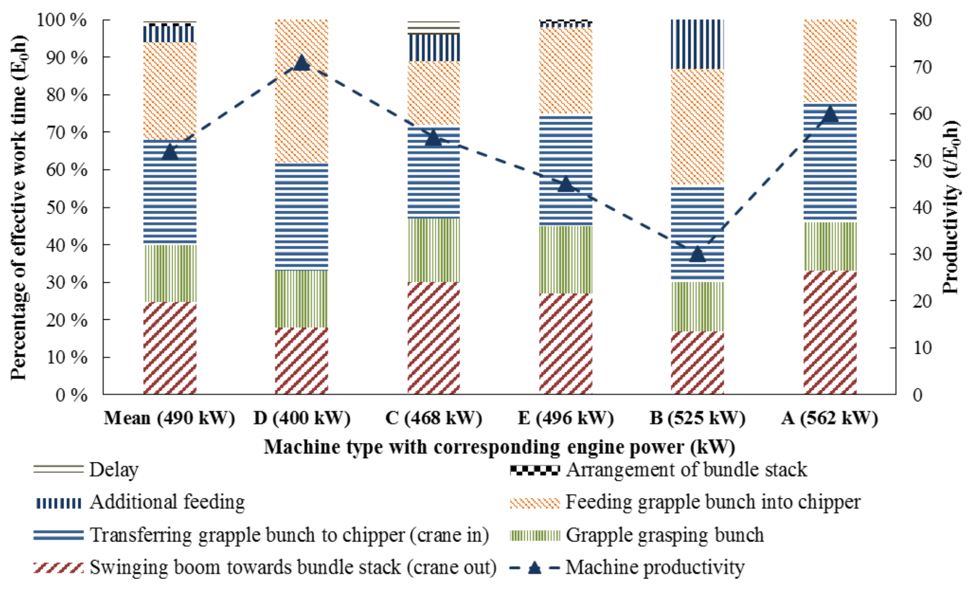

Figure 3. Effective hour chipping productivity (t/E_0h) of forest chips by dry mass basis and distribution of working time among tested machines.

content was estimated to be due to size of the bundle storage between late autumn and late winter, as well as place and formation of piles preventing the bundles from drying enough. However, as raw material particle size distribution and productivity of comminution were the primary focus, high moisture content did not have an adverse influence on the study.

The chips of machine type B held the highest proportion of fine fraction of diameter under 3.15 mm and machine type C the lowest (Table 2). In the study of Jylhä (2013) the proportion of fine fractions increased when using sieves of smaller diameter. However, in our study, machine types C and B produced minimum and maximum proportions of fine fraction (Figure 1) using the same the sieve sizes (Table 1, Figures 1). Spinelli et al. (2014) found that dulling of the cutting blades significantly decreases chipping productivity, increasing the proportion of fine and oversize particles. In this study, the operation time of 15-30 min per each machine indicates that the cutting blades were sharp throughout the entire operating time period. Furthermore, the plastic netting used in compressing bundles did not hinder chipping. In the study of Jylhä (2013), moisture content decreased from 56 to 54 and 53% with decreasing sieve sizes from 80x150mm, 40x60mm, and 30x30mm. Jylhä (2013) states that the result indicates that chipping of smaller particles increases the friction, allowing transpiration of water from chips.

In our study, no clear trends were exhibited between sieve size and moisture content of chips. The chips comminuted by machine type B had the highest moisture content (Table 2) and largest proportion (33.7%) of particles < 3.15 mm in diameter (Figure 1, Table 2). However, this is most probably the result of uneven moisture content of the bundles in storage. Additionally, the machine was being operated for the first time, which could have influenced both the performance and quality. Results of Jylhä (2013) and our study indicate that sieve size is important for adjusting particle size distribution during chipping operations. In the study of Jylhä (2013), the proportions of the chips in diameter classes 3.15 < 8, 8 < 16 and 16 < 31.5 mm were 17, 29 and 35% using a sieve size of 80x150 mm. In our study the proportions were 18.1, 29.3 and 32.7% with the sieve size of 80x120 mm. Median particle size in the study of Jylhä et al. (2013) was 14.3 mm, while our study was 13.0 mm. The chippers of our study were equipped with sieves, effectively removing coarse fraction > 45 mm. Eliasson et al. (2015) and Kons et al. (2015) show that sieve size had only a modest effect on the particle size distribution for a large drum chipper. This is due to the fact that the sieve's main role in a large drum chipper is to recirculate oversized particles, which means that the chip size is primarily determined by the knife configuration and settings (Eriksson et al. 2013, Eliasson et al. 2015).

The F machine type, crushing the raw material, did not have a sieve process and therefore could not remove coarse fractions > 45 mm (Figures 1). In this study, with the exception of raw material of machine type C, the proportions of fines < 3.15 mm in diameter were relatively high. The relatively high proportions are likely due to the large percentage of pre-commercial tops and branches that make up small-diameter whole tree bundles. Jirjis (2005), Spinelli et al. (2005), Nati et al. (2010) and Nuutinen et al. (2014) have found that chips comminuted from whole-trees included significant amounts of fine fraction < 3.15 mm.

However, Kons et al. (2015) found whole-tree bundle chips proportion of fines < 3.15 mm at 2.6%, which is significantly less than previous studies (Jirjis 2005, Spinelli et al. 2005, Nati et al. 2010, Nuutinen et al. 2014). Kons et al. (2015) studied effects of sieve size and assortment on wood fuel quality during chipping operations. The study was carried out using a drum chipper with technical features comparable to the chippers of our study. In total five different assortments were chipped utilizing Fixteri-whole-tree bundles. The bundles were stored around 3 months before chipping. The moisture content of bundle-chips were 45 and 46% dependent on sieve size. In SFS-EN ISO 17225-1 standard, average standard particle size dimension for two studied sieve sizes of the whole tree bundle chips was P31S (84.6%) F10. Respectively, the chips comminuted by four studied chippers of our study had the same main fraction as in the study of Kons et al. (2015) (Table 3). However, in the study of Kons et al. (2015) 63% of the dry mass of the whole-tree bundle chips was between 16 < 31.5 mm, whereas in our study the proportion varied from 8.4 to 46.6% (Figure 1). In spite of lower moisture content recorded in the study of Nuutinen et al. (2014) than in our study, the particle size distribution found by Nuutinen et al. (2014) was comparable with the particle size distribution results of our study. Nuutinen et al. (2014) studied the CBI 5800 fast-running grinder for processing of stumps, logging residues and whole-trees. In the study the SFS-EN ISO 17225-1 standard particle size dimension for whole-trees was P31 (77%) F15 and moisture content 40w-%.

In our study, the average productivity based on dry mass of chipping the whole-tree bundles was 52 t/E_0h. In the study of Kons et al. (2015), the dry mass productivity for the Fixteri Fx15a whole-tree bundles was 32 t/E_0h whereas the productivities of delimbed whole-trees and logging residues were significantly lower accounting for 16 and 14 t/E_0h. In the study of Nuutinen et al. (2014) the productivity based on dry masses of grinding logging residues was 29 t/E_0h, 25 t/E_0h for whole-trees and 17 t/E_0h for stumps. The higher productivity in chipping of whole-tree bundles compared to grinding productivities of logging residues, whole trees and stumps resulted from increased size of grapple bunch per crane cycle. Nuutinen et al. (2014) found the average weight of grapple bunch for logging residues, whole trees and stumps to be 237 kg, 260 kg and 119 kg, whereas the average grapple bunch of all chippers of this study was 466 kg. The recorded video material was insufficient to statistically compare the productivities of the individual machines, therefore the differences presented are only indicative. Our study revealed no clear positive trend of achieved productivities as the power input of the machine engine increased. This is illogical, but likely demonstrates that machine engine power is not the only influencing factor in comminution productivity.

However, the average productivity level of all tested machines indicates the feasibility of the whole-tree bundles as a comminuting raw material. The results of Kons et al. (2015) and Nuutinen et al. (2014) compared to findings of our study indicate that whole-tree bundles are potential solutions to efficiently produce forest chips from small-diameter wood. Differences in achieved productivities and fuel qualities among various chipping and grinder systems were evident, thus further examining the effects of technology and raw material is necessary to discern influences on productivities and quality of produced forest chips.

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Accurate estimation of wood chip volume to increase efficiency in allocating chipper and transport capacities

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Abstract
Chipping operations at the forest roadside are today the standard procedure for forest wood chip production in Bavaria. The accurate estimation of the amount of wood chips that can be expected in a planned operation is necessary for the efficient allocation of chipper and transport capacities. The most common approach is to measure or estimate pile volume and to convert this volume into the expected wood chip volume using conversion factors. During the project, 101 wood piles were measured and six different geometrical formulas used to calculate pile volume. The amount of wood chips produced from these piles was measured in order to determine accurate conversion factors. The conversion factors are influenced by the density of the pile. Recommended conversion factors for forest residues lie between 0.3 and 0.5, for energy roundwood between 1.2 and 1.8 (bulk cubic metres of wood chips per cubic metre pile volume).

Keywords
wood chips, quantity estimation, conversion factors, logistics

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1. Introduction

With growing demand for renewable energy from wood, the production of wood chips is today a standard procedure in Bavarian forestry. Chipping is organised at forest roadside as a decoupled production step. Forest owners may assign different contractors for harvesting, skidding, chipping and transport, and sell their products through different market channels. Where several actors are involved, it is necessary to have accurate estimations of quantities of raw materials and products. These estimations are used for the efficient allocation of personnel and machine resources, as a control measure along the production chain, and for sales planning.

Practitioners have developed estimation methods for wood chip volume that are based on three types of data: The total amount of wood harvested during the operation, the number and dimension of trees, or the dimensions of wood piles for chipping.

In harvesting operations in older stands, where saw logs are produced alongside energy wood for chipping, the wood chip quantity can be estimated by the overall volume of saw logs. In Bavarian conditions, a good rule of thumb for spruce stands is to expect 0.3 to 0.6 bulk cubic metres (bcm) of wood chips for every solid cubic metre of saw logs harvested, depending on stand density and the minimum diameter of saw logs (BaySF 2009).

In smaller piles, tree parts (crowns) may be counted. Depending on the minimum diameter of saw logs produced, which is equivalent to the diameter of cut surfaces visible on the front side of the piles, different quantities of wood chips per crown can be produced. Wittkopf (2005) examined this in detail and found that for 10 cm diameter at crown base, 0.1 bcm of wood chips can be expected, for 20 cm diameter the amount is 0.75 bcm.

Especially for small and medium sized forest enterprises, the method using the dimensions of piles is most common and most practicable. This is a two-step approach: First, the pile volume needs to be measured (or estimated) in an efficient but accurate way. Second, a fitting conversion factor must be used to calculate the expected wood chip volume. The problem in measuring pile volume is the heterogenic form of the piles, with no fixed length of tree parts and possible changes in width and height from front to back.

Conversion factors between pile volume and wood chip volume can be derived from various sources. The Austrian standard Ö-Norm M7132 (ÖN 1998) declares a wood volume of 0.4 solid cubic metres per bcm of wood chips (particle size G30) and of 0.35 solid cubic metres per stacked cubic metre of branches and brushwood and of 0.7 solid cubic metres per stacked cubic metre of logs respectively. A combination of the given factors leads to conversion factors of 0.88 or 1.75 bcm of wood chips per stacked cubic metre pile volume, depending on the raw material. Kress (2010) analysed operation records of a Swiss forestry contractor. The pile shape is defined as a cuboid and different correction factors are used. A complex formula is also developed to calculate wood chip volume, which is described as pretty accurate. However, this uses input parameters that are rather difficult to determine, such as the percentages of coniferous and hardwood species and of tree parts above 7 cm in diameter. BaySF (2009) recommends a simplified approach: The pile volume is calculated as volume of a cuboid, where the height is the educated guess of the mean height. The conversion factor is then 0.6 bcm per cubic metre pile volume (higher when crown base diameters are 15 cm or above, lower when brushwood proportion is high).

To date, the reports on inaccuracies of all described methods and on problems in allocating the right capacities are numerous. Discrepancies of up to 100% of the estimated wood chip volume are common. During a research project funded by the Bavarian State Ministry of Food, Agriculture and Forestry and conducted in cooperation with the Technology and Support Centre (TFZ), the complete wood chip production chain was examined. One of the goals of the project was to analyse estimation methods and recommend an approach which is both accurate and easy to apply.

2. Material and Methods

2.1 Measurements in the field

During field studies, 101 wood piles for chipping were measured using tape measure, direction poles, and height measuring sticks. The base and top length, maximum height and mean height of the front side and the back side, and the depth on either side were measured. The aim was to have extensive data on each pile that could then be used to calculate different geometrical shapes.

On a sample area of 20% of the front side, the cut surfaces of tree parts were recorded. All visible cut surfaces were counted and measured, resulting in the percentage of cut surfaces on the front side and the diameters of tree parts.

The wood piles were categorized by type of raw material (forest residues and energy roundwood). The piles were chipped with mobile drum chippers directly into containers. Wood chips were levelled in the containers with pitchforks and the volume of wood chips produced from each pile was measured using tape measure and yard stick.

2.2 Geometrical analysis

Six geometrical formulas were used to calculate the volume of the piles.

V_{Cub}: Volume of cuboid with maximum height

V_{CubM}: Volume of cuboid with mean height

V_{Pri}: Volume of prism

V_{FrPy}: Volume of frustum of a pyramid

V_{Cyl}: Volume of cylinder

V_{HFrCo}: Volume of halved frustum of a cone

The corresponding shapes are shown in Figure 1. The formulas are given in the following. Abbreviations are explained in Table 1.

Volume of cuboid with maximum height

The cuboid with maximum height is the simplest formula used.

$$V_{Cub} = l_{bf} * h_{maxf} * d_{mean} \tag{1}$$

Volume of cuboid with mean height

This cuboid shape uses the mean height, which is determined by dividing the front side into sections and measuring the height of each section (Figure 2; Right).

$$V_{CubM} = l_{bf} * h_{meanf} * d_{mean} \tag{2}$$

Volume of prism

Seeing a pile as a prism shape, the surface area of the front side is calculated as trapezium.

$$V_{Pri} = A_f * d_{mean} \tag{3}$$

$$A_f = \frac{l_{bf} + l_{uf}}{2} * h_{maxf} \tag{4}$$

Volume of frustum of a pyramid

Extending the prism formula, the frustum of pyramid uses two different surface areas for front and back side, each one calculated as a trapezium. The volume of frustum of a pyramid is the one with most input parameters. It is therefore used as reference for assessing the accuracy of the other formulas in further analysis.

$$V_{FrPy} = \frac{d_{mean}}{3}(A_f + \sqrt{A_f * A_b} + A_b) \tag{5}$$

$$A_f = \frac{l_{bf} + l_{uf}}{2} * h_{maxf} \tag{6}$$

$$A_b = \frac{l_{bb} + l_{ub}}{2} * h_{maxb} \tag{7}$$

Volume of cylinder

Seeing a pile as a horizontal straight cylinder, the front and back side are identical. The surface area is calculated as halved ellipse.

$$V_{Cyl} = A_f * d_{mean} \tag{8}$$

$$A_f = \frac{\pi * \frac{l_{bf}}{2} * h_{maxf}}{2} = \frac{\pi}{4} * l_{bf} * h_{maxf} \tag{9}$$

Volume of halved frustum of a cone

Extending the cylinder formula, the frustum of a cone uses two different surface areas for front and back side, each one calculated as a halved ellipse.

$$V_{HFrCo} = \frac{d_{mean}}{3} * (A_f + \sqrt{A_f * A_b} + A_b) \tag{10}$$

$$A_f = \frac{\pi * \frac{l_{bf}}{2} * h_{maxf}}{2} \tag{11}$$

$$A_b = \frac{\pi * \frac{l_{bb}}{2} * h_{maxb}}{2} \tag{12}$$

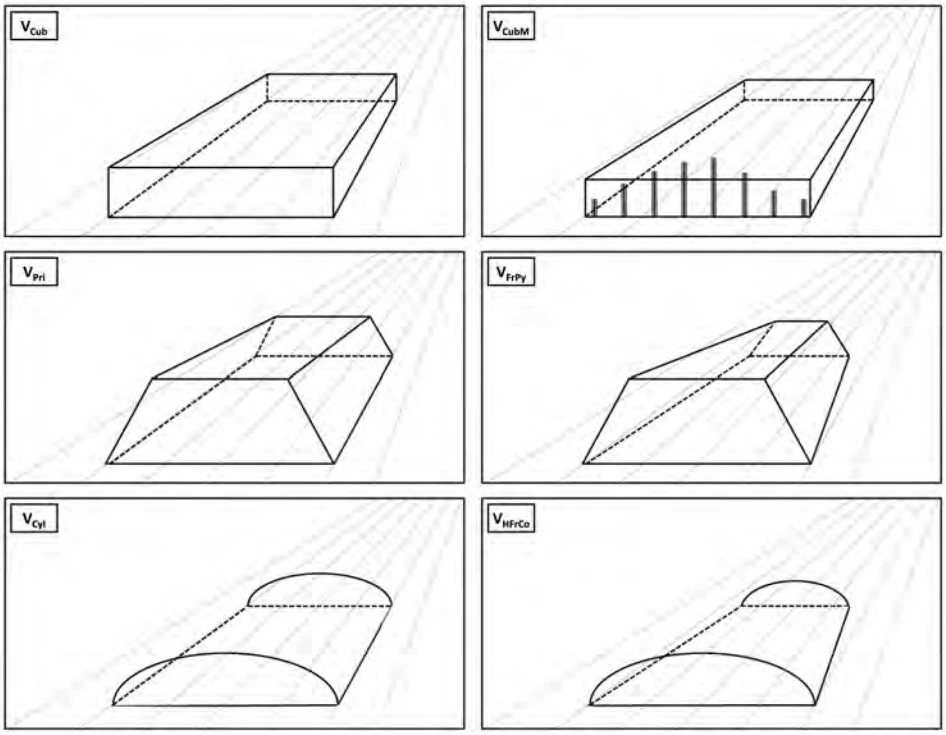

Figure 1. Overview of geometrical shapes used to calculate wood pile volume.

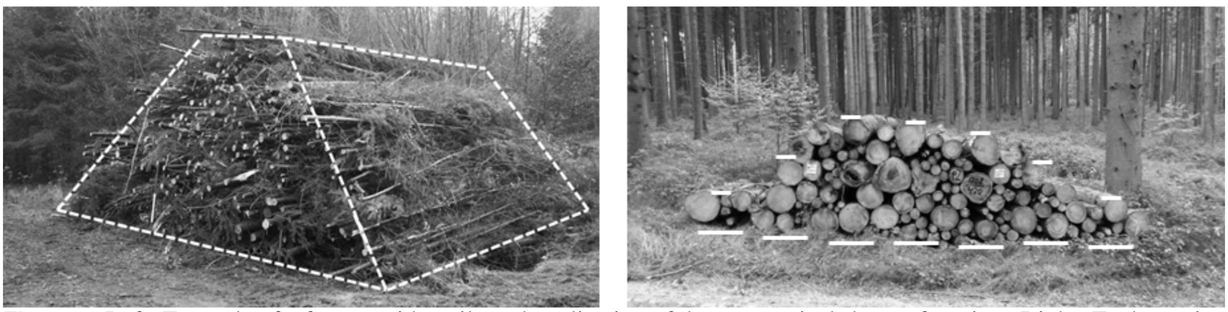

Figure 2. Left: Example of a forest residue pile and application of the geometrical shape of a prism; Right: To determine mean height, an energy roundwood pile is divided into 1 m wide sections and the height in the centre of every section is measured.

Table 1. Abbreviations in the six geometrical formulas used to calculate wood pile volume.

Abbreviation	Parameter
l_{bf}	Base length of front side
l_{uf}	Upper length of front side
l_{bb}	Base length of back side
l_{ub}	Upper length of back side
h_{maxf}	Maximum height of front side
h_{meanf}	Mean height of front side
h_{maxb}	Maximum height of back side
d_{mean}	Mean depth
A_f	Surface area of front side
A_b	Surface area of back side

3. Results

3.1 Geometrical shapes

Extensive measurements were conducted on 101 piles at forest roadside (70 forest residues, 31 energy roundwood). The front side and depth on either side were measured on all 101 piles. The back side was measured on 72 piles. The mean height of the front side was determined on 19 piles. Measuring the mean height of the back side was not practicable in forest conditions. The frustum of a pyramid was seen as the most accurate shape to describe the true shape of the majority of piles. The formula used for calculating its volume is also the one with most input parameters. V_{FrPy} was therefore used as reference for assessing the accuracy of the other formulas with less input parameters. Figure 3 shows the relation of the other calculated volumes to V_{FrPy}. As expected, the volumes of cuboid with maximum height (V_{Cub}) display the highest deviation for both forest residues and energy roundwood. A higher number of input parameters tends to result in higher accuracy in relation to V_{FrPy}. Measurements on the back side are included in V_{FrPy} and V_{HFrCo}. Changes in height and width along the depth of the piles are taken into account in these two formulas only.

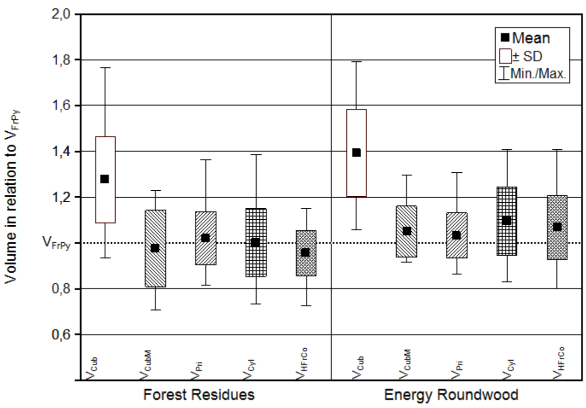

Figure 3. Volumes of geometrical shapes in relation to volume of frustum of a pyramid (V_{FrPy}).

3.2 Conversion factors

The amount of wood chips produced was recorded for 56 piles (36 forest residues, 20 energy roundwood). In 30 cases, the volume was measured by the research team, in 26 cases, the volume was determined by the machine operator. For forest residues, 1 cubic metre pile volume resulted in 0.32 ± 0,15 bcm wood chips (Figure 4). For energy roundwood, the factor was 1,59 ± 0,35.

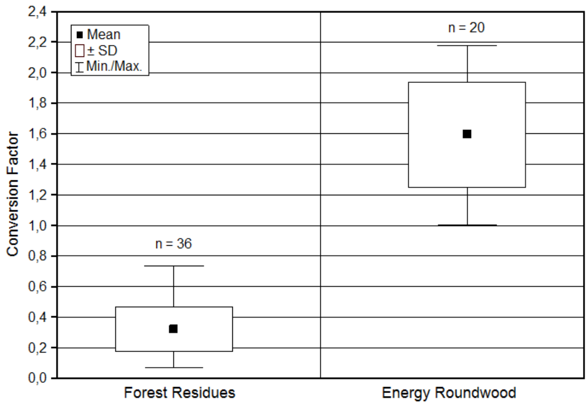

Figure 4. Conversion factors from pile volume to wood chip volume for forest residues and energy roundwood.

3.3 Cut surfaces on front side

Visible cut surfaces on the front side were measured in sufficient sample size (20% of front side area) on 29 piles (11 forest residues, 18 energy roundwood). Due to time constraints and safety issues it was not possible to realise the time-consuming measurements on more piles. Especially forest residue piles were difficult to measure as they usually do not have a two-dimensional front side. Tree parts that lie further back may be hidden by other branches. Measuring the cut surfaces on energy roundwood piles proved to be fairly easy.

The mean percentage of cut surfaces on the front side was 20.2 ± 8.9% for forest residues and 61.5 ± 8.6% for energy roundwood. A significant correlation between this percentage and the conversion factor can be seen in Figure 5. In contrast, the influence of the mean diameter of tree parts was not significant.

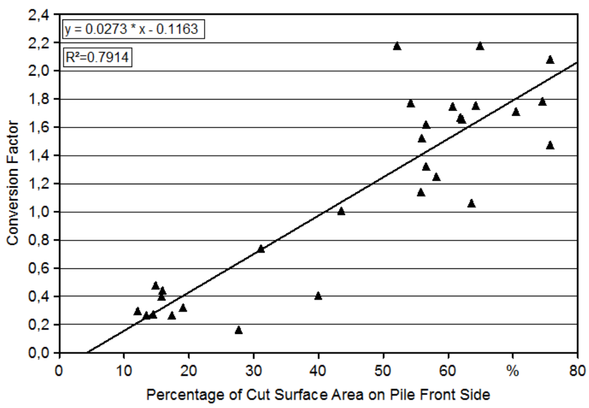

Figure 5. Correlation between the percentage of cut surface area on the front side of wood piles and corresponding conversion factors from pile volume to wood chip volume.

Table 2. Typical conversion factors for forest residues and energy roundwood, depending on the percentage of cut surfaces on the front side of the pile.

	Forest Residues			Energy Roundwood		
Percentage of cut surfaces on front side [%]	15	20	25	50	60	70
Conversion factor	0.3	0.4	0.5	1.2	1.5	1.8

4. Development of a practicable estimation method

Based on the presented findings, a practicable method for estimating wood chip volume was developed using the two-step approach.

4.1 Estimation of pile volume

The effort for measuring increases dramatically with the number of input parameters needed for the volume formulas. As value added is rather low for wood chips, a quick and easy method should be used. As the two types of raw material (forest residues and energy roundwood) have different characteristics and the produced wood chips can realise different prices, they are treated separately. V_{FrPy} and V_{HFrCo} take the back side of piles into account and are very accurate. However, measurements on the back side are not practicable in real operations.

Measuring the mean height using the sectional method (Figure 2; Right) is relatively easy and it is a standard measure for industrial assortments such as pulpwood. As energy roundwood piles do not show extreme changes from front side to back side in height and width, V_{CubM} leads to adequate results. 70% of volumes lay between 0.9 and 1.1 times V_{FrPy}. A correction of ±10% of V_{CubM} can be used when energy roundwood piles are untypically irregular. The volume of energy roundwood piles may be calculated as follows, using the formula for the volume of cuboid with mean height:

$$V_{EneRou} \approx l_{bf} * h_{meanf} * d_{mean} \pm 10\% \tag{13}$$

Forest residue piles are more irregular and wood chips have lower qualities, leading to lower prices. In addition, the amount of wood chips per cubic metre pile volume is much lower, leading to much less value added per pile. The irregularity would lead to more input factors needed, creating more costs, which could not be refinanced. Comparison of the different geometrical shapes showed that V_{Cyl} is relatively accurate for such piles, with 70% of volumes lying between 0.9 and 1.1 times V_{FrPy}. V_{Cyl} needs only few input parameters: base length and maximum height at front side and mean depth. The volume of a forest residue pile may be calculated as follows, based on the formula for the volume of cylinder (π/4 is simplified as 0.8):

$$V_{ForRes} \approx 0.8 * l_{bf} * h_{maxf} * d_{mean} \pm 10\% \tag{14}$$

4.2 Conversion factors

The percentage of cut surfaces on the front size of a pile has influence on the resulting conversion factor. Table 2 shows typical values for forest residues and energy roundwood. To find the right conversion factor in the field, rules of thumb are needed. Measuring the percentage of cut surfaces is very time consuming and not always feasible, especially with irregular forest residue piles. Therefore, typical data for the raw materials should be used.

All forest residue piles examined in this study showed a percentage below 40%, mean percentage was 20.2%. Conversion factors from 0.3 to 0.5 are therefore recommendable. The energy roundwood piles showed percentages of 43.5-75.7%, mean percentage was 61.5%. Conversion factors of 1.2 to 1.8 are recommended, depending on the density of the stems in the pile. Local experience will help find fitting factors within these boundaries.

Acknowledgements

This work was funded by the Bavarian State Ministry of Food, Agriculture and Forestry (grant number K/10/17). We also thank our colleagues Florian Zormaier and Florian Mergler of LWF and Daniel Kuptz, Hans Hartmann, Peter Turowski and Albert Maierhofer of the Technology and Support Centre (TFZ) for their contribution in this research.

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Topic 7

Logistics

Optimum bucking method for clear-cutting operations in Nasu Forest Owners' Co-operative, Tochigi prefecture, Japan

K.Aruga*, Y. Mizuniwa, R. Uemura, C. Nakahata

Abstract
This study established equations for estimating the costs of processor processing and forwarder forwarding operations considering log sizes, by investigating clear-cutting operations on middle- and gentle-slope terrains. It also utilized the established equations for developing a cross-cutting pattern algorithm for maximizing profits. Using this algorithm, the optimum bucking level was estimated and compared with the investigated results, which indicated an increase in the extracted rates and volumes from the investigated results, for both terrains. As revenues increased, profits also increased by 2.20 and 1.50 times the investigated results, for middle- and gentle-slope terrains respectively. Furthermore, the extracted volumes increased by 1.01 and 1.66 times the investigated results respectively, leading to an increase in total profits of 2.22 and 2.48 times. On middle- and gentle-slope terrain, saw logs constituted 45.0% and 44.6%, and 90.4% and 89.4% of the investigated and estimated results, respectively.

Keywords
clear cutting, optimum bucking, cost, log volume

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1. Introduction

Japan depends on the import of oil, coal, and natural gas for the majority of its energy supply. The country's energy self-sufficiency rate was just 5% in 2010 (Forestry Agency, The Ministry of Agriculture, Forestry, and Fisheries of Japan, 2013). To secure a stable supply of energy, alternatives to fossil fuels, such as renewable energy sources including; solar, wind, river, geothermal heat and biomass, need to be developed. Among various biomass resources in Japan, woody biomass particularly attracts attention because of its abundance and the potential for its energy use to contribute towards revitalizing forests and forestry product industries, which have been depressed for the last 30 years. It is also important to maintain the relevant ecological, economic, and social functions of man-made forests, which are lagging in terms of tending operations.

In July 2011, the Feed-in Tariff (FIT) Scheme for Renewable Energy Use was introduced in accordance with a new legislation entitled Act on Purchase of Renewable Energy Sourced Electricity by Electric Utilities. Under the FIT program, electricity generated from woody biomass must be procured for 20 years at a fixed price (without tax) for (a) unused materials such as logging residue (at 32 yen/kWh, USD 1 = 119 yen), (b) general materials such as sawmill residue (at 24 yen/kWh), and (c) recycled materials such as construction waste wood (at 13 yen/kWh) (Agency for Natural Resources and Energy, 2012). The power generated from unused materials has been made eligible for incentives, and this is expected to promote the use of logging residue in the near future.

Because delays in thinning present a serious problem for planted forests in Japan, numerous studies have examined the profitability of commercial thinning operations (Ishikawa et al., 2008; Nakahata et al., 2014; Sawaguchi et al., 2009). Japan's forest resources have become adequately mature for final felling operations. The share of the planted forest area exceeding 50 years of age was 35% in 2007 and is expected to exceed 60% by 2017 (Forestry Agency, The Ministry of Agriculture, Forestry, and Fisheries of Japan, 2013). However, the expected profit from final felling (1,170,000 yen/ha) does not cover the expenses of reforestation over the next decade (1,560,000 yen/ha) (Forestry Agency, The Ministry of Agriculture, Forestry, and Fisheries of Japan, 2013). Therefore, many forest owners are unwilling to conduct final felling operations and instead, opt to extend the cutting age, anticipating increased revenues from an increase in log volumes and prices. Furthermore, a few forest owners are unwilling to undertake regeneration operations even on unsuitable natural regeneration sites after the final felling operations.

The Nasu Forest Owners' Co-operative extracts smaller-diameter logs for producing pellets or pulp in addition to larger-diameter logs for saw timber or laminated lumber, from commercial thinning operations. Although the extraction of smaller-diameter logs increases revenues, it also increases costs and subsequently reduces profitability. Nakahata et al. (2013) investigated the commercial thinning operations of the Nasu Forest Owners' Co-operative. They analyzed the relationships between log size and operational cost of processing and forwarding, and developed equations for estimating operational costs based on log sizes. The operation costs estimated using the equations were found to be higher for the extraction of smaller-diameter logs. Thus, Nakahata et al. (2014) determined optimum bucking methods for maximizing the profits and optimum extraction rates for small-sized logs.

The Nasu Forest Owners' Co-operative has been willing to conduct final felling operations because of less demand for large logs (of diameter >40 cm). Mizuniwa et al. (2015) estimated the economic balances from clear-cutting operations (including planting and tending operations) conducted for 15 years on middle- and gentle-slope terrains. They found that the operations on both terrains were profitable. This study established equations for estimating the costs of processor processing and forwarder forwarding operations considering log sizes (based on investigations into clear-cutting operations on middle- and gentle-slope terrains), and developed a cross-cutting pattern algorithm for maximizing profits, which incorporated these cost estimation equations as did Nakahata et al. (2014). Using this cross-cutting pattern algorithm, the optimum bucking level was estimated and compared with the investigated results.

2. Material and Methods

2.1 Study sites

The two study sites were located in Nasu, Tochigi Prefecture, Japan. The sites A and B were moderately and gently sloping, respectively (Table 1). The average slope angles of Sites A and B were 28°and 6°, respectively. Clear-cutting was done on Sites A and B in 2013 (58 years old) and 2010 (50 years old), respectively. Both sites were planted with Japanese cedar, also known as sugi (*Cryptomeria japonica*), the major plantation tree species in Japan. The areas of Sites A and B were 0.77 and 1.45 ha, respectively. At Sites A and B, the values for average diameter at breast height (DBH), tree height, and stem volume were, respectively, 30 cm, 23 m, and 0.89m^3/stem and 28 cm, 22 m, and 0.71m^3/stem, respectively. The harvested and extracted volumes at Site A were, respectively, 711.18 and 638.65m^3/ha higher than the 641.19 and 472.56m^3/ha, respectively, at Site B. However, the stem density at Site A was 800 stems/ha less than the 900 stems/ha at Site B. The mechanized operation system included chainsaw (Husqvarna 550XP G) felling, grapple loader (Hitachi ZAXIS135US with Iwafuji GS90LJV) bunching, processor (Hitachi ZAXIS135 with Iwafuji GP-35A) processing, and forwarder (Iwafuji U-4SBG) forwarding. Strip road networks were established at 3.5 m width with grapple buckets (Hitachi ZAXIS135US with Matsumoto System Engineering MSE-45ZR).

2.2 Methods

The optimum bucking method for maximizing profits was determined using the following process: 1) determine the taper curve formula, 2) estimate the extracted volumes, 3) estimate revenues, 4) estimate expenses, 5) estimate economic balances, and 6) determine the optimum bucking method for maximizing profits. The stem diameter *d* (cm) at height *h* (m) above the ground was estimated using the following taper curve formula (Inoue and Kurokawa, 2001).

$$d = \frac{\{a(1-\frac{1.2}{H}) - 0.9a + 1.8\}(1-\frac{h}{H})}{\{a(1-\frac{h}{H}) - 0.9a + 1.8\}(1-\frac{1.2}{H})}D \tag{1}$$

where H denotes the tree height (m) and D denotes DBH (cm). The coefficient a was estimated as follows:

$$a = \frac{(18-\frac{21.6}{H}) - 12.6\sqrt{\frac{7}{10f}}}{(2-\frac{2.4}{H}) + (0.7-\frac{8.4}{H})\sqrt{\frac{7}{10f}}} \tag{2}$$

where f denotes the breast height form factor, estimated as follows:

$$f = \frac{4Vn}{\frac{HD^2\pi}{10{,}000}} \tag{3}$$

The extracted logs were classified as saw, lamina, and chip logs (through an interview with the Nasu Forest Owners' Co-operative). Saw logs were 3.00, 3.65, and 4.00 m long with their top-end diameters exceeding 10, 26, and 10 cm, respectively. Lamina and chip logs were both 2 m long, with their top-end diameters exceeding 16 and 6 cm, respectively. Saw logs were sold at a log auction market at prices between 7,500 and 13,000 yen/m^3. Lamina logs were sold at landings for a laminated lumber factory at prices of 5,000 yen/m^3. Chip logs were sold at landings for a pellet plant or chip production factory at prices of 3,000 yen/m^3. The cutting height was assumed to be 20 cm above the ground (Iehara and Kurokawa, 1990). The possible combinations of log lengths bucked from felled wood were estimated, and the values for log volume v (m^3/log) were estimated using those for log length l (m) and top-end diameter of log, using the estimated value of d.

$$v = \frac{d^2 l}{10{,}000} \tag{4}$$

The values of felling cycle time CT_C (s/stem) were related to those of stem volume Vn (m^3/stem) using regression analysis, at Site A (Fig. 1, Eq. 5). The figure shows the average CT_C versus average Vn at Site B and the regression equation (Eq. 6) for thinning operations, established by Nakahata et al. (2011).

$$CT_{Cc} = 69Vn + 61 \tag{5}$$

$$CT_{Ct} = 136Vn + 111 \tag{6}$$

Thereafter, equations for estimating the productivities (Eq. 7) and costs (Eq. 8) of felling operations at Site A were established using the values for labor (2,550 yen/h) and machinery expenses incurred for maintenance, management, depreciation, and fuel and oil (Table 2, Japan Forest Technology Association, 2010).

Table 1. Study site

	Site A	Site B
Clear felling (year)	2013	2010
Species	Japanese cedar	Japanese cedar
Age (year)	58	50
Area (ha)	0.77	1.45
Slope angle (°)	8	6
Road density (m/ha)	769.31	272.37
DBH (cm)	30	28
Height (m)	23	22
Stem volume (m^3/stem)	0.89	0.71
Stem density (stem/ha)	800	900
Harvested volume (m^3/ha)	711.18	641.19
Extraction rate	0.9	0.74
Extracted volume (m^3/stem)	0.8	0.53
Extracted volume (m^3/ha)	638.65	472.56

Table 2. Machinery expenses

Machine	Expense [yen/h]
Chainsaw	130
Grapple loader	4,645
Processor	5,480
Forwarder	3,789

$$P_{Cc} = \frac{3,600Vn}{69Vn+61} \tag{7}$$

$$OE_{Cc} = \frac{45}{Vn} + 51 \tag{8}$$

The productivities and costs of felling operations at Site B were estimated as 45.82 m^3/h and 58 yen/m^3, respectively and those of bunching operations, respectively, at Sites A and B were estimated as 11.47 m^3/h and 640 yen/m^3, and 26.51 m^3/h and 423 yen/m^3, respectively (Mizuniwa et al., 2015)

The values of average delimbing and cross-cutting time *tpp* (s/log) were related to those of average log volume *Vla* (m^3/log) using regression analysis, at Sites A (Eq. 9) and B (Eq. 10), as shown in Fig. 2. The figure shows the regression equation (Eq. 11) for thinning operations, established by Nakahata et al. (2013).

$$tpp_{c1} = 95.3Vla - 0.1 \tag{9}$$

$$tpp_{c2} = 29.2Vla + 3.8 \tag{10}$$

$$tpp_{t} = 84.0Vla + 9.1 \tag{11}$$

The values of piling time of processing operations *tpl* (s/stem) were related to the number of logs *n* (logs/stem) using regression analysis, at Sites A (Eq. 12) and B (Eq. 13), as shown in Fig. 3. The figure shows the regression equation (Eq. 14) for thinning operations, established by Nakahata et al. (2013).

$$tpp_{c1} = 12.7n + 23.4 \tag{12}$$

$$tpp_{c2} = 4.5n + 8.1 \tag{13}$$

$$tpp_{t} = 5.6n + 9.1 \tag{14}$$

The tree grabbing and tops processing times of processing operations, respectively, at Sites A and B were 14 and 10 s, and 10 and 9 s, respectively. Therefore, the values of processing cycle time CT_p (s/stem) at Sites A and B can be expressed using Eqs. 15 and 16.

$$CT_{Pc1} = (95.3Vla + 12.6)n + 46.9 \tag{15}$$

$$CT_{Pc2} = (29.2Vla + 8.3)n + 27.1 \tag{16}$$

Thus, the costs of processing operations at Sites A and B can be expressed using Eqs. 17 and 18.

$$OE_{Pc1} = \frac{(212.6Vla + 28.1)n + 104.6}{Vla * n} \tag{17}$$

$$OE_{Pc2} = \frac{(65.1Vla + 18.5)n + 60.4}{Vla * n} \tag{18}$$

The values of loading and unloading time of forwarding operations *tel* (s/cycle) were related to the number of loaded logs *n* (logs/cycle) using regression analysis, at Sites A and B (Fig. 4, Eq. 19).

$$tel_{Fc} = 5.41n + 650.37 \tag{19}$$

The average forwarding velocities with unloading and loading, respectively, were 1.61 and 1.81 m/s, and 1.77 and 1.42 m/s, at Sites A and B, respectively. The values of forwarding cycle time CT_{PF} (s/cycle) were expressed using the forwarding distance *L* (m/cycle), at Sites A (Eq. 20) and B (Eq. 21).

$$CT_{Fc1} = 1.18L + 5.41n + 650.37 \tag{20}$$

$$CT_{Fc2} = 1.27L + 5.41n + 650.37 \tag{21}$$

The forwarding volume V_F (m^3/cycle) was estimated using the relationship between *Vla* and *n* (log/cycle), at Sites A and B (Fig. 5, Eq. 22).

$$V_{Fc} = 12.2Vla + 3.54 \tag{22}$$

Thereafter, the equations for estimating the costs of forwarding operations at Sites A and B can be expressed as Eqs. 23 and 24.

$$OE_{Fc1} = \frac{1.18L + 5.41n + 650.37}{6.93Vla + 2.01} \tag{23}$$

$$OE_{Fc2} = \frac{1.27L + 5.41n + 650.37}{6.93Vla + 2.01} \tag{24}$$

Apart from these direct expenses, those related to strip roads, truck transportation, machine transportation, insurance, handling fees to the Forest Owners' Co-operative and the log market, and piling fees in the log market were estimated. Strip road expenses were estimated assuming labor expenses of 2,550 yen/h, backhoe machinery expenses of 5,096 yen/h, strip road construction length of 139.64 m, and productivity of 18.42 m/h for Site A whereas no strip road construction was necessary at Site B because of its gentle sloping. Truck transportation expenses were estimated to be 1,300 yen/m^3 for saw logs, and nil for laminated lumber and small-sized logs because of landing sales. Machine transportation expenses were estimated to be 5,000 yen/machine, considering 4-5 machines to be transported: a backhoe, a grapple-loader, a processor, and two/one forwarder(s) at Site A/B. Insurance costs were estimated to be 20% of the direct expenses. Handling fees to the Forest Owners' Co-operative and the log market were estimated to be 5% of the total and saw log revenues, respectively. Piling fees in the log market were estimated to be 700 yen/m^3.

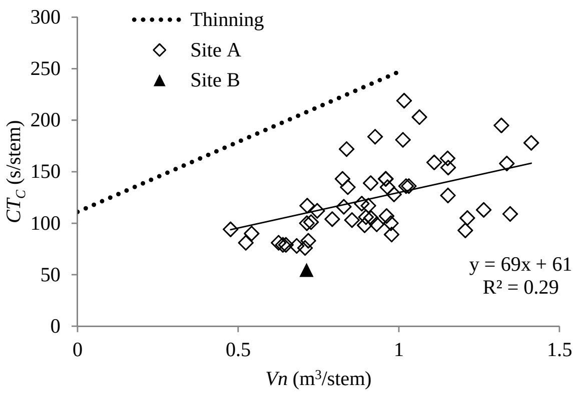

Figure 1. *Vn* and CT_C for chainsaw felling

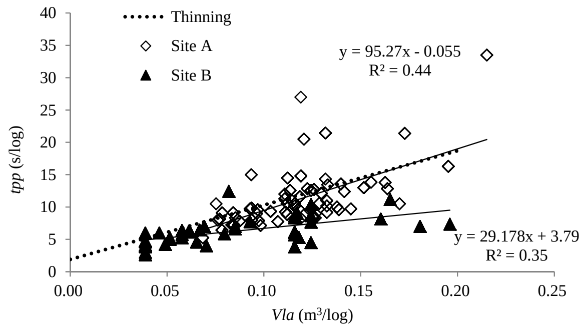

Figure 2. *Vla* and *tpp*

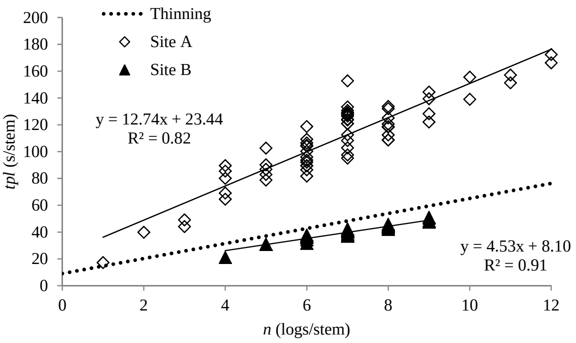

Figure 3. *n* and *tpl*

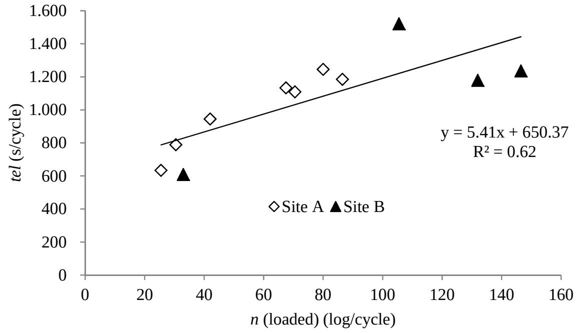

Figure 4. *n* (loaded) and *tel*

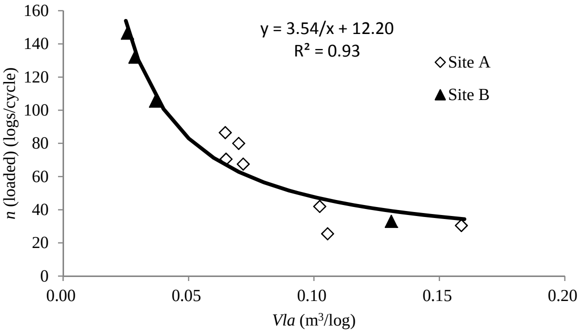

Figure 5. *Vla* and *n* (loaded)

3. Results and Discussion

The rates and volumes of extraction were observed to increase from the investigated results at Sites A and B. Particularly, the extracted volume at Site B increased by 1.66 times (Table 3). At sites A and B, respectively, saw logs

Table 3. Results

	Site A	**Optimum bucking**	**Site B**	**Optimum bucking**
Saw log rate	0.450	0.904	0.446	0.894
Lamina log rate	0.263	0.001	0.115	0
Chip log rate	0.187	0.002	0.176	0.005
Extraction rate	0.898	0.906	0.737	0.898
Extraction volume (m^3/ha)	639	646	348	576
Revenue (yen/m^3)	7,513	11,881	9,021	11,851
Total revenue (yen/ha)	4,798,177	7,680,354	3,141,834	6,820,250
Strip road construction (yen/m^3)	118	117	-	-
Felling (yen/m^3)	265	116	78	86
Bunching (yen/m^3)	640	618	423	302
Processing (yen/m^3)	565	529	271	252
Forwarding (yen/m^3)	786	309	845	305
Direct cost (yen/m^3)	2,352	1,690	1,617	946
Truck transportation (yen/m^3)	652	1,297	786	1,293
Machine transportation (yen/m^3)	51	51	40	30
Insurance (yen/m^3)	470	338	323	189
Handling 1 (yen/m^3)	364	594	447	593
Handling 2 (yen/m^3)	260	593	372	592
Piling (yen/m^3)	351	698	423	696
Indirect cost (yen/m^3)	2,147	3,571	2,393	3,392
Cost (yen/m^3)	4,499	5,261	4,010	4,338
Total cost (yen/ha)	2,873,286	3,400,920	1,396,602	2,496,519
Profit (yen/m^3)	3,013	6,620	5,012	7,513
Total profit (yen/ha)	1,924,252	4,266,259	1,745,579	4,323,514

Handling 1: Forest Owners' Co-operative
Handling 2: Log market

constituted 45.0% and 44.6% of the investigated results and 90.4% and 89.4% of the estimated results. In accordance with the increased saw log extraction rates, revenues increased by 1.58 and 1.31 times the investigated results at Sites A and B, respectively, resulting in the increase in total revenues by 1.60 and 2.17 times the investigated results, respectively.

Direct costs decreased compared to the investigated results at Sites A and B. Particularly, the direct cost at Site B decreased by 0.59 times (Table 3). The values of *Vla* increased from 0.124 to 0.158 m^3/log and from 0.083 to 0.164 m^3/log at Sites A and B, respectively. The direct costs estimated using the equations developed in this study were found to decrease in accordance with the increase in *Vla*. However, truck transportation expenses, and handling and piling fees in the log market increased in accordance with the increased saw log rates. Therefore, total costs increased.

As the increases in revenues were larger than those in costs, profits increased by 2.20 and 1.50 times the investigated results at Sites A and B, respectively. Furthermore, as the extracted volumes increased by 1.01 and 1.66 times the investigated results at Sites A and B, respectively, the total profits increased by 2.22 and 2.48 times of the investigated results at the respective sites.

The lamina and chip log volumes derived using the optimum bucking method were smaller than the actual values because this model did not consider the contracts related to annual supply obligations and stable prices made with factories. Although this model did not consider the log quality, bucking operations need to consider this as low-quality logs are sold as lamina or chip logs instead of saw logs. Therefore, future studies must consider supply obligations and log quality, although the latter can be difficult to predict.

The LiDAR technology is commonly used for obtaining basic information on terrain and vegetation. Airborne LiDAR was capable of measuring crown surfaces and calculating tree heights and the number of trees. Thus, stem and stand volumes were estimated using the information on crown volumes, tree heights, the number of trees, and so on (Ito et al., 2011). However, airborne LiDAR was unable to measure the stem shape and stem volumes directly (Kato et al., 2014). In contrast, terrestrial LiDAR was used by Murphy et al. (2010) to obtain a detailed description of the stem shape (such as taper, sweep and lean). The subsequent study applied terrestrial LiDAR for developing the optimum bucking algorithm.

Acknowledgement

This study was supported by JSPS KAKENHI (Grant Numbers 24580213 and 15H04508).

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Optimizing logistics of saw logs for a medium sized sawmill

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Abstract
The supply chain of saw logs is crucial for the added value in a sawmill. During winter conditions (temperature below 0°C), the logistics are less crucial as low temperatures retain the quality of the logs. However, during other times of the year, the quality of logs deteriorates faster. For example, storage decreases moisture content, which may inflict cracks, insects or fungi that affect the quality of the finished product. Water sprinkling of log piles is one way to mitigate the negative effects of storage. However, environmental concerns have limited the use of sprinkling. There are many sawmills in Finland that do not have the permits to sprinkle their storage. This makes it very essential to adjust the supply chain to maximize profit; considering logistics, production costs and the costs of losing value of finished goods.
We have studied the logistics of a simulated sawmill in order to model the costs of different parts of the supply chain. Furthermore, we have optimized the logistics, including transport and storage to minimize the total cost, including costs for downgraded logs.

Keywords
logistics, storage, sawlogs, optimization

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1. Introduction

For sawmills it is vital to keep the supply of logs as fresh as possible. Storage has the potential to be problematic, due to the critical influence of moisture content of the wood. Sapwood of Nordic conifers (Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst)) commonly have a moisture content of more than 60% (green weight) when harvested. As wood dries, it is more susceptible for fungal infections. Further drying complicates the debarking and the processing. If the moisture content goes below the fibre saturation point (FSP), which is close to 23%, cracks and deformation of the wood start occurring (Persson et al. 2003) (cf. Figure 1).

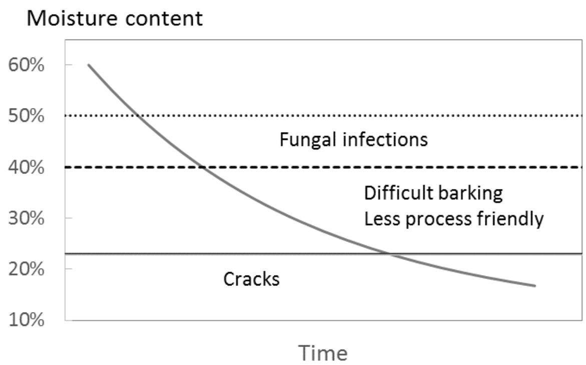

Figure 1. Effects of drying on wood quality (after Persson et al. 2003).

It has been a well-established procedure to transport logs as soon as possible to the sawmill after harvesting and then to store them under water sprinkling systems to hamper the drying process. However, many sawmills in Finland cannot utilize this method, as utilization of water sprinkling systems has become forbidden in many places. Primarily due to environmental concerns and a fear that leaching of water from storage piles may affect the ground water quality, sawmills have to consider other strategies.

The objectives of this study are to find an optimal storage policies for a medium-sized sawmill in Finland.

2. Material and Methods

2.1 Material

Sawmill

Our study was modelled on an assumed sawmill in the central of Finland with a yearly production capacity of 220000 m³ of sawn goods. With a 50% recovery rate was estimated, meaning that approximately 440000 m³ of round wood is required. All round wood is delivered by truck to the mill. The yearly production is spread to 11 months per year. During July, the sawmill is closed. When operational, the sawmill is prohibited from utilizing water sprinkling systems to control moisture content of the wood, due to environmental reasons. The logs are stored at the sawmill for an average of 2 weeks.

Harvesting data

Volumes harvested varies throughout the year. From statistical data gathered by Natural Resources Institute Finland (Luke 2015), the average monthly proportion of harvested sawlogs were calculated (Fig. 2). Unfortunately, the data is for the whole of Finland; monthly data is not available with finer resolution. It could be assumed that the differences between the months are lessened due to the country wide data set, as the thawing period in spring starts at quite different dates in southern and northern Finland.

The volumes delivered to the sawmill are assumed to follow the same seasonal variation as the calculated averages. So, the 440000 m³ were divided accordingly. As an example, in September 10% of the yearly harvesting of pine logs is made, and for the modelled sawmill it means that 44000 m³ are harvested during the month. The monthly figure is then divided by the number of days in the month, in this case 30. Hence, the daily harvesting is 1467 m³ in September.

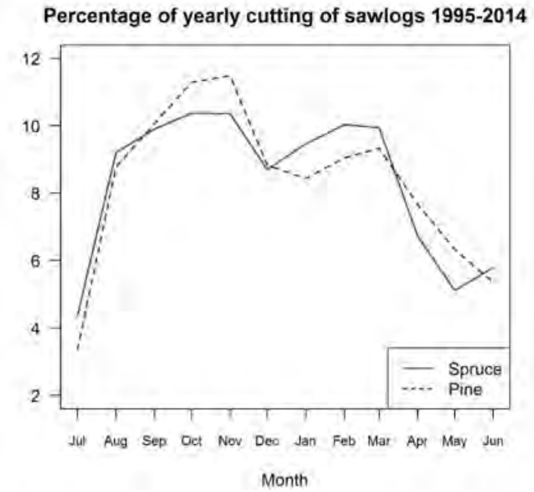

Figure 2. Monthly proportion of harvesting of sawlogs; average for Finland 1995-2014 (Luke 2015).

Weather data

In order to simulate the drying process of logs, weather data from one weather station in central Finland (Hyytiälä, 141 m a.s.l., 61.84591 N; 24.28696 E) was used (FMI 2015). The average daily temperature (°C) and relative humidity (%) were used for the simulation (Fig. 3). Temperatures below 0 °C are not considered as the drying halts in freezing temperatures.

2.2 Methods

Drying process

A model of the drying process developed by Person et al. (2003) was used to simulate the loss of moisture. The model is as follows:

$$\begin{aligned} MC_l = c_1 \sum_1^n (daytemp_i * daydry_i) \\ + c_2 exp \sum_1^n (daytemp_1 * daydry_i) \end{aligned} \quad (1)$$

where

MC_l Loss of moisture content

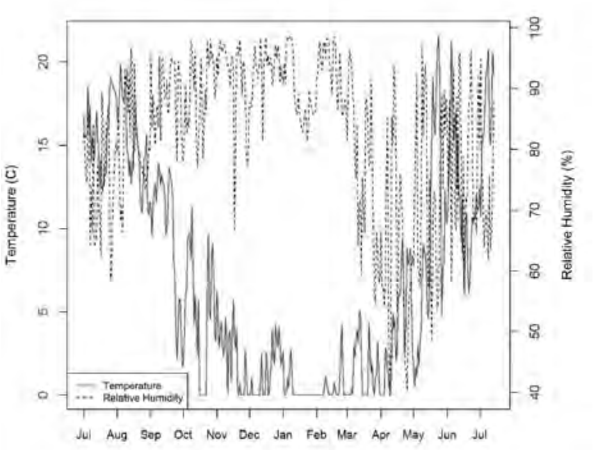

Figure 3. Daily average temperature (°C) and relative humidity (%) during one year at Hyytiälä weather station, FMI (2015).

$daytemp_i$ Average temperature (°C) during day i (0 if < 0 °C)

$daydry_i$ 100% - average relative air humidity (%) during day i

exp Exposure to sun and wind (can vary between 0% and 300%)

c_1 Constant = 0.000216

c_2 Constant = 0.000253

The model is based on Swedish data, but should also be valid for Finnish conditions.

Logistics

Once the trees are felled and processed by a harvester (CTL harvesting), they are assumed to stay on the harvest site for three days before being forwarded to the road-side, where they are put in piles. The sawmill has limited space for storage and can only store some 25000 m³. The sawmill is not allowed to use water sprinkling system of its storage, due to environmental concerns. It is assumed that the sawlogs are stored at the sawmill for an average of 2 weeks, except in June when the mill storage is fully used to have an empty storage as the vacation starts (July). This means the roadside storages will vary the most.

As can be seen from the equation above [Eq. 1] the exposure to sun and wind is found to be a significant factor. Processed logs (not yet forwarded) on the harvesting sites are very exposed, while piles in a shadowed location are much less exposed. To decrease the exposure it would be possible to cover piles e.g. with paper. This a standard procedure for energy wood, but with the primary aim of preventing remoistening (Fig. 4). Furthermore, studies on energy wood indicate that the actual drying process slows down with a coverage (Röser et al. 2011).

Figure 4. Paper covered pile of energy wood (photo J. Rikala).

In accordance with the guidelines of Wilhelmsson et al. (2005) we have assumed the exposure coefficient for different storage locations (Table 1).

Table 1. Exposure coefficients used in the study.

Place of storage	Exposure [%]
On harvest site	200
Exposed pile	80
Covered pile	20
At sawmill	80

Costs

There are costs associated with covering piles. In addition down grading of logs due to storage damages can occur. The estimated costs are shown in Table 2. The costs of covering the piles is based on the material and labor costs, with 80% of the costs coming from the cost of paper, and 20% of the cost assigned to the labor.

Table 2. Costs used in the study.

Item	Cost (€/m³)
Cover pile	1
MCl* 5-10%	5
MCl 10-15%	10
MCl >15%	15

*MCl = Moisture Content loss

Optimization

In order to minimize the costs, the problem was formulated using a Goal programming framework (Jones and Tamiz 2010). In this case, there is a trade-off between the costs associated with covering the log pile, and the costs associated with decreased value of timber. A three step penalty function is used, to associate costs with a specific range of moisture content loss (Table 2). The objective to the problem formulation is:

$$min(z) = \sum_{d=1}^{D}\sum_{i=1}^{I}\sum_{t=1}^{T} s_{dit} y_{di} x_i p_t + \sum_{i=1}^{I}\sum_{t=1}^{T} s_{dit} w_i x_i p_t + \sum_{i=1}^{I} c_i \tag{2}$$

where:

D is the total number of days under consideration,

I is the total number of piles in the model (in this context, it is associated with the harvesting date),

T is the total number of penalties considered,

s_{dit} is a Boolean value which takes a 0 if the moisture content loss for the pile harvested in time i processed at day d is below the threshold for penalty t, otherwise it takes a 1,

y_{di} is the fraction of the pile harvested during time i processed at day d,

x_i is the quantity of timber for the pile harvested at time i, p_t is the penalty associated with threshold t, w_i is the proportion of the pile harvested at time i left un processed, and c_i is the cost associated with covering the pile harvested at time i.

The model is also subject to a variety of constraints that ensures the sawmill processes a constant daily amount of timber during the operational period (1317 m³). There are also accounting constraints to ensure the logic of the model (for instance it is not possible to process greater than 100% of a particular pile). Additionally, a set of constraints are used to check if the moisture content of the pile meets or exceeds the predetermined thresholds.

The model was solved using a commercial optimization package, IBM CPLEX 12.6 on an 8 core 3.4 GHz computer with 16 Gb of random access memory. The mixed integer program solved to optimality after approximately 2 minutes of processing.

3. Results

For this specific case, there are two periods when covering a portion of piles impacts the maintenance of log quality (Figure 5). A portion of the logs are covered in July and early August, this corresponds to the time when the sawmill is not active. The second period occurs in the late spring, at a time when the amount of wood harvested greatly exceeds the amount required by the sawmill.

In total, 10165 m³ of logs were covered over the year horizon. During down time of the sawmill, a total of 3896 m³ of logs were covered, which corresponds to essentially the amount harvested during the second week of harvestings. During the spring period, the remaining 6269 m³ of logs were covered, as the amount stored constantly exceeded that which could be used.

4. Discussion

In the study many parameters had to be estimated from literature. It is sometimes rather difficult to translate actual results into specified parameter values. Further studies should include sensitivity analyses of different parameters.

We have suggested that paper covering will slow down drying. The paper covering of sawlogs is not a common

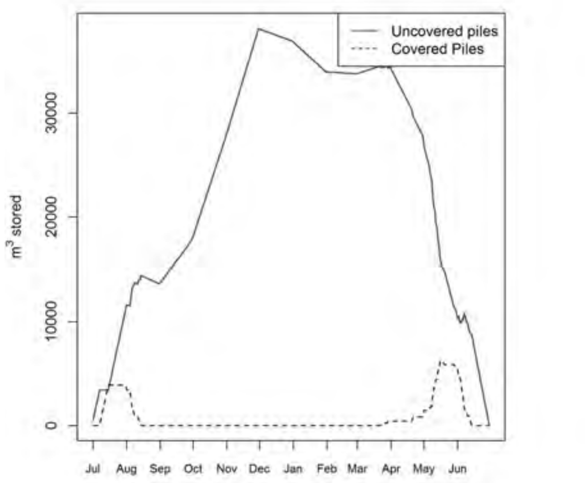

Figure 5. Amounts of covered and uncovered piles over the year horizon.

practice, and covering is mostly done of energy wood to prevent remoistening. The drying process of sawlogs are also dependent on log diameter, pile size and on possible debarking (debarking increases drying rate). As much of the drying is taking place from the end of the logs, covering the end of the logs would probably increase the effect. For very valuable logs one practice is to seal the ends with some sort of chemical (e.g. lacquer). Another method, is to place the piles in optimal locations, protected from sunshine and wind (Wilhelmsson et al. 2005). To be able to track the exposure, the forwarder driver likely has the best possibility to make a qualified estimate of the exposure. If this is reported, the planning of further transport could be better planned.

The simulation is based on weather data from a one year time period. To further analyze the importance of weather, data for several years should be included, in order to find best strategies for operational logistics. The costs for covering and downgrading of logs are quite arbitrary. The relation between those costs may have a significant impact on the result and should be studied more.

The results of the study are as expected, as it follows common recommendations that spring and summer are the critical periods for log storage (e.g. Nylinder and Fryk 2011). The suggested portion to be covered were surprisingly low, just over 2% of the total volume. Further studies have the potential to allow for wider analysis of the problem and provide further details in examining the effects of policy.

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Optimization and logistics of chip distribution using LiDAR technology and network analysis in a mountainous region of Northern Spain

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Abstract
The cost of transporting chips represents an important part of total operation costs, as although wood chips are light, they are voluminous. The need for tools and techniques to support the development of forest road networks in forest management, which is the foundation for optimizing logistics, is becoming increasingly important. This study aims to optimize wood chip transport by analysing transport networks with the Network Analysis extension of ArcGIS software.
The best routes between biomass supply points and consumption centres were calculated and the areas with optimal (depending on distance criteria) road access to forest biomass around demand points were delimited. For such work a complete transport network that includes both roads and forest tracks is necessary. Data from LiDAR technology was used to carry out the digitization of forest tracks, using this technology avoided the drawbacks of traditional methods (orthophotos and GPS data).

Keywords
wood chips, GIS, route optimization, forest road network, LiDAR

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1. Introduction

The production system of wood chips comprises several steps, and includes forest operations, transport and processing. The cost-effective supply of chips depends therefore on the costs of logging, extraction, chipping and transporting. In turn, these forest operations depend on factors related to the forest network, such as track density, slope, width or type of firm (Cavalli and Grigolato, 2010).

In general, the transport of timber has a number of particular difficulties, such as the heterogeneity of the product, its low density and high moisture content, the limited infrastructure in forest areas and orographic difficulties.

Various studies show that the transport cost of forest biomass from the production area to the consumer center is between 8 to 40% of total biomass costs (Anttila et al, 2011; Moller and Nielsen, 2007; Panichelli and Gnansounou, 2008). Some such authors differentiate between forest roads (tracks) and roads (national, regional and local), considering that transport on tracks accounts for about 8% of total costs and that on roads for around 24% (Panichelli and Gnansounou, 2008).

In recent years in the bioenergy field, authors such as Panichelli and Gnansounou (2008), Ranta (2005) and Yoshioka and Sakai (2005) have used Geographical Information Systems (GIS) for various purposes: calculation of biomass stock and its characteristics, estimation of transport cost or selection of the best locations for new biomass plants. GIS has also been used to bring about advance in the optimization and planning of transport routes in the forestry sector. Authors such as Anttila et al. (2011), Cavalli and Grigolato (2010), Duran-Fernández (2007), Kinoshita et al. (2008) and Moller and Nielsen (2007) have conducted studies of the supply and demand of biomass and analysis of their supply costs. Hohn et al. (2013) and Viana et al. (2010) used GIS tools to find the best location of specified biogas plants and wood-fired power plants.

To work in this line, and can perform transportation network analysis, a previous digitization of existing roads and tracks network in the study area is required and the creation of a GIS database with the main characteristics of these ways: width, radius of curvature, firm, state, sidings, etc.

Nowadays, LiDAR (Light Detection and Ranging) technology is being introduced in the field of cartography due to it enabling the fast modelling of terrain in areas with difficult access. Previously, the digitization of tracks with satellite images is quite complicated, since in many cases the tracks are hidden by the trees and it is very difficult or even impossible to locate them accurately (White et al., 2010). With LiDAR technology, these problems are reduced, because it has a "semipermeable" character which ensures that forest tracks hidden by trees or even old logging roads that are occupied by scrub are displayed. Using this new technology, the large number of field trips that are required with GPS, to seek out and use four-wheel drive vehicles to drive along tracks to establish their routes are greatly reduced, which saves both time and money.

The overall objective of this study was to identify optimal supply areas around several woodchip consumer centers, which met certain criteria of accessibility depending on the distance travelled by the road network. Once these areas were identified, the best routes to transport chips from the Supply Points to the Demand points were calculated.

The specific objective was to digitize the tracks around a supply point using LiDAR technology and connect them with the road network to carry out certain network analyses: service area and best routes.

2. Material and Methods

2.1 Study area

This study was focused on four biomass consumption points, more precisely, chips (Demand points), supplied by the same company even though they are located in three different regions of Spain: Asturias, Galicia and Castilla la Mancha (Cuenca, Guadalajara and Toledo). These Demand points all belong to private companies which use biomass either for generating heat and electricity for their own use, or they are biomass power plants which produce electricity for public consumption (APPA, 2011).The forest areas where the biomass for chip production is extracted (Supply points) are situated in Asturias (n=1) where the principal productive species is *Pinus pinaster* and Castilla León (n = 4) where it is *Populus sp*.

2.2 Transportation network

In order to create the transportation network, cartographic material coming from the IGN (National Geographical Institute) was used, specifically, data from the Numeric Cartographic Base (BCN200, 2014). To analyze the transportation network through the extension Network Analyst implemented in ArcGIS 10, an initial database (Geodatabase) was created containing the following variables: road type, speed depending on type of vehicle and road, distance and time for each segment in the network.

In the road network (BCN200) there are only a few tracks registered. This becomes a problem when designing any network analysis related to the forestry sector. For one of the Supply points used (considered a specific zone as pilot area), the relevant forest tracks were digitalized using LiDAR data and were then combined with the road network to achieve the complete transportation network for that Supply point. For the remaining Supply points, only road transportation was taken into account.

The first step in analyzing the LiDAR data was to remove outliers from the points cloud using the software FUSION (McGaughney, 2009). After this, points corresponding to the ground were separated from the ones belonging to vegetation and other objects situated on the ground (buildings for example).

On the one hand, Digital Elevation Model (DEM) was created interpolating ground points in FUSION. On the other hand, Map Algebra and Hillshade tools implemented in ArcGIS 10 were used to get the best resolution as possible to visualize the tracks in the DEM. Once LiDAR data were processed, tracks digitalization was carried out in the pilot area corresponding to one of the Supply points.

2.3 Network analysis

Once the transportation network was built (roads and tracks in the pilot area, and only roads in the rest of them), analyses were carried out on them through the extension Network Analyst (ArcGIS 10).

After that, different supply areas were identified around each Demand point having set a maximum road transportation distance, which was determined by the chip distribution company. In this way, distance (50, 100 and 150 km) was taken as impedance variable (travel cost through the network). When generating the polygons for each service area, the option “overlapping” was chosen in order that each Demand point had its own services areas and to see the overlapping areas for in the near points.

Finally, using the closest facility tool, the best routes were calculated, as a function of time, along roads and tracks between Demand and Supply points. This troubleshooter uses the Dijikstra algorithm to find the best routes, i.e. it seeks the shortest trajectory between an origin point and one, or several, destination points. This algorithm respects the configurations establish by the user, such as the one-way restrictions, turn restrictions and barriers, while minimizing the cost attributes specified by the user.

3. Results

3.1 Transportation network

Figure 1 shows some of the different tests which were carried out to create the DEM by precise filtration and separation of the points corresponding to the ground from the points corresponding to the vegetation and objects on the ground. Figure 1a provides a detail of an example of soft filtering where only 18% of the points were removed. This proved to be insufficient because there was a large amount of vegetation in the area hindering tracks identification. In contrast, Figure 1b shows the result of applying strong filtering parameters (81% of points removed), which turned out to be too intense. In Figure 1c, where 49% of points were removed, this percentage was enough to eliminate most of the points belonging to vegetation but without removing ground points.

Figure 2 demonstrates how the use of LIDAR displays hidden tracks, making it possible to digitalize them in a more precise way. In the ortophoto (Figure 2a), it seems there are only two tracks in the area but examination of the DEM makes it clear that there is a third track hidden below the vegetation, which can thus be included in the digitization (Figure 2c).

In Figure 3 the complete transportation network (roads and tracks) in the pilot area under analysis is shown.

3.2 Network Analyst

The Service areas corresponding to the four Demand points are shown in Figure 4. The different supply radii are highlighted for each point (50 (green), 100 (yellow) and 150 km (red)). Blue spots represent demand points and red, supply points. The transport network is shown in black.

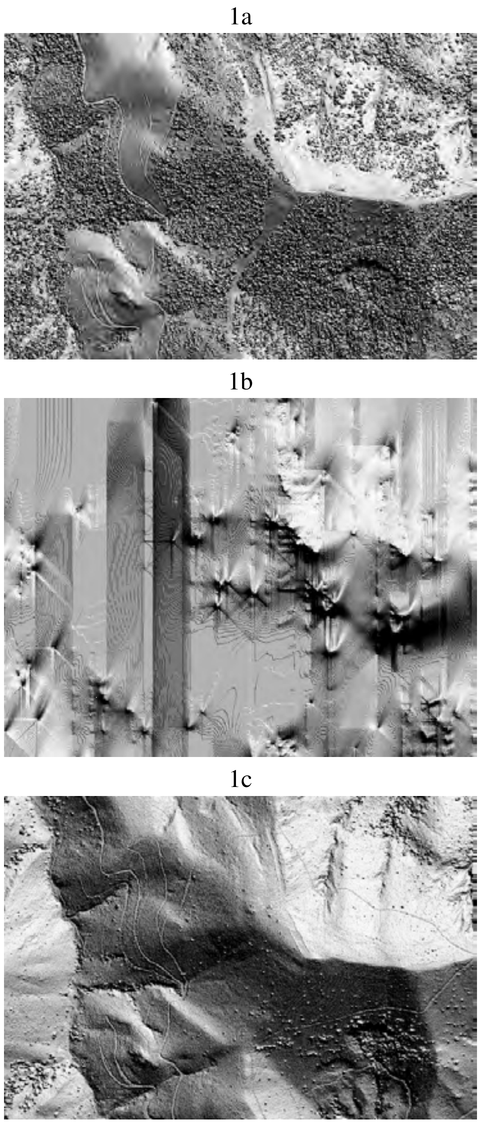

Figure 1. Tests carried out in the ground filtering process. 10a: DEM created from soft filtering. 10b:DEM created from too intense filtering. 10c: DEM created with the best combination of filtering parameters.

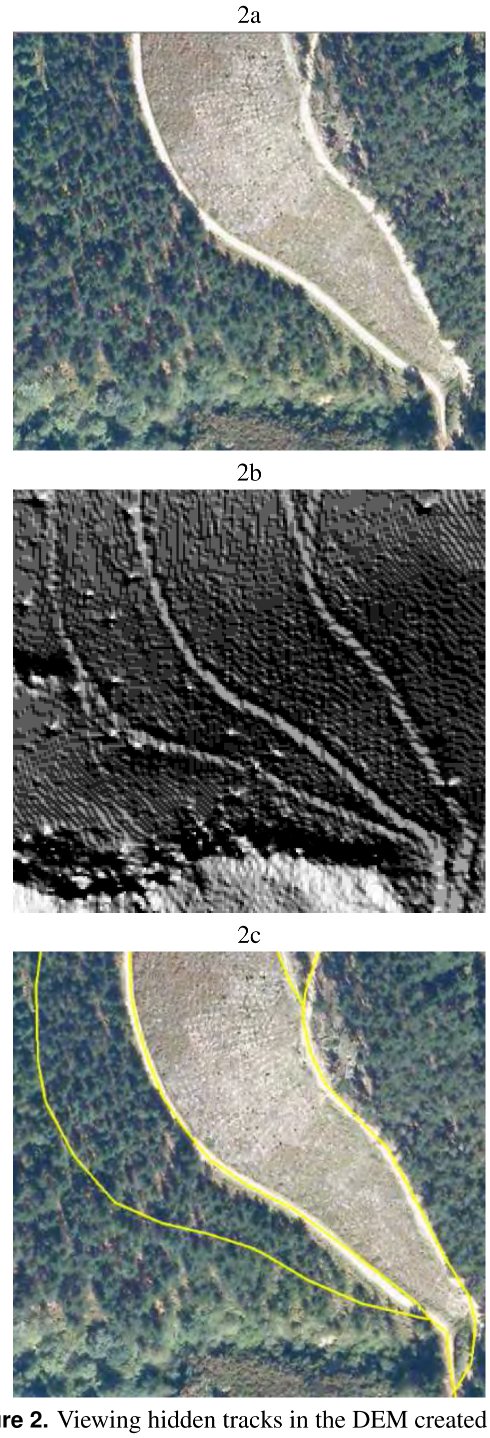

Figure 2. Viewing hidden tracks in the DEM created from LiDAR data. 2a: ortophoto of the project area, where two tracks are displayed. 2b: DEM image of the same area, where three tracks are displayed.2c: ortophoto with the three tracks digitalized.

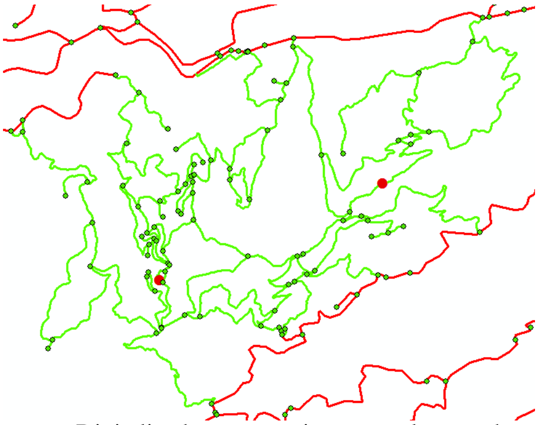

Figure 3. Digitalized transportation network around Supply point.

In Figure 5, some of the service areas of the different Demand points overlap, so it is no possible to differentiate these areas from each other. However, thanks to the option of overlapping polygons chosen to calculate the service area, the service area of each Demand point can be identified separately, along with the area of overlap between each of them. Figure 5 serves as an example and the service areas within Demand points are represented. Overlapping zones of the service areas of these two points are in grey.

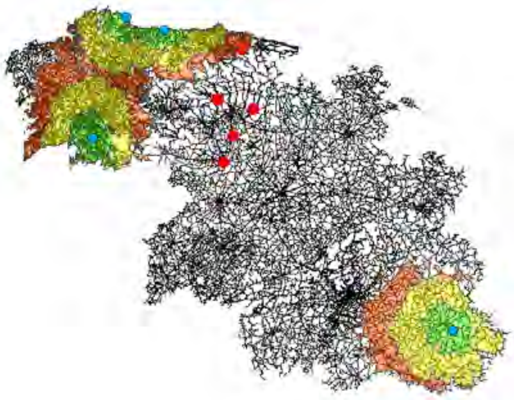

Figure 4. Service areas for the four Demand Points.

In Table 1, time and distance for each optimum route are shown. Both variables have been calculated for the different vehicles (truck, forwarder) which might travel by road or track between Demand and Supply points.

In total, 24 routes were calculated. Each of these routes is the fastest one between Supply and Demand points, that is, the one which takes least time taking into account type of road and vehicle, speed limits, etc. In addition, Table 1 also shows which Demand point is closest to each Supply point.

In Figure 6 some of the optimum routes are represented with different colours. Not all of them are visible because some overlap, in their entirety or at some stage.

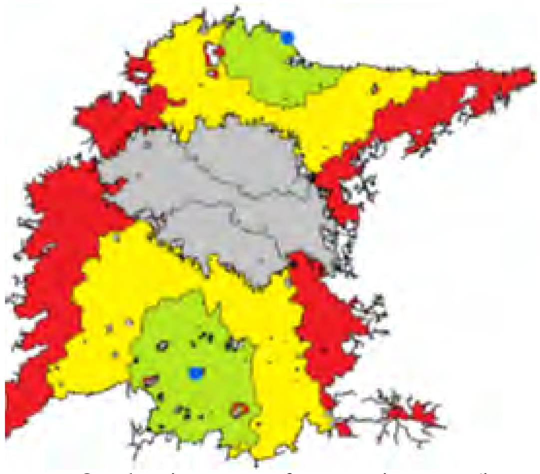

Figure 5. Overlapping zones of two service areas (in grey).

Figure 6. Examples of some of the optimal routes between Supply and Demand points.

Table 1. Digitalized optimal routes from each Supply point to the 4 Demand points.

Supply points (origin)	Demand points (destination)	Truck distance (km)	Forwarding distance (km)	Truck time (h)	Forwarding time (h)
Benavente (Zamora)	BIOALLARLUZ – NORVENTO BIOMASA	207.804	0	2.949	0
Benavente (Zamora)	BIOMASA NAVIA -ENCE	282.284	0	3.995	0
Benavente (Zamora)	ECESA	307.229	0	4.459	0
Benavente (Zamora)	PINASA BIOMASA – COMETA (GRUPO LOSAN)	439.619	0	6.227	0
Gradefes (León)	BIOMASA NAVIA -ENCE	251.202	0	3.588	0
Gradefes (León)	BIOALLARLUZ – NORVENTO BIOMASA	277.651	0	4.134	0
		323.019	0	4.659	0
Gradefes (León)	PINASA BIOMASA – COMETA (GRUPO LOSAN)	499.336	0	7.262	0
Nava (Asturias)	BIOMASA NAVIA -ENCE	128.92	2.91	1.875	0.208
Nava (Asturias)	ECESA	200.737	2.91	2.946	0.208
Nava (Asturias)	BIOALLARLUZ – NORVENTO BIOMASA	352.673	2.91	5.302	0.208
Nava (Asturias)	PINASA BIOMASA – COMETA (GRUPO LOSAN)	642.909	2.91	9.07	0.208
Nava 2 (Asturias) -	BIOMASA NAVIA -ENCE	125.665	4.19	1.862	0.299
Nava 2 (Asturias) -	ECESA	197.483	4.19	2.933	0.299
Nava 2 (Asturias) -	BIOALLARLUZ – NORVENTO BIOMASA	349.419	4.19	5.29	0.299
Nava 2 (Asturias) -	PINASA BIOMASA – COMETA (GRUPO LOSAN)	639.655	4.19	9.057	0.299
Rioseco de Tapia (León)	BIOMASA NAVIA -ENCE	188.645	0	2.684	0
Rioseco de Tapia (León)	ECESA	260.462	0	3.755	0
Rioseco de Tapia (León)	BIOALLARLUZ – NORVENTO BIOMASA	245.803	0	3.759	0
Rioseco de Tapia (León) -	PINASA BIOMASA – COMETA (GRUPO LOSAN)	530.752	0	7.485	0
Valencia de Don Juan (León) -	BIOALLARLUZ – NORVENTO BIOMASA	239.79	0	3.375	0
Valencia de Don Juan (León) -	BIOMASA NAVIA -ENCE	245.721	0	3.489	0
Valencia de Don Juan (León) -	ECESA	290.47	0	4.286	0
Valencia de Don Juan (León) -	PINASA BIOMASA – COMETA (GRUPO LOSAN)	464.837	0	6.661	0

4. Discussion

The criterion of identifying service areas based on distance has been used in other studies to calculate the shortest transport routes and find the location of future biomass consumption centers, such as those of Korpinen et al. (2013) and Viana et al. (2010) carried out in Finland and Portugal (respectively) These authors, however, dealt with much shorter distances (2 and 35 km respectively), due to the more concentrated distribution of Supply points, which allows consumption points to obtain forest biomass without major displacements.

Creation of such areas could help forest biomass distributors, for example, to look for other possible Supply Points within service areas created with specific criteria or generate these service areas around existing Supply points and locate potential consumption points within those areas. Authors like Hohn et al. (2013) carried out this type of analysis using ArcGIS software tools. In addition the service areas could also be used to determine the location of future biomass consumer centers (Viana et al. 2010).

In Figure 4, it can be observed from the Supply points under analysis that only one supply area is within the service area of one of the Demand points. The other Supply points are outside the service areas, so a priori it seems to indicate that biomass access and distribution to and from these points would incur a higher cost than necessary from the point of view of transport logistics.

The precise location of the overlap zone between service areas enables competition to be identified, i.e. areas where forest biomass could be exploited by various Demand points. One option to avoid this competition might be the distribution of the biomass in the area of overlap between the different Demand points converging there.

Calculation of the best routes between Supply and Demand points was carried out taking into account transportation time depending on the average speed for each type of road. In other works, best routes are identified based on the cost of transport (€/t) (Cavalli and Grigolato, 2010; Karttunen et al, 2013; Moller and Nielsen, 2007; Panichelli and Gnansounou, 2008), but in this case that information was not available.

The average route distance was 321 km, higher than for example in works by Hohn et al. (2013), Karttunen et al. (2013) and Korpinen et al. (2013), who found an average distance below 200 km, and sometimes even below 100 km in many cases. However, in a study carried out also in the north of Spain, such as Panichelli and Gnansounou (2008), the distances of over 300 km found were similar to our results.

In the future we must work to make available more data and better technologies in order to be able to carry out more precise analyses of routes. To do this, it is essential to have a complete and updated forest track network, and it requires further work and progress in digitalization of tracks using LiDAR, as well as automating this procedure.

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Topic 8

Road construction & maintenance

Technology of paving carriageways of permanently passable forest roads by shedding cover aggregates with the thixotropic mixture

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Abstract
The paper presents the results of research and the practical applications of a new technology based on the patent CZ 304 374, that is used for the pavement or reinforcement of forest road carriageways burdened with heavy machines. The principle of the technology lies in the shedding of the skeleton, consisting of coarse crushed aggregates (fraction 32 – 63 mm) with a special tixotropic mixture of ash, cement and water, which can be made in a common concrete mixing plant. As shown by the experience of more than twenty structures, the technology has a wide use.

Keywords
forest roads, strengthening, roadway, fly ash, mixture bounded with hydraulic binders

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1. Introduction

KAPS-LE technology abbreviation comes from the full name in Czech language, which means "ash suspension reinforced gravel for forest roads". The predecessor of the KAPS technology is described as a bedding layer of road infrastructure in the Czech standard ČSN 73 6127-4. New KAPS-LE technology is protected by the CZ 30437-4 patent and was first presented to the international professional public in the article "New Technology for Long-Term Strengthening of Forest Roads - KAPS-LE" in the Croatian Journal of Forest Engineering (in print, 2015). This article described the principle of the KAPS-LE technology, described the technological operations, the inclusion of the technology among other used layers of reinforcement of the forest roads, the test site of the Training Forest Křtiny strip, including the load test using impact load deflectometer (FWD), and the framework for economic evaluation.

The second submitted article of the same authors extends the technology introduction to a whole range of new experience, knowledge and measurements that were obtained from more than twenty construction sites and test sites in the Czech Republic. The first verification of the practical implementation of new KAPS-LE technology with the minimization of construction mechanization requirements was carried out in 2008. Since 2011, test sections and constructions have been realized on forest areas in the Czech Republic in a constantly growing number. The diverse conditions of constructions and specific measures demonstrate the universal use of the new KAPS-LE technology on forest hauling roads and congested areas of handling warehouses (manipulation areas).

2. Material and Methods

Published results of the measurement of the load impact by impact load deflectometer (FWD) show that a KAPS-LE layer in the thickness of 200 mm on an unconsolidated ground has a modulus of elasticity E1 = 9000 MPa. This unexpectedly high value led to a logical consideration after reduction of the thickness of the layer. Standard layer thickness of 200 mm, however, has its justification for both theoretical and practical reasons. Proven principle of layer thickness as at least three times the size of the maximum thickness of grain matches this thickness well. A layer of KAPS-LE is built from stone of a 32-63 mm fraction, three times the maximum grain is 189 mm, i.e. practically 200 mm. The second principle is based on the level of the carrying capacity of the unconsolidated bedding, which can be significantly distorted by the movement of technological transport (aggregates and ash-cement suspension). If the consideration of a smaller thickness is of a rational justification, it would be necessary to work with a higher capacity of the bedding under the KAPS-LE layer.

The second direction of ideas was inspired by the actual request originating from the practice. There is 12 795 480 meters of forest roads in the Czech Republic with a year-round use of the L1L category, of which 11 360 480 meters are with an asphalt or a panel cover (Bystrický, Sirota, 2015). The vast majority of asphalt covers is made of penetration macadam. A large part of these roads is after twenty to thirty years of operation not suitable for use. An effective way of recycling and recovery of these roads in a different way than a simple superimposition of another layer of asphalt concrete have been sought, especially if the roads have large uneven parts with created rails. A technological procedure combining the two requests was look for, that would provide:

1. Leveling the surface of the original cover made of the penetration macadam by a re-profiling,
2. Preservation of residual load-bearing capacity of the previous layers for KAPS LE saving layer.

The technical solution was found by using effective ground milling machine and smooth implementation of thinner layers of KAPS-LE on the re-profiled surface of the penetration macadam. This new procedure was awarded the industrial protection as a utility model No 27 208 Recovered cover surface, in particular for damaged forest and a purpose built roads and driveways made of penetration macadam. The application of the invention passed the patent check successfully.

3. Results

The technical solution for the new opportunity of use of KAPS-LE technology was verified on a forest road in the location “Na Síčkách” in MP Lesy, spol. s r.o. On the original worn cover from the penetration macadam was elected a strip in length of 200 m according to the diagram in Fig. 1.

The first objective of the test part was to verify whether available and in the Czech Republic used heavy ground milling cutters located behind a powerful tractor meet the expectations for the desired re-profiling of the PM cover. Two cutters from different manufacturers and different mechanism of diminution attended the test: the HEN RAMBO R 180 WS cutter (Fig. 2) and the FAE STC/R 150 cutter (Fig. 2). Both cutters managed by three travels (the Center and the two driving tracks cover) have reached the required adjustments of the cover, and with a very encouraging daily capacity of work and economic costs. Re-profiled cover from penetration macadam was subsequently consolidated and covered by a layer of crushed stone 32-63 (Fig. 2) in the thickness of 120 mm (before consolidation – section S3, S4). Thanks to the precise leveling of points marked in the original, re-profiled and consolidated cover and the final KAPS-LE overlay has reached the desired thickness of the layers with high precision: 95.5 mm (designed thickness 100 mm) and 147.8 mm (designed thickness of 150 mm).

The most expected result of this test was to measure the load impact by Carl Bro FWD PRI 2100 deflectometer, which was carried out six weeks after the completion of the construction of KAPS-LE. The 83 points differentiated and measured the thickness of the layers (100 and 150 mm), and driveway (left, right, center), and the evaluation of the effectiveness of both types of cutters and comparative measurements on the original unrepaired cover. The results of the measurements were mentioned in the first article in the summary in Table 2 – results of the measurement of elasticity module FWD (see below) and in Fig. 2 - Modules of elasticity KAPS-LE and the bedding on the forest road MP (section 2).

A major result of all load measurements carried out so far is a big affinity of the obtained values of the flexibility module E1 regardless of the thickness of the layer of KAPS-LE. Modules of elasticity E1 = 8091 MPa (thickness 100 mm), E1 = 9676 MPa (150 mm thickness); E1 = 8433 MPa (200 mm layer thickness) prove that the designed layer flexibility module KAPS-LE will move in a range of E = 8000 - 9600 MPa and, therefore, is actually ten times higher (!) than the designed layer module of penetration macadam (E) = 800 MPa.

3.1 The universal use of KAPS-LE layers in type structures

Successfully authenticated KAPS-LE layer in various thicknesses of 100 mm, 150 mm and 200 mm is at the same time an optimum range for the proposal of type structures. The thickness of a layer of less than 100 mm (min. 80 mm) does not have justification from the point of view of the grains of aggregate and, moreover, this thickness provides an equivalent replacement for bearing layer of macadam (90 mm) according to CSN 73 6127-2 standard. Greater KAPS-LE layer thickness than the 200 mm is technologically feasible, but due to high load carrying capacity it is questionable whether such a layer would be economical. In justified cases, it is preferable to choose a combination of layers.

Table 1 and 2 contains the first draft of the basic typological layout of the construction of the road and consolidation with the KAPS-LE technology.

3.2 Multilayer road construction with KAPS-LE

Road constructions listed in Table 2 were successfully tested in practice and built on an extremely weak surface or vice versa as highly bearing layers for loaded handling warehouses with round timber of industrial wood processing facilities.

The forest road of Horečková is located in the floodplains of forests along the Morava river (Fig. 3). In order to achieve a long-term bearable road, a construction of the No. 2 model according to Table 2. was used. Stabilization of soil in the bedding with lime in the amount of 3% to a depth of 400 mm, carried out by a powerful road cutter WIRTGEN has created a load bearable basis for a layer of unconsolidated aggregates SD 0-32 in a thickness of 100 mm, and subsequently a shelter layer KAPS-LE in a standard thickness of 200 mm has been constructed. The same structure was carried out on a consolidated surface of the handling wood warehouse of the Forestry high school in Hranice na Moravě (Fig. 3). Application of soil stabilization with lime is a very effective technology, however it requires a suitably shaped terrain. It cannot be used in places where ungraded aggregates or quarry stone was previously used.

Such a situation occurred in the building of consolidation of the round timber warehouse of the JILOS Horka, s.r.o. company. The access route to the bark process line is daily loaded with 30 truckloads of wood. The works were limited by the timetable (Fig. 4) of the ongoing construction. Instead of stabilizing the substrate with lime a double layer of KAPS-LE was used in the thickness of 200 mm and 150 mm respectively. Surface area of 3 200 m² was built including a drainage in 12 working days (Fig. 4).

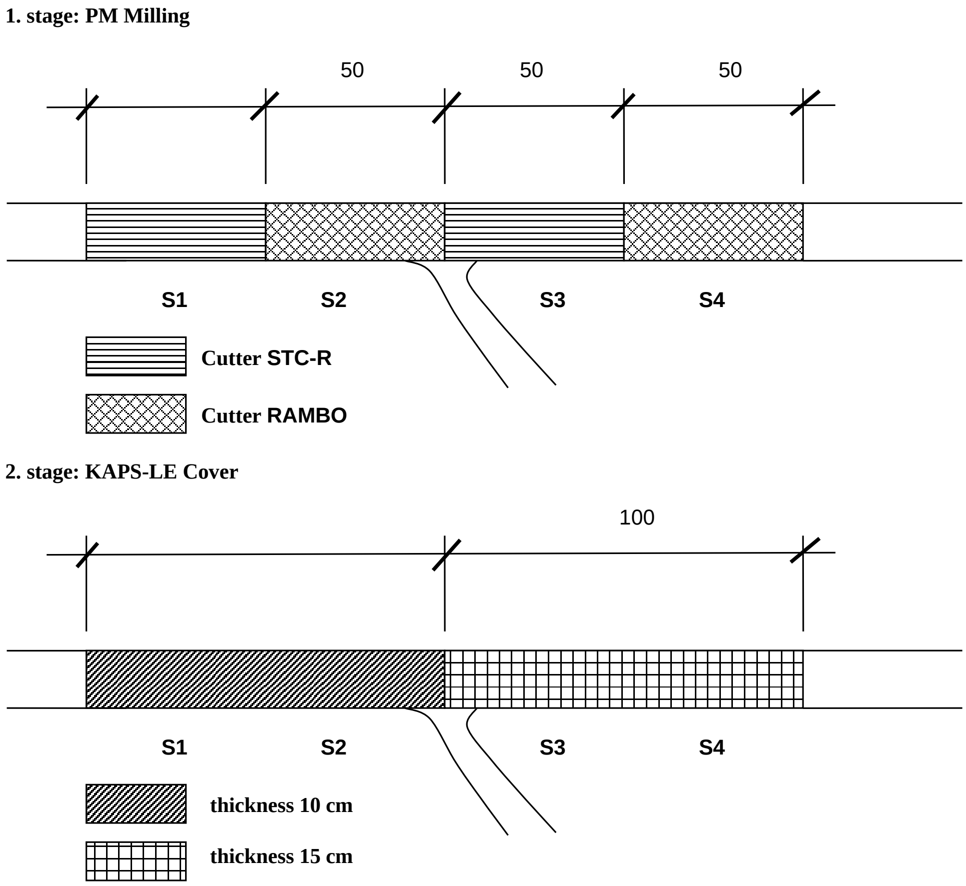

Figure 1. Schematic of the test strip with the recycling of penetration macadam.

Figure 2. Cutter HEN RAMBO R 1800 WS at the re-profiling of a cover from penetration macadam (left). Cutter FAE STC/R 150 at the re-profiling of a cover from penetration macadam (middle). Freshly completed KAPS-LE layer on a re-profiled cover from penetration macadam (right).

Table 1. Types of structural layers of KAPS-LE according to the thickness.

The name of the type	The thickness of the layer	Type of bedding	Other construction layers
ULTRA SLIM	100 mm	- re-profiled cover from PM - bedding capability	–
SLIM	150 mm	- re-profiled cover from PM - broken bedding	–
STANDARD	200 mm	previously driven-over unreinforced bedding of the road	–

Table 2. Type layer with KAPS-LE.

Road construction		Destination
KAPS-LE SD 0 – 32, 0 – 63, recyclate	200 mm 150 mm	- forest road not driven-over before - new construction, bedding with low bearing capacity
KAPS-LE SD 0 – 32, 0 – 63 Soil stabilization with lime	200 mm 100 mm 400 mm	- extremely unbearable plain, flood areas - handling warehouses and areas built on unmade ground
KAPS-LE	150 mm	- handling warehouses and areas built with the gradual consolidation of the bedding
KAPS-LE SD 0 – 32, 0 – 63	200 mm 200 mm	

Figure 3. Forest road of Horečková in floodplains (left). Adjustment of the soil with lime (dispenser of natural binder and soil cutter) (right).

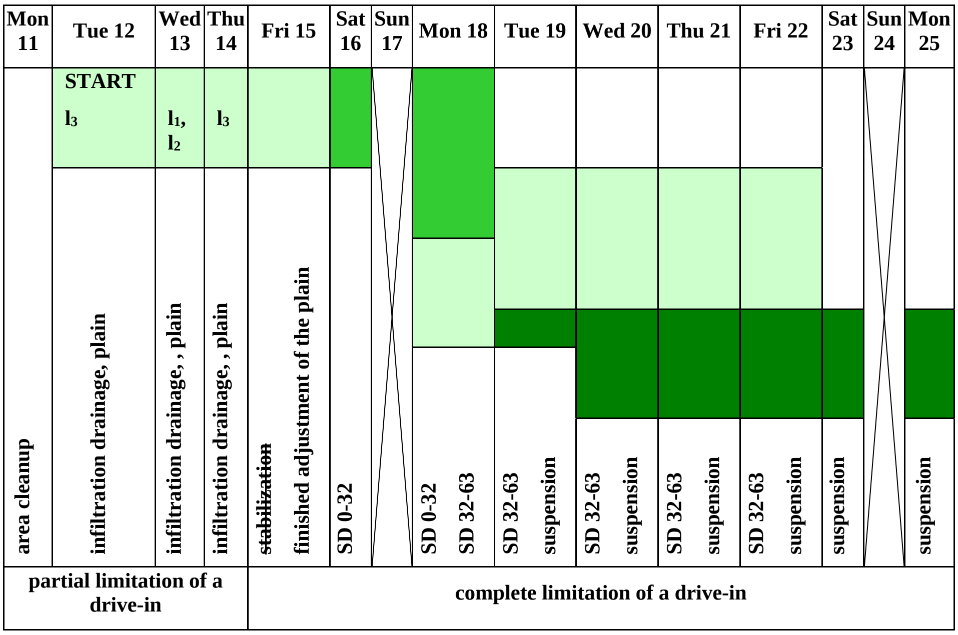

Figure 4. A schedule of the first stage of the JILOS Horka company round timber warehouse area reinforcement.

Figure 5. Handling warehouse JILOS Horka company, stage I (left). Implementation of the longitudinal culvert with a plastic pipe and a vault from KAPS-LE (right).

3.3 Monolithic culverts using KAPS-LE

Building of a long-term strengthening of forest roads without sufficient drainage of plains and ground is always risky. However, a part of the drainage are also necessary culverts, which increase the technical and economic performance of the building. KAPS-LE technology has shown its advantages as a convenient way how to quickly and economically build culverts along the route of the forest path.

Plastic pipe DN 400 mm or DN 600 mm are put into the dug trench and loaded with coarse aggregate of fraction 32-63 mm up to the level of the plain. This load is then repeatedly poured with ash-cement suspension and consolidated with a vibrating plate. It was established that the thixotropic suspension of thinner consistency fills in the gaps thanks to the vibration up to the depth of 800 and 900 mm, and after its freeze it creates along with the fortified aggregate a monolithic dome above the plastic pipe. After this culvert is carried out in this way it is possible to let heavy technological transportation even the day after, with a load of aggregate on the KAPS-LE layer. Material for making monolithic vaults above the culvert is the same as the material for continuous cover of forest roads. Longitudinal culverts can be built along with the path cover itself (Fig. 5).

3.4 Covers from KAPS-LE in the extreme inclines above 20%

CSN 73 6108 standard specifies the maximum longitudinal gradient of forest logging roads to 12%. Due to the configuration of the terrain, it is sometimes difficult to comply with this requirement. Higher longitudinal path gradient brings additional problems during heavy rains, when particularly unbound covers are facing washing away of the aggregate. The question whether it is possible to build a reinforced cover with the KAPS-LE technology in a longitudinal inclination of over 20%, was successfully resolved in construction of two forest roads - Sladska (22%) and forest path Pod obrazkem (23%). It turned out that the transportation of aggregate by trucks and ash-cement suspension by agitation truck is feasible. The only change was to use a lighter vibratory roller with two smooth runners, which were however necessary to back-up with a rope winch on a tractor. If the runners are sliding during the compaction phase, a rope winch has to assist in the upward move of the roller.

It also turned out that there is no technological obstacle of stamping the steel cross-drains (Reverdo, Viaqua, etc.) to the KAPS-LE cover. Cross-drains are stored in the furrows in the gravel layer and the shedding of suspensions is then driven-over by a roller, so it is perfectly inserted into the cover (Fig. 6). To increase the anti-skid properties in these extreme longitudinal gradients a transverse, grooving (of the surface) with broomsticks was used.

3.5 Advantages and limitations of the KAPS-LE layers

Calculated service life of the KAPS-LE layer was set to 25 years. Therefore, it is necessary to wait for the practical confirmation of this calculation. But the built sections in operation and after the winter periods do not show any signs of damage. The implementation of one cross section of KAPS-LE finished layers due to addition of a culvert has confirmed the theoretical assumptions about fixation of the aggregate skeleton and high resistance against mechanical damage and destruction (Fig. 6).

Important notice prior to a decision to build a layer of KAPS-LE, however, concerns the surface properties. KAPS-LE creates a rough technological surface with the projection of stone skeleton mosaic. The texture of the surface corresponds with the used material and technology implementation. Layer is not laid by a finisher as a layer cover type of asphalt or cement concrete and does not create a smooth surface required e.g. on sports routes for inline roller skating or recreational cycling. Cycling is not harmful for KAPS-LE, but its specifically designed for heavy transportation loads including fire fighting machinery and military combat vehicles.

3.6 Prospects for further expansion of the KAPS-LE technology

From the perspective of short-term innovation it is sometimes difficult to correctly assess the meaning of technical innovations. For KAPS-LE it can be however estimated that it is a generational breakthrough in the so far used types of forest road consolidation. Note that the penetration Macadam ("tarred macadam") was patented just 100 years ago, in 1914. The massive application of penetration macadam in the 1960s and 1970s of the 20th century on forest roads has never been overcome with a generational change – covered asphalt mixtures of aggregates, asphalt, asphalt concrete, asphalt carpet. The mineral concrete, introduced in the Czech Republic in the early 1980s of the 20th century, promised return to enhanced unconsolidated layers. However, durability and strength resulting from the fragmented material properties due to the load of the forest roads also have certain limits when it comes to the technology of mineral concrete. KAPS-LE technology as a highly bearing and endurable layer in long term similar to a concrete plate brings a radical innovation on places where it is required by traffic and loads on the forest roads.

The future lies in the rational decision, where it is locally appropriate to use only unconsolidated layers, asphalt layer or cement hardened layer (KAPS-LE). It is not about competition, but about strategic planning. Using the KAPS-LE technology it is possible to build not only routes for transportation, but it can be sophisticatedly used to fix bottlenecks in the routes of other hardening (culverts, crossovers, extreme inclinations, paved areas, storage, etc.).

4. Discussion

An extensive set of knowledge, which is concentrated in these two articles requires some explanation. It can be said that in this case there has been an extremely successful interdisciplinary concentration in the theoretical sphere, to an effective and mutually enriching connection of theory and practice, research and its use. The author and the owner of the CZ 304374 and UV 27208 patent is the SILMOS s.r.o. company, which operates as a National Center of Technical Standardization and between the years of 1991-2005

Figure 6. Embedding of steel cross-drains to the KAPS-LE cover (left). Mechanized spreading of ash-cement suspension (middle). Cross section of the KAPS-LE layer (right).

managed the transformation of technical standards and regulations for road construction up to the total takeover of European standards in this area from CEN/TC 226, CEN/TC 227 and CEN/TC 278. Introducing the new technology in the field of forestry would have been unthinkable without the professional patronage and cooperation with the Mendel University in Brno, which is the Alma mater for hundreds of graduates on the leading positions in various management functions. It necessary to acknowledge at least some of them, particularly the PhD students of the University, who allowed the realization of buildings with KAPS-LE on entrusted forest properties.

For all Ing. Tomáš Minx, Ph.D.(property Mensdorff-Pouilly, Boskovice), Ing. Karel Ježek, Ph.D. (Jilos Horka s.r.o.), or the very first supporter and promoter of the technology, Ing. Miroslav Matoušek (property KINSKÝ Žďár, a.s.). The technical step of cooperation is concluded in the accredited laboratory IMOS Brno, a.s., division of road development with more than fifty years of tradition, where there are carried out both the strength tests of the ash suspension as well as the measurements of impact load deflectometer under the leadership of the company chief Ing. Petr Meluzín.

The fact that the KAPS-LE technology becomes the subject of expert discussions and still wider application in practice confirmed the traditional meeting of the foresters of the Highlands (Vysočina), whose Jubilee 20. anniversary (5 June 2015) is mono-thematically dedicated to the KAPS-LE technology. The meeting is accompanied by a collection of seven lectures, issued under the name A new technology for strengthening of the forest roads – KAPS-LE and the practical demonstration of the construction section and measurement of the FWD load-bearing capacity. Rather modestly endowed project IGA Faculty of Forestry and Wood Technology (FFWT) MENDELU No 71/2013-2015 thanks to the involvement of several top experts brings stimulating results not only in the past annual reports, publications, but also in a film about the KAPS-LE technology.

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Reconstruction of the forest road network model with linear fuzzy modelling in the conversion of the coppice forests to high forest enterprises

H. H. Acar [1]*, E. Dursun[2]

Abstract
In Turkey, forestry activities are carried out over an area of about 21.2 million ha. Operating such large, scattered and mainly mountainous forest areas requires a good road network. 5.7 million ha of this forested area is covered by offshoot of coppice forests. 1.7 million ha of the forested area is made up of productive coppice forest and 4.0 million ha consists of unproductive coppice. This study aims to reconstruct the forest road network during the conversion of coppice forests to high forest enterprises. The research area is lying within the boundaries of Amasya Regional Directorate of Forestry. The digital maps and management plans to be used in the study were obtained from this directorate. During the construction of road network of Yaylacık Forestry Unit, the forest road maps and plans were utilized using 1/25000 scale maps and digital maps of the region. An optimal road network map was generated based on the field assessments and the GIS studies. Then, new road network model was developed to plan optimum path routes by taking into account the obtained data and to reveal the problems that may occur in this process and to reorganize the forest road network in the conversion of the coppice forests to high forest enterprises. Coppice areas in Turkey are the bond grove areas. Therefore, the revision of the forest road network is definitely required. For this purpose, the new technical conditions for the conversion of forest road networks were modeled and the capability of the linear fuzzy modeling was investigated in this study.

Keywords
forest Road Network, GIS, linear fuzzy modeling, coppice forests, high forest enterprises, modeling studies

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1. Introduction

In Turkey, forestry activities are carried out over forest land which is about 21.2 million hectare. Operating such large, scattered and mainly mountainous forest areas requires a good road network. 5.7 million hectare of this forested area is covered by coppice forests caused by offshoot. 1.7 million hectare of the forested area is productive coppice forest and 4 million hectare consists of unproductive coppice. 625 thousand hectare unproductive coppice area has been turned to productive coppice by General Directorate of Forestry (GDF) to create energy forest since 1978.

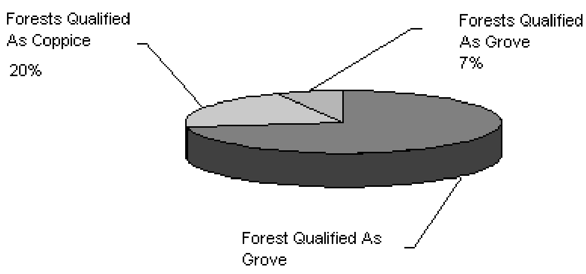

Figure 1. General forest forms and rates.

The necessity of rearranging and modeling of present road networks which are not adequate become evident within and after the process of converting coppice operations to grove operations. When the quantity of forest road is reached to targeted amount in Turkey, road density is expected to be 20 m/ha in the productive forests of which yield per hectare is more than 250 m³.

Recently, there is not adequate forest road network except from tractor ways and skidding traces in coppice forests within the scope of regulation. Constructing a new road network is seen as inevitable during the process of converting 5.7 million hectare coppice forest to grove.

Forest roads are one of the most important infrastructures in forestry activities. The costs of road construction and maintenance can reach at quite high values. Approximately 50 million Turkish Liras is spent annually during constructions of forest roads and maintenance works. These costs can reach up to very high rate of 20 - 25 percent of GDF's annual budget. Besides, superstructures were completed on approximately 17 percent of forest roads in Turkey (Acar and Eker, 2001). Mostly, all the other forest roads are native roads (raw road). Asphalt pavement is used in the roads located in national parks, recreation fields and some town roads. Therefore, road surfacing works should be also considered for forest roads.

Forest road length in Turkey has reached to 163072 km, including 143005 km production road, 17474 km fire safety road, 832 km tower access road, and 1761 km forest depot road by the year of 2010. Thus, 77.6 percent of planned forest roads are completed. It was reported that the average of 1000 km new forest roads were constructed and 1000 km of low standard forest roads were repaired annually (OÖİKR, 2001). Even though targeted road density is 20 m/ha in productive qualified forests, it should be considered that road density quantity will be more when coppice forests converting to grove areas. It can be said that about 50000 km forest road should be constructed in the years ahead in order to reach aimed road length.

The main roads and secondary roads which are connected each other by stream roads, slope roads and access roads are suitable for realization of multi-faced functions and benefits of forests. Transporting all kinds of products which are obtained by a forest ensemble continually and suitable for purpose and carrying out all kinds of forestry services are called as forest road network (GDF, 2008). Forests are opened up for forest operations by road networks which should have enough length and density in order to transport forest products from stump to forest road sides (landings) and main forest depots with lowest expenses (skidding, carrying etc.).

2. Material and Method

The flow cart of forest road network planning model applied for converting coppice to grove was indicated in Figure 2. The research area is located within Yaylacık Forest Sub-district Directorate at Tokat Forestry Enterprise Directorate which takes place in the borders of Amasya Forestry Regional Directorate (Table 1). Dominant tree species are black pine, yellow pine, beech, juniper, hornbeam, poplar and oak in the study area.

Table 1. Forest stand data.

Normal Forest Field	11573,5 ha
Degraded Forest Field	8799,5 ha
Forested Field	20373,5 ha
Non-forested Field	15435,0 ha
Total field	**35808,5 ha**

In the study area, road network planning was made in 1992 to answer all of the possible forestry activities. Under the light of these ideas, 322+4 km road was planned, while158+8 km of the road section was formed by existing roads which were constructed before, and 163+6 km of the road section was included into the plan as new road in 1992. Forest roads network plan developed in 1992 is still active in study area. According to this plan there should be total of 756 km road, including 322+4 km forest road, 135+0 km town road, 3+0 km road in the field. 420+650 km forest road, 42+250 km town road and 66+550 km road are predicted to take place in forested field. It is determined that road density is 15.6 m/ha.

2.1 Classification and Combining Data

UD rates percentages which were counted in Ms-Excel by comparing (Join) by means of codes which were appointed before to each raster grids composed as belonging to decision variables determining aim functions define to raster data by classification. Data were prepared to make criteria to each decision variable by defined before classification (Reclass by ASCII File) which is under the positional adding of ArcGIS 9.3 software.

2.2 Determining Variables and Designing Model

Aim functions which were to be applied to model ere determined for forest road network criteria. Three criteria were determined to design the model: slope, aspect, and topographic condition. Slope was evaluated as 10 point margin, topographic situation choices are evaluated as 6 class sub criteria.

2.3 Scaling Variables

Maximum and minimum scaling right was given to each class which belongs to decision variables. Rates about convenience points were counted by taking arithmetic average of maximum and minimum points. By pointing the importance level among points (p) of each sub criteria of aim functions determiner slope, topographic structure and aspect decision variables 0 as ineffective absolute absence, 1 was maximum and 10 was minimum rates (r), the convenience point counting belonging each decision variable was prepared.

Sub criteria belonging to decision variable which was used to determine aim functions was counted in linear regression equality estimation model Ms-Excel. The equality of which R^2 rate was counted as the highest was used for standardization by distributing within 0 and 100 in the next estimation model. Rate (r) which was determined to each class belonging sub criteria was converted percentage (%) statements by the help of linear model. Sub criteria of UD was prepared to provide attendance of decision variables prepared in CBS based working environment to model.

2.4 Determining Linear Fuzzy Rational Memberships

Decision variable points belonging to each function were included to fuzzy membership for linear fuzzy rational model. UD points belonging to sub criteria was normalized between 0 and 1 by taking square root with linear fuzzy rational.

Contour maps with 1/25000 including the borders of Yaylacık Forest Sub-district Directorate were used to form topographic structure of the field and numeral field model. Then, slope and aspect analyses maps were produced from numeral field model by using 3D Analyst module of ArcGIS program.

Areal distribution of Yaylacık Forest Sub-district Directorate Forest functions was calculated by evaluating and digitizing function map belonging to research field in NetCAD environment. Present forest roads were digitized by controlling road network plan of Yaylacık Forest Sub-district Directorate and utilizing satellite picture. In the field which has high stand closeness, roads were transferred to electronic environment by means of GPS along with satellite picture.

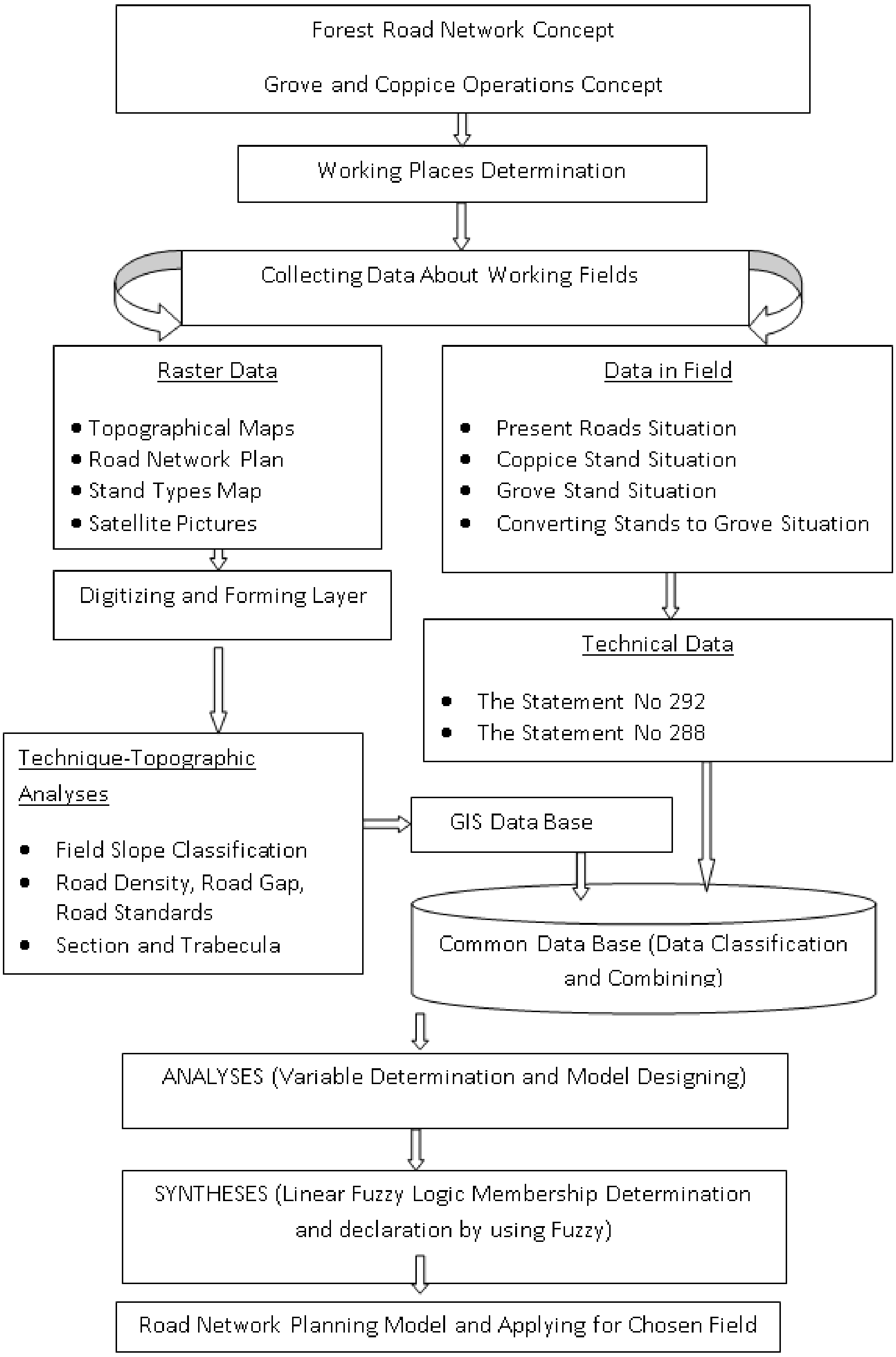

Figure 2. The flow cart of forest road network planning model applied for converting coppice to grove.

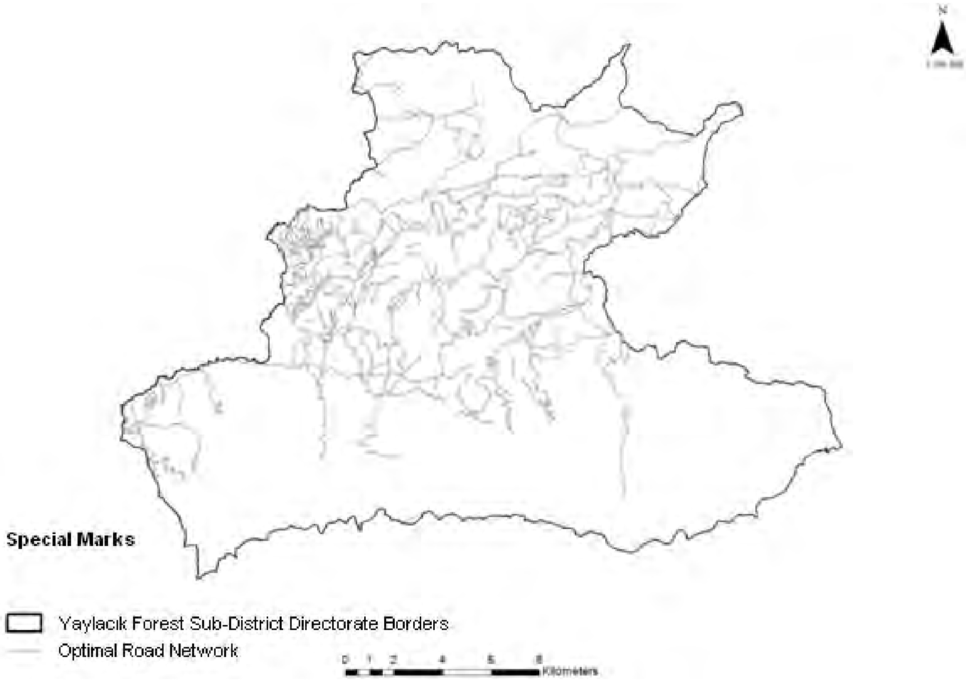

Figure 3. Yaylacık Forest Sub-district Directorate optimal road network plan.

Forest roads map was formed and be ready to control by the help of these maps. Slope, aspect and height classification were made to topographic analyses by using numeral field model.

Forest road geometric elements were scaled and road type was determined after field planning and pre-test workings. Data recording was made on forest roads by scaling and observation. Geometric features of the road were determined by scaling; the other features were determined by observation. Road etude report was used for recording field data. Concerned measurements and observations were made by complete inventory method by moving with vehicle from the beginning and at the ending points of the present roads.

2.5 Forming Optimal Forest Road Network Plan

Low and high road slope points, adverse slopes, various road density points, fields put into operation and technique details in the present and planned road were presented after processing road network plan and present situation to map. About hundred percent of putting into operation (optimum road density is 20m/ha and optimum road closure 500 m) was tried to be reached after analyzed present forest road network plan and completed forest roads according to technique and forest transportation. For that reason, optimal forest road network plan was formed different from present forest road network and by giving new road code numbers.

3. Results and Discussion

It was determined that 46 percent of the field was level and gentle slope land and 45.9 percent was middle and slope land. Forest roads were seen convenient according to slope features.

When areal distribution of aspect groups was taken into consideration, it is seen that 24.03 percent of the field was in north aspects, 52.78 percent was in south aspects. 14249.8 ha of Yaylacık Forest Sub-district Directorate has production, 7069.4 ha has saving soil, 24.2 ha has saving utility water, 15.8 ha has recreation, 13314.4 ha has open place, 47.9 ha has water and 581.5 ha has settling and cemetery function.

Road density in Yaylacık Forest Sub-district Directorate forest lands was determined as 15,71 m/ha when taking into consideration that forest road density should be minimum 20 m/ha within today's condition. Optimal road density was formed by taking into consideration the analyses made in the field and workings made in GIS environment (Figure 3). In the forest road network plan which has totally 332 km road length, present forest road network was evaluated and a 90 km road was planned additionally. As a result of this, the rate of putting into operation was raised 88 percent. 390 km of the present and planned roads passes through forest. According to this, nominal road density was determined as 20.71 m/ha, general road density was 12.34 m/ha. Therefore, forest road density was raised by 20.71 m/ha along with optimal forest road network. This provides 20 m/ha forest road density which was chosen as target in Turkey.

4. Conclusions and Recommendations

Optimal road network is formed which should take place in working field according to principles stated in instructions named as forest road network plans regulations. As a result of the research, it is stated that there are totally 52 present and planned forest roads in the field and all the roads are in the standards of B type forest roads. Total present road length is 332 km in Yaylacık Forest Sub-district Directorate and re-planned road length is 90 km.

Optimal road density is formed by taking into consideration the analyses made in the field and workings made in CBS environment. In the forest road network plan which has totally 332 km road length, present forest road network is evaluated and a 90 km road is planned additionally. As a result of this, the rate of putting into operation is raised 88 percent. 390 km of the present and planned roads passes through forest. According to this, nominal road density is determined as 20.71 m/ha, general road density is 12.34 m/ha.

Recently, there is not adequate forest road network except from tractor ways and skidding traces in coppice forests. Developing a new road network is seen as inevitable for converting 5.7 million hectare coppice forest to grove. Forests will need forest road network in different density and standards according to their functions. Determining quantity and distribution of forest road which can be needed for each function is so important to forest road optimization. In the process of planning road network in forestry fields, field information should be obtained in a correct and current way and these information should be used for forest road planning.

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Topic 9

Extraction & Transport

Forest road network planning accordance to single selection silviculture method and environmental considerations based on AHP method using GIS

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Abstract
Planning forest road networks is one of the executive pillars of scientific and appropriate management of forest areas and a method towards the sustainable development of forest stands. The goal of constructing forest roads is to; transport forest products, do services, maintenance and supportive affairs, provide access to the depths of the forest, connect forest areas and villages, and tourism aspects etc. (JamshidiKoohsari et al., 2008). So far, design has mainly taken place on the basis of economic and exploitation objectives. One of the main purposes of this study is to present a method for designing forest road networks with regards to environmental considerations and in accordance with the silviculture method of single selection. For this purpose the required data, maps and positive and negative points were extracted in the form of data layers, then these factors were used to provide a suitability map. After the classification and valuation of internal classes of maps, all features and layers were weighted using Multi Criteria Evaluation (MCE) and Expert Choice software and the coefficient importance of each factor was obtained. Then by combining the characteristics and constraints, which was performed by overlaying the layers according to their importance coefficient using ArcGis software the valuated suitability map was obtained. Then six paths were designed by software (PEGGER). Finally the designed paths were compared in terms of compliance with the environmental factors, and the optimal variant was selected.

Keywords
forest road, friction layer, suitability map

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1. Introduction

Forest roads, just like the public roads have different tasks and roles in performing main activities of forest projects and other forest affairs that its impact is undeniable. Exploitation of forests should be done in the way to ensure the survival of the forest and its continuous production, in addition to rational use of its products. In such circumstances, any interference should be in proper understanding and complete knowledge of the ecosystem. Given the extent of forests, population growth and technological progress, if there is no systematic plan for the exploitation and protection of forests, these forests will gradually propel toward the extinction. In present century, the The correct planning and management of natural resource, and on top of them forest conservation arise to achieve sustainable development and one of the appropriate strategy, is accurate planning and implementation of forestry projects. In this regard, forest road network is considered as one of the main keys for economic, protective and supportive development plan of forestry projects and has an underlying role in organizing the region.

One of the most important and most crucial study steps in designing forest road network is the initial route design (conductor) or Phase Zero Study. One of the interesting points in designing new methods is to avoid designing path crossing from ecologically sensitive areas in phase zero studies or initial design to prevent environmental damage and further consequences.

Todays, the use of GIS and DEM capabilities in routing forest roads is automatically possible. Using the existing tools, designers of forest and mountain roads can quickly analyze many variations of road and also evaluate the environmental and economic conditions by using of GIS capabilities (Rogers, 2005). Now, given that the country's northern forests are in the mountainous and sloping areas and have a uneven aged structure and the silviculture method to manage this type of structure is a single selection, which will lead our forests to be uneven aged, creating an appropriate plan which is consistent with the principles of single selectionsilviculture method and evaluation environmental factors to using aAnalytic Hierarchy processis of the objectives of this research. The principles which are considered in it are of the important goals of this research.

In a research on the environmental impact assessment of road construction on forest environment using GIS, applied two methods of overlapping layers and Leopold interaction matrix which has been modified for Iran. In this study, by overlapping the maps of slope, aspect, elevation, soil, plant communities and canopy density, the map of environmental units was obtained and was usedthe special ecological model of road construction in seven categories to achieve the ecological potential map for determining the optimal route of road,. Also the evaluation has been done with two matrices of 14 × 29 (construction phase) and 7 × 29 (exploitation phase) and it has been concluded the area faults, Marnie parent rock, and the area soil heavy texture are the effective factors in possible increase of the forest soil landslide and erosion caused by road construction. (Sajjadi 2006),

(Survinen et al, 2003) addressed a study titled as optimal routing of the road using GIS. In their research, they formed the cost level based on factors of machine, land, tree cover and weather conditions. In the next step evaluation was done on the routes and it was concluded that a large number of factors can be identified and extracted on maps and applied in the evaluation and by using a sufficient number of factors, the best route can be designed according to the GIS capabilities.

(Musa and Mohamad 2002) began to search for a new method based on GIS for forest road network process. In this study, three road networks were developed by three different methods which in two of them, the geographical information system and design in the traditional way were used. As a result of this investigation, GIS method in these studies showed a good capability. They stated that the route designed by GIS can be used as the primary route by the administrator or designer to find the optimal location of forest road network to select the final route at the end.

Moretti (2003) by conducting a study at one of the Indian states designed routes with the least cost to exit the forest products using remote sensing and GIS. In this study, the required maps were prepared for the desired area using IRS satellite data and the river was also considered as an option for transportation. Cells related to the river were valuated. Finally, by preparing the friction map and applying the cost functions, economic optimum route was achieved so that a part of which was passed through the river and the router of economic optimum route was obtained.

2. Material and Methods

2.1 The characteristics of the study area

The study area is located the Shanderman series 2 known as MianVishe series of the Shanderman watershed. The selection of this area was because of having required diversity in terms of lands, slope and elevation above sea level.

Shanderman series 2 is located at the southwestern part of the corporation of Shafarood and between longitude of 49 to 49.03° east and latitude of 37.34 to 37.38° north. Height of the lowest point of series above sea level is 250 m and height of its highest point is 1550 m. The average of annual temperature is 15.7 °C, the average of maximum annual temperature is 21° C and average of minimum annual temperature is 10.5 °C. Average annual rainfall is 989.7 mm so that the lowest and highest amount of rainfall is in Tir, and Sharivar and Mehr, respectively.

2.2 Procedure

After reviewing various sources and according to preliminary visits of the study area, the effective factors were identified in routing the road and at the first step it was attempted to harvest positive points such as sand and gravel, natural terraces, schools, etc.) and negative points (such as slippery and erosion places, etc.) by a GPS device. Then affecting environmental factors were extracted in the form of layers of information such as slope, aspect, land stability, soil stability, favorable areas for depot, regenerations and inventory per hectare in friction map. Since one of the major environmental factors in road design is soil stability.

Mainly one of the road network design problems in the traditional way is inability to involve multiple layers including soil stability layer etc, and it is because in the current method there is limitation at selecting the number of factors and at the same time, this method does not have much capability to use spatial data and information.

In this study, at first, in order to the exact determine soil type it was attempted to harvest 40 soil samples in different areas and with distribution across the whole field so that, on average, one sample plot was harvested per parcel. For sampling, a borehole was dug to a depth of 60 cm (practice area of road construction) and its soil was harvested to determine the size and percent of the soil constituent particles. With different hydrometric tests, the percent of soil constituent particles was determined and by using soil texture triangle, the area soil type was found and finally the complete soil texture map was prepared using Kriging interpolation model.

At this step, the ecological model of rock and soil potential was used to prepare the stability map. In this model, by using the type of soil and rock, the stability of soil for roads construction can be found. In fact, the model determines that the area conditions is appropriate for road construction or not, or that the area has a weak potential. Accordingly, considering the geological map and field visits by Scientists in geology at the soil sampling points, rock samples were collected (Given that the majority of samplings were done close to trenches of the road) andidentifiedthe rocks type by using microscopic techniques in the laboratory,. In the next step, by overlapping the maps and using the ecological model of rock and soil potential (doctor Makhdoom) the soil stability was determined to design road so that ultimately, the map of soil stability was prepared and accordingly, the area was classified into three categories of good, average, and poor in the terms of stability.

On the other side, in designing the forest roads network, flat or low-slope areas are considered as suitable places for deck.Since the road construction in these areas will lead to lowering the mount of excavation and embankment in the route. Thus, along,were identified all flat and low slope areas and natural terraces and places which have ideal conditions in terms of depot and wood collection point by the field operationthe place that have a very high capability for crossing the roadand positioned by GPS device and harvested. Among the other factors that were affected in the design of road, there are regeneration places or hand planted stands. Basically in road construction, regeneration in a large extent or regeneration with special species is important and is considered as an effective factor in route design;so in this study it has been tried to position the regeneration areas, hand planted forests and areas with special species, and implement them on a map and finally prepare the information layers. Furthermore, given the low extent of hand planted stands

2.3 Friction layer

In designing the road network it is tried to avoid each route passing through some areas, such as Fountain, cliffs, falling and sliding points, mines, very high slopes and generally negative mandatory points. For this purpose, a layer called friction (restriction) was prepared. So that all places and negative points were produced in the form of a raster layer and the were determined map cells with a zero value as the areas with restriction for the route to cross.

2.4 Suitability map

Data were compared in order to incorporate the restrictions and characteristics of various parameters in decision-making and the data integration on the basis of their importance. The most common multi-criteria evaluation method is linear weighting method and one of the weighting technique is the pairwise comparison method (Malchofsky, 1999) that in this method, a weight was given to each characteristic; and was formed a comparison matrix and factors were compared as paired and were calculated their weights using EC (Expert Choice) software. In the next step, coefficient of importance of parameters was involved in layers of information by ArcGis software (the value of every cell of map and their internal classes) and by multiplying them on a restriction map, was obtained the suitable plan which its domain of values is equal to a domain in which the characteristics are standardized (domain of internal classes of maps). Thus, the weighted maps were combined and ultimately suitability map was obtained. For ease and accuracy of design of forest road network, the final map were classified and coded considering the range of values (Reclassification). To designoptimal routes with the aim of forest road network planning was used the capabilities of PEGGER software. So, for better design and rapid analysis, multiple options were studied for each route of road. Finally, six variants of road network were designed on the final valuated map so that for all options, designs were in such a way that the routes will cross from the areas with high-value.

2.5 Environmental assessment of designed variants

At this step, in order to minimize and further reduce of environment damage, it is necessary that different variants were compared in terms of environmental. So that the road that passes through the highest values will be the route that is the least environmental damage and that route, in the terms of compliance with environmental considerations was selected as the best option. It is notable that for better comparison of variants, according to the passing from classes with different values, each class is given a coefficient with a value between 1 and 5. Finally, a number will result from the sum of multiplying the percent of road passes from relevant class, in desired coefficient for each variant . So that the higher number shows that the desired road passes from the highest cellular values of map and the aforementioned option is selected as the superior variantin terms of compliance with environmental factors.

Figure 1. Coefficient of importance (weight) calculated for each characteristic.

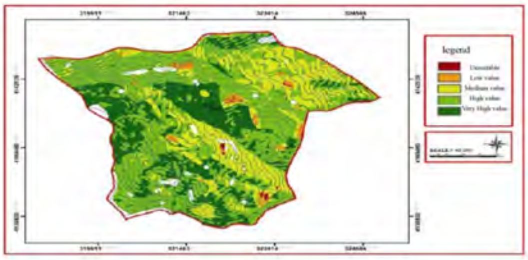

Figure 2. The final map resulted from overlapping the layers for planning the road.

3. Results

The results from consideration ofslop map showed that the highest frequency of slope classes is for the slope class of (30-60) with 48.6% and the minimum frequency is for slope class of (> 80%) with 8.83%, the fact that a small percent of the area surface has a slope higher than 60% represents the suitability of area for the planning the road in terms of slope.

The results from soil stability study showed that about 83.62% of the area has good and average stability. Most of the area has good and medium stability and it indicates that the area in terms of soil stability has fairly suitable capability road cross the road. Having about 92.9% of the area surface with medium and high volume per hectare represents a fairly good volume in the region. In other hand depot place map Revealed the suitable region to wood depot is low.

3.1 Multi Criteria Evaluation

To prepare the final map and environmentally evaluate different variants better, each characteristic was weighted using multi-criteria evaluation methods. The results of the calculation of characteristics weights are shown based on expert opinion in Figure 3.Using this method, incompatibility coefficient was equal to 0.07 and given that this amount is less than 0.1, it is possible to use weights obtained in the continuation of the study.

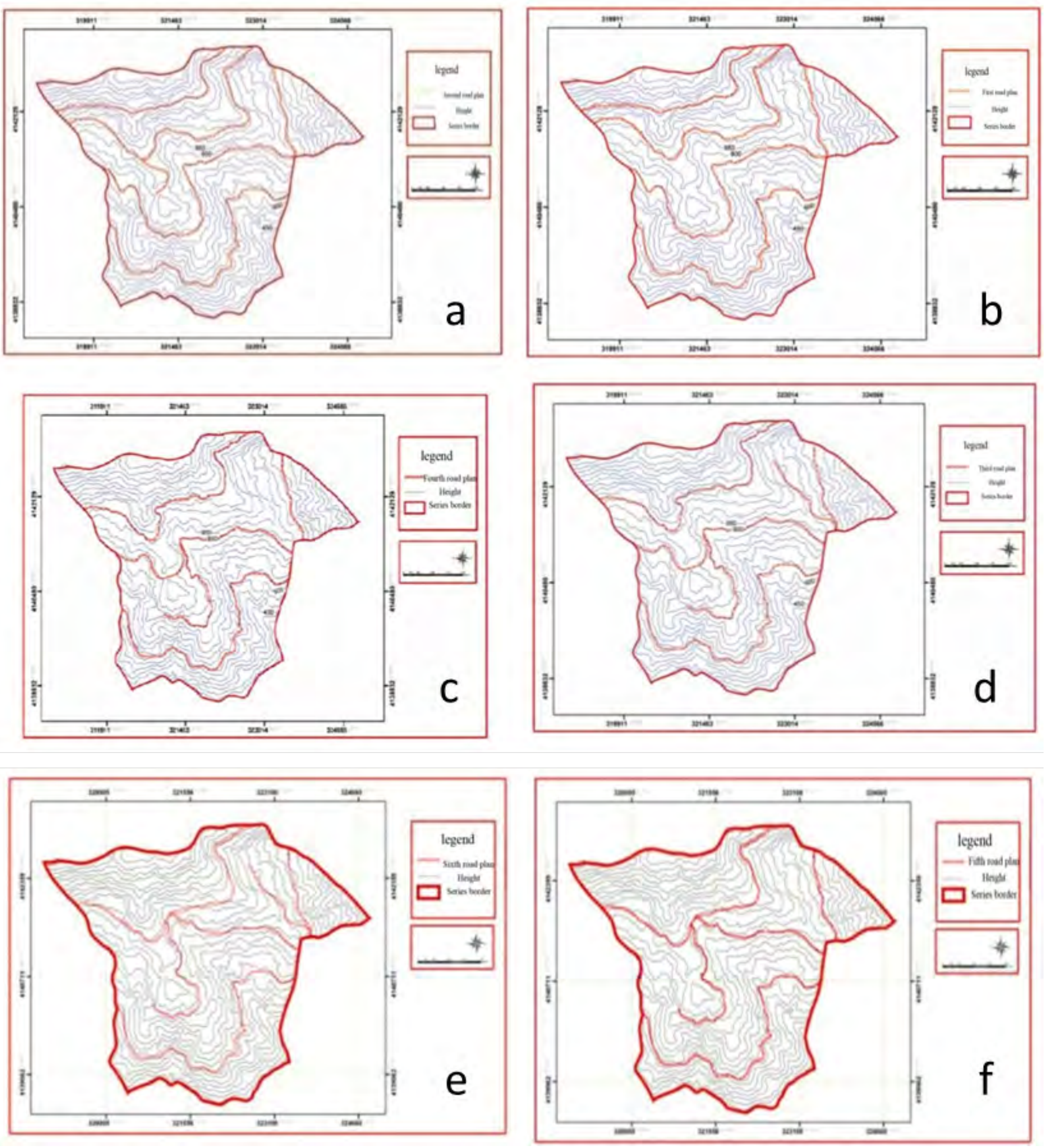

Figure 3. Planning of road .A. Constructed option in the area (available)

Table 1. The preliminary results obtained from environmental assessment for option 1-6.

Option	Class (code)	Percent of route passing from each class	Coefficient	Multiplying the percent of road passing from relevant classes in the desired coefficient
1	2	0.016957775	2	0.033391555
	3	18.38222.825	3	55.14668475
	4	52.94217399	4	211.768696
	5	286.586399	5	143.2932
2	2	0.292445167	2	0.584890334
	3	18.19658	3	54.58976442
	4	52.2826969	4	209.130788
	5	29.2282697	5	146.1413485
3	2	0.69637883	2	1.39275766
	3	21.64743335	3	64.94230005
	4	48.9658002	4	195.8615201
	5	28.6908078	5	143.454039
4	2	0.637174586	2	1.274349172
	3	27.25286729	3	81.75860187
	4	45.80375023	4	183.2150009
	5	26.3062079	5	131.53110395
5	3	28.62994061	3	85.88982183
	4	45.771042239	4	183.0841696
	5	25.599017	5	127.995085
6	3	22.34814143	3	67.04442429
	4	49.3883264	4	197.5521306
	5	28.2638593	5	141.3191297

Table 2. The final results obtained from environmental assessment for the different options.

Variants	Total of multiplying the percent of route crossing from relevant classes in desired coefficient for each valuated class
1	410.2424962
2	410.4467912
3	405.6506168
4	397.7789915
5	396.9690764
6	405.9156845
Available in series	399.2902866

3.2 The results from examining the Suitability Map

Based on the value domain that was given to the final suitability map, the map was classify into five categories so that each of the classes identifies the overall ability of area and its relative value in terms of the priority for route to cross. The results of coverage percent given by each class in the desired area are as below. The final map shows that 74.35% of the area surface has classes with high values (areas covered with light green to dark green) and about two percent of the area surface has a very low value for crossing and this indicates that in general the area has a good capability to planning route; Figure (2) shows the final map resulted from overlapping the maps (areas that cannot be crossed are marked with white).

3.3 Environment assessment of options

Given the prepared final suitability map and classifing it into five classes based on the given valuated domain assigned to the map and encoding them and that, performed designs are based on further crossing from areas with high value was obtained the amount of designed routes crossing from areas with different values according to the performed classification. The following figures indicate the amount of designed routes crossing from areas with different classified values.

4. Discussion

Lack of attention to environmental issues and attention to economic issues and exploitation from forests caused that this projects does not have necessary standards In terms ofcompliancewithenvironmental issues. In this study it has been tried that According to the environmental issues, the designs made in such a way that routes pass from areas with high-value as much as possible, so the target areas further have necessary conditions and stability for road construction. Prioritization of options regarding the environmental assessment is equal to option 2, 1, 6, 3, built in series (available), 4 and 5, respectively. Figure (4) shows the prioritization of options. According to the obtained results, option 2, 1 and 6 have the highest values in terms of environmental assessment prioritization, respectively. Thus, it can be said that these options pass from very favorable areas for the construction of road and in other words, have the least environmental damages. (Cutler et al., 2006) in their study used AHP to identify the priorities for road maintenance as well as determine the benefits obtained from completing the repair or improvement of a project. AHP was used to organization of Analytic Hierarchy process the problem. In the end it was concluded that AHP is a suitable framework for quantitative measurement of environmental factors and their use in modeling and algorithms planning.

In this regard, (Ahmadi et al 2005, Rafatnia et al, 2006 and Soleymanpoor 2010) also used the pairwise comparison method in analytic hierarchy process and considered it as a good way for weighting and noted this method as a appropriate framework for group decision making. The use of multi-criteria evaluation process in GIS environment provides the possibility of combining different characteristics with different importance and doing by traditional method (manually), not only is difficult, but also takes too much time.

(Abdi 2008) in his studies for road the planning with the least environmental costs and (Huang 2003) for the road planning with minimal security risk have used Multi-Criteria Evaluation Process and designed the optimal route. (Pantech et al 2007) in their study assess the main road length and skidding trail, networking percent and skidding distance and public road length of the area using GIS. Then, according to these data and other area data, they determined standards and generalized them to similar areas.

(Akay et al 2004) provided a model for designing the forest road network based on the Digital Elevation Model derived from LIDAR data and were used the affecting various factors in design by GIS software and was designed the possible routes were assessed and a route with minimum cost using this model. Also(Rogers 2005) considered a PEGGER Software in the form of geographic information systems and GIS software and was proposed a method as an alternative to traditional methods for determining the route on the topography map.

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Semi-automated traffic counting method for forest roads

B. Kisfaludi*, P. Primusz, J. Péterfalvi

Abstract

A camera surveillance system was developed to take photos of the users of a forest road in Hungary. The aim of the research was to identify main road user types (pedestrian, cyclists, cars and trucks) and to count the users. More than 70,000 photos were taken since the summer of 2012. The evaluation of this amount of photos by human work proved to be very labour-intensive. Therefore a semi-automated method was developed for a more effective evaluation. The method is based on open-source computer vision and machine learning algorithms. 11,000 photos were manually assessed to create training and test database for evaluating our image classification method. Trucks were underrepresented in the database so they were excluded from the evaluation. Under ideal circumstances the method was able to locate road users and can distinguish humans from cars on a photo taken by the surveillance system. Therefore only bad photos (burnt-out, shadowy, dusk etc.) and pedestrian-cyclist separation need human contribution. By using the computer-aided method up-to-date data will be available for the forestry company and ongoing research.

Keywords

traffic analysis, forest road, camera surveillance, automated image processing

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1. Background

In Hungary no method exists to obtain precise traffic data on forest roads, though some research aimed at this goal (Héjj, 1987). Therefore a traffic counter tool was developed for traffic analysis purposes. It was installed on a highly trafficked forest road in Hungary in 2012. The system has been providing raw traffic data – photos of road users – since then. Processed traffic data would be necessary for road use and inter-visitor conflict assessment. Traffic analysis of forest road networks may become available by spatially extended traffic counting (Janowski and Becker, 2003). By knowing network traffic data, road owners are going to be able to count with public needs when planning road maintenance, road development, road network extension and forest operation works. Therefore our goal was to develop a method to determine traffic properties from digital still images.

2. Material and Methods

2.1 The traffic counting system

Our system takes a digital still image of road users crossing a given section of a forest road. Still images are stored due to limited storage space and the expected rare supervision opportunities. The outline of the system can be seen on Figure 1. The system is triggered when a rod user crosses the beam of one of the two optical sensors. When triggered, the security camera takes a photo at 1280x800 pixel resolution. The camera is positioned on the side of the road at approximately 4 metres height. Photos are stored on the camera's SD card during the day. Photos are transferred to the central unit at night, when road usage is lowest. As there is no mobile coverage on the site, photos have to be downloaded manually.

Until now, more than 70,000 photos have been taken by the system. Visual assessment of 11,000 photos had been done by assessors. The majority of the photos were taken between May and September throughout the years 2012, 2013 and 2014. This database was used for testing our automation ideas. Unfortunately still image assessment is more difficult than the assessment of video clips. It is so because on video clips moving objects – that usually represent the foreground – can easily be detected. We hereby present a method that is able to automate the image assessment process.

2.2 Image analysis

We wanted to use image analysing methods to automatically classify road users into groups. The most important groups are pedestrians, cyclists, cars and trucks. Image analysis process can be divided into two main steps. First is road user location, second is road user classification.

2.2.1 Road user location

The first step of our image analysis process is to decide which pixels of the image belong to the background and which might be the road users. Background separation has two main cases: In the first case the background image is known. In this case the background image should be subtracted from the image in order to get the foreground. Our database does not contain suitable background images for every photo therefore another method should be used.

In the second case the exact background is unknown, which makes the background removal much more difficult. In this case the background of an image can only be esti-

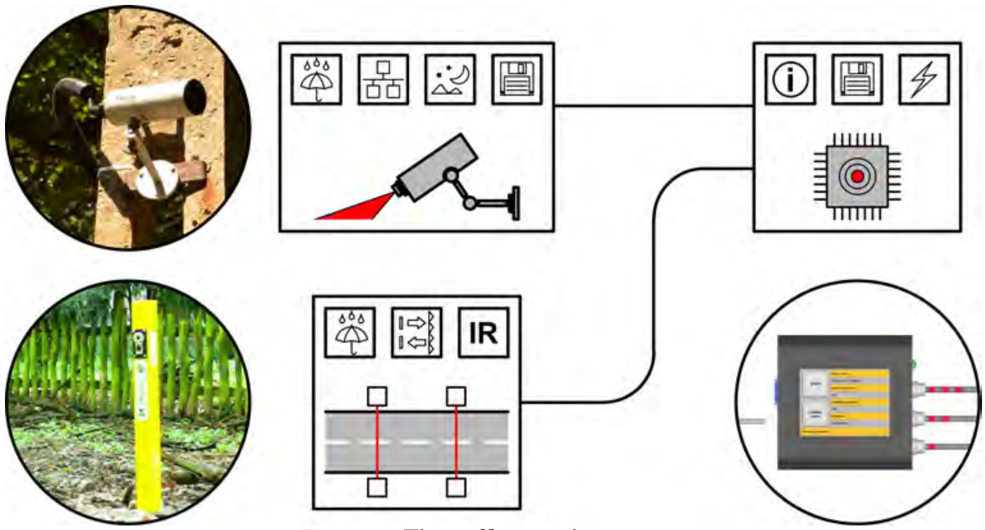

Figure 1. The traffic counting system.

mated. For successful background estimation it is essential to have images with different foreground locations. In this case images can be averaged as an approximation of the background. Averaging should be performed on a temporal subset of the whole database in order to minimize the changes in illumination. Background model construction is a more efficient method for background estimation than averaging. For the images of a given period of time the colour histogram of a pixel coordinate is calculated. Pixels that are always part of the background can be described with one group of colours. Histograms of pixels that can be both background and foreground usually have more peaks. The colour group with the most members can be considered as the background colour. Background and foreground colours can be separated with clustering methods. If great variation in illumination is expected – as it is the case in our project – clustering should be done with more than two groups for different illuminations (Stauffer and Grimson, 1999).

There is another background estimation method for independent images. This is called image segmentation. The image is divided into blobs, which then can be assessed. For segmentation the “Similarity Map” of the image was created. This is the result of a filter that shows how similar is an 8x8 pixels cell of the image to its surrounding eight cells (also the size of 8x8 pixels). Similarity between the cell and one of its neighbours is represented by a value between 0 and 1. It was calculated by using the ExhaustiveTemplateMatching algorithm of the Aforge.Net image processing framework (www.aforgenet.com). A cell was assigned the average similarity value of the calculated similarities for each of its surrounding cells. Lower values mean less similarity that indicates places where some interesting thing can be found on the image. Cell similarity values got thresholded to obtain a black-and white image. The blob finder filter of Aforge.Net was applied on the resulting image to locate bounding boxes of the found blobs (Figure 2). Under ideal conditions road users are represented in the group of found blobs. Blobs located on the road surface were selected for further analysis as these are the most probable road user representations.

2.2.2 Road user location

After locating the blobs that may contain road users a decision should be made on which blobs really represents road users. Road users then should be classified. This task can be performed with methods ranging from simple template matching to machine learning algorithms. Latter require more time and expertise, but usually give significantly more satisfactory results. Therefore a state of the art, Bag of Visual Words and Support Vector Machine based image analysis method was used that applies machine learning algorithms. The BoVW (Bag of Visual Words) method determines the frequencies of pre-taught visual properties (visual words) on an image and classifies the image based on the resulting histograms. The method requires an image database as input, where images had been already classified. This database was our 11,000 processed photos with more than 23,000 located and classified road users. Three main categories – pedestrians (14,600), cyclists (3,400) and cars (4,500) – were selected for analysis. 70% of the dataset was selected for training images. 30% of the images served as the test database.

Image classification is made in four main steps (Tsai, 2012):

1. Feature detection
2. Feature description
3. Codebook generation
4. Image classification

The BoVW class of the Accord.Net framework (Souza, 2014) was applied to build the bag of words model. Feature detection (based on the work of Evans (2009)) The aim of feature detection is to locate interesting points on an image. Interesting points can belong to edges, corners and blobs. Feature detection was done by the SURF (Speeded Up Robust Features) algorithm as implemented in the Accord.Net framework (Souza, 2012). SURF uses a Hess matrix based filter to detect interesting areas. This filter is able to detect

Figure 2. Result of the blob finder algorithm.

blob-like formations and corners on grayscale images. Assume the grayscale image as an elevation model (lighter means higher). The determinant of the Hesse matrix shows the curvature of the surface around a given point. The algorithm considers local extremities in curvature as interesting point locations. As interesting points can occur in different sizes, SURF applies the filter in different scales. Feature description (based on the work of Evans (2009)) The surroundings of the interesting points should be described with scale, rotation, illumination and affine deformation invariant parameters. Feature description was also carried out with SURF. Scale invariance was ensured in the feature detection step. Rotation invariance was ensured by determining the orientation of the feature. Orientation determined the rotation angle of the rectangular descriptor matrix. The matrix was divided into 4x4 subregions. Haar-wavelet responses were calculated in both x and y directions for 25 random sampling points within each subregion. Responses represent the orientation of the evaluated area, and its values can be positive or negative. A subregion can be described with the summed wavelet responses (dx and dy):

$$v_{subregion} = [\sum dx, \sum dy, \sum |dx|, \sum dy] \quad (1)$$

This way every subregion delegated four values, therefore the result of the 4x4 subregion was a 64 element vector, called the feature vector. This descriptor is remarkably invariant to changes in scale, rotation, illumination and contrast. Codebook generation Feature detection and description was performed on the training and the test image datasets. The resulting feature vectors of the training dataset were divided into 36 feature vector regions as we decided to characterize each image with 36 visual properties. Each feature vector in a region corresponds to the same visual code word. The Binary Split algorithm of Accord.Net was applied for assigning each feature vector its corresponding code word, thus generating the codebook for the bag of words model. Binary split kernelling is faster than the regularly used k-means kernelling while giving satisfactory results (Schwardt and Preez, 2003). These 36 code words were used to represent each image in the whole image dataset. Image classification with SVM (Support Vector Machine) The feature vectors of each image in the whole dataset were assigned to their corresponding code words. An image was represented by the histogram of the occurring code words on it. As a result the category and the code word histogram of each image in the image dataset became known. The correspondence between the class of the images in the training dataset and their histograms was taught to a machine learning algorithm called SVM. The SVM implemented in the Accord.Net framework was used. For kernelling SVM takes histograms as vectors and separates the vector-space with a hyperplane in a way so the margin between the two halves is maximal (Shawe-Taylor and Cristianini, 2004). This method can divide the vector-space into only halves therefore nested SVMs were used for multi-class kernelling. The SVM “knew” which histogram-vectors should be grouped together and developed the classes accordingly. The characteristics of three road user groups – pedestrians, cyclists and cars – were taught to the SVM. The performance of the BoVW model based SVM was verified on the test image data set.

3. Results and discussion

The image dataset that was used for the development of a semi-automated image classification method contains 11,000 digital still images. On these images around 23,000 road users were located and classified by visual interpretation. The distribution of the assessed road users can be seen on Figure 3. It is clearly visible that the vast majority of the road users were even pedestrians, cyclists or cars. The low number of heavy machinery and trucks can be explained with the time span of the images as they were taken mostly out of the forest operations season. Figure 4 shows the inward and outward ratio of the three main user classes. It is worth noticing that the number of cars going inward is almost the same as the number of those going outward. That phenomenon can be explained with two facts. The road is closed to public traffic not far after the counter and the head office of the forestry company is located on the beginning of the road. Therefore most of the cars have a reason to return to the beginning of the road. Pedestrians and cyclists move more freely thus the bigger differences in the inward and outward values.

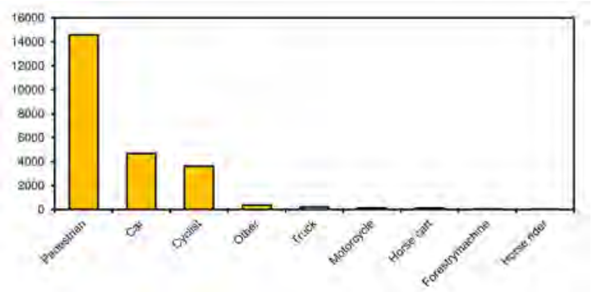

Figure 3. Distribution of road users.

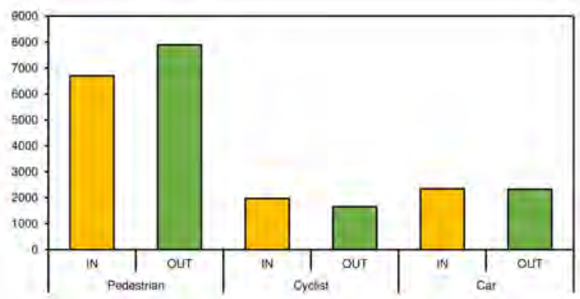

Figure 4. Inward and outward traffic.

The described semi-automated image classification process was applied to the images of the three main user groups to evaluate the performance of the method. On images where the illumination conditions were appropriate – no strong sunlight and dark shadows – our Similarity Map based road user location worked quite well. The performance of the BoVW model based SVM was verified on the test image data set. The performance of the SVM can be represented by the confusion matrix. It shows how many test images of a user class were classified into the appropriate class and how many false category assignments occurred. The visual representations of the confusion matrices for inward and outward traffic are shown on Figure 5 and Figure 6. It can be seen that pedestrians were almost always – in more than 90% of the cases – recognised as pedestrians. The misfortune is that the majority of cyclists are recognised also as pedestrians. By comparing inward and outward results it can be stated that inward cyclists tend to be more recognisable as cyclists (24%) than outward cyclists (5%). This may be because more characteristic details of the bicycle might be visible when facing the camera. Four fifths of cars were classified properly. The one fifth falsely classified as pedestrian was unexpected and has not been explained yet.

In conclusion it can be stated that our method was able to locate road users on digital still images if the illumination conditions were near optimal. It was able to distinguish between cars and humans in 80% of the cases. Pedestrian and cyclist separation is a difficulty that should be solved in order to complete the automation of image classification.

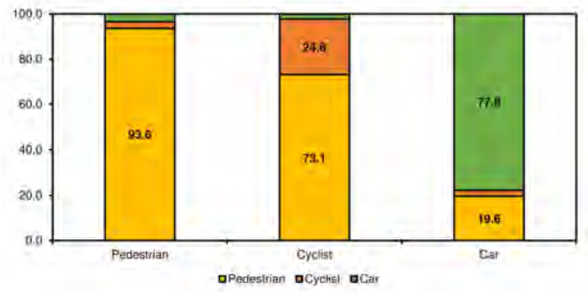

Figure 5. Confusion diagram of the inward traffic.

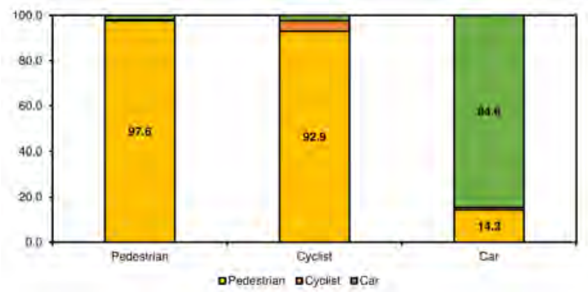

Figure 6. Confusion diagram of the outward traffic.

4. Further research

Storing digital video clips instead of still images is considered in order to make background removal more efficient. The bigger space requirement of video clips can be compensated by more frequent data retrieval even by internet transfer if mobile data coverage would be available. Images with extreme range of luminance levels are usually taken during the summer months between noon and 15 pm. By taking more photos in quick succession with different exposure times a high dynamic range image could be produced. Due to normalised luminance levels background segmentation might be performed significantly better on these images. Preliminary analysis of road user blobs shows that cars and trucks can be separated from pedestrians and cyclists based on the width/height ratio of their bounding boxes. If this will prove to be true, the confusion between cars and pedestrians could be minimized. Cyclist and pedestrian separation is the most important task. It could be solved by using different parameter set for the BoVW model or by using another model for image representation. The layout of the traffic counter system is under rearrangement that is expected to lead to better quality images with better view angle that can improve classification methods. After reinstalling the system two optical sensors are going to be in operation therefore direction and speed of road users could be determined. It is assumed that pedestrians are usually slower than cyclists, therefore they might be separated based on speed data.

5. Summary

A traffic counter system is being used to collect traffic data of a forest road in Hungary. The system provides digital still images of road users crossing a given section of the road. A semi-automated image classification process was developed to help to deduct road usage characteristics from the photos. Nearly 11,000 photos were manually classified to provide a basic dataset for the evaluation of different automation methods. Our image classification process uses a self-developed similarity map of the images as a basis for image segmentation and background-foreground separation. This method works satisfactory if the illumination conditions of the evaluated photo are near optimal. Foreground pixels were searched for blobs and blobs located on the road's area are selected for classification. Road user classification is based on the Bag of Visual Words representation of the selected image parts and is carried out by a machine learning algorithm called Support Vector Machine. Our method can sufficiently recognise cars, while it cannot separate cyclists and pedestrians. We hypothesise that with more winter data and further improvements of the method it is going to be able to recognise pedestrians, cyclists, cars and trucks.

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Load space utilization of a Valmet 860.4 forwarder

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Abstract
Forwarders are most common machines used for timber extraction in Croatian lowland forests.
This paper deals with the; mass, volumetric and length utilization of load space, of the eight-wheeled Valmet 860.4 forwarder during extraction of timber assortments and energy wood. While considering different methods of timber processing in an oak regeneration felling.
Results showed that the mass utilization of load space is higher than the rated load capacity during extraction of technical roundwood, while volumetric and length utilization is less than the nominal values of the length and volume of forwarder load space. The minimum value of mass utilization is determined during extraction of forest energy wood residuals which affects the costs and profitability of such a machine in these conditions.

Keywords
forwarder, load space, utilization, oak, logs, energy wood

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1. Introduction

Utilization of loading space has a significant impact on forwarder transport efficiency. Forwarder loading space is designed for extracting round wood and as such is dimensionally adapted so that average weight of load is approximately equal to the nominal capacity of forwarders. Coniferous cultures prevails in the Scandinavian and Central European countries, so in forwarder timber extraction wood products are mainly made to equal length (cut to length method - CTL) which approximately corresponds to the length of the loading space of forwarders. In such cases the mass utilization of loading space is almost always optimal. Wood assortments in Croatia are made according to current Croatian standards which divides wood assortment into different quality classes (cut to quality method - CTQ), result of which is that there are assortments of different lengths, at least 2 and up to 6 meters or more in combined logs. When using CTQ method mass utilization of forwarder loading space, was largely achieved while the length and volume utilization is usually below capacity of loading space.

Size (mass, volume and length) of load is a parameter that directly affects the productivity of forwarders. Size of load defined by mass depends on technical features of the vehicle, size of the loading space and rated load capacity of forwarders. Due to the theoretical possibility of vehicles, Poršinsky (2005) states that the size of the load is also affected by terrain characteristics such as the soil condition, slope and surface barriers. Load size is significantly affected by dimensions and shape of round logs being transported (curvature, expressed root collar, lumps). Also the size of the load, especially its mass, is affected by wood density which is especially obvious during transportation of energy wood.

With increasing use of biomass for energy usage of forwarders for its transportation has become more common. As

(a)

(b)

Figure 1. Forwarder loading space with the possibility of increasing its volume during transportation of energy wood.

the energy wood is mostly comprised of branches and tree crowns, so when loading the loading space is very quickly filled to the maximum and due to the low density of such loads mass utilization of forwarder is significantly lower. Major manufacturers of forwarders such as Komatsu Forest have already made the forwarders with variable loading space volume (figure 1a) movement of supporting arms increase loading space volume and surface for transportation of energy wood (Pandur et al., 2009), and thereby increasing the mass utilization of loading space. A similar system was developed by John Deere at its forwarder (figure 1b). Viitikko et al. (2012) published patent for forwarder loading space which also uses moving supporting arms and is intended for energy wood extracting. Bosner et al. (2008) investigated how load features (curvature of round wood and wood quantities) affect axle load forwarders.

2. Material, methods and aim of research

Forwarder Valmet 860.4 was used for wood assortments and energy wood transportation from oak stands where final felling was conducted. The research was conducted in forest management unit Debrinja (forest administration Vinkovci, forest office Strošinci) in two adjacent sections where in first section (64f2) forwarder was used for extracting technical roundwood and subsequently energy wood, and in the second section (64f1) for extracting technical roundwood, long firewood and subsequently for extracting forest residues. Thus, the study included four different wood products where forwarder was used for their extraction. Characteristic for the research stand are dimensions of the oak trees (over 140 years of age), which have well-developed treetop with branches of over 20 cm in diameter, but because of its curvature those branches couldn't be industrial roundwood. For this reason, a preparation of treetops and branches of felled trees had to be made. Preparation was made in that way that forest worker with chainsaw was cutting the treetops and branches to an acceptable length for easier loading and unloading. The mass of each load was measured by a portable measurement platform described by Zorić et al. (2012), while the dimensions (length, mean diameter and volume) of technical roundwood and long firewood were taken from shipping letters.

Figure 2 shows a dimensions of researched forwarder Valmet 860.4 loading space. Based on the measured dimensions of the approximate volume of loading space was calculated, and it was 15.83 m³. Rated load capacity of researched forwarder was 14,000 kg.

The aim of this research is to determine the mass, length and volume utilization of forwarder Valmet 860.4 loading space while extracting various wood products from final felling oak stand.

3. Results

Table 1 shows the descriptive statistics for all loads extracted by forwarder Valmet 860.4 from two researched forest sections. The average mass of technical roundwood load from sections $64f_2$ was 14,710 kg and ranged from 9,540 kg to 20,910 kg. On average, in one load there was 20 assortments of total average volume of 15.08 m³. Average volume of technical roundwood assortment was 0.8 m³, and the average length of the assortments was 3.43 m.

The average mass of load while extracting technical roundwood and long firewood from section 64f1 was 14,058 kg and ranged from 7,470 kg to 17,700 kg. The average load volume was 14.1 m³ with 23 assortments in average. The average volume of assortment was 0.68 m³ and the average length was 3.71 m. According to the results it can be seen that long firewood decreases average mass of the load even though the average number of assortment in load are higher and assortments are longer in average.

While extracting energy wood average mass of the load was 7,996 kg and ranged from 6,030 kg to 11,150 kg while mass of forest residues load had an average mass of only 2,743 kg and ranged from 1 690 to 3,250 kg.

In table 2 results of forwarder Valmet 860.4 loading space utilization are shown during extraction of four different wood assortments. Maximum utilization of loading space to the nominal mass of forwarder was while extracting technical roundwood only, with an average of 104.9% with ranged from 68.1% to 149.4%. Slightly less mass utilization was achieved while transporting technical roundwood and long firewood with an average of 100.4% and range from 53.4% to 126.4%. During extraction of energy wood average mass utilization of loading space was 57.1% with a range from 43.1% to 79.6%, while mass utilization with average of only 19.6% and range from 12.1% to 23,2% was achieved during extraction of forest residues.

Volume utilization of forwarder loading space while extracting technical roundwood was on average of 95.3% with ranged from 69.8% to 148.2% while transportation of technical roundwood and long firewood had an average utilization of 89% with a range from 55.6% to 110.3%.

Length utilization of forwarders loading space during technical roundwood extraction was on average 78% with ranged from 63.9% to 94.1%, while transportation of technical roundwood and long firewood had an average length utilization of an average 84.3% with range from 68.3% to 111%.

4. Discussion and conclusions

While extracting technical roundwood with forwarder a higher mass utilization was observed but at the same time volume and length utilization was under 100%. Wood assortment in Croatian forestry are produced by application on cut to quality method which is the reason why there are different length assortments on landing site (figure 3). If assortments were produced by application of cut to length method mass utilization of forwarder loading capacity would be much greater than in this research (105%). This is another confirmation that the forwarders are designed for the Scandinavian countries where coniferous tree species are dominant, which wood density is in average a half of the density of oak tree. This means that if a forwarder for the oak assortments extraction was constructed its loading space could be shorter on average by approximately 15% while maintaining the same nominal capacity. The next solution is

Figure 2. Dimensions of researched forwarder Valmet 860.4 loading space.

Table 1. Statistical analysis of load features.

Debrinja 64f$_2$						
	Technical roundwood					**Energy wood**
N	57					48
	Load mass, kg	N	V,m³-bruto	m³/piece	L, m	Load mass, kg
Median	14,710	19	14.86	0.8	3.4	7,855
Mean	14,689	20	15.08	0.8	3.43	7,996
St. Dev.	2,196	5	2.1	0.22	0.27	1,051
Minimum	9,540	12	11.05	0.43	2.81	6,030
Maximum	20,910	31	23.46	1.4	4.14	11,150
Debrinja 64f$_1$						
	Technical roundwood and long firewood					**Forest residues**
N	41					6
	Load mass, kg	N	V,m³-bruto	m³/piece	L, m	Load mass, kg
Median	13,770	23	14.17	0.66	3.65	2,925
Mean	14,058	23	14.1	0.68	3.71	2,743
St. Dev.	2,370	7.6	2.1	0.25	0.36	578
Minimum	7,470	13	8.8	0.28	3.03	1,690
Maximum	17,700	43	17.46	1.18	4.88	3,250

Table 2. Statistical analysis of loading space utilization of forwarder Valmet 860.4.

Debrinja 64f$_2$				
	Technical roundwood			Energy wood
N	57			48
	volume (m³)	length (m)	loading capacity (kg)	loading capacity (kg)
	15.83	4.4	14,000	14,000
Loading space utilization. %				
Median	93.9	77.2	105.1	56.1
Mean	95.3	78	104.9	57.1
St. Dev.	13.3	6.3	15.7	7.5
Minimum	69.8	63.9	68.1	43.1
Maximum	148.2	94.1	149.4	79.6
Debrinja 64f$_1$				
	Technical roundwood and long firewood			Forest residues
N	41			6
	volume (m³)	length (m)	loading capacity (kg)	loading capacity (kg)
	15.83	4.4	14,000	14,000
Loading space utilization. %				
Median	89.5	83.1	98.4	20.9
Mean	89	84.3	100.4	19.6
St. Dev.	13.1	8.3	16.9	4.1
Minimum	55.6	68.3	53.4	12.1
Maximum	110.3	111	126.4	23.2

Figure 3. Extraction of technical roundwood (Debrinja 64f$_2$).

Figure 4. Extraction of enery wood (Debrinja 64f$_2$).

Figure 5. Extraction of forest residues (Debrinja 64f$_1$).

to increase the rated capacity forwarder while maintaining current dimensions of the loading space.

During energy wood and forest residual extraction mass utilization of forwarder Valmet 860.4 is nearly half of its nominal capacity. Utilization of loading space is less solely because of the low density of transported load, but also because rarely set support arms (STIC) of loading space and small size (length) branches in forest residue.

In the forwarder market there are structural solutions of this problem (Figure 1) and it can be ordered as an option when acquiring a new forwarder.

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The estimation of extraction (haulage) distance for forest harvesting using a terrain model of 3D virtual globe of Google Earth®

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Abstract
Accurate estimation of extraction distance is very important in logging planning for the success of forest harvest plans. Generally, planar maps are used in logging planning. In these maps, the 2D horizontal distance shows a different value from the actual value under influence of terrain slopes.
In this study, the Artvin Regional Forest Headquarters (RFH), Giresun RFH and Trabzon RFH that forms the Eastern Black Sea Region (EBSR), has been selected as the research area. For the identification of the region, a total of 207 sample plots were selected at a 20x10 km spacing by performing systematic sampling that take into account the size of the surface area of the region using GE images and Netcad®GIS7 software.
According to the study results, the GE 3D maximum extraction distance was found as 716.8 m, with the 2D plan map maximum distance at 575.7 m. The General Directorate of Forestry's (GDF) extraction distance used for the calculation of logging costs is 597 m in the EBSR. The 2D plan map extraction distance is shorter by 19.7% than the 3D extraction distance for the logging planning, this rate cannot be neglected. Also, the average extraction distance value, which was obtained from GDF's cutting operation that is not based on any foreground, was also found be 16.7% shorter than its terrain distance.
3D distances which can be easily measured, has specified terrain features and qualifications for improving the success of the plans should be preferred as a decision making data at the operational scale logging planning based on harvest plans.

Keywords
forest harvest, logging planning, extraction distance, 3D distance, Google Earth®, Netcad® GIS7

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1. Introduction

Forest resource planning process includes such elements as preparation of an overall land-use plan, field identification of areas suitable for accomplishing management objectives, and environmental analysis of proposed projects by an interdisciplinary team of resource specialists (Kellog et al. 1998). The research of forest operations includes the study of timber harvesting, ergonomics, mechanization, construction, economic aspect and planning of operations, all within the framework of a sustainable forestry development (Stankic et al. 2012).

Determining the optimal logging systems for a timber harvest area is a difficult task because many considerations need to be taken into account including timber volume and distribution, terrain and environmental conditions, costs and productivity, and the existing road infrastructures (Kamarudin and Chung 2014).

The best logging practices had three primary objectives in planning the logging operation: 1. reduce damage to the residual stand, 2. reduce unnecessary waste of timber, and 3. improve the efficiency of extraction operations (Barreto et al. 1998). The most important factor affecting skidding productivity is piece size and that extraction distance comes only after other more important elements, such as winching distance (Spinelli and Magagnotti 2012). The wood skidding direction influences the efficiency and costs of logging operation. The accuracy of skidding performance assessment for certain areas can be improved, and the cost calculation can be made more reliable if the share and the location of specific wood skidding direction are known (Krc and Kosir 2008). Skidding costs are primarily dependent on the applied skidding method and extraction distances (Turk and Gumus 2010, Krc and Begus 2013).

Timber extraction distance from stump to nearest forest access road distance such as skidding, cable yarding, haulage or ext., distance is generally calculated on 2D planar maps. Extraction distance should be calculated with evaluation of compartment topographical features, trees locations that will be cut, logging systems selection and ext. Extraction distance is very important for logging planning due to the lack of forest road network and very high slope gradient at Eastern Black Sea region of Turkey.

In most of the recent studies, logging planning has been mad on 2D planar maps or GIS environment using vector or raster data sets. Operational scale logging planning maps can be produced directly from aerial photographs at a scale of 1:5,000 which is adequate for logging planning (Sauder and Weilburn 1989, Pentek et al. 2005, Devlin et al. 2008, Najafi et al. 2008). Even if well designed, maps do require a high capability of abstraction from readers: they are not compellingly understandable. The following limitations of analogous maps as communication channels which are partly also valid for digital 2D maps: (1) maps must be flat; (2) due to more or less uniform scale, a map provides only a single level of detail; (3) maps are static; (4) map production is usually slow. Contrarily, virtual globes or digital globe viewers (such as Google Earth, NASA World Wind, ArcGIS Explorer, etc.) are appealing, very intuitive and easily understandable. In this respect they overcome the limitations mentioned above. Freely available virtual globes with high spatial resolution contextual data enable the dissemination of analytical information derived from earth observation data to a broad audience. Advantages of this are: (1) the amount of integrated data is reduced; (2) this saves time in situations where rapid information delivery is required; and (3) data rights of the original data are respected (Tiede and Lang 2010).

Planar and slope distance affected under terrain gradient differences are very important especially in steep slope terrain. This differences affection to the logging costs. In some of the recent studies, 3D GIS datasets were used for the tractor or cable crane skidding planning (Tucek and Pacola 1999, Mihelic and Krc 2009).

Slope distance can be estimated by using local 3D GIS datasets. But, it has difficulties such as quality data handling and processing at larger planning units especially roughly steep terrains like Turkish forests. Open source high resolution 3D virtual globe has important advantages for description of forest area specifications such as road layouts, stands boundary, extraction paths and direction, terrain slopes and average slope distance. All of these are crucial to success of the logging planning.

Global environmental change has become an issue causing concern in both the scientific and policy-making community. Earth system science is developed as an interdisciplinary science to address global environmental change issues. Significant technological advancement is needed to provide the measurement, monitoring, modelling, analysis and assessment tools for solving problems at global scales (Yu and Gong 2012). Geospatial data which can be operated online tools is becoming increasingly important for many uses, from expert scientific domains to social media interaction. (Stannus et all. 2014, Chen et al. 2009). With the latest developments in virtual globe technology, it is now possible to develop a seamless and continuous multi-scale 3D visualization platform (Wu et al. 2010). A 3D terrain is constructed on Google Earth to present better terrain awareness for the operators (Lin and Lee 2014). Martinez-Grana and et al. (2014) have been presented a fast and efficient method for transforming traditional 2D maps to 3D maps using the tools available within the GE virtual globe.

The GoogleEarth® service is the most well-known and used internet service that provides free-of-charge access to the global collection of georeferenced satellite imagery. GE now hosts high-resolution (0.5 meter) imagery allows human observers to readily discriminate between major natural land cover classes and to discern components of the human built environment, including; individual houses, industrial facilities, and roads (Farah and Algarni 2014). GE grew to over 100 million users on the Internet within one year of its release. Other programs are becoming available with some similar capabilities, including World Wind and ESRI's ArcGIS Explorer (Sheppard and Cizek 2009). The GE virtual globe has been widely embraced by earth scientists, educators, government officials and the general public as an important and everyday tool to conduct research, exchange ideas and share knowledge with a global perspective in a natural and intuitive way, mainly because it possesses the ability to support the OpenGIS KML Encoding Standard (Zhu et al. 2014).

In Turkey there is no official harvest planning and logging planning in universal sense. The maintenance and regeneration works of forest is carried out according to silviculture plans located in the forest management plans. Forest management plans include compartment information and the total volume of trees that will be cut for the purposes of silviculture plans. There is not any operational plan for the cutting work. In these planning that is required to enter at forest operations in the future the usage of the extraction distances, which can be measured easily, has represent ability of the forest land surface features and can be increased success of plans, are very important.

The aim of this study is evaluating of the usage of google earth 3D virtual globe data for determining of timber extraction distance will be used at logging planning. This research will contribute for logging planning success of Turkish forestry.

2. Material and Methods

This study has been conducted at Eastern Black Sea Region (EBSG) that is including of Artvin, Giresun and Trabzon Regional Forest Headquarters (RFH). In this region, Artvin, Bayburt, Giresun, Gumushane, Rize, Trabzon and Ordu provinces are located. The total of 1,398,588 ha of forested area located in the research region corresponds to 6,45% of the forest area of Turkey. The total tree volume of the region is 28.738.023 m³ (GDF 2012).

GE virtual globe and calculation tools have been used for the determination of Maximum Extraction Distance (MED) and Average Terrain Slope (ATS) which are effective factors for selecting of the logging systems. A total of 207 sample plots were determined by 20x10 km spacing's by performing systematic sampling that taking into account the size of the surface area of the region using GE images and Netcad®GIS7 software. Forest lands boundaries have been identified by using forest stand types of the Artvin, Trabzon and Giresun RFH's build in the GIS database of the Turkish General Directorate of Forestry. Sampling plots outside the forest area have been removed. Total of 183 points out of 207 were determined (Figure 1).

3D MED and ATS were measured at the determined sample plots considering the closest forest roads. Firstly the extraction route were determined and designated using of

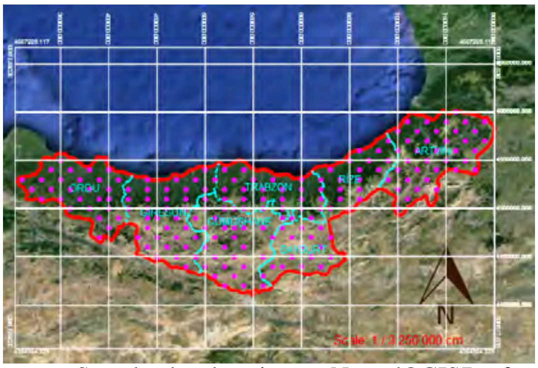

Figure 1. Sample plots locations at Netcad®GIS7 software used GE images.

the GE add-road module for measurement. After that, MED and ATS values captured by using show elevation profile module of GE of the designated extraction route and the values were recorded to a MS Excel sheet (Figure 2).

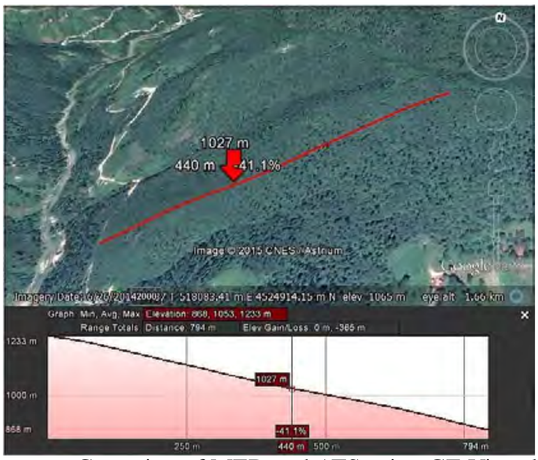

Figure 2. Capturing of MED and ATS using GE Virtual Globe.

Planner map distances (PMD) used at traditional logging plans were calculated by using of 3D MED and ATS values with trigonometric transformations at MS Excel sheets.

In the last part of this study, extraction distance which was used for cost calculation of Turkey General Directorate of Forestry and 3D MED obtained from GE were compared with each other.

For this purpose, cutting compartments located at Eastern Black Sea region between 2010 and 2012 was determined and was sampled by examining of the official logging records. The total number of the cutting area is 1089 at Eastern Black Sea Region. Trabzon RFH has 341 compartment, Giresun RFH has 324 compartment and Artvin RFH has 424 compartment. The following formula was used to determine the minimum number of samples (Demirutku, 2005):

$$n = \frac{N * t^2 * p + q}{d^2 * (N-1) + t^2 * p * q} \tag{1}$$

In the equation:

N = EBSR cutting area number

n = sampling number

p = the possible presence percentage of a measured feature in the main body (this ratio has been approved as 50%)

q = 1-p

t = theoretical values in the table t at a certain degree of freedom and detected in 5% error level

d = ± deviation

Sample number was determined using the below equation.

$$No = \frac{1089 * 1.96^2 * 0.5 * 0.5}{0.05^2 * (1089-1) + 0.96^2 * 0.5 * 0.5} = 284.205 \tag{2}$$

The minimum sample number was calculated 285 with 95% confidence level at EBSR. 120 logging area files at Artvin RFH, 91 logging area files at Giresun RFH and 91 logging area files at Trabzon RFH was accepted as selected sample by taking into account of weighted average. The selection of the logging files was random.

3. Results and discussion

The 3D MED measurement was made at 183 samples plot in the study area. MED has been found to vary from 315 m to 1126 m according to the results of measurements (Figure 3). The lowest extraction distance was measured at sample plot (no:29) which is located in the province of Rize. The highest extraction distance was measured at sample plot (no:76) which is located in the province of Ordu.

3D and 2D extraction distances were respectively found as 686 m and 547 m according to the results of the measurement made on 43 sample plot at Artvin RFH. Planar distance was calculated to be 20.3% less than the actual slope distance. Giresun RFH covers the provinces of Giresun and Ordu and is represented by 56 sample points. 3D and 2D extraction distances were respectively found as 718 m and 582 m at Giresun RFH. The difference of distances between 3D and 2D was found as 18.9% due to the less average terrain slope than to the other two the regions. Trabzon RFH covers the provinces of Trabzon, Bayburt, Gumushane and Rize and was represented by 84 sample points. 3D and 2D extraction distances were respectively found as 747 m and 598 m on regions and the difference ratio was 19.9% (Table 1).

B.C. Ministry of Forests had defined terrain stability classes (B.C. Ministry of Forests 1999). Region forest lands can be classified as 5th class (> 70%) very steeply sloping land. Because of the very steeply sloping of the region's forested area, work here requires to be done more careful. The effect of the terrain slope constitutes 19.7% differences between actual terrain distances and measured from planar

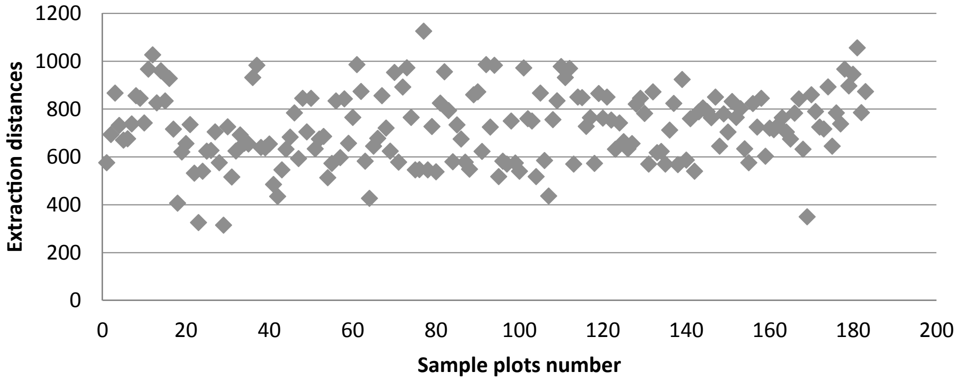

Figure 3. The distribution of the extraction distances at sample plots.

Table 1. Measured and calculated extraction distances and slope gradient derivate form GE Virtual Globe.

RFH	Sample Plot No.	ATS (%)	3D MED (m)	2D MED (m)	Difference ratio (%)
Artvin	43	76	686	547	20.3
Giresun	56	72	718	582	18.9
Trabzon	84	75	747	598	19.9
Average		74.2	716.8	575.7	19.7

maps. So, the plan distance located between two points on the map is shorter 19.7% than the actual terrain slope distance.

MED was determined 602 m in Artvin RFH, 616 m in Giresun RFH and 572 m in Trabzon RFH according to the data derived from number of 302 logging files that prepared for calculation of extraction costs by GDF. Average extraction distance obtained from logging files is 597 m. This value more than 2D planer map distance, but less than 16.7% from 3D virtual globe extraction distance. These values demonstrate the shortcoming of the harvesting systems, which are being implemented in Turkey.

4. Conclusion

GE receives increasing interest every day from the environmental sciences all over the world and has been used in scientific studies with offered open source spatial data. In this study, GE 3D virtual globe and Netcad®GIS7 software were used and these software was found as capable to estimate the extraction distance.

According to the study results, the GE 3D MED was found as 716.8 m, 2D plan map MED as 575.7 m and GDF's MED used for the calculation of logging costs as 597 m at EBSR. 2D PMMED is shorter 19.7%, the rate cannot be neglected, than 3D MED for the logging planning. Beside this, AEM value, which was obtained from GDF's cutting operation that was not based on any foreground, was also found 16.7% shorter than its terrain distance.

3D distances which can be easily measured, specified terrain features and has qualifications for improving the success of the plans should be preferred as a decision making data at the operational scale logging planning based on harvest plans.

Turkey GDF is not being used the harvest or logging plans at a conventional scale. Having very steep terrain classes according to the land capability class of EBSR forests, that contains a significant portion of the forests in Turkey, shows absolute need of preparing of the logging planning.

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Payload management of forestry trucks using different weighing systems in Australia

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Abstract
A project was carried out to investigate the impact of four different weighing methods on over/under load of forestry trucks operating in Forestry Corporation of New South Wales (FCNSW) under two types of roads; gazetted (approved for higher legal gross vehicle weight limits) and non-gazetted (standard public road gross vehicle weight limits). For all the technologies tested there was found to be a substantial under-loading issue ranging from 5.3 to 6.4 tonnes per load on gazetted roads while the same technology achieved a much better outcome on non-gazetted with a range of 1.4 tonnes under-loaded to 0.1 tonnes over-loaded on average. The results point to a more significant role for policy and methods than the technology used for in-forest weighing in achieving effective payload management in forestry haulage.

Keywords
forest transport, payload management, onboard scales, loading/transport efficiency

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1. Introduction

Trucking is often the most expensive phase of a timber-harvesting operation, accounting for as much as 40 percent to 60 percent of the total harvesting cost (Shaffer and Stuart, 1998). As a result, all possibilities for reducing the cost of trucking forest products or improving the efficiency of their transport should be examined (Bolding et al. 2009). Several factors such as payload, trip time and fuel efficiency can impact transport efficiency (Acuna et al. 2012, Ghaffariyan et al. 2013). Trucks should be loaded to their maximum legal weight every time as higher payloads will reduce transportation costs which can lead to increased wood demand (Lukason et al. 2011).

A low cost and simple technique to reduce load variability is for the truck driver to frequently communicate with loader operator to effectively estimate load weight, ideally using an onboard weighing devices on the loader or truck. The three basic types of onboard weighing devices are onboard truck scales, portable platform scales, and grapple scales. Both onboard and platform scales can provide single axle and tandem weights as well as net payload weight, while grapple scales record the weight of the wood in the grapple and accumulate grapple loads to calculate net payload weight. These scales can help to increase average payload while reducing overweight fines or mill penalties (Bolding et al. 2009; Overboe et al. 1998). In a Canadian study (Dayson, 2010) a comparison of the delivery point platform scale and onboard truck scale weights of each truck's total payload showed the difference varied from -0.1% to 0.9%. McNeel (1990) evaluated the effect of modified tractor and trailer log truck scales on truck loads. On average the mean net load weight increased by 2.07 tons when on-board electronic scales were used. Gallagher et al. (2004) analysed the difference in GVW between trucks that use scales and trucks that do not use scales (either in-woods platform scales or electronic on-board scales) where they found that weighed trucks in wood had higher net payload than other trucks. Variation in payload has negative consequences for both under-loading and overloading. Under-loading increases hauling cost, decreases profit, contributes to mill bottlenecks, and puts more trucks on the highway. Overloading may lead to citations, safety hazards, equipment damage and mill penalties (Bolding, 2008). According to a study in the USA, the wood suppliers with the most uniform weights (less weight variations) had a hauling cost savings of 4% to 14% (Hamsley et al. 2007). The moisture content can also impact the payload of trucks and transportation cost which can be managed to improve truck efficiency (Ghaffariyan et al. 2013). Beardsell (1986) determined using scale house (weighbridge) data and using weighing devices to buffer the problem of gross vehicle weight (GVW) variability: The first method involves the mill setting a target GVW range, and sending reports on a systematic basis to suppliers indicating their performance relative to the performance of other mill suppliers. Brown (2008) studied the wood transport systems in Australia and indicated the current fleets exhibit a wide range of tare weights within each vehicle configuration indicating there is potential for considerable savings in transport costs by equipment selection and management of tare weights.

Maximum payload and allowable axle load can be also impacted by the quality of the roads. Improving road standards (forest roads and highways) can also reduce road user costs which can contribute to the sustainability of the forest industry and increase the total amount of fibre that can be economically harvested. As an example the Minister's council on Forest Sector Competitiveness recommended subsidies to the forest industry for maintaining primary forest roads in Ontario, Canada (Hajek et al. 2008). Gazetting of a road is a process of assessing designated routes to determine if they can physically and safely carry a higher load than the standard classification. If all water crossings, road geometry, other users, etc. are found to be within defined safety and technical limited the route is identified as gazetted. Truck configuration in this study was 7-axle b-double tractor-trailers. These heavy vehicles covered in this study are allowed an extra 5,500 to 6,000 kg on their gross mass vehicle limit (GMVL) depending on the vehicle configuration and contractor status. Non-gazetted roads have the standard GMVL of 50,000 to 51,500 kg for 7-axle b-doubles depending on their configuration and contractor status.

There is little information available on the effect of the weighing method or road type on the over/under loads of the forestry trucks in Australia. Thus this project was carried out to investigate the impact of four different weighing methods on over/under load of forestry trucks operating under contract to the Forestry Corporation of New South Wales (FCNSW) on two types of roads; gazetted (approved for higher legal gross vehicle weight limits) and non-gazetted (standard public road gross vehicle weight limits).

2. Material and Methods

Data was collected from existing log-haul operations in New South Wales without any prior notice to the operations to help ensure normal operations were observed. Figure 1 shows the log truck loaded by a grapple loader with pine logs. The trees were felled and processed mechanically by harvester-processors. Then the logs were extracted to the road side by special forestry equipment called forwarder. The logs were stacked by forwarder into piles along the road side to be loaded later by grapple loader.

Figure 1. Log truck loaded by pine logs at the forest road side being prepared to travel to mill.

Using data collected and maintained for commercial purposes by the mills receiving the logs, a 12-month dataset was extracted to ensure a sufficient range of data was obtained. The dataset included records for just over 17,700 deliveries by just over 50 individual trucks including 7-axle b-double configurations, operated by 4 contractors. Gross, tare, load volume and net weights were recorded at each mill using weighbridges certified as legal for trade. The descriptive statistics of these parameters are presented in Table 1 and Table 2 for both types of road.

Table 1. Descriptive statistics of recorded parameters for each truck load for gazetted roads.

	N	Mean	Standard deviation
Gross weight (t)	13050	50.37	2.23
Tare (t)	13050	18.6	1.4
Volume (m^3)	13050	31.88	2.52
Nett weight (t)	13050	31.78	2.57

Table 2. Descriptive statistics of recorded parameters for each truck load for non-gazetted roads.

	N	Mean	Standard deviation
Gross weight (t)	4704	49.53	1.45
Tare (t)	40704	18.67	1.45
Volume (m^3)	40704	30.95	2.02
Nett weight (t)	40704	30.86	2.04

The forest manager also provided:

- The gross mass vehicle limit (GMVL) for each vehicle ID for both gazetted and non-gazetted routes
- The in-forest weighing system(s) used by each truck ID
- Status of the driver for each truck ID (hired driver or owner/operator)
- Which routes between wood sources and mill destinations included in the data base were gazetted and non-gazetted

The in-forest weighing methods were then grouped into four categories:

- Loader scale – weight measured using a load cell system incorporated in the grapple of the loader
- Truck scale (driver) – truck based scale using either load cells or air pressure sensors integrated into the truck and trailer suspension and fifth-wheel; operated by a hired driver
- Truck scale (owner/operator) - truck based scale using either load cells or air pressure sensors integrated into the truck and trailer suspension and fifth-wheel; operated by the owner of the truck
- Loader and truck scale – both loader and truck scales being used

The datasets were then examined and outliers and corrupted entries (weight recorded was less than 60% of the GMVL – i.e. half loads, vehicles having made less than 5 deliveries in the 12 month period, missing or unknown vehicle ID, etc.) were removed leaving just over 17,700 records for analysis, 13,050 on gazetted roads and 4704 on non-gazetted roads. The datasets were then statistically analysed to explore the relationship between the in-forest weighing methods and over or under loading.

2.1 Statistical evaluation

The over/under load was calculated by subtracting gross weight from GMVL. The database was divided into two different categories (weighbridge data on gazetted roads and non-gazetted roads) to be separately analysed. A frequency histogram of the data with a fitted normal curve was prepared by SPSS 21 for each data category. The normality of the data was proved by checking the frequency histograms then an analysis of variance (ANOVA) was applied to test the hypothesis of equality of the average of over/under load per each scaling method. As a post-hoc test, Duncan's multiple range test was then applied to derive the homogenous subsets (Zar, 1974; Yazdi Samadi et al. 1998) to compare the differences between the pair of treatments. This test could identify what treatment (in this case study means scaling method) was significantly different of the others. There are various post-hoc tests to apply including least significant difference (LSD), Student-Newman-Keuls test (SNK), Tueky, Dunnett and Duncan multiple range test. SNK method seems to be more powerful test than other methods such as least significant difference (LSD). For LSD method, in independent comparison within pairwise comparison of the treatments, for some of them the probability level (α) would be larger than determined probability. With larger number of treatments the error will be higher. Duncan and Tukey methods do not have this disadvantage of the LSD but the disadvantage of Tukey is that it shows less significant differences as it applies largest range for the multiple range tests. However SNK method does not have such a disadvantages (Yazdi Samadi et al., 1998). In this case study Duncan results were double checked with Tukey and SNK outcome and the statistical significance level of 5% ($\alpha = 0.05$) was applied in the data analysis. The statistical hypothesis of this project was expressed as follows;

Hypothesis:

H_0: Average under/over load of loader and truck scale = Average under/over load of loader scale = Average under/over load of truck scale (contractor) = Average under/over load of truck scale (owner contractor)

H_1: Average under/over load of loader and truck scale $\neq$ Average under/over load of loader scale $\neq$ Average under/over load of truck scale (contractor) $\neq$ Average under/over load of truck scale (owner contractor)

3. Results

3.1 Over/under load on gazetted road transportation

The descriptive statistics of the over/under load of each scaling method have been presented in Table 3. Highest standard error (0.09 t) occurred for the over/under load data of truck scales (contractor or owner contractor types) while lowest standard error belonged to under/over load of loader scale (0.03 t). The frequency histogram is shown is Figure 2 which indicates the data follows a normal distribution. The skewness and kurtosis values of this data set were 0.09 and 0.44 respectively while the mean value for over/under load was -5.66 t with a standard deviation of 2.46 t.

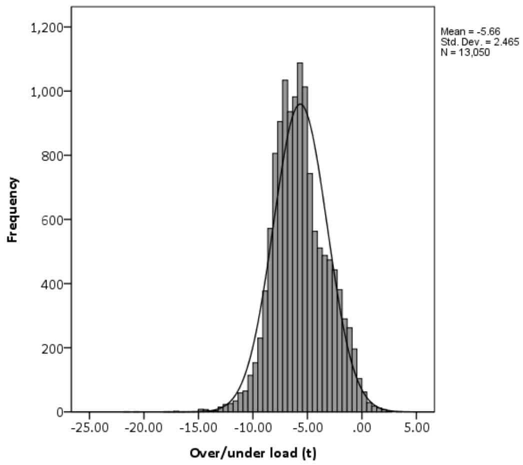

Figure 2. Frequency histogram for data on gazetted roads.

The null hypothesis was rejected which indicated there was significant difference among the means of over/under loads for different scaling types for data collected on gazetted roads (Table 4). There was no significant difference between the means of the over/under loads between loader and truck scale and truck scale (contractor). However both these groups were significantly different from loader scale and truck scale (owner contractor) in terms of the means of the over/under loads (Table 5). Application of Tukey and Student-Newman-Keuls approaches resulted similar results to the Duncan. Loader and truck scale had the lowest mean under load (-5.31 t) while truck scale (owner contractor) usage resulted in the largest mean under load (-6.44 t) (Figure 3).

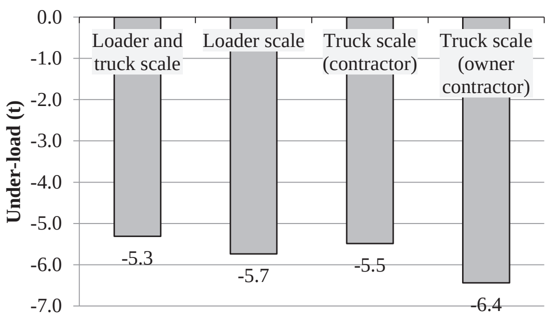

Figure 3. Means of under-loads for four types of scaling methods on gazetted roads.

Table 3. Descriptive statistics for under/over load (t) for gazetted roads.

Scaling method	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound
Loader and truck scale	2861	-5.31	2.25	0.04	-5.4	-5.23
Loader scale	9289	-5.74	2.56	0.03	-5.79	-5.69
Truck scale (contractor)	475	-5.48	1.97	0.09	-5.66	-5.31
Truck scale (owner contractor)	425	-6.44	1.84	0.09	-6.62	-6.27
Total	13050	-5.66	2.46	0.02	-5.7	-5.62

Table 4. Analysis of variance for gazetted roads.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	676.85	3	225.62	37.43	0
Within Groups	78636.48	13046	6.03		
Total	79313.34	13049			

3.2 Over/under load on non-gazetted road transportation

Table 6 includes descriptive statistics of over/under load for each scaling method on non-gazetted road transportation. Over/under loads from using loader scale and truck scale (owner contractor) had lowest standard error (0.03 t) while largest standard error was occurred in the case truck scale (contractor) application which was about 0.06 t. The frequency histogram of the data is shown in Figure 4. The skewness and kurtosis values of this data set were -1.64 and 20.58 while mean value for over/under load was -0.67 t with a standard deviation of 1.53 t.

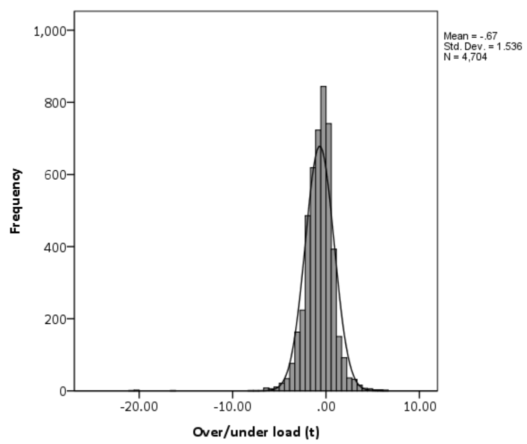

Figure 4. Frequency histogram for data on non-gazetted roads.

For operations on non-gazetted roads, there was a significant difference between the means of over/under loads for different scaling methods (Table 7). There was no significant difference between means of over/under load of using loader scale and truck scale contractor. However both groups were different from loader and truck scale (contractor) and truck scale (owner contractor) in terms of load variation (Table 8) (similar results were achieved by Tukey and SNK methods). The loader and truck scale had the largest mean under load (-1.43 t) while truck scale (owner contractor) resulted in a small mean over load (+0.09 t) (Figure 5).

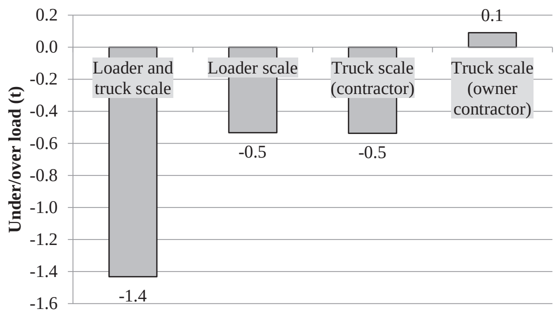

Figure 5. Means of under/over loads for four types of scaling methods on non-gazetted roads.

4. Discussion

The results of this study indicated mean under loading varied from 0.5 t to 6.4 t for both types of roads and mean over loading occurred only for one case (0.1 t). These results contrast with those of an American case study (McNeel, 1990) where an increase of 2.1 t mean load weight was achieved through using on-board electronic scales. Although it is not clear in our case study whether introduction of onboard scales increased mean load weights, it is clear that maximum payloads have not been reached in most cases. Significant savings can be achieved through eliminating load variation. Beardsell (1986) found gross annual saving were $ 153,000 and $ 431,000 for two different mills and Deckard et al. 2011 predicted the potential impact on the southern United States wood supply chain at between $ 44.1 million and $ 87.1 million. In our case study if the under loading of the trucks could be eliminated then the potential saving for the company could be between $ 3 million and $ 7 million.

In comparing the study results for the two types of roads there is clearly a substantial under loading issue on the gazetted roads as compared to the non-gazetted roads. Because the same operators with the same technology achieved

Table 5. Homogeneous Subsets obtained by Duncan method for gazetted roads.

	N	Subset for alpha = 0.05		
		1	2	3
Truck scale (owner contractor)	425	-6.44		
Loader scale	9289		-5.74	
Truck scale	475			-5.48
Loader and truck scale	2861			-5.31
Sig.		1	1	0.16

Table 6. Descriptive statistics for over/under load (t) for non-gazetted roads.

Scaling method	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
Loader and truck scale	1103	-1.43	1.68	0.05	-1.53	-1.33
Loader scale	2593	-0.53	1.5	0.03	-0.59	-0.47
Truck scale (contractor)	467	-0.54	1.39	0.06	-0.66	-0.41
Truck scale (owner contractor)	541	0.09	0.59	0.03	0.04	0.14
Total	4704	-0.67	1.53	0.02	-0.72	-0.63

Table 7. Analysis of variance for non-gazetted roads.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1008.73	3	336.24	156.69	0
Within Groups	10085.46	4700	2.15		
Total	11094.19	4703			

Table 8. Homogeneous subsets obtained by Duncan method for non-gazetted roads.

	N	Subset for alpha = 0.05		
		1	2	3
Loader and truck scale	1103	-1.43		
Truck scale	467		-0.54	
Loader scale	2593		-0.53	
Truck scale (owner contractor)	541			0.09
Sig.		1	0.96	1

a much better outcome on the non-gazetted roads, these results suggest that the GMVL available was technically not achievable on the gazetted roads (i.e. not enough truck volume capacity available to add the extra weight) or the operators were not aware of or not inclined to load the extra GMVL available (i.e. not certain what routes were gazetted or not). The log length and product type did not have any significant correlation with the load variation which can explain these factors did not influence the under and over loads in this case study. Because the data were collected post-operations without any direct observations of the operations not much insight can be given on the reason but given the under load is so consistently close to the extra GMVL allowed on gazetted roads the lack of awareness or inclination seems the most likely. Post study discussions with the operations managers revealed that the rate system at the time of the study had no incentive for the operators to load the higher weights on gazetted roads (same 4/t-km rate for both route types so revenue targets are met with non-gazetted loads on both route types), which is an issue that has been addressed with new contract arrangements. A follow-up study is being considered to explore the influence of this new contract arrangement.

Looking at the three results together it appears the benefit of using the loader scale and truck scale in combination is not necessarily realised in practice with the non-gazetted roads showing a considerably poorer outcome than when the technologies are used separately. This suggests work methods and techniques can play as great a role if not greater than the technology itself and should be explored with future research.

5. Conclusion

Good payload management was demonstrated to be achievable with the technology evaluated, though policy and methods appear to play a greater role than the technology itself. Further research on the performance of the different weighing technology under different policy frameworks and methods of usage need to be explored to better understand how best to achieve efficient payload management in Australian forest haulage operations.

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Topic 10

Environmental & Human Impacts

Life cycle assessment and techno-economic analysis of energy crops utilization for biofuels in the North-Eastern United States

W. Liu, J. Wang*

Abstract
Together with life cycle assessment (LCA), a techno-economic (TEA) model was developed to examine the environmental and economic benefits of utilizing energy crops for biofuels and bio-products. Three energy crops of hybrid willow, switchgrass and miscanthus grown in marginal agricultural land or abandoned mine land in the Northeastern U.S. are considered in the analytical process for the production of diesel, bio-power and pellet fuel. The LCA model included; feedstock development, harvest, transportation, storage, pre-processing, energy conversion, distribution and final product use. The TEA model considered all the cost components in the LCA, and also the capital and operating costs of bio-refinery. Sensitivity analysis was conducted to assess the effects of; energy crop yield, transportation, conversion efficiency, alternative pre-treatment, capacity of facility and the internal rate of return (IRR). The results showed that the environmental impacts in terms of GHG emissions, fossil energy consumption, and water use were more sensitive to biofuel types than to feedstocks. The required selling price (RSP) of bio-fuel was higher than that of pellet fuel and bio power. Willow biomass presented lower environmental impacts and RSP than miscanthus and switchgrass. Sensitivity analysis also indicated that transportation was a major factor affecting both GHG emissions and delivered costs. Environmental impacts and RSP were also sensitive to conversion efficiency and yield.

Keywords
life cycle assessment, economic analysis, energy crops, bio-product, marginal land

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1. Introduction

Biomass is being considered as a carbon neutral energy resource. It is preferred to be a substitution of fossil energy resources to reduce the greenhouse gas emissions. The interest in the usage of cellulosic biomass for biofuels and bioproducts has been steadily increased due to the environmental and energy dependence concerns (Paul 2009). Biomass could be used to produce different forms of bioenergy products, such as firewood, pellet, electricity, ethanol, and biofuels. However, biomass feedstock production usually requires more land cover change to provide the same amount of energy as fossil fuels (Searchiger et al. 2008). Consequently, the production cost to produce bioenergy from biomass is typically higher than fossil fuels (Brown 2015).

Many analyses have been conducted on biomass supply chains in terms of economic, environmental or life cycle assessments. Earlier economic analysis of biomass utilization focused on biomass-fired power plants (Kumar et al. 2003, Perilhon et al. 2012), such as optimization of plant size based on available biomass, and the cost of different sized pellet facilities (Sultana et al. 2010, Pirraglia et al. 2013). On the other hand, life cycle assessments (LCA) were conducted separately to analyze environmental impacts of biomass utilization. GHG emissions could be reduced 30-63% through utilizing biomass pellet fuels instead of natural gas (Fantozzi and Buratti 2010), and 56-77% from pyrolyzed biofuels compared to fossil fuels (Snowden-Swan and Male 2012).

Although the utilization of biomass presents lower environmental burden, the handling cost of biomass is usually higher than fossil fuels (Sharma et al. 2013). The techno-economic analysis conducted on fast pyrolysis estimated that the cost of this biofuel can range from \$0.4/gallon to \$3.07/gallon (Ringer et al. 2006; Wright et al. 2010). Brown (2014) recently reviewed techno-economic analysis of fast pyrolysis and found the required selling price (RSP) changed from \$1.93-\$3.70/gal of gasoline equivalent. A range of costs were shown using different boiler systems for bio-power generation (IRENA 2012), including the capital cost of \$1.8-\$5.7 million/MW and operational and maintenance cost contribution 9%-20% of total cost. Cost of pellet facility also varies dramatically according to the physical location and capacity of pellet facility, ranging from \$122/ton to \$170/ton (Sultana et al. 2010).

The plantation of energy crops such as hybrid willow and warm-season grasses on abandoned and marginal agricultural and mine lands in the Northeastern U.S. can provide sustainable bioenergy production in this region. These energy crops could provide flexibility for processing plants because crops can be strategically deployed spatially and temporally to optimize efficiency of biofuels production (Hinchee et al. 2009). Furthermore, these crops will provide a stimulus to the rural economies of this region by converting marginal agricultural and abandoned mine lands to productive and profitable use. These crops have high growth rates, and will be genetically enhanced for robust adaptation to the biotic and abiotic stresses encountered in the region, efficient processivity, and high energy content.

There appears a necessity to analyze the environmental and economic impacts of utilizing bioenergy crops for major possible pathways at a regional scale. In this study, three bioenergy crops (hybrid willow, switchgrass and miscanthus) were considered to produce three bioenergy products, i.e.: bio-fuel, bio-power and pellet fuel. The objectives of this study were to: (1) develop a cradle-to-grave life cycle assessment (LCA) model to examine the environmental impacts of utilizing the energy crops for bioenergy products in the northeastern U.S., (2) perform an economic analysis of the bioenergy feedstock supply chains, and (3) conduct sensitivity analysis of the production of the bioenergy products according to energy crop yield, transportation distance, conversion rate and pretreatment strategy, facility capacity and internal rate of return (IRR).

2. Material and Methods

2.1 Study Area and Base Case Scenario

The study area is the northeastern U.S., including New York, Pennsylvania, West Virginia and others. The available marginal agricultural land and abandoned mine land are over 2.8 million ha (Graham 1994) and 0.5 million ha (Rodrigue and Burger 2004), respectively. These regions are generally with rocky and sloped soils and is compatible to the development of perennial energy crops. The temperate climate in this region also provides the conditions of producing biomass of higher yields. Three biomass feedstocks: hybrid willow, switchgrass and miscanthus were included in this study, which are being considered as the dedicated energy crops in the Northeastern U.S. The physical properties of these three feedstocks were described in Table 1. Three bioenergy products: biofuel of fast pyrolysis, bio-power, and pellet fuel. The requirement of feedstock was in Table 1. The capacities were 1,000 bbl/day, 20 MW and 200,000 dry tons per year for bio-fuel, bio-power and pellet fuel facilities. Table 1. Physical properties of the three energy crops and feedstock equirements for three bioenergy products.

2.2 Economic Analysis

Cost in field operation of energy crops were adjusted based on the settings by Duffy (2013) and Schweier and Becker (2012). This included the machines for land preparation, plantation, fertilizer and pesticide spray, harvest. The round-trip transportation of wood chips and bales were assumed to be \$0.38 ton^{-1} mile^{-1}(Kerstetter and Lyons 2001). Average storage cost of feedstock was assumed \$5 dry ton^{-1}. The capital cost, operational and maintenance cost of fast pyrolysis were adjusted from the results of techno-economic analysis conducted by Wright et al. (2010). Average costs of biomass fired power plant in IRENA's report (2012) were used as facility cost to produce bio-power. A techno-economic analysis by Sultana et al. (2010) provided costs to operate a pellet facility. Internal rate of return was assumed 15% in base case. Required selling price (RSP) at facility gate was calculated.

2.3 Life Cycle Assessment

2.3.1 System Boundary and Life Cycle Inventory

The system boundary of this cradle-to-grave LCA model (Fig. 1) included land preparation, plantation establishment, harvest, transportation, storage, preprocessing, energy conversion, distribution and final usage. The environmental impacts will be assessed in terms of the GHG emissions, blue water consumption, fossil fuel consumption and human health impacts. The health impacts considered in this study were carcinogenics, respiratory effects, ozone depletion and human toxicity. The functional unit (f.u.) was 1,000 MJ of energy equivalent bioenergy product produced in the system. The LCA model was developed using the environmental modeling tool SimaPro v8 (PRé Consultants 2014).

2.4 Sensitivity and Uncertainty Analyses

The sensitivity analysis was considering yield of energy crop, conversion rate, transportation distance and IRR. The configurations of all the parameter were in Table 2.

3. Results

3.1 Base Case Analysis

The cost of each component in the supply chain was analyzed by feedstock and energy product (Fig. 2). Operation and maintenance usually cost more than other components, which was ranging from 10% in miscanthus to bio-power to 50% in willow to pellet fuel. Willow had lower cost in plantation and harvest than the other two energy crops. Storage was a small portion of total cost, which only accounted less than 1%.

RSP was calculated for the three bioenergy products: \$/bbl for bio-fuel, \$/MWh for bio-power, and \$/dry ton for pellet fuel (Table 3). For the production of same bio-energy product, Product from willow had lowest RSP which was 0.5%-5.8% lower than the other two crops. And switchgrass had highest RSP. RSPs were also converted to per MJ basis for comparisons (Table 3). The production of bio-fuel required highest RSP.

The most emissions occurred in the "Storage and preprocessing" and "Production" processes. The bio-power production presented the lowest GHG emissions among the three bioenergy products, with an emission of less than 10 kg CO_2 eq per 1,000 MJ of electricity produced. Among three feedstocks, using willow shrub for bio-power generation demonstrated the lowest emission at 5.96 kg CO_2 eq. There were more obvious differences of LCA impacts among the three bioenergy products than among the three energy crops (Fig. 3). Two-way ANOVA showed that more than 95% of the LCA impact variance was explained by different utilizations of bioenergy products.

Table 1. Physical properties of the three energy crops and feedstock equirements for three bioenergy products.

Physical properties					
Name	Moisture Content (w.b.)	Ash Content	Energy Density (HHV: MJ/kg)	Yield (odt/ha)	Citations
Willow	0.44	0.0233	19	10.7-14.1	Fahmi et al. 2008 Stolarski et al. 2013
Switchgrass	0.34	0.04	18	6.6-12.6	Bai et al. 2010 Sokhansanj et al. 2009 Fahmi et al. 2008 Khanna et al. 2008.
Miscanthus	0.34	0.03	17	10.9-24.7	Fahmi et al. 2008 Khanna et al. 2008 Miguez et al. 2009 Brosse et al. 2012

Feedstock Requirements			
Product	Particle Size	Moisture Content(d. b.)	Citation
Bio-fuel	<2 mm	<10	Brown and Holmgren 2007 Jones et al. 2009.
Bio-power	<2 in	<50	Mann and Spath 2001 EPA 2007
Pellet	<1/4 in	<10	Chen 2009 Fantozzi and Buratti 2010

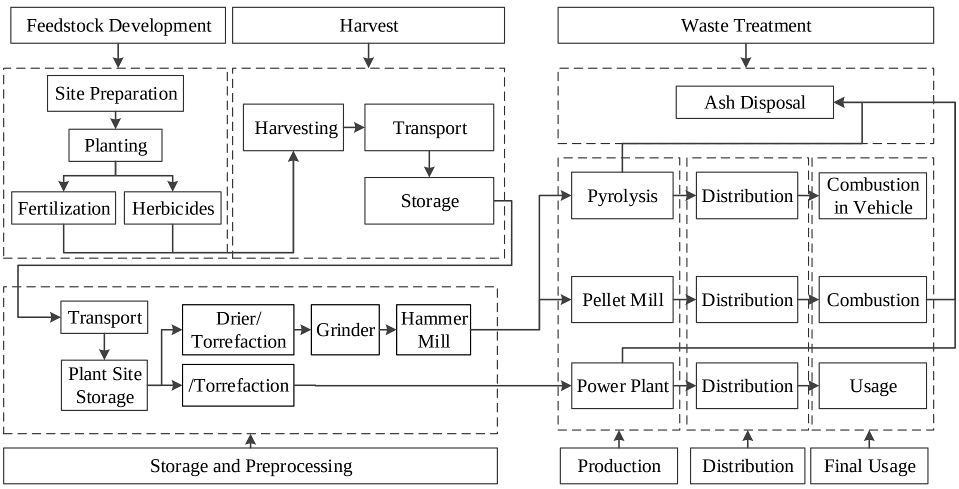

Figure 1. System boundary and processes of the three energy crops for three bioenergy products.

Table 2. Parameter configurations for base case and sensitivity analysis.

Parameter	Base Case	Sensitivity Setting
Willow – Yield[a]	12.4 ton/ha	10.7 - 14.1 odt/ha
Switchgrass – Yield[a]	9.6 ton/ha	6.6-12.6 odt/ha
Miscanthus - Yield[a]	17.8 ton/ha	10.9-24.7odt/ha
Transportation[b]	50 miles	10 – 100 miles
Bio-fuel - Conversion rate[c]	0.39 tons feedstock/bbl of fuel	0.33-0.45 odt feedstock/bbl of fuel
Bio-power – Conversion rate[c]	0.84 tons feedstock/MWh of bio-power	0.63-1.05 odt feedstock/ MWh of bio-power
Pellet – Conversion Rate[d]	1 ton feedstock/ton of pellet	-

[a] *Yield increases from minimum to maximum yield by 10% of their difference.*
[b] *The distance increases by 10 miles each time.*
[c] *Amount of feedstock demand increases from minimum to maximum yield by 10% of their difference.*
[d] *No Waste was assumed to produce pellet.*

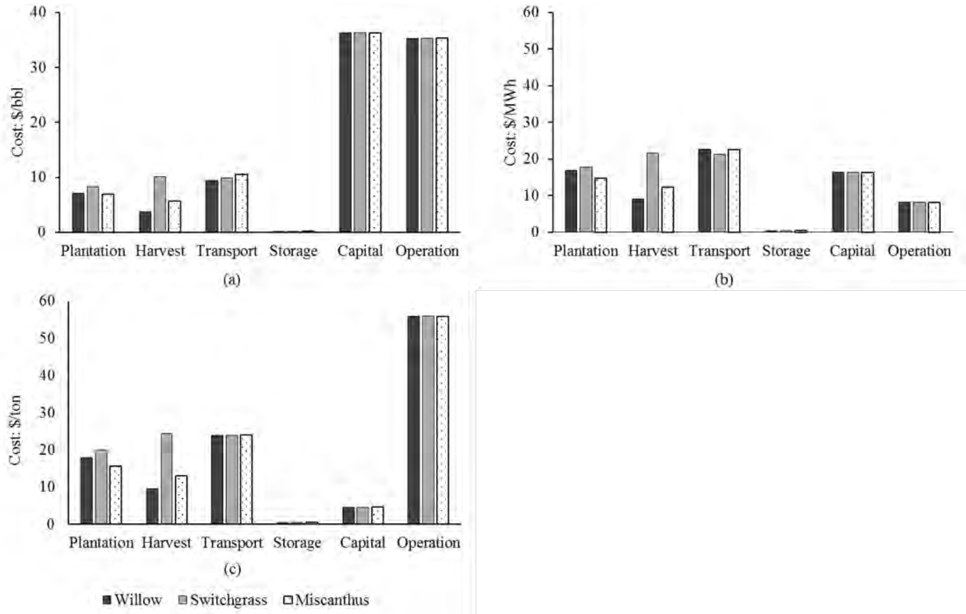

Figure 2. Cost components of the biomass supply chain by energy crops and bioenergy products: (a) bio-fuel; (b) bio-power; (c) pellet.

Table 3. Required selling price of bioenergy products by energy crops.

Crops	Bio-fuel: $/bbl ($/MJ)	Bio-power $/MWh ($/MJ)	Pellet: $/ton ($/MJ)
Willow	158.99(0.0316)	112.2 (0.0311)	116.1 (0.0061)
Switchgrass	164.66 (0.0327)	124.4 (0.0345)	132.9 (0.0074)
Miscanthus	159.48 (0.0317)	113.3 (0.0315)	117.2 (0.0069)

3.2 Sensitivity analysis

Several factors affect the RSP of bioenergy products including yield of energy crops, transportation distance of biomass, conversion rate and required IRR. In the production of biofuel and bio-power, the RSP was very sensitive to IRR and conversion rate. Transportation distance was the third most sensitive factor.

Both conversion rate and transportation distance had prominent influences on the environmental impact indices when biomass was used for liquid fuels and electricity. However, the impacts were not significant when biomass was used for pellet fuel production, except considering fossil energy consumption and human toxicity by changing transportation distance. By comparing the environmental impacts with changing yield of energy crops, it always had higher influence to produce bio-fuel and bio-power than to produce pellet fuel. Blue water consumption did not have obvious change along the change of yield of crops

4. Discussion

4.1 Cost Analysis and RSP

Operation and maintenance was usually the major cost component which made up to 50% of the total cost and followed by cost in transportation, crop plantation and harvest. The production of pellet fuel had low cost in feedstock logistic and capital cost and high cost for electricity consumption at facility, so the percentage of operation and maintenance cost at pellet mill was higher than other two bio-product production systems. Willow always had lower cost than perennial grasses because of its high energy content which cause lower amount of biomass consumption to produce same amount of energy equivalent bio-product. In this study, bio-char and off-gas were recycled in the process of fast pyrolysis (Jones and Male 2012), or the operation and maintenance cost to produce bio-fuel could be even higher. Because less pre-treatment was required in power plant, the operation and maintenance cost was lower in power plant. But if different boilers were used, the cost could be even higher (IRENA 2012).

Because of efficient harvest system and low amount of feedstock demand, bio-products from willow always had lower RSP than perennial grasses. Switchgrass had much lower yield than miscanthus, so the RSP of bio-products from switchgrass was higher than miscanthus. But the miscanthus tends to have low yield where the states have cold and dry weather (Miguez et al. 2009). The RSP of liquid fuels produced by fast pyrolysis was 2.34−2.48/gal, which was in Brown (2015) indicated range. The average annual price of electricity in 2013 by state in Northeast was ranging from $78.1/MWh in West Virginia to $159/MWh in Connecticut according to EIA Electric Power Monthly report (2015). The RSP of bio-power was in this range, so the biomass fired power plant could be economic feasible in some states. The pellet price was lower in this study may be because of lower cost in feedstock logistics than direct

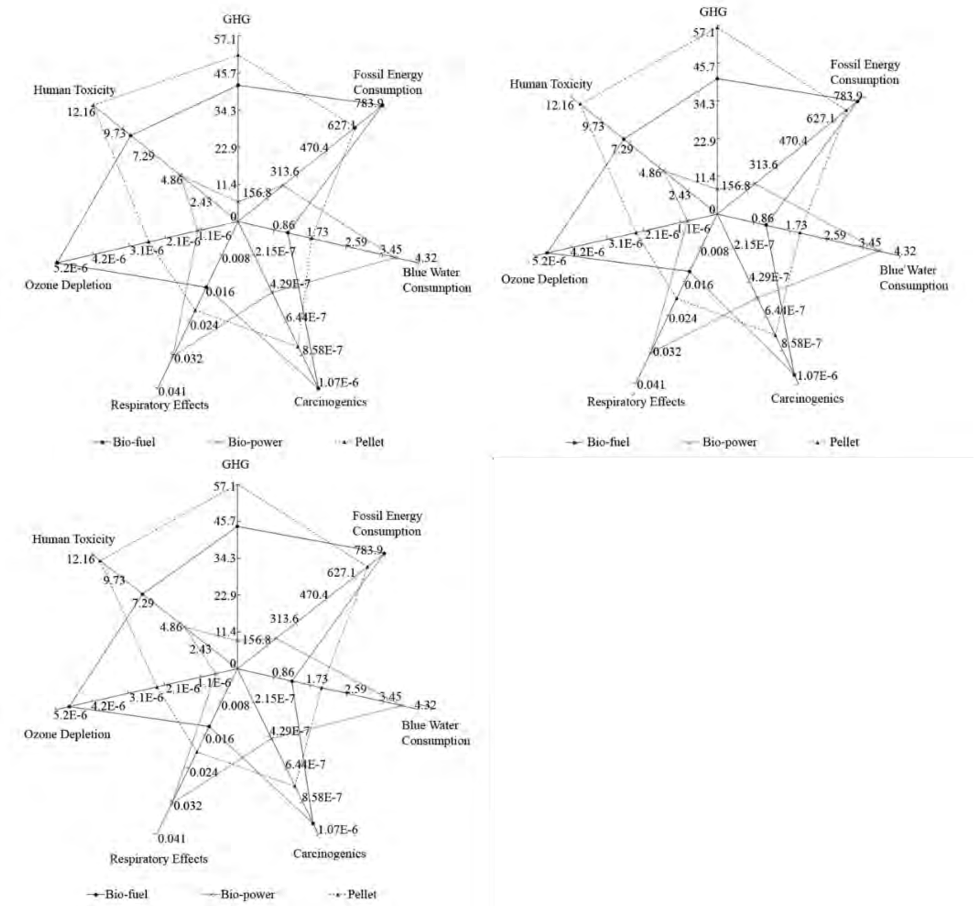

Figure 3. LCA impacts of GHG emissions, fossil energy consumption, blue water consumption and human health impacts by energy crops: (a) willow by bioenergy products; (b) switchgrass by bioenergy products and (c) miscanthus by bioenergy products.

purchase and lower capital cost for large scale pellet facility.

4.2 Environmental impacts

Most of the GHG emissions occurred in the “Storage and preprocessing” and “Production” processes at facility site. So the change of GHG emissions among different bioenergy products could be mostly explained by the different procedures at facility. The production of bio-power emitted less GHG emissions than the production of bio-fuel or pellet fuel. This is because the heat and electricity provided by biomass in power plant were provided by biomass, thus the energy conversion rate is low and more feedstock is required in power plant (Perilhon 2012). The GHG emissions were higher when produce pellet fuel because of the high electricity consumption for operating pellet mill, dryer, grinder and hammer mill. This electricity consumption was considered as fossil energy produced by coal in the LCA model. If the electricity consumed to produce bio-fuel and pellet fuel was generated by biomass or other renewable resources, the emissions could be lower. Fast pyrolysis is an energy intensive process to produce bio-fuel, the energy consumption was reduced through recycling byproducts, off-gas and bio-char, for preheating (Jones and Male 2012). Power plant typically needs more water for cooling, and consequently the water consumption of bio-power generation is higher than the production of bio-fuel and pellet fuel.

More energy is required to process miscanthus than switchgrass and willow due to its properties which make it recalcitrant than other crops according to the experiments in Idaho National Laboratory. Willow has higher energy content than perennial grasses, as well as specific physical and chemical properties (Stolarski et al. 2013), allowing it to be processed or handled easily. Low ash content also ensures willow has a relatively higher energy conversion rate to bioenergy products (Fahmi et al. 2008). Ash was collected and sprayed in the field as fertilizer without further negative environmental impacts.

We found that most of the variations of LCA impacts could be explained by different processes of three bioenergy products. The difference was due primarily to the different conversion rate, feedstock planting and harvesting systems. The combustion of biomass in bio-power generation produced a relatively higher level of PM2.5 that could possibly cause respiratory problems of workers. The emission of smoke and dust in power industry is usually higher than in other industries (Yi et al. 2012). The high emission of human toxicity materials during the production of pellet fuel is mainly because of the fossil fuel derived electricity usage.

4.3 Sensitivity and Uncertainty Analyses

Conversion rate had less effect on GHG emissions in power plant than in the production of bio-fuel. This is because feedstock in power plant did not need to be dried though there was more feedstock required in power plant to produce same amount of energy. The improvement of conversion also reduces the fossil energy consumption, water consumption, human health effects because of the reduction of feedstock demand.

Fossil energy consumption and human toxicity were sensitive to transportation distance because of most of toxic emissions were contributed by transportation fuel combustion. The environmental burden of bio-power showed high sensitive to feedstock transport distance. This is because power plant requires large amount of biomass to produce 1,000 MJ energy equivalent bio-power. The actual yield could be lower than the yield estimated in this study because the yield in the first two or three years was pretty low to establish the stand.

Longer transportation distance will quickly increase the biomass logistics cost. It is essential to reduce the transportation distance in biomass logistics models. However, large scale facility always requires longer distance. For fossil fuel facility, cost will be reduced in large facility, but this is not always the case for bio-facilities. Larger facility requires more biomass which could increase the biomass handling cost. Increasing yield of energy crops, increasing plantation acreage of energy crops, improving conversion rate and reduce scale of facility will reduce the transportation distance. IRR was sensitive to produce bio-fuel because large proportion of total cost was investment of capital cost. The sensitivity of RSP to conversion rate in power plant was because a little change of conversion rate will bring more change on demand of feedstock. In willow to bio-product systems, willow handling system always had low proportion of cost, so it was less sensitive to yield and conversion rate.

Acknowledgement

This research was supported by Agriculture and Food Research Initiative Competitive Grant No. 2012-68005-19703 from the USDA National Institute of Food and Agriculture. The authors would like to thank Jacob J. Jacobson, Jaya Shankar Tumuluru, Neal Yancey, Allison E. Ray of the Idaho National Laboratory for providing useful data and thoughtful suggestions. The authors are also grateful to Drs. Peter Woodbury, Jude Liu, Larry Smart, Armen Kermaian, and Stacy Bonos for providing field dada and valuable suggestions on crop yield and field operational processes.

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Evaluating the influence of root collar on stump height following mechanized forest operations

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Abstract
Modern large-scale forest operations are often performed by fully mechanized harvesting systems. In Germany, the most widely used system in thinning stands is a single-grip harvester used for felling and processing trees and a forwarder or a tractor with trailer combination for forwarding the logs from the felling site to a forest road accessible by truck. Due to machine and stand related characteristics such as; reach of the harvester boom, visibility, and terrain topography, the height of remaining tree stumps can vary greatly. High tree stumps may pose different economic and technical disadvantages. Aside from a reduction in product recovery, high stumps can complicate future entries if smaller equipment such as farm tractors with low ground clearance are used. The objective of this project is to examine if correlations exist between the height of the remaining tree stump and the shape of the above ground root collar, stem diameter, and distance to the machine operating trail
In total, 202 randomly selected sample stumps and the surrounding terrain were scanned with terrestrial LiDAR in spruce stands near Freising, Germany. The collected data was processed into a 3D-Model and then analyzed. Preliminary tests using a FARO Focus 3D laser scanner showed promise as an appropriate and quick system to evaluate stump architecture and the surrounding terrain topography.
This study found that the distance to operating trail was not an influencing factor either on stump height or on stump diameter. Furthermore, in contrary to our hypothesis, complex above ground root collars did not seem to cause higher stumps.

Keywords
terrestrial laser scanner, stump height, stump diameter, root collar, full mechanized operations

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1. Introduction

A recent change in German forest was the growing use of mechanized felling techniques like cut to length operations with harvester and forwarder. The obvious benefits are the increasing working safety, the combination of different working steps into one process and also monetary profits. While chainsaw felling has no tree size or tree shape limitation, harvesters can reach their operational limit with large diameter trees or with trees exhibiting relatively large diameters and complex root systems, thus leaving high stumps in the forest. Such stumps can be unwanted obstacles making it harder to pass through the forest or move wood without damaging standing trees. It should also be of interest to harvest as much biomass as possible and produce longer logs especially in the lower section of the tree, with high diameter, to provide higher returns for the product.

Concerning biomass, measurements have mostly been done manually with simple techniques, tables, and often often were estimations rather than actual measurements.The terrestrial laser scanner (TLS) provides an easy, fast, and precise method to measure forest structures by sending out an infrared laser beam scanning the surrounding environment.

In a study in British Columbia, Canada, 1,658 stumps were measured to compare chainsaw felling with mechanised felling using a feller-buncher in stump height to diameter, species and ground slope. Figuring out that “mechanical felling results in lower stumps, by an average of 5.5 cm, relative to chainsaw felling, but stump height was significantly affected by species, slope and average stump diameter” (Han, Renzie 2005). However, very limited research has been completed with TLS to measure stump properties in order to investigate the influence of above ground root collar on stump height following mechanized felling.

Initially developed to assist issues in the industrial building sector, the use of TLS in forestry settings is increasing in frequency. TLS data have already been used to estimate forest data like sub-canopy architecture (Hilker et al. 2010), leaf area index (Moorthy et al. 2008; Strahler et al. 2008), tree height, diameter and diameter at breast height (Watt & Donoghue 2005; Hopkinson et al. 2004; Henning, Radtke 2006; Maas et al. 2008), and specific tree properties such as stem volume (Yu et al. 2013).

The most noticeable advantages of this system are definitely the possibilities of capturing data without distracting or damaging the forest environment. Once recorded, the data can be used to measure all important variables without the need of going back to the site of interest if something is missing. All taken measurements can be retraced and repeated if necessary, and while scanning the whole surrounding environment additional variables can be added while working.

To make mechanized forest operations as effective as possible it is necessary to understand and identify physical barriers at the tree to cut as low as possible. Therefore this study uses TLS to find correlations between stump height, diameter, and root collar to describe stump height following mechanized operation in terms on physical values.

2. Material and Methods

2.1 Research site and experimental design

Two test sites were established near the town of Freising within the so-called Thalhausener Forst (48°25'01.0"N 11°41'52.4"E) located in the southern part of the state of Bavaria in Germany. Following regularly scheduled thinning operations, 103 stumps were measured in the district Rappenberg and 99 in the district Wippenhausenereinfang. The sites were chosen because of two main reasons: 1- fully mechanized operations were used, and 2- their proximity to the Technische Universität München campus in Freising. The harvesting was performed during February and March 2015. To exclude the varieties of different mechanical specifications, the study area just involved the trees that had been harvested by the same machine and operator. The forest is mainly stocked with mixed stands of spruce (Picea abies) and beech (Fagus sylvatica) mixed with a few Douglas fir, larch and oak trees. The felling and our measurement was done in a spruce dominated stand.

In total, 202 fresh harvester-felled stumps containing all diameters and species, the corresponding machine operation trail and surrounding forest areas were scanned with a ground based terrestrial laser scanner. There were no subjective pre-selection of the stumps; all have been recorded as they were felled by the harvester. We wanted all of the 202 trees to be harvested and processed with the same machine (Valmet 921) and harvester head (Komatsu 360.2; Table 1). Therefore coherences between different harvester configurations and the stump variables can be excluded. Due to the very limited spatial extent of the test site, similar stand and terrain conditions were present.

Table 1. Harvesting head properties.

Roller opening. max	[mm]	550
Blade opening	[mm]	640
Width, max	[mm]	1,720
Height till vertical blade	[mm]	1,650
Roller diameter	[mm]	460
Height incl. rotator	[mm]	1,800

2.2 Instrumentation

In-field data collection was performed with a FARO Laser Scanner Focus ³D. The Faro laser scanner is a ground based high-speed three-dimensional laser scanner for detailed measurement and documentation. The laser scanner uses laser technology to produce detailed three-dimensional images of complex environments. The resulting images are an assembly of millions of 3D measurement points, referred to as a point cloud. The laser scanner works by sending an infrared laser beam into the center of its rotating mirror, which deflects the laser beam on a vertical rotation around the environment being scanned. The entire scanner is rotating180° to scan the surrounding environment. Scattered light from surrounding objects is then reflected back into the scanner. To measure the distance, the laser scanner uses phase shift technology, where constant waves of infrared light of varying length are projected outward of the scanner. Upon contact with an object, they are reflected back to the scanner. The distance from the scanner to the object is accurately determined by measuring the phase shifts in the waves of the infrared light (Faro Laser Scanner Focus3D User Guide). To better address the goals of this research, the scanning configurations were set to a resolution of 1/5 and quality of 3X, which translated to a point to point distance of 7.67 mm at a distance of 10 m.

For the data analysis we used Trimble RealWorks a 3D operating software that is capable of working with significant point clouds

2.3 Sampling and data collection

Prior to the commencement of all scans, stumps of interest (harvested mechanically during the last thinning) were pre-identified and a 1 m long wood stake was inserted into the ground near each stumps to facilitate their identification within the point cloud. Results from the first test scans showed that moss on the stumps or branches in proximity to the base of the stumps could cause difficulties during the processing phase. Therefore, all stumps were manually cleaned of moss and material (branches, leafs, dead material, humus). Depending on the location of the scanner in relation to the target stumps, surrounding vegetation was also removed if it was deemed problematic and could potentially interfere with the scans. The roots and stumps were uncovered until the top of the soil layer.

At good conditions a stump was scanned from three sides to capture the surface with optimal effort. One scan was always taken from the machine operating trail to be able to display it in the software with good accuracy. When possible the scans followed a diagonal pattern on one or both sides of the machine operating trail. At locations with thick vegetation or complex root systems, the number of scans was adjusted to assure that no blind spot would be present.

2.4 Data analysis

After scanning, the data was transferred to the software Trimble RealWorks and the single point clouds merged to a project point cloud (Figure 1A). To keep the amount of data manageable the scans were sampled with a spatial sampling of 10 mm.

The intended stumps were identified and imported to the project through the scan explorer using the complete database. To break down the amount of points a spatial sampling of 2 mm was used on the stumps before a mesh for further measurements was created. If scans deviated in accuracy causing scan shadows they were removed. A mesh is a surface that consists out of small triangles connecting three points in mm scale out of the point cloud, making proper measurements on stump characteristics possible. To measure the distance to the operating trail a mesh was also done for the ground by removing all points out of the cloud higher than a defined value to get only the bottom points. A 50 mm spatial sampling was performed before meshing to keep the data amount and processing time manageable. The cut surface of the stump was defined as starting point for every following measurement.

The distance between stump and operation trail was measured from the middle of the stump surface to the middle of the operation trail in a 90° angle. Therefore a line was generated following the middle of the track and used as reference for the 90° measurement (Figure 1B).

According to Han & Renzie 2005, average stump diameter was calculated to the nearest centimeter using two diameter measurements going through the geometric center of the stump surface (Figure 1C). This measurement was repeated at a 5 cm and 10 cm below the top of the stump.

The stump height was measured according to Han & Renzie 2005 to the nearest centimeter from the ground level on the high side at the stump to the height at the geometric center.

The stumps were segmented with the "contouring tool" every 5 cm from the top. All points lying on the exact line are displayed dividing the stump into 5 cm high slices. Those rings are similar to contour lines on a map and were used for further measurements regarding diameter, root angles, and collar (Figure 1E).

To describe the above ground root collar every angle between the created levels were measured to a horizontal line. The first angle is always the angle from the edge of the stump cut surface to the 5 cm line below. The angles were measured at the maximum extent of the visible roots following down to the ground (Figure 1E).

The analysis of the data was executed in Microsoft Excel and R Statistics.

3. Results

3.1 Stump diameter

After all 202 stumps were scanned with the TLS and analyzed in Trimble RealWorks the data set shows a normal distribution of diameter as shown in Figure 2. A deviation from the normal distribution can be noticed at 25 cm for diameter at cut surface and at 45 cm for diameter 5 cm below the cut surface. The average stump diameter measured at the cut surface is 37.9 cm, 5 cm below 41.4 cm and at 10 cm below the surface equals 43.3 cm. The frequency of wider diameter is increasing generally over the first 10 cm, as the mean is increasing slightly over the first 10 cm (5.4 cm) the maximum diameter increases about 15 cm. While the diameters are increasing three zero values are measured 10 cm below the stump surface. This is caused by stumps that are not high enough that the second segmentation line at 10 cm can be displayed and measured properly.

3.2 Stump height

The distribution of the stump height that was measured is presented in Figure 3. In general it illustrates a normal distributed histogram with an obvious deviation at 25 cm and an average stump height of 30.8 cm. The lowest stump was 8 cm high whereas the highest 57.1 cm. Half of the stumps were between 22.8 and 38.7 cm high. A Pearson correlation coefficient was calculated for diameter and height with 0.44.

3.3 Distance to trail

To be able to evaluate the influence of distance from the stump to the machine operating trail as a factor affecting stump height, this distance was also defined for all 202 stumps showing that 88% (177 stumps) of the recorded stumps were in the reach of the harvester boom (10 m maximum). More specifically, 43% (86 stumps) were located closer than 5 m to the operation track and in this range most of the stumps were felled at a distance of 3 m. 25 stumps were further away than the harvester is able to reach with the used configurations (Figure 4A). For our dataset no correlations were found both between distance to trail to stump diameter and distance to trail to stump height (Figure 4B, C). Therefore distance to trail can be neglected for further considerations.

3.4 Number of roots

We assumed that above ground root collar is affecting stump diameter and height. This effect would scale up if multiple roots are located at the stump. Therefore we had a first look at how many above ground roots can be visually detected per stump. It emerged that as we had measured 675 roots, 59% of the trees are supported by 3 or 4 above ground roots and only 7 stumps showed no visible above ground roots and were therefore excluded from further root-related considerations.

3.5 Influence of root collar

To estimate the influence of root collar on stump properties we applied a simple category system. Every measured angle was linked to an index-value. As a root with steep angle over 80° does not affect the increase of the diameter as much as e.g. a root with a relatively flat angle of 50°, it is given a lower index value (index-value: 1). The flatter the root-angle becomes, the higher the given index-value. The classification was done as shown in Table 2.

The index-values of every above ground root for the first three segments from the cutting surface (0-15 cm) was summarized for every stump and then plotted with height and diameter. For a better display the data was divided in diameter segments showing a bubble diagram for every diameter segment with the summarized index-value at the abscissa, stump height on the ordinate and diameter at cut surface as bubble size (Figure 6). If the diameter classes are evaluated individually a correlation can be found between height and index-value showing that a higher index value (flatter root angles) causes lower stump heights (Figure 6A,

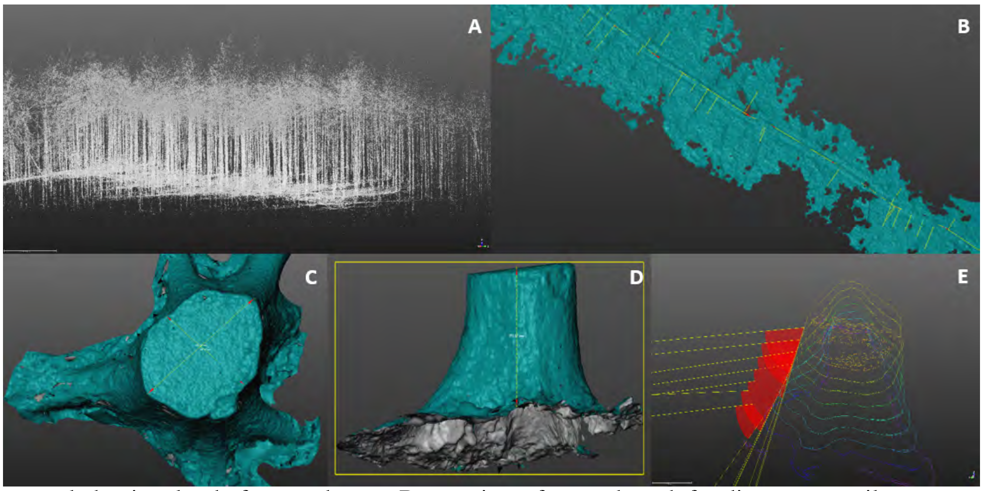

Figure 1. A: sampled point cloud of research area; B: top view of ground mesh for distance to trail measurements; C: stump mesh with diameter measurements; D: stump mesh with stump height measurement; E: displayed 5 cm segment lines for angle measurements.

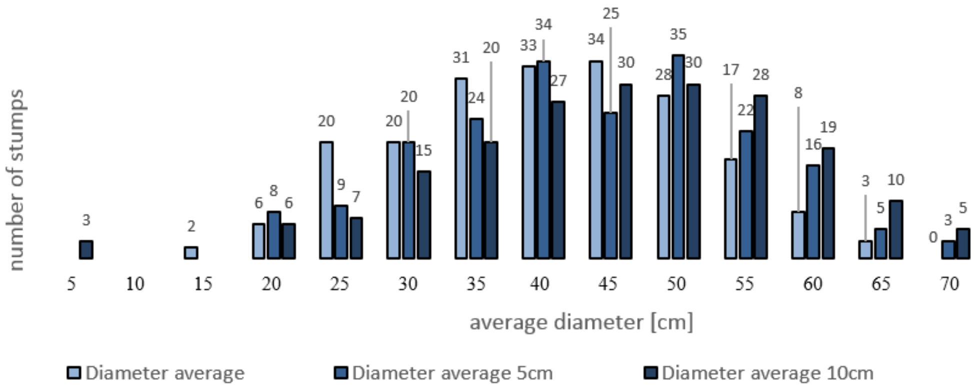

Figure 2. Stump diameter frequency distribution at: cut surface; 5 cm below cut surface; 10 cm below cut surface.

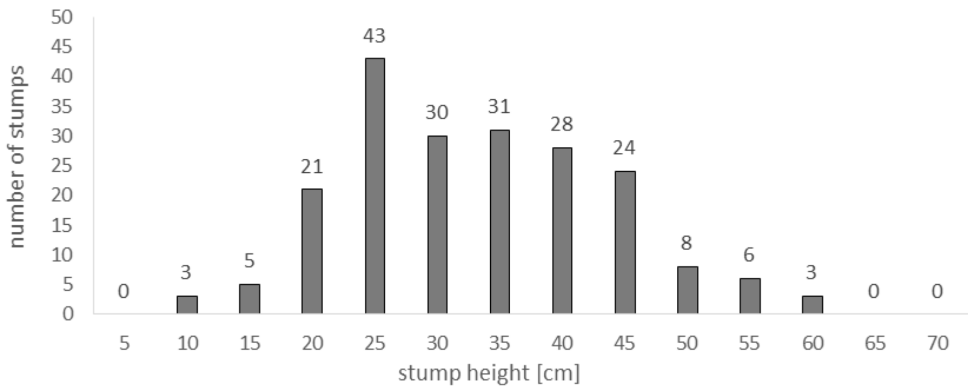

Figure 3. Histogram - stump height measured per stump.

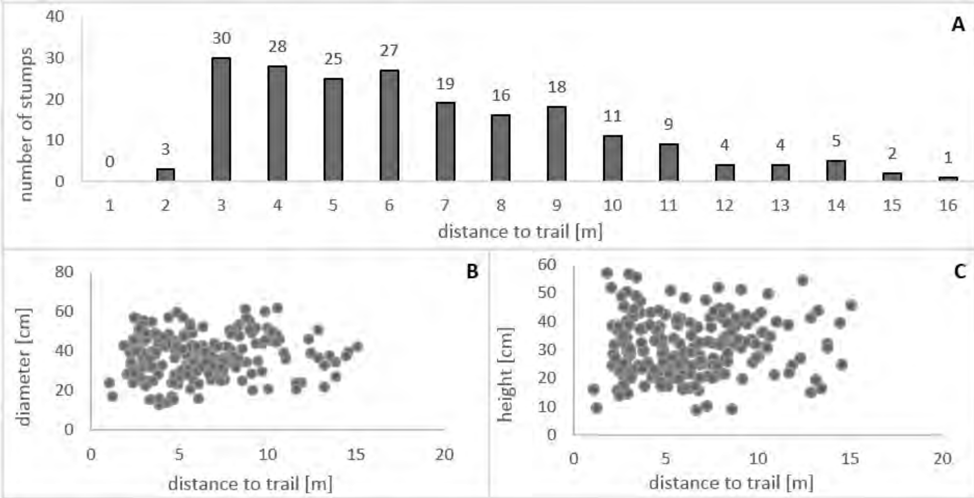

Figure 4. Histogram - distances from stumps to the operating trail; B: Diagram - distance to trail to stump diameter; C: Diagram - distance to trail to stump height.

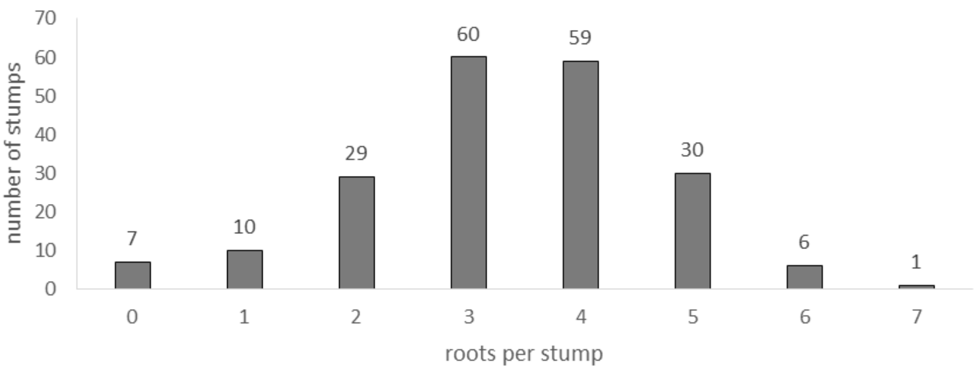

Figure 5. Histogram – number of above ground roots per stump.

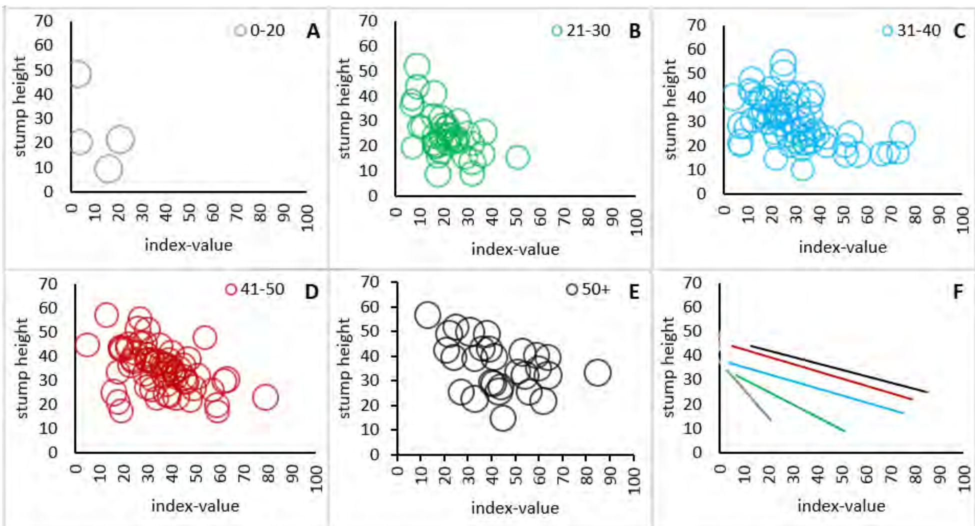

Figure 6. Stump height to index-value for five diameter classes. A: diameter class 0-20cm; B: diameter class 21-30cm; C: diameter class 31-40cm; D: diameter class 41-50cm; E: diameter class 50cm plus; F: linear trend lines of all five diameter classes.

Table 2. Root collar classification.

Root-angle	Index-value
90°-80°	1
79°-70°	2
69°-60	3
59°-50°	4
49°-40°	5
39°-30°	6
29°-20°	7
19°-10°	8
9°-0°	9

B, C, D and E). Combining the diameter classes in one plot shows that depending on the diameter the samples are drifting to the top right as showed in Figure 6F with, for a better distinguishability, the linear trend line for every diameter class.

4. Discussion and conclusions

The requirement of precise measured forest data is a growing field. Biomass that is left behind can limit the possibility to access the forest with machines and equals to unused biomass. This unused biomass can be a loss of monetary profits if the taper of the stump is not too pronounced and so a longer log with high diameter can be harvested and sold. Therefore, to investigate physical obstacles that are hindering the harvester head from going further down the stump to gather more tree biomass, 202 harvester felled stumps were measured and analyzed. For this purpose TLS provides a fast, reliable and effective system to satisfy the need of data for research projects. The corresponding software convinced with multiple tools making measurements to the nearest mm possible.

It shows that the distance to the machine operating trail had no influence on stump diameter and none on stump height. Of course the diameter of a tree is a limiting factor regarding to the maximum reach of the harvester but for our research we had a consistent deviation of all stump diameter up to the maximum reach of the boom. Having some distances measured further away than the maximum reach of the machine, this can be explained with difficulties of projecting the machine operating trail precisely for some samples because of too high and dense vegetation at the end of the field recording. For further projects therefore it is necessary to scan early at the beginning of the growing season or cut down vegetation such as Impatiens glandulifera. The I. glandulifera became a really big problem by covering up the operating trails and masking them in the scans. Another hypothesis for those unfitting distances could be that sometimes the operator cuts “pockets” at the side of the trail to drive into and harvest trees that are further away.

Like in Figure 2 and 3 displayed our dataset showed a normal distribution for stump height and diameter. This is a result of no pre-selection before scanning. The dataset had a consistent deviation of diameters with no gaps caused by missing diameter values but for further investigations it would be good to select and only take stumps with diameters above a certain value, to focus on stumps where physical characteristics really become obstacles to the used harvester head. In this research a considerable amount of stumps had smaller diameters and therefore no rational reason was given why not to cut at a lower level. The affecting factor for those stumps related to stump height seems to be the working procedure of the operator. To prove that, further investigations should be done addressing the operator and his decisions which is being addressed in an associated study.

For this study calculations on stump height and diameter showed that a weak linear correlation between those two values exist. A Pearson correlation coefficient for height and diameter of 0.44 was calculated. Knowing that flatter angles have an higher influence at the increase of stump diameter (Pearson cor. coef.: 0.49), we assumed that there should be also an influence on stump height. But after further calculations no linear correlation was found between height and above ground root angle. The Pearson correlation inclines to zero (0.1). To investigate those correlations further an index-system for the root angles was implemented after a relation between the number of roots per stump and diameter was found. It was important not to underestimate the influence of the root count even if the angles might have been steep, because the investigation showed that e.g. three roots with steep rate of climb can affect the diameter increase same or even more than one root with a shallow rate of climb. Flat root angles received a higher index-value than steeper roots. After summarizing all index-values over 15 cm from the top surface, the index was plotted with height and diameter to display possible relations. For the entire dataset no clear correlation was observed. After dividing the dataset into diameter segments (Figure 6) a trend appeared showing that higher index-values (=flatter angles) cause shorter stump heights. The trend was consistent through all five diameter classes but having only 4 values for the first diameter class (0-20 cm), this is not representative and can only be seen as a hint not as a result. Therefore it is absolutely necessary to increase the dataset for further investigations. These findings interfere with our hypothesis that flat root angles are effecting stump diameter and therefore indirectly causing high stumps. It appears that if the stump was getting more complex the operator tried to cut as low as possible. Unfortunately we could not find proof for this assumption in our dataset. So it is necessary to investigate this fact by directly examining the working procedures of the operators as mentioned above.

By comparing the diameter segments (Figure 6F) a second trend can be seen. The bubble clouds are moving to the right top. This also seems to be caused by the increasing diameter and not by flatter angles. The initial trend is staying the same through the diameter classes just getting weaker at higher diameters.

To investigate this trend the dataset needs to be enlarged particularly for diameters near to the maximum capability of the harvester head. Furthermore, stands at different locations and growing conditions should be measured to have a wider view on above ground root complexity. However this study gave a first impression what is necessary but also possible for investigations on root collar and stump height in the future.

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Impact of traditional and arboricultural timber harvesting methods on the extent of damage to natural regeneration in the shelterwood

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Abstract
Sustainable forest management, based on ecological, economic and social principles, is a great challenge for today's forest operations. This means that all activities, including those related to logging, must ensure minimal damage to the forest environment. This is important in a shelter wood system, where existing natural regeneration must be protected. This paper presents a study of the impact of two different timber harvesting systems on natural regeneration. The research was carried out in an oak–Scots pine tree stand in which two experimental plots were chosen. In the first plot, the traditional logging method was used, based on tree cutting, delimbing, and cross-cutting with a Husqvarna 365 chainsaw. In the second plot, arboriculture method was used, consisting of delimbing the standing trees with a Husqvarna 338 XPT chainsaw as the first technological operation. In both methods, timber was extracted with a LKT 82 Turbo skidder. The location and extent of undergrowth damage were ascertained. The location was determined using a Topcon GTS-100N electronic tachometer. A Topcon HiperPro integrated with GPS receiver was used to determine the geographical coordinates of the undergrowth. The extent of damage to the undergrowth was categorized into 3 classes: fatal damage with no prognosis of survival, broken trees (with 6 sub-classes), and other damage. Measurements were taken separately after tree felling and timber extraction. Additionally, a map was produced of the extent of the damaged zones using ArcGis software. The obtained results indicate that the arboriculture method is more beneficial for the future development of the stand because only 17.1% of the undergrowth was damaged. The traditional method resulted in a significantly higher level of damage, reaching 88.5%. Due to the fact that the arboriculture method has much higher costs, its use is recommended only in stands which are particularly valuable.

Keywords
shelterwood, logging, arborist, damage to the undergrowth

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1. Introduction

Sustainable, multifunctional forest management is an attempt to reconcile economic, safety and social issues in one forested area. The priority of environmental aims in specific countries and legal acts on forests undoubtedly increased the degree of difficulty in carrying out the work of harvesting and transporting timber. At the same time, the dynamic technological advances of recent years require that rational activities be put into practice. This in turn requires greater competence in the proper use of equipment by persons directly involved in forestry work.

Timber harvesting, including cutting, felling and skidding trees, causes specific damage to the forest environment. This is particularly true of complex fellings, where establishment cuttings or overstory removals are often carried out to enable the proper development of the next generation of trees, leading to considerable damage and destruction, the size of which may endanger or even prevent the achievement of the objectives pursued earlier. Introducing technologically advanced equipment may be highly risky. For this reason, the choice of methods used for timber felling and extraction must be chosen very carefully. They should be maximally safe for the environment while enabling regeneration to occur as quickly as possible.

Studies of the impact of using specific logging technologies in the forest environment have been conducted for a relatively long time. Initially, they were limited to analyzing the size and effect of the mechanical damage to tree stems. This impact, however, is much broader (Fröding, 1992; Giefing, 1995; Moskalik, 1997; Paschalis and Porter 1994; Putkisto, 1988; Stajniak and Suwała, 1997). Of greater danger may be:

- disruptions in the availability of minerals from the felled trees due to the removal of the biomass from the forest ecosystem,
- damage to the undergrowth, self-sown seedlings and saplings,

- damage to the structure of the forest soil,
- pollution from gas exhaust, diesel fuel and grease,
- soil erosion occurring as a result of logging and extraction,
- a decrease in the growth of trees in areas where the machinery is transported.

The most commonly used indicator of the impact of machines on the forest environment is the degree of damage to the remaining trees. To a large extent, this determines the technical quality of the future tree stand and negatively affects volume increment (Sauter and Busmann, 1994). Generally, the amount of damage during timber harvesting and skidding does not exceed 10%. Sometimes, however, the damage is greater. This occurs when the machinery moves freely across the entire area without the previous designation of skid trails or when large machines enter a young tree stand. The dimensions of such machines are too large to operate in such densely planted stands (Fiedorenczik and Tyrłan, 2000; Jodłowski, 2000; Lasák, 1990).

In naturally renewing stands, the degree of damage sustained by trees at other heights in the tree stand is also significant. Damaged trees remaining in the forest are often a future source of poor quality raw material with certain flaws. Far less research has been conducted in this area, compared to studies of damage to the main stand. In mountain stands, where timber was extracted by horse, 25% of the young growth was damaged, whereas this rate was 35.5% when a tractor was used (Muszyński, 1995). Damage to saplings of 6.8% was found with the use of the long wood system in a beech stand, where chain saw felling and preliminary logging were carried out with a two-step skidding process, the first using a horse (to extract to the skid trail) and then a tractor skidder (skidding along the trail) (Sowa et al. 2000). Other studies found that more than half of the damage to saplings and undergrowth already occurs during tree felling, with the average proportion of damaged trees at a level of 14% (Suwała, 2003). Košir (2008) states that the manual-machine process of timber harvesting causes great damage to naturally regenerating areas. An analysis carried out in Slovenia showed that damage to regeneration in coniferous stands is 19% and 21% in hardwood stands.

The aim of this paper is to present the impact of two different timber harvesting methods – traditional and arboricultural – on natural regeneration.

2. Material and Methods

The study site was located in south-eastern Poland, in the Wiśniówka Forest District (section 97b). The pine and oak stand is managed using the IIIb complex felling method; overstory removals were planned for the area. The total area of the study site is 3.14 ha, with the removals to be carried out in 0.58 ha. The lower layer of the tree stand (young growth), which is the subject of the analysis, consisted of the following:

- oak 40% – 15 years of age, average height 4 m, tree cover 0.6,
- oak 30% – 25 years of age, average height 8 m, tree cover 0.6,
- oak 20% – 8 years of age, average height 2 m, tree cover 0.6,
- fir 10% – 30 years of age, average height 5 m, tree cover 0.6.

The operational area was divided into two similarly sized sections. In one section, trees were felled using the traditional method (0.30 ha), in the other, using arboricultural techniques (0.28 ha).

2.1 Description of the used technological processes

Traditional method

A chainsaw operator performed the felling and logging. He cut the full tree, then delimbed it and cut into specific assortments. Long wood skidding was carried out with an LKT 82 Turbo tractor. Medium-sized timber was extracted with an Ursus 80 4x4 tractor equipped with a Palms 101 trailer with a capacity of 11 tons.

Arboricultural method

Climbing techniques are used to log timber in this process. The work begins by climbing the tree with the help of spurs and relevant climbing equipment (harnesses, ropes, lifelines). Then, at the highest possible the arborist secures a descending rope and begins delimbing the tree from the top. Usually, the first cut is to remove the tree top. After delimbing the entire tree, the arborist descends to the ground using the rope and proceeds to delimb the next tree. The next stage is to clear the branches under the tree to have it felled safely. After delimbing 5–6 trees (Fig. 1) and clearing the branches, the stems are then felled. Skidding was performed with an LKT 82 Turbo tractor. In order to protect the naturally regenerating area, the skidding operator did not drive onto the site, but remained on the road or skid trail, using ropes and winches to pull the logs to the tractor. The logs were then sorted after skidding in a landing sort yard.

2.2 Description of the study method used

Damage to the undergrowth was classified according to the following categories:

I destroyed trees,

II broken trees:

- **a.** unlikely to survive,
- **b.** broken shoot apex above the last whorl,
- **c.** broken stem below the last whorl,
- **d.** broken side branches (up to 20% of total),
- **e.** broken side branches (from 21% to 40% of total),
- **f.** broken side branches (over 40% of total).

III trees with other damage:

- **a.** tree out of plumb,
- **b.** torn off bark.

Figure 1. Delimbed trees prepared for felling (R. Sokulski).

Damage was determined and classified separately for cutting and skidding. In order to illustrate the size and location of damage to the undergrowth, measurements were made using the rectangle offset method. The first step was to measure coordinates. For this purpose, the GPS was set at two points, and then these points were stabilized in the field. Next, references to these points were established using a tacheometer (Fig. 2). Trees were measured with the use of a mirror, which was placed next to each measured point. During the measurements, the tacheometer automatically assigned numbers to the trees, which we supplemented with information on the type of species. The degree of damage and the number and species of the trees were recorded in field forms.

Figure 2. Measuring the distribution of trees using a tacheometer (M. Nowikowska).

3. Results

Figure 3 clearly shows large differences in the amount of damage occurring in both logging processes. The traditional method of logging caused five times more damage than the arboricultural method. After the cuts made by the chain saw operator, only ca. 11% of the trees remained undamaged. The arboricultural method allowed over 80% of the trees to avoid being damaged.

The small amount of damage to the undergrowth using the arboricultural method occurred during the delimbing of standing trees. Falling branches were caught by lower-lying undelimbed branches. Thus, the impact of the fall on the future tree stand was minimized. Trees were delimbed and felled in such a way as to cause the least amount of damage to the saplings. The direction in which the trees fell was guided by a rope, so they could be cut in any direction. Table 1 presents a detailed list of data on the location and amount of damage caused during felling.

During skidding, more damage to the natural regeneration was observed with the arboricultural method (6.77%). In the traditional method, damage was about 4.43% less (Fig. 4), since the chainsaw operator had already destroyed a large proportion of the future tree stand during felling, so that the LKT tractor and forwarder trailer were able to move around almost without causing additional damage.

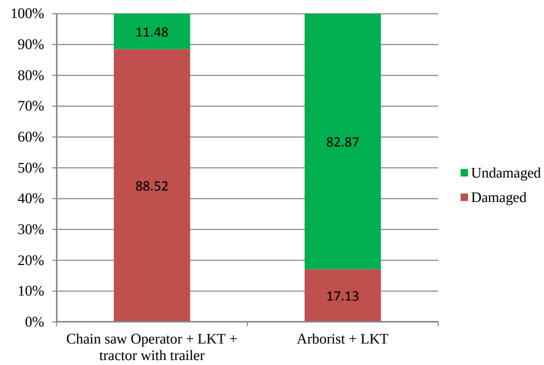

Figure 3. Damage to the undergrowth as a result of wood cutting and extraction.

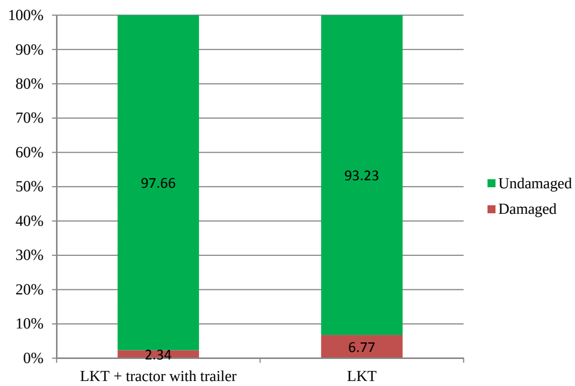

Figure 4. Damage to the undergrowth as a result of wood extraction.

Table 1. Summary of damage to undergrowth after felling.

Category of tree damage			Arboricultural		Traditional chainsaw operator	
			No. trees	(%)	No. trees	(%)
Undamaged [BUSZK]			874	89.64	130	13.82
Felled trees	I – destroyed trees [ZNC]		13	1.33	761	80.87
	II – broken trees	not likely to survive [NRP]	2	0.21	3	0.32
		broken shoot apex above the last whorl [ZWN]	7	0.72	2	0.21
		broken stem below the last whorl [ZWP]	34	3.49	16	1.7
		broken side branches (up to 20%) [PGC]	16	1.64	0	0
		broken side branches (from 21% to 40%) [PGB]	7	0.72	3	0.32
		broken side branches (over 40% [PGA]	0	0	2	0.21
	III – other damage	tree out of plumb [DOP]	21	2.15	23	2.44
		torn off bark [ZDK]	1	0.1	1	0.11
Total			975	100	941	100

4. Discussion

The richness of forest ecosystems is significant not only economically, but also culturally and socially, while the management of such holdings entails a certain specificity, complexity and responsibility in selecting appropriate logging procedures. This is particularly true for complex fellings, where the seedlings and saplings comprising the future main stand require maximum protection. The results of the actions undertaken are visible only after a specified time. Then one can see whether the decisions made, which are difficult to correct, brought the desired effect. For this reason, particular stages of work should be carried out very precisely and with appropriate sensitivity.

The significantly different levels of damage to areas of regeneration used in various ways indicates the need to view damage differently in young, near-mature, and mature forests. In stands where an important role is attributed to the protection of valuable regeneration stock, it is recommend that they will be better accessed with a network of skid trails and logged using the long wood system with combined felling and mixed extraction (Stańczykiewicz, 2006; Košir, 2008).

The results obtained indicate that the arboricultural method is more beneficial for the future development of the stand because only 17.1% of the undergrowth was damaged. Damage is significantly higher using traditional methods, reaching 88.5%. The level of damage resulting from using the traditional method is decidedly higher than the level found by other authors. This is probably due to the high proportion of oak in the main tree stand (60%). The wide crowns of this species contributed to the significant area of damage.

As the study results show, traditional methods used for complex logging cause destruction and damage, which affect the development of the tree stand in the future. For this reason, efforts should be made to select proper felling and skidding techniques. The additional financial costs incurred by a felling process that minimizes damage can be compensated by the future production and quality of the timber.

5. Conclusion

1. Sustainable and multifunctional forest management, based on ecological premises, is a major challenge for modern forestry. Currently, great emphasis is placed on using technological processes in logging operations that have the least negative impact on the forest environment. This is particularly true of partial fellings (shelterwood system) with very valuable areas of natural regeneration.

2. The use of traditional technology for felling and skidding during overstory removals caused damage to more than 88% of the undergrowth. The arboricultural method caused decidedly less damage, at a level just over 17%.

3. When felling trees using the traditional method, the highest level of damage – 80.87% – was in the category of “destroyed tree”. In turn, the highest level of damage for the arboricultural method – 3.49% – occurred in the category of "broken stem below the last whorl".

4. The damage resulting from tree felling with the traditional method was classified into three categories of damage. The highest percentage of damage (approx. 41%) was due to torn off bark, slightly less (almost 32%) was due to completely destroyed trees; the remainder of damaged trees were out of plumb (slightly more than 27%). In the arboricultural method, the highest percentage of damage was due to destroyed trees (almost 40%). Trees out of plumb accounted for more than 37%, and torn off bark – over 18%.

5. Qualified workers should be hired to harvest trees using the complex felling method, with basic knowledge of felling methods and an understanding of the need for their use. Of great importance in this case is the precision with which trees are felled in the chosen direction, which allow damage to be avoided to the lower layers of the tree stand.

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Topic 11

Steep Terrain & Cable yarding

Research of kinematics and dynamics of tracked timber harvesting vehicle running gear

V. E. Klubnichkin*, E. E. Klubnichkin

Abstract
The multi-link mechanism is examined using the running gear of the tracked timber harvesting vehicle LZ-5 as an example. We have opted for the UM Tracked Vehicles software to conduct the research as it is more suitable for solving the given task. The first step was to test the structure of the undercarriage of the TTHV with use of pre-created solid models of the undercarriage elements. Then we added the solid model of the timber harvesting vehicle LZ-5 from SolidWorks with all the geometrical and physical parameters and main elements. The next step was to set the soil model, which will be used in the experimental research of the TTHV. Then the external impact on the TTHV dynamics were examined. After the model had been created and all necessary external conditions had been set, virtual experimental research (tests) were conducted.

Keywords
tracked running gear, multi-link mechanism, tracked vehicle, motion dynamic, simulation

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1. Introduction

The multi-link mechanism has been examined on the example of the running gear of tracked timber harvesting vehicle LZ-5. The running gear of the tracked timber harvesting vehicle (TTHV) represents a multi-link mechanism as it is composed of the caterpillar chains housing a large number of pin-jointed tracks. We have opted for software UM Tracked Vehicles to conduct a research as it is more suitable for solving the given task. The main load on the TTHV transmission is made by the combustion engine and running gear from the side of the driving sprockets which in their turn interact with the tracks and undercarriage impacted by the track microprofile and soil characteristics. The first step is to set a structure of the undercarriage of the TTHV under test with use of pre-created solid models of the undercarriage elements. Then we add the created solid model of timber harvesting vehicle LZ-5 from SolidWorks with all geometrical and physical parameters and main elements. The next step is to set the soil model which will be used in the experimental research of the TTHV. The soil model shall be selected from the soil models' database. Then the force interaction models is examined. Interaction between the roller and the caterpillar chain. This model generalizes to the interaction between the roller and the polyline which simulates the internal surface of the caterpillar. The next step is to build a model of interaction between the TTHV driving sprockets and the caterpillar chain tracks. Then the external impact on the TTHV dynamics is examined. Consideration has been made for the track microprofile and path curvature. After the model has been created and all necessary external conditions have been set, virtual experimental research (tests) are conducted. During the design engineering, such virtual tests make more economic sense than the actual test of the prototype.

2. Material and Methods

The running gear of the TTHV represents a multi-link mechanism as it is composed of the caterpillar chains housing a large number of tracks pin-jointed between each other (Klubnichkin et al., 2010; Wong, 2009). To conduct research of kinematics and dynamics of the TTHV running gear and further evaluate loading of the transmission elements, we have reviewed several software application packages which are able to implement such type of research, including MSC ADAMS View, ADAMS Tracked Vehicle (ATV) Toolkit and UM Tracked Vehicles (Universal Mechanism), etc. (Pogorelov, 1997; Pogorelov, 2005; Drapalyuk et al., 2012; Klubnichkin, 2012a; Bukhtoyarov et al., 2014). Following the software review result, we have opted for software UM Tracked Vehicles as it is more suitable for solving the given task. Let us review the use of this software package to explore kinematics, dynamics of the running gear and evaluate loading of the TTHV transmission elements at the curvilinear motion and crossing of single obstacles. The main loads on the TTHV transmission are made by the combustion engine and running gear from the side of the driving sprockets (Klubnichkin et al., 2012b) which in their turn interact with the tracks and undercarriage impacted by the track microprofile and soil characteristics (Said Al-Milli et al., 2010; Klubnichkin et al., 2013, Kotikov et al., 2008, Klubnichkin, 2008). For this reason, the first step is to set a structure of the undercarriage of the TTHV under test with use of pre-created solid models of the undercarriage elements.

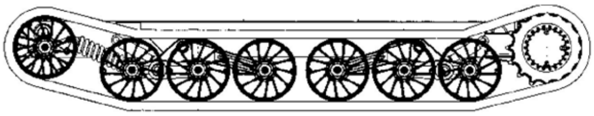

Figure 1. Setting a structure.

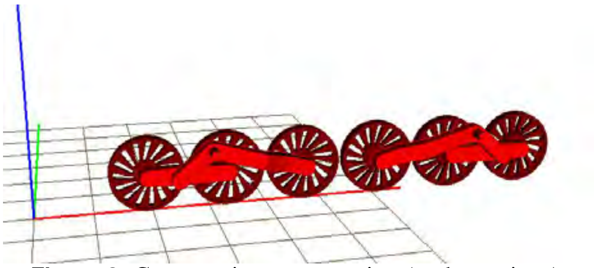

Figure 2. Constructing a suspension (undercarriage).

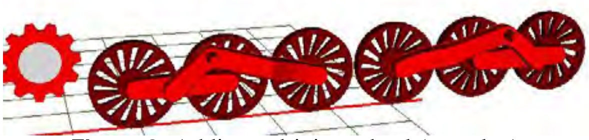

Figure 3. Adding a driving wheel (sprocket).

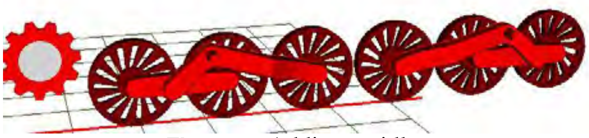

Figure 4. Adding an idler.

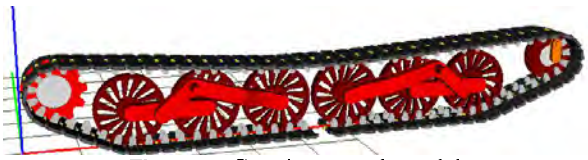

Figure 5. Creating a track model.

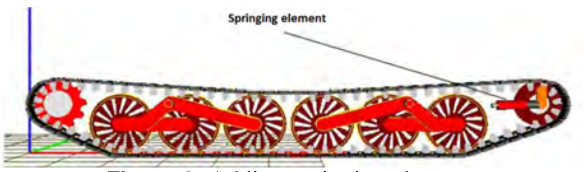

Figure 6. Adding springing elements.

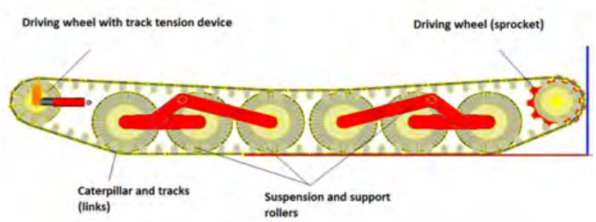

Figure 7. Name of main elements. TTHV basic coordinate system.

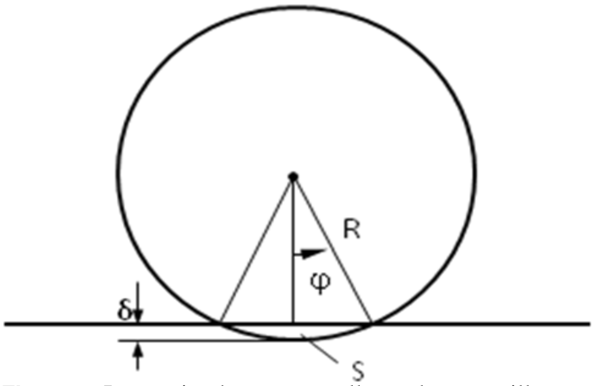

Figure 8. Interaction between a roller and a caterpillar chain.

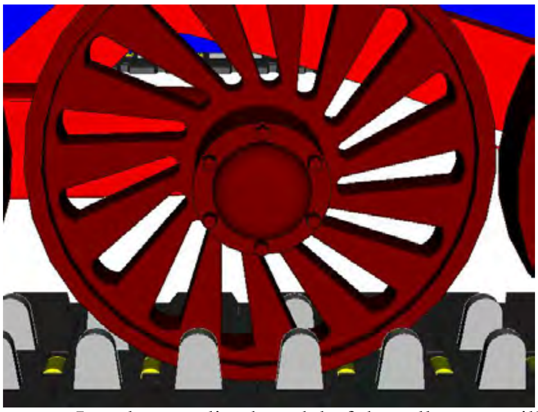

Figure 9. Local generalized model of the roller-caterpillar chain interaction.

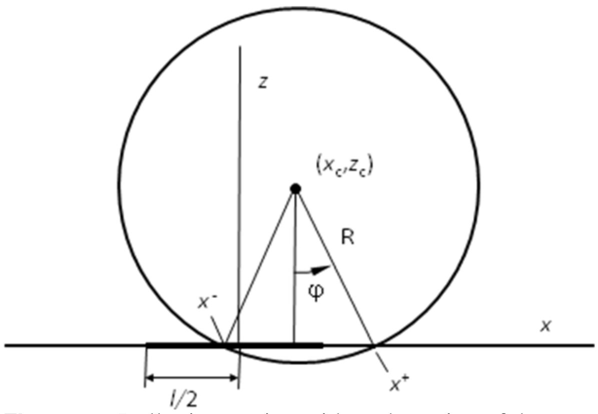

Figure 10. Roller interaction with each section of the polyline (track).

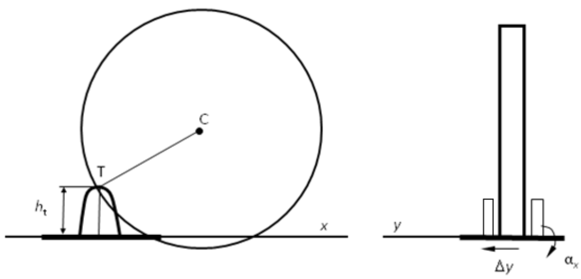

Figure 11. The force and the moment prevent lateral displacement of the track.

Figs 1 - 6 represent step-by-step setting of the undercarriage elements with running gear. The names of the main undercarriage elements are given in Fig. 7.

Then we add the pre-created solid model of timber harvesting vehicle LZ-5 from SolidWorks with all geometrical and physical parameters and main elements. The next step is to set the soil model which will be used in the experimental research of the TTHV. The soil model shall be selected from the soil models' database. Two main soil models are used: rigid foundation (linear dissipative contact and friction) and soils with subsidence. Then the force interaction models is examined. Interaction between the roller and the caterpillar chain.

$$F =_{\kappa} S \tag{1}$$

The interaction model is based on the assumption that the force of the hard penetration area S is proportional. As a result we have the following force-penetration dependence:

$$F = P\left(\frac{\delta}{\delta_0}\right)^{\frac{3}{2}} \tag{2}$$

$$c(\delta_0) = \frac{\mathrm{dF}}{\mathrm{d}\delta} = c\left(\frac{\delta}{\delta_0}\right)^{\frac{1}{2}} \tag{3}$$

where δ_0 is a deflection under load P
and $c(\delta)$ is a stiffness-deflection dependence

Figs 8-10 show interaction between a roller and a caterpillar chain. This model generalizes to the interaction between the roller and the polyline which simulates the internal surface of the caterpillar. The normal load is a combination of forces of the roller interaction with each section of the polyline (track).

$$F_y = -c_y \Lambda y - d_y \Delta y \tag{4}$$

$$M_x = -c_{ax}\alpha_x - d_{ax}\omega_x \tag{5}$$

The force and the moment prevent lateral displacement of the track and its turn about a vertical axis (track shoe horn) (Fig. 11).

The next step is to construct a model of interaction between the TTHV driving sprockets and the caterpillar chain tracks. The method of engagement of the driving wheel is analyzed (Fig. 12). The type of engagement is defined: lantern, ridge, toothed. Calculated is a model of yielding contact with friction which considers precise geometry of the tooth and driving wheel profiles.

Then the external impact on the TTHV dynamics is examined. The track microprofile is considered. The normal distribution law is presented in formula (6)

$$\varphi(y) = \frac{1}{\sigma_y\sqrt{2\pi}} exp\left(-\frac{y^2}{2\sigma_y^2}\right) \tag{6}$$

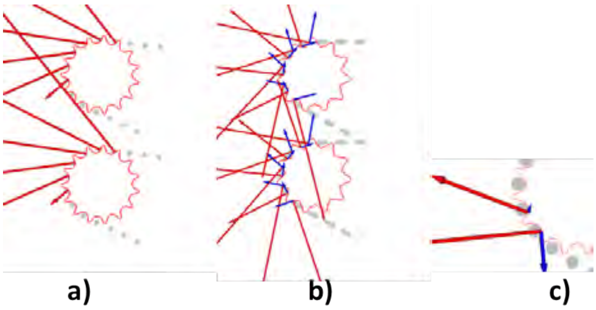

Figure 12. A model of yielding contact with friction which considers precise geometry of the profiles of the sprocket tooth and pin tooth. a, b, c are different types of engagement.

where σ_y is a microprofile root mean square deviation, m

Path curvature. The path curvature probability density function is described by the normal law with precision sufficient for practical research:

$$\phi_s(\kappa) = \frac{1}{\sigma_k\sqrt{2\pi}} exp\left(-\frac{k^2}{2\sigma_k^2}\right) \tag{7}$$

In a similar way to the microprofile characteristics, it can be assumed that the probability density function of the tilt angle with due consideration of its maximum possible value which can be overcome by the TTHV is described by the following law:

$$\phi_{s_{\alpha_0}}(\kappa) = \frac{exp\left(\frac{\alpha_0^2}{2\sigma^2}\right)}{2\pi\sigma} \tag{8}$$

The linear motion resistance factor f_{rp} is a positive-definite random value. Raleigh distribution can be used to evaluate its probability density.

$$\phi_s(f_{\Gamma P}) = f_{\Gamma P}\frac{1}{\sigma_{\Gamma P}^2} exp\left(-\frac{f_{\Gamma P}^2}{2_f^2}\right) \tag{9}$$

where σ_f is a microprofile root mean square deviation, m

After the model has been created and all necessary external conditions have been set, virtual experimental research (tests) are conducted.

According to the mathematical model in the application software package: UM Tracked Vehicles the following tests have been performed to master and test correct operation of a 3D solid model. Auxiliary tests, including: balance, track tension and initial velocity calculation. Main tests: straight line motion with crossing single obstacles 100, 200, 300 and 400 mm high located every 6 meters, curvilinear motion, curvilinear motion with variation of curvature sign and test cutting area (Figs 13, 14). During actual and virtual experimental researches the data obtained during measurement of the path microprofile were used (Klubnichkin, 2008).

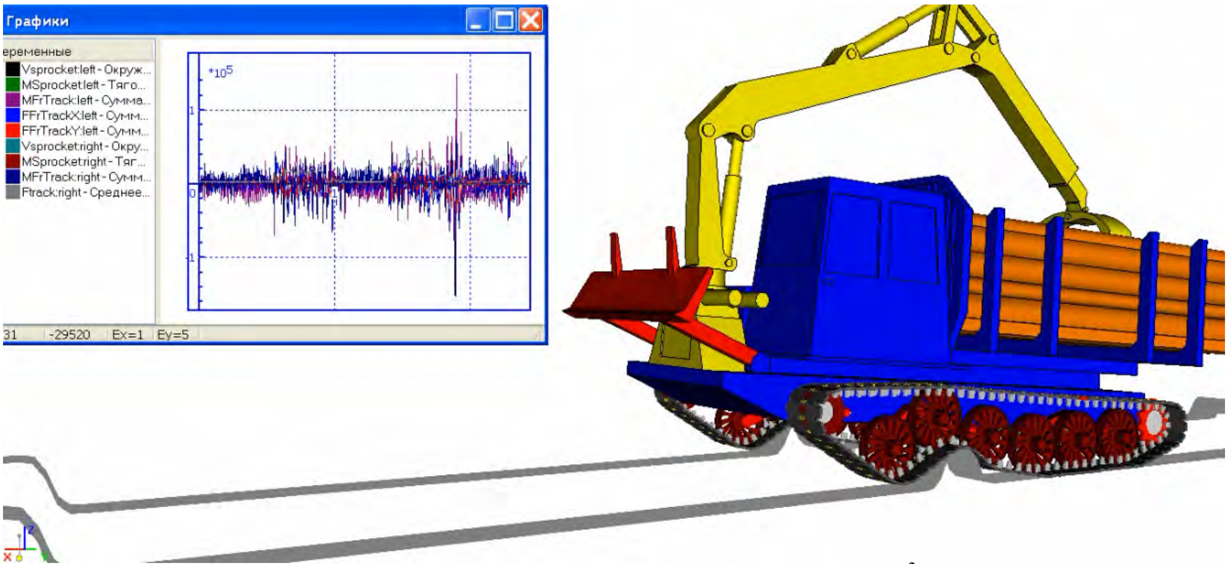

Figure 13. Virtual experiment of TTHV carrying a package of wood assortment Qp=12m^3 and crossing single obstacles 100, 200, 300, 400 mm high.

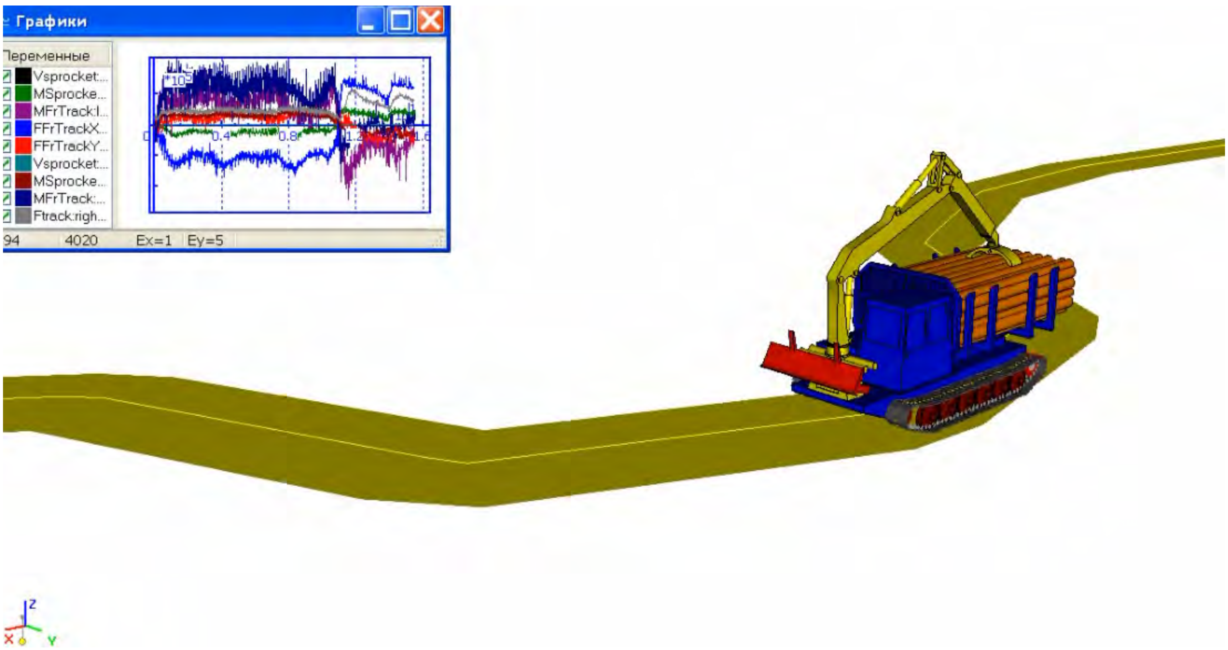

Figure 14. Virtual experiment of TTHV moving along curvilinear trajectory and carrying a package of wood assortment Qp=12m^3.

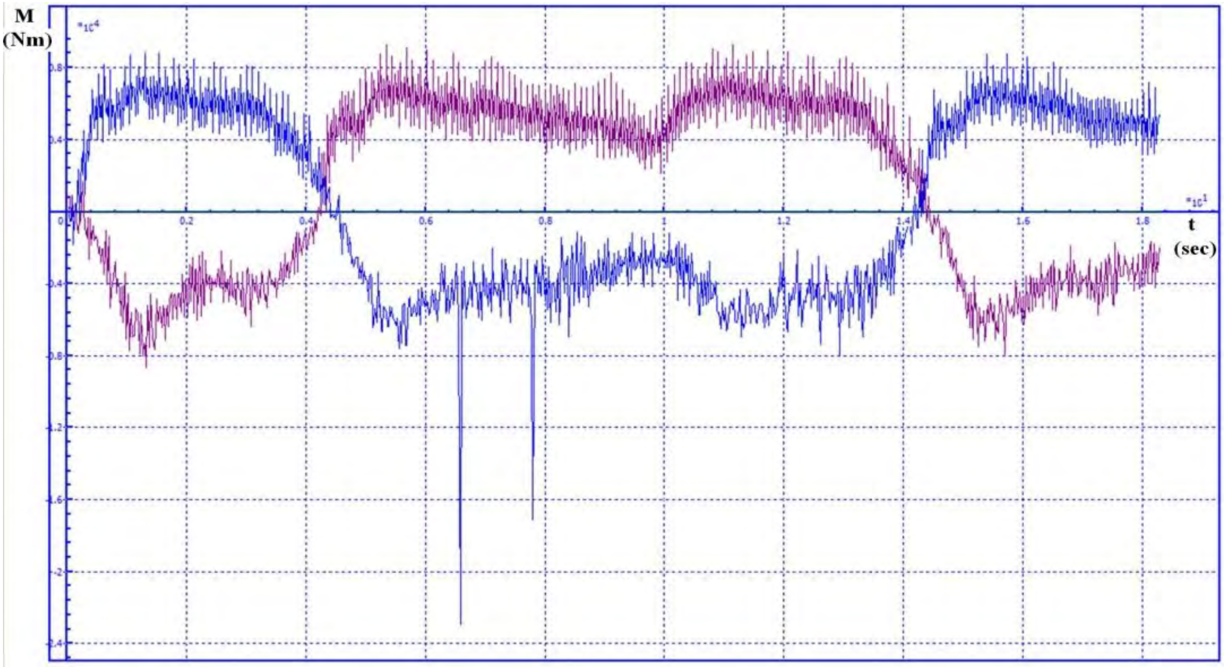

Figure 15. Driving sprocket torques at the curvilinear motion of TTHV in 1st gear with TTHV carrying a package of wood assortment Qp=12m^3. Blue colour is a RH driving sprocket torque, purple colour is LH driving sprocket torque.

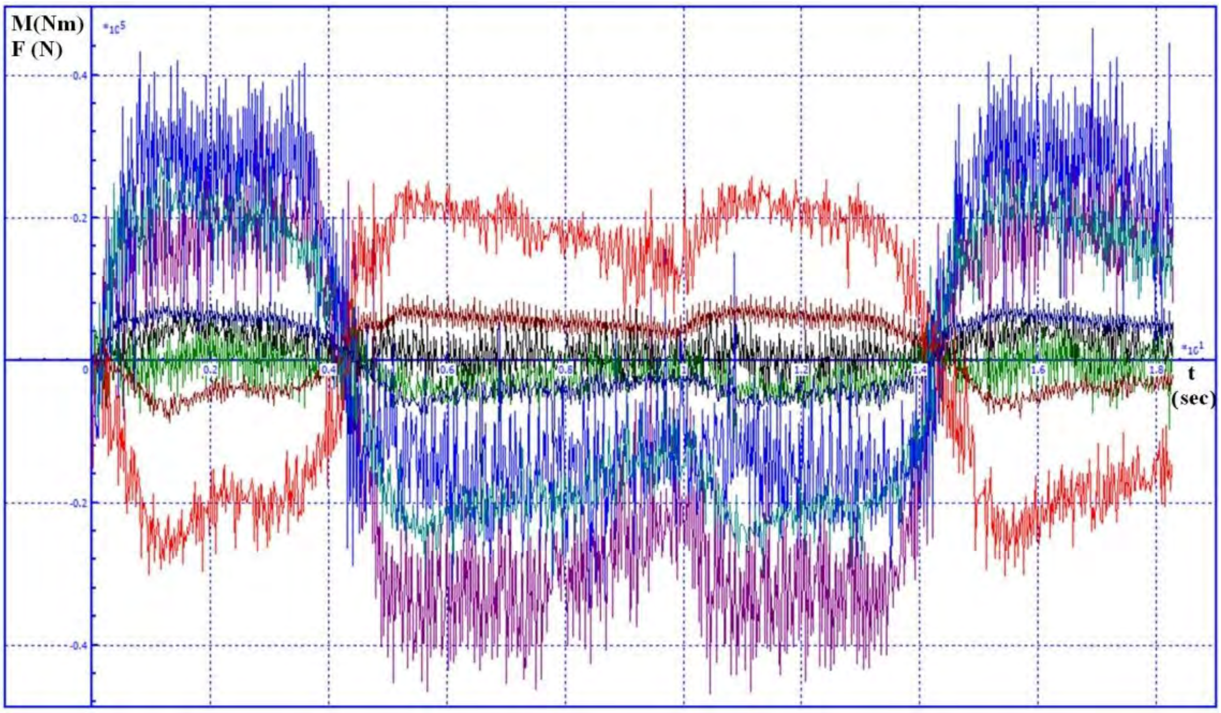

Figure 16. The fragment of results of the computer simulation of interaction of the LH and RH caterpillar tracks with the ground contacting area at the TTHV curvilinear motion with due consideration of the driving sprockets' torques, Vtr= 2.6 km/h; wood assortment volume Qp=12m^3. Black line is a total force of interaction of the LH caterpillar tracks with ground contacting area along axis Y; green line is a total force of interaction of the RH caterpillar tracks with ground contacting area along axis Y; red colour is a total force of interaction of the LH caterpillar tracks with ground contacting area along axis X; turquoise line is a total force of interaction of the RH caterpillar tracks with ground contacting area along axis X; purple colour is a total torque of interaction of the LH caterpillar tracks with ground contacting area; blue line is a total torque of interaction of the RH caterpillar tracks with ground contacting area; brown colour is a LH driving sprocket torque; dark blue is a RH driving sprocket torque.

3. Results

Following the results of the conducted researches the methods of the theory of random functions have been used to lay down the law of fluctuating loads acting on the TTHV elements during its movement. When the above statistical characteristics of random functions were found, the obtained values were examined in a train of intervals for equidistant time moments followed by recording of the values of variable functions at those time moments. All these functions have been approximated by respective analytical expressions followed by construction of diagrams of ergodic stationary processes. The statistical characteristics of the explored processes depended on the beginning of the countdown to the reception of the established modes. The fragments of the performed researches are presented for analysis in the well-readable graphical view (Figs 15, 16).

4. Conclusions

Application package UM Tracked Vehicles features special options for environment simulation, for example, soil and snow. In this work we have described the use of application software packages ADAMS View, ATV Toolkit, UM Tracked Vehicles to explore kinematics and dynamics of the running gear with the tracked timber harvesting machine moving a curvilinear trajectory and crossing single obstacles along the path microprofile. During the design engineering, such virtual tests make more economic sense than the actual test of the prototype.

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An analysis of whole tree harvesting in North Italian cable logging operations

C. Lombardini*, F. De Francesco, G. Aminti

Abstract
Five cable logging operations were selected in the Como Lake area - in Northern Italy - with the purpose of exploring the effects of introducing whole tree harvesting as a replacement of traditional full-length stem harvesting. For each operation, two adjacent and parallel lines were set up, with the same length and removal intensity. On one line harvesting proceeded as usual and trees were motor-manually felled and delimbed, yarded as full length stems, and finally crosscut and stacked at the landing using a chainsaw and an excavator. On the other line, trees were motor-manually felled, yarded whole and mechanically processed at the landing. All work time was recorded, separately for different activities. Output was also measured and allocated to different assortments. All fuel consumption was recorded, which allowed estimating financial and energy cost. After harvesting, a complete assessment of the amount of residues left in the stand was also conducted, using a standardized sampling method. Time consumption per unit product was 20 to 40% lower for the whole tree system, compared with the traditional full length stem system. Fuel consumption per unit product was also 20 to 30% lower for the whole tree system. The whole tree system did not result in the complete removal of all residue biomass. In fact, whole tree harvesting resulted in a reduction of the residue load between 30% and 65%. Even after whole tree harvesting, at least one third of the logging residues was left in the forest.

Keywords
mountain, biomass, yarder, residues

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1. Introduction

Forests cover 40% of the Alpine landscape and have an important role in supporting the alpine economy (Onida 2009). Alpine forests also have a protective function as they prevent soil erosion and shield settlements from avalanches and rock fall. The need to guarantee both cost-effective wood production and careful hydro-geologic protection makes alpine forestry especially complex. Furthermore, the typical access constraints of the Alpine territory often prevent the introduction of modern harvester-forwarder technology, which is a main solution to cost containment in the face of increasing fuel and labor cost (Spinelli and Magagnotti 2011). As a consequence silvicultural treatment is often delayed and results in a skewed age distribution. That contributes to the high vulnerability of Alpine forests to the effects of climate change. Therefore, it is crucial to optimize forest operations in order to guarantee timely regeneration and maximize resiliency.

When slope gradient exceeds 40%, ground-based harvesting technology cannot offer good results and cable logging is preferable. Cable yarding is the most common steep slope harvesting technique world wide and it is especially popular in the Alps, in fact the most modern yarder developments originate there. In 2012, there were over 350 cable logging contractors in alpine Italy alone (Spinelli et al. 2013). On steep terrain, cable yarding is the cost-effective alternative to building an extensive network of skidding trails and results in a much lower site impact compared to ground-based logging. On the other hand, cable yarding is inherently expensive because it is normally deployed on difficult sites. For this reason, cable logging offers lower profit margins compared to ground-based logging. This justifies a stronger optimization effort, supported by a deeper knowledge of technical cost and market rates.

In particular, efforts have been devoted to increase the mechanization of cable logging operations. The most widespread solution adopted so far consists in whole-tree extraction, which allows increasing the productivity of tree processing (i.e. delimbing, crosscutting and stacking). Once the trees are delivered to the landing, processing becomes faster and safer, due to the easier work conditions. What is more, processing can be mechanized by deploying dedicated multi-functional machines (i.e. processors), which cannot normally negotiate steep terrain but can station at the landing and work on the trees after extraction. In any case, a loader would be needed at the landing for stacking the trees, and the introduction of mechanized processing would only require the additional investment in a processor head, not in a complete machine.

However, whole-tree (WT) extraction is coming under increased criticism because of the risk for soil nutrient depletion (Wall 2012), as it may result from the removing nutrient-rich top and branch material. Supporters of whole-tree harvesting object that only part of the total above-ground biomass is removed, and lots of branch and top material is left on the forest floor, regardless of the harvesting system. A compromise solution would consist in removing the tree top and most of the branches before extraction, but leaving the stems in their full length – hence the definition of full-length system (FLS). However, topping and coarse delimbing before extraction may incur higher cost than just felling.

In an attempt to answer such questions, the authors conducted the present research, with the direct goal of comparing the WT and FLS systems in terms of productivity, cost and biomass release. Obviously, a meaningful comparison of the two techniques should be conducted at the system level, and include biomass release as well.

2. Material and Methods

Five cable logging operations were selected in the Como Lake area - in Northern Italy (Tab. 1). For each operation, two adjacent and parallel lines were set up, with the same length and removal intensity. On one line, the FLS system was applied: trees were motor-manually felled, topped and coarsely delimbed, yarded as full length stems, and finally crosscut and stacked at the landing using a chainsaw and an excavator. On the other line, the WT system was applied: trees were motor-manually felled, yarded whole and mechanically processed at the landing, using an excavator-base processor (Figure 1).

All work time was recorded, separately for different activities. Output was also measured and allocated to different assortments. All fuel consumption was recorded, which allowed estimating financial and energy cost. After harvesting, a complete assessment of the amount of residues left in the stand was also conducted, using a standardized survey method developed within COST Action FP0902.

3. Results and discussion

Labour productivity was between 15% and 60% higher for the WT system, compared with the FLS system (Figure 2). Adoption of the WT system also resulted in a higher fuel efficiency: the unit consumption (l odt-1) of chainsaw mix decreased between 14 and 48%, whereas the unit consumption of diesel fuel decreased between 2 and 30%. However, fuel cost was a very small part of total cost, which was generally higher for the WT system due to the capital commitment necessary for the acquisition of a processor head. The result were smaller savings in total harvesting than one initially expected. Nevertheless, WT harvesting was generally less expensive than FLS harvesting, and the savings varied between 1 and 32 € odt^{-1} (or between 1 and 27% of the original cost recorded for FLS). In fact, in one case WT harvesting was more expensive than FLS harvesting.

The main advantage of the WT harvesting was to remove tiresome, dangerous and inefficient stump-site processing, and to increase extraction efficiency by allowing faster accumulation of larger loads WT harvesting resulted in lower residue loads in the forest. In the case of conifers, application of WT harvesting resulted in a reduction of

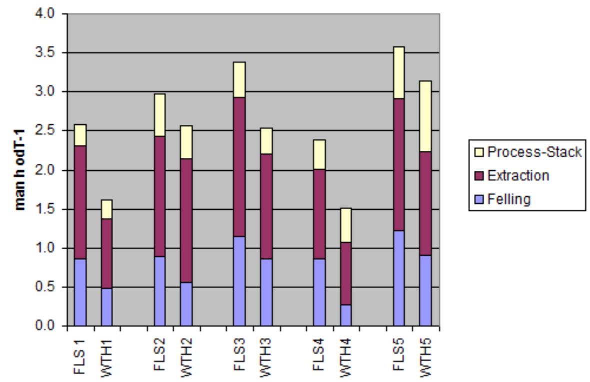

Figure 1. Labour productivity.

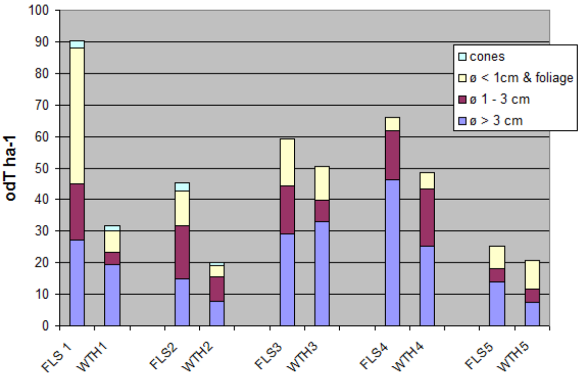

Figure 2. Residues assessment.

Figure 3. Cable logging operation .

Table 1. Cable logging operations characteristics.

Test (Site)	#	1	2	3	4	5
Surface	ha	2,00	4,46	4,30	3,96	1,40
Altitude	m a.s.l.	1250	1300	1325	950	800
Slope gradient	%	35	50	42	60	70
Species		Norway spruce	Norway spruce	Beech	Beech	Hornbeam, chestnut
Management		Plantation	Plantation	Coppice	Coppice	Coppice
Treatment		Gap cut	Gap cut	Selection cut	Selection cut	Selection cut
Age	years	60	51	50	50	30
Removal	$m^3\ ha^{-1}$	428	67	123	123	78
Harvest intensity	% volume	100	39	52	74	50
Harvest tree	m^3	0,535	0,268	0,217	0,273	0,204
Harvest tree	odt	0,230	0,115	0,147	0,185	0,088

residue loads by half. Such reduction was much smaller with coppice stands, and varied between 20 and 25% as a result of winter cutting (no leaves on the branches) and of a more intense product recovery (firewood). In any case, residue loads were very high in all cases, including after WT harvesting.

4. Acknowledgements

The research leading to these results has received funding from the INTERREG Programme: P.I.T. SAPALP - P.O. “Formazione partecipata: Saper imparare a vivere sostenibile” – id. 1377399.

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Case study of the Active 70 cable yarder in New Zealand plantation forests

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Abstract
The majority of yarders working in New Zealand forest industry are older models from the Pacific Northwest, with Madill and Thunderbird alone making up 67% of the units in operation. These yarders are typically very large with tower heights around 30 meters. With increasing demand, one option for contractors is modern small to medium sized yarders that are more automated and might offer both ergonomic and cost-efficiency benefits. However, these systems are not proven in larger scale plantation forestry. The aim of this study was to assess the performance of the Active 70 yarder. The assessment included; productivity measures, time studies, assessment of breaker-out work levels and a noise volume assessment.
The study found a productivity of 23.4 m³ per productive machine hour, with an average utilization rate of 65% resulting in 15.3 m³ per scheduled machine hour. The heart rate study found that the breaker-outs worked hard for prolonged periods over the time period of the study. It was found that anyone within a 10 meter range of the machine for extended periods should wear hearing protection, with volumes in this area surpassing 80 decibels.

Keywords
komaseperated

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1. Introduction

Commercial plantation forestry currently covers 7 percent of New Zealand's land area, equating to 1.7 million hectares. Of this area, 44 thousand hectares is harvested annually, resulting in a recovered harvest volume of almost 30 million cubic meters. This has a value of 4.5 billion dollars and is the third largest export product for New Zealand (NZFOA, 2013). Although it is a large industry, it is a lower value land use and as such often occupies steep, remote and erosion prone land.

Harvest generally occurs at 28 years of age and is based on a clear fell system. There are two main harvesting systems; ground based and cable yarder based. The method selected is based on the terrain, with steep gradients and rough terrain often making cable yarding a necessity. In New Zealand the cost (average) of harvest using cable based machinery is $35.90 per tonne while ground based harvesting costs $26.90 per tonne (Visser, 2014a). This price difference is of high importance, with an increase from 15 percent in 1976 of the total volume harvested in New Zealand (Fraser, Murphy, & Lersesk 1976) to 40 percent in 2014 (Visser, 2014a). This indicates a higher proportion of harvested areas now being in steep and rough terrain, where ground based methods are not viable.

There has been a large amount of research into cable yarding internationally with the focus generally concerning productivity and worker safety, Harrill and Visser (2014) provide a thorough review of the available literature. One of the proposed solutions to these issues is the utilisation of modern machinery.

The cable yarding equipment currently used in New Zealand is almost entirely of North American design or build (Visser, 2013) and is generally based on designs from pre-1980. This machinery is considerably larger and more powerful than the European counterparts that exist internationally (Heinimann, Stampfer, Loschek, & Caminada, 2001; Liley, 1983). Although there has been extensive research and development on these systems to make them more efficient and safer, the base machinery is still generally less advanced than its European counterparts.

On average in New Zealand the value of logs allows profitable harvesting to occur. Reducing costs would increase profit margins across the industry and facilitate the harvest of areas that are currently considered cost prohibitive to harvest. Areas that are cost prohibitive to harvest are often small, steep and remote. The potential value of being able to harvest these areas is high, with 40 percent of the total planation forest area being in blocks of less than 10 hectares and a large proportion of this area needing cable harvesting (NZFOA 2013). These figures alone indicate that there is a large amount of forest area which is likely to be very expensive to harvest. The seriousness of this situation is highlighted in the Whanganui region, in which under current pricing conditions 5 to 10 percent of the area of forest blocks under 1000 hectares will not be viable to harvest (Park, Manley, Morgenroth, & Visser, 2012).

Personnel safety is a key consideration concerning cable logging. More ergonomic equipment is likely to result in comparatively lower workloads for the workers, resulting in lower fatigue rates. Results show that fatigue is felt by all workers on site, including machine operators (Inoue, 1996; Kirk & Sullman, 2001) and is recognised as being one of the largest safety issues within the forestry industry (Lilley, Feyer, Kirk, & Gander, 2002). Workers that reported high levels of fatigue also reported higher rates of near miss incidents over the previous 12 month period (Lilley et al., 2002). A higher level of near misses translates into higher probabilities of incidents. The causes of the high fatigue levels are believed to be the high work load and long hours that are associated with the New Zealand forestry industry.

Improved ergonomics may also have positive effects on production, with a study in the forestry industry (although focused on planting) finding that although the heart rate levels remained constant, productivity levels decreased significantly over rougher terrain (Sullman & Byers, 2000). This indicates in a more ergonomically friendly work environment, workers can be more productive for similar work inputs.

The focus of this study is on modern small to medium sized cable yarders. One such example is the recently introduced Koller 602H from Austria (Ellegard 2015). The Koller 602H is a trailer mounted cable yarder which weighs 15 tonnes, with an extended height of 10-11.5 meters and a 147 kilowatt engine. As that machine was not operational at the time of the intended study, the focus was shifted to the Active 70. The Active 70 yarder is a new model that has been developed by Active Engineering, based in Rotorua, New Zealand. The yarder has a 70ft (21.3 m) inclined tower, 384 kW engine and is equipped with a 28mm skyline, 22mm mainline and 22mm haulback. Features uncommon to most New Zealand cable yarding systems include: use of a motorised slack pulling carriage with radio controlled carriage drop line, improved cab with simplified controls and better vision, an integrated computer system with GPS tracking of choker setters, tension monitoring of skyline and mainline and a modern quiet diesel engine.

The goal of this project was to investigate the productivity and economic performance modern small to medium sized yarders and assess their potential of working in NZ plantation forests.

2. Methodology

The study site was located in Tahorakuri Forest managed by PF Olsen Ltd, 10 kilometres north of Taupo, New Zealand. The study area was part of a larger harvest area of 20.2 hectares. The forest was planted in 1987/88 and the area to be harvested had a stocking of 307 stems per hectare and a mean tree size of 2.2 m³ equating to 647 m³/ha. The trial took place over five consecutive days from the 15th to the 19th of June, 2015. The yarder was located on the same landing over this period, with one yarder shift and five line shifts recorded (Figure 1).

Over the study period the yarder employed a standing skyline system using a Bowman motorised carriage (Figure 2) operated in the shotgun rigging configuration. In New Zealand only 4 percent of loggers use mechanical

Figure 1. Active 70 yarder operating from the landing at the study site in Tahorakuri Forest.

slack pulling carriages regularly and only 28 percent have used them in the previous five year period (Harrill & Visser, 2014b), making them relatively rare. The carriage was equipped with three electronic chokers which were connected to stems by two choker setters. All line shifts were performed by a 30 ton excavator used as a mobile tail hold. This system employed was typical of what the crew normally used and was most experienced with. Weather conditions were mainly clear, with intermittent light showers and wind on the 15th and 19th; but not considered significant enough to influence the results.

Figure 2. Bowman motorised slack pulling carriage with radio controlled drop line.

The productivity was assessed by a time and motion study, recorded over the week. Cycle time was collected by recording the start and end of each cycle by stop watch. Volume per cycle was estimated by the number, length and large end diameter of the logs in each cycle. Outhaul distance was captured by the GPS tracker on the carriage, and checked by manually shooting the distance to the carriage using a Nikon Forest Pro range finder and slope measurement tool. Heart rates were measured using a strap mounted pericardial heartbeat transmitter. This connects wirelessly to a wrist watch sized (and mounted) storage unit. This method is considered accurate and has minimal interference on the ability of workers to do their job effectively (Kirk & Parker, 1996; Kirk & Sullman, 2001; Stampfer et al., 2010). There are multiple indices that can be applied for presentation heart rate data. Three of the most common and simple indices of heart rate data are going to be used to understand trends; these are the "relative heart rate", the "50% of working heart rate" and the "ratio of resting heart rate to working". These indices have been demonstrated as effective techniques for assessing the physiological strain of forest workers.Common terms used in these indices are displayed in Table 1. Under this assessment prolonged physical work should score between 30 and 40 percent (Astrand & Rodahl, 1986). Breaking out in one New Zealand study scored 36.3 percent ± 3.1 percent (Kirk & Sullman, 2001). Lammert (1972) suggested that this method is a good technique for assessing strain with "1" classified as hard continuous work. A study that utilized this method found that breaking-out had a score of 0.85 ± 0.04 and was therefore not classified as hard continuous work. This may be influenced by very short breaks as loads are hauled to the landing (Kirk & Sullman, 2001).

This ratio system is commonly used across a large number of industries and can be easily calculated from published previously published data. Kirk and Sullman (2001) found that with a score of 1.84 ± 0.1 choker-setting was a more demanding job than faced by steel workers or cane cutters, both believed to be highly demanding occupations.

It needs to be noted that there are multiple factors which can contribute to work levels and productivity, other than just the machinery (Kirk & Parker, 1994; Sullman & Byers, 2000). Example factors include; slope, roughness of terrain/obstacle and climatic conditions (Kirk & Parker, 1996; Kirk & Sullman, 2001).

The noise level of a machine is measured in decibels. Cable yarders are traditionally loud machines, and prolonged exposure can lead to a number of health related issues, the most common being industrial hearing loss. The data was collected using a sound (decibel) monitor resting on a workers pick-up truck that was parked close to the yarder each day. The data presented was collected by taking the maximum volume (A weighted) of the machine at two second intervals over the period of the working day. The decibels were averaged across the collection days and then the number of decibels at varying distances was calculated.

It should be noted that the monitor was also exposed to operational noise that occurred on the landing including chainsaws and large excavators (Figure 3). The additional sources of noise may have had a slight influence on the results, but due to the average over eight hours/day it was expected to be minimal.

3. Results

3.1 Productivity analysis

The average cycle time was 9.4 minutes, corridor 2 had the longest average cycle time of 12.0 minutes and corridor 5 had the shortest of 8.6 minutes (Table 2). The average cycle volume was 3.5 m^3, with corridor 3 having the lowest at 2.7 m^3 and corridor 5 having the largest at 4.6 m^3. On average there was 35 cycles completed per day. Corridor 2 had the lowest at 17 and corridor 1 had the highest at 50.

Figure 3. Example of operation noise near decibel meter, meter located behind camera.

The average volume extracted over the study period was 128 m^3 per corridor resulting in a total week volume of 640 m^3.

Differences in corridor volumes were because of factors that affected the amount of cycles completed or the volume carried per cycle. Factors influencing the cycles included a lack of deflection resulting in limiting loads, variable extraction distances and mechanical and operational delays.

Intermediate ridges reduced available deflection and had a significant effect on the maximum payloads that could be extracted per cycle; this was particularly an issue for corridor 3. The yarder was moved for the fourth corridor to mitigate this issue. This movement of the yarder coupled with the movement of the tail hold for corridor 5 improved deflection and allowed the largest payloads of the study period to be retrieved. Extraction distances were significant predictors for productivity when matched to individual cycles.

The machine operation hours were analysed to assess how many hours the machine was productive during the time that the crew needed to operate it were present. This is expressed as the 'utilization rate' which is simply the ratio of PMH to the scheduled machine hours (SMH). Productive hours are the amount of time the machine is working; this time was calculated by adding all the individually recorded cycle times together. Scheduled hours are the total amount of time the crew is on site and the machine could potentially be operated. Utilization rates for each corridor are shown in Table 3.

The overall utilization rate for the week was 65%. The corridors that had below average utilization rates were corridor 1 and corridor 4. The low utilization rate of corridor 1 was caused by a delayed yarder start due to a safety briefing and a large surge pile on the landing that needed to be processed before more stems could be extracted. There was also a mechanical delay due to a carriage breakdown that stopped the operation for 54 minutes. The low utilization of corridor 4 was caused by a delayed start due to a crew breakfast, safety meeting and yarder shift.

Other factors that contributed to the 65% utilization rate included lunch breaks and line shifts. It should be noted

Table 1. Common terms in indices for presentation ofheart rate data.

Working heart rate (HRw)	Average heart beats per minute (bpm)
Maximum heart rate (HRmax)	220 - age
Resting heart rate (HRr)	Average 10 minute heart rate value in a sitting position
Relative heart rate at work	((HRw – HRr) / (HRmax – HRr))*100
50% of working heart rate	HRr + (HRmax – HRr) / 2
Ratio of resting heart rate to working	HRr/HRw

Table 2. Summary of recorded observations for each skyline corridor during the study of the Active 70 yarder.

Corridor	1	2	3	4	5	Average
Average delay-free cycle time (min)	10.1	12	8.8	8.9	8.6	9.4
Average cycle volume (m^3)	3.7	3.9	2.7	2.9	4.6	3.5
Cycles per corridor	50	17	42	20	48	35
Corridor volume (m^3)	184	66	112	57	219	128
Average extraction distance (m)	107	142	146	122	181	140
Deflection	7%	2%	2%	8%	7%	5%

that common utilization rates for cable yarding systems are around 65-70% (Harper, 1992); without the delayed starts for corridor 1 and 4 and the significant mechanical delay for corridor 1, a similar average would have been achieved.

The figures above allow the calculation of productivity measures expressed as m^3/PMH or m^3/SMH. Corridor 5 had the highest production rate for both productive and scheduled machine hours at 31.6 m^3 and 23.4 m^3 respectively. Corridor 4 had the lowest rate of productivity per SMH at 8.1 m^3 while corridor 3 had the lowest productivity per PMH at 18 m^3. The observed rates were below the New Zealand average of 23.8 m^3/SMH for cable logging operations (Visser, 2014). However, the study site was a more difficult than average site, which was believed to be a key factor in the low productivity.

3.2 Heart rate data analysis

The two choker setters wore heart rate monitors for the full five days of the study. The purpose of collecting this data was to assess the workload of choker setters using the Bowman motorised slack pulling carriage (Figure 2). The heart rate monitors consist of a watch and elastic strap worn around the chest which record the wearer's heart rate every 5 seconds; which show the heart rates trends over the day. There were no issues with watches being lost or data corruption over the time of the trial, resulting in over 70 hours of usable data.

It is believed that the motorised slack pulling carriage could be easier for the choker setters to use, rather than other carriage systems. This is because of the ability of the choker setters to control the drop line release, resulting in lower work rates as the slack and chokers can be paid out as needed by the motorised carriage.

Typically a resting heart rate will be between 40 and 80 beats per minute (bpm)(Astrand & Rodahl, 1986). Heart rate patterns vary depending on the individual, with large amounts of variation present in resting and active heart rates. Differences in heart rates can be attributed to: age, genetics, fitness, health issues, smoking and body type. There were differences between Choker Setter 2 and Choker Setter 1's heart rate data, with Choker Setter 2 having a resting heart rate of 70 bpm and Choker Setter 1 having a resting heart rate at 62 bpm. Choker Setter 2 had an average daily maximum value of 174 bpm; Choker Setter 1 had an average daily maximum of 148 bpm. The overall daily averages were 99 bpm and 109 bpm for Choker Setter 1 and Choker Setter 2 respectively. The averages between workers are a prime example for the need to use indices to standardise data as differences clearly exist due to non-workload related factors.

Table 5 shows the results of three indices that are commonly used for standardising and assessing the workload of individuals. These indices allow the work levels of Choker Setter 2 and Choker Setter 1 to be compared across a number of different studies. Indicies also show the scores across the days of the study, which show how over the week the level of work differed. These differences are because some corridors are harder/easier to work in than others. This can be due to; land gradient, walking hindrance, piece size and terrain roughness (Figure 3). Because of this, these factors were recorded for each line shift observed over the week.

3.2.1 Relative heart rate

This measures the continuity of the work being done, prolonged continuous work scores 30-40%. This study had a score of 31.5%, which indicates that this work is in the prolonged continuous work category.

3.2.2 50% of working heart rate

If the value is greater than 1, the job is classified as hard continuous work. This study had a score of 0.97, which indicates that setting chokers using a Bowman carriage in the conditions studied is just under the hard continuous work category.

3.2.3 Ratio of resting to active

Heart rate analysis compares the ratio of resting heart rate against the average working heart rate. This study found an average of 1.56. It should be noted that steel workers and cane cutters have scores of 1.28 and 1.38 and are considered to be very labour intensive roles, indicating that choker

Table 3. Time consumption and calculated utilisation rate for the Active 70 yarder during the study period in Tahorakuri Forest.

Corridor/Time	1	2	3	4	5	Sum
Productive machine hours (hours)	7.7	3.5	6.2	2.9	6.9	27.2
Delay time (hours)	6.2	0.6	1.2	4.1	2.4	14.5
Scheduled machine hours (hours)	13.9	4.1	7.4	7	9.3	41.7
Utilisation rate	55%	84%	84%	42%	74%	65%

Table 4. Summary of productivity by skyline corridor for the Active 70 yarder during the study period.

Corridor/Measure	1	2	3	4	5	Average
m^3 per productive machine hour	24	18.9	18	19.4	31.6	23.4
m^3per scheduled machine hour	13.3	16	15.1	8.1	23.4	15.3

setting at the study site required a high level human work input.

The overall conclusion for this study is that based on the indices above, both Choker Setter 1 and Choker Setter 2 worked hard and for prolonged periods over the time period of the study.

Figure 4. Example of steep and brushy terrain choker setters were exposed to in corridor 1 of the study site.

A previous study in which choker setter's heart rates were recorded provides data which were used for comparisons (Kirk & Sullman, 2001). The key difference in the 2001 study was the use of a system employing butt rigging instead of a motorised carriage, which required works to pull chokers and slack without the aid of a motorised carriage.

This study had a relative heart rate score of 31.5%, while the comparison study scored 36.3%. This study had a 50% of working heart rate score of 0.97, while the comparison study scored 0.85. This study had a ratio of resting to active of 1.56, while the previous study on choker setters found an average score of 1.83. The comparison study indicated that Choker Setter 1 and Choker Setter 2 had a reduced workload compared to the choker setters from another study. The difference is likely to be that the comparison study was using butt rigging while Choker Setter 1 and Choker Setter 2 were using a remote controlled motorised slack pulling carriage.

3.2.4 Noise level analysi

s The decibels of the yarder at varying distances are shown in Table 6. It was found that with a five meter exposure of the machine there are sufficient decibels to cause hearing damage to 95% of workers, if the worker is exposed to this volume 8 hours a day for an extended time period without hearing protection. Based on these findings anyone working within 10 meters of the yarder should wear hearing protection.

4. Conclusion

The Active 70 yarder is a new yarder produced in New Zealand. When paired with a motorised slack pulling carriage the system reached and average productivity of 23.4 m^3/PMH and utilisation rate of 65%; which was influenced by extraction distance and available deflection. The motorised slack pulling carriage has the potential to reduce workloads for choker setters compared to other methods; but heart rate data collected during the study showed that the work is labour intensive and can be classified as "prolonged continuous work." The Active 70 yarder has a more modern quiet engine compared to other yarders, but persons working within 10 meters should still wear hearing protection to aviod industrial hearing loss.

5. Acknowledgements

The authors would like to thank the McKay and Olsen logging crew and Hamish McPherson from PF Olsen Ltd for helping organise the study. We also appreciate the support of Future Forest Research and the NZ Forest Owners Association for this project.

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Table 5. Averaged heart rate indices between the two choker setters for each corridor during the study period.

Corridor/Indices	1	2	3	4	5	Average
Relative heart rate at work (%)	35.8	33.2	31.4	28.5	28.4	31.5
50% of working heart rate	1.05	1	0.97	0.92	0.92	0.97
Ratio of resting to active	1.72	1.56	1.55	1.5	1.47	1.56

Table 6. Estimated decibel ratings at various intervals from the yarder.

Distance from yarder (m)	Volume (dB, A)	Risk of hearing damage
1	100	significant
5	86	significant
10	80	moderate
20	74	minimal
50	66	minimal
100	60	minimal

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Evaluation of cable yarding method by means of multi-decision making and GIS in postfire harvesting

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Abstract
Forest fires arise because of various reasons such as natural factors and/or carelessness-negligence. It is noted that forest fires as a result of climate change and global warming will occur more frequently in the near future. From the results of these extraordinary cases emerges big damages. This damage happens both during and after the disaster.
The aim of the study was to test the applicability of cable yarding after forest fire. It is expected that as a result of this study will be important to prevent more losses. As a result of the study, it was shown that cable yarding method was an effective method in terms of time and the protection of the quality of the product in post-fire harvesting.

Keywords
post-fire harvesting, cable yarding, GIS, multi-decision making

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1. Introduction

Forests are greatly damaged by biotic and abiotic factors. This damage is increasing for inability of correct planning after disaster. The damage has to be carefully considered for a moment before the planning has to be done and the field should be prepared for the next vegetation period. The time is of utmost importance in post-fire harvesting in addition to economical, ecological and social factors. Accurate and quick planning should be done to avoid loss of quality of the product due to damages as erosion and water loss after disasters such as forest fires.

In Turkey, several studies have been conducted to evaluate the fire after viewing their work to improve efficiency of production and appropriate methods. A model has been developed to calculate value of fire-killed timber as a function of time since death and yarding distance using helicopters as the preferred logging method (Akay et al., 2006). In 2009, Eker and Çoban described the general structure of Post Fire Harvest and Transport (YASHAT) related to harvesting and transport processes, and introduced the system structure that would ensure availability of this model. Çoban and Eker (2010) were found out that It has been proposed that current road network plans should be re-examined especially for fire sensitive forest areas, emergency road plans should be prepared and these plans should be keep up to date. Öztürk et al., (2011) examined modern production machines being used for the production works in the burnt areas after forest fires. A plan was prepared using model with the most correct method to discharge the area immediately after fire. In conclusion, after the fire of the crisis and the best way to manage the area with the principle of sustainability in order to ensure maximum benefit from the operational planning is required (Bilici, 2014).

Cable yarding systems have the potential to minimize site and stand impacts on sensitive sites (Thompson et al., 1998) and to reduce soil erosion and damages on young trees that are left (Camp, 2002).

In post fire quick and effective assessment is required. Because the burning areas should be planted as soon as possible. Therefore, the correct extraction technique must be found. The product is damaged during the fire. In order to prevent these losses the use of cable yarding was evaluated in the burnt areas. High pitched and large areas after a forest fire, cable yarding can be used for removal of the product from further damage. There are many sizes and types of cable yarders. The payload capacity, yarding distance, and lateral yarding distance of these systems help determine their suitability for different areas. For this purpose, the suitable fields has been found with using multidimensional decision-making systems and GIS.

Figure 1. The three-stage model of AHP (Saaty and Vargas, 2001).

This study used one of the most famous methods for making multi-criteria decisions called the Analytic Hierarchy Process (AHP). AHP significantly helps decision makers on multi-criteria and multi-alternative problems to finalize the decision process. The first step in the AHP is to develop a graphical representation of the problem in terms of a goal, criteria, and alternatives (Figure 1).

Firstly, the criteria that are used in the analytical hierarchy were defined. The criteria for evaluating the use of the cable yarding were determined. Literature review and field characteristics, depending on the criteria that have been identified. It is shown in Table 1.

Table 1. Criteria used in the Analytic Hierarchy Process.

CRITERIA	SYMBOL	ALTERNATIVE
Slope (%)	SL	0-10
		11-20
		21-33
		34-50
		51-..
Mainline Length (m)	L	0-300
		301-600
		601-2000
Road Density (m/ha)	R	0-15
		16-20
		21-...
Volume (m^3)	V	0-500
		501-1500
		1501-..

In large areas and situations that require quick decision making, the use of the cable yarding can be evaluated with the help of GIS. Therefore the criteria related to the maps can be created. Thus, a multidimensional assessment can be made with GIS and AHP.

2. Material and Methods

2.1 Material

Antalya, which has Mediterranean climate, is a dense area of fire frequency of maintenance. The study area was selected as the Taşağıl Antalya Regional Directorate of Forestry due to dense of forest fires. The study area is hectares 25822.6 in forest plans of Forest Service. Study was carried out after forest fire in the any area consisted of 41 forest compartments (Figure 2).

Average terrain slope was 70% with an average skidding distance of 800 m. Terrain condition on the skidding paths was rough and stony, with some rock blocks. There several cable yarding models in Turkey. In Turkey, forest skylines are various categories such as 1) short distance skyline (300 m – Koller K300), 2) middle distance skyline (600 m – URUS MIII) and 3) long distance skyline (2000 m – Gantner)(Öztürk et.al 2007).

2.2 Methods

In this study, the possibility to use cable yarding has been evaluated with analytical hierarchy process (AHP). AHP, a multi-criteria decision method, was developed by Saaty in 1976. Saaty's scale of relative importance, which has a range of values from 1 to 9, will be used. This scale is given in Table 2.

As it can be seen through Table 2, the rankings in comparisons must be as follows; 1 for equal importance, 3 for moderate, 5 for strong, 7 for very strong importance. If one element of the comparison is extremely important than the other, 9 points must be given. Other choices can be used if the decision-maker feels hesitant between two values. Through these comparisons, pairwise comparison matrices are acquired.

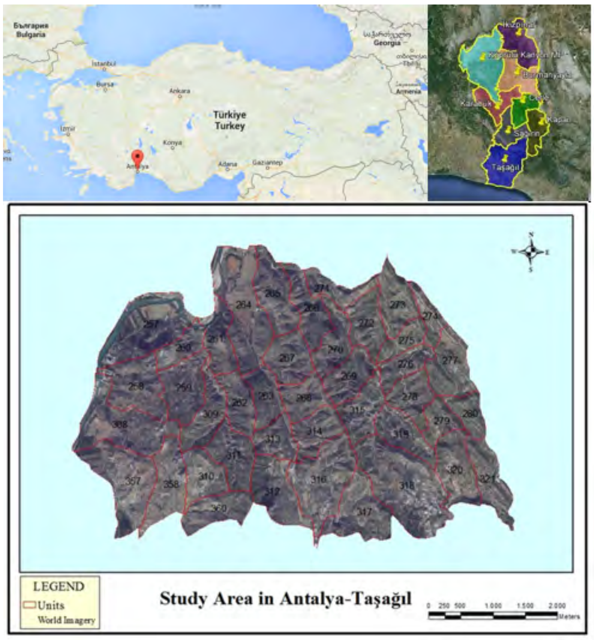

Figure 2. Study Area.

Objectives, criteria and sub-criteria have been determined, once the criteria and sub-criteria inter-binary comparison matrices were created for the determination of severity. The calculation of the weight vector involves two main steps: first, a binary comparison matrix has to be normalized; second, from the values of the normalized, weights are calculated.

The validity of the consistency was checked by calculating the consistency index and rate. The following formulas are used to calculate the overall consistency of the matrix (Shrestha et al., 2004).

Table 2. Fundamental scale used in AHP.

Definition	Importance
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate values	2, 4, 6, 8

Accordingly, if the consistency ratio (CR) is usually 10% or smaller, it is accepted that the matrix is consistent. (Saaty et al., 2003; Wind and Saaty, 1980, Özşahin, 2014).

The method in the next stages of relative weights obtained were processed to map alternative factors in the vector data format. Each of the specified criteria is shown in the form of layers in a GIS environment. GIS vector and

$$CR = \frac{CI}{RI} \tag{1}$$

$$CI = \frac{\lambda max - n}{n-1} \tag{2}$$

$$CYS = 0.38\ Slope + 0.29\ Mainline\ length + 0.21 Volume + 0.13 Road\ density \tag{3}$$

CR = Consistency Ratio
CI = Consistency Index
RI = Random Index
CYS = Suitablity of cable yarding

raster data were converted to the data type transmitted into the environment as the re-classification process is subjected to.

Each of the criteria used in the analysis are illustrated with a layer of ArcGIS software. Each criteria has been converted into raster data format that is used. Raster data in a format described in order to be subjected to a common analysis of the criteria. Each criterion reclassify was put into operation. After this process is done, the analysis is made by using a tool weighted total. Each entry criteria were basically raster data. Then the map were analyzed according to the formula 3.

According to this formula suitable sites have been identified. Grading the results of the analysis also unsuitable, suitable, very convenient were classified according to three levels.

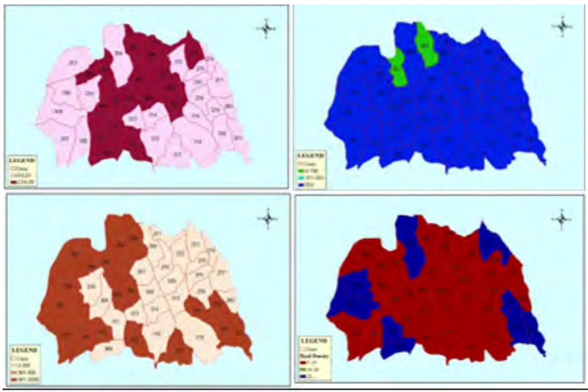

Figure 3. Maps of suitable cable yarding criteria of the study area.

3. Results

After making all the specified criteria for obtaining data on the extent of the conversion priorities/determination process it has been initiated by weight of AHP. Criteria for pairwise comparisons (optional) matrices formed, decision-making criteria were prioritized based on the reviews of the group separately. Normalization process was applied to criteria for the analysis. Weights of the factors were obtained by the use of pairwise comparison method (Table3). The following maps have been created by field properties and AHP values (Figure 3).

The result of the formula used at ArcGIS maps has been created. Maps were made mainly with overlay. The results are classified in the form of unsuitable, suitable and very suitable, and the map was created (Figure 4).

According to the results, the study area is classified into; compartment of 20 unsuitable, compartment of 10 suitable, compartment of 11 very suitable (Table 4). Also, it has been found that which cable yarding models can be used. It has been determined that ıt can be harvesting 3 compartment with Koller- K300, 2 compartment with Gantner, 16 compartment with URUS MIII. Thus, according to field characteristics and different criteria it could be determined in the suitable compartments for the cable yarding. It can be easily modified criteria and alternatives. In a short period of time with this process, terms of economic, social and ecological and the fields will be able to provide the opportunity to find the most appropriate methods.

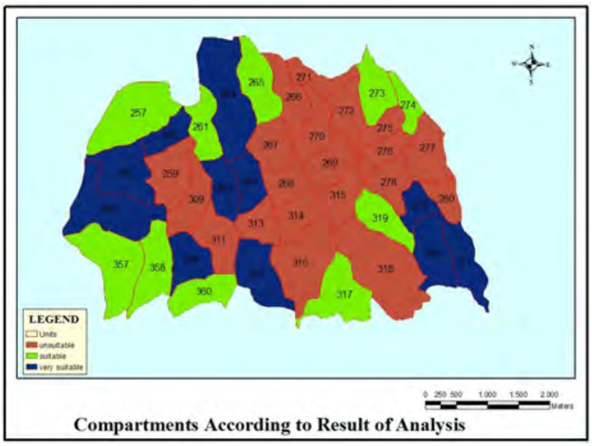

Figure 4. Map of suitable areas for using cable yarding.

According to the results, the study area is classified into; compartment of 20 unsuitable, compartment of 10 suitable, compartment of 11 very suitable. Also, it has been found that which cable yarding models can be used. It

Table 3. Relative weights of main and sub-criteria.

CRITERIA	SYMBOL	ALTERNATIVE	RELATIVE WEIGHTS	RELATIVE WEIGHTS
Slope (%)	SL	0-10	0,06	
		11-20	0,16	
		21-33	0,23	0,38
		34-50	0,26	
		51-..	0,29	
Mainline Length (m)	L	0-300	0,24	
		301-600	0,33	0,29
		601-2000	0,43	
Road Density (m/ha)	R	0-15	0,56	
		16-20	0,38	0,13
		21-...	0,06	
Volume (m^3)	V	0-500	0,18	
		501-1500	0,35	0,21
		1501-..	0,47	

has been determined that ıt can be harvesting 3 compartment with Koller- K300, 2 compartment with Gantner, 16 compartment with URUS MIII. Thus, according to field characteristics and different criteria it could be determined in the suitable compartments for the cable yarding. It can be easily modified criteria and alternatives. In a short period of time with this process, terms of economic, social and ecological and the fields will be able to provide the opportunity to find the most appropriate methods.

Table 4. Compartments according to result of analysis.

	Compartment Nr.		
	Unsuitable	Suitable	Very Suitable
	259	257	258
	266	261	260
	267	265	262
	268	273	263
	269	274	264
	270	317	279
	271	319	308
	272	357	310
	275	358	312
	276	360	320
	277		321
	278		
	280		
	309		
	311		
	313		
	314		
	315		
	316		
	318		
Total	20	10	11

4. Discussion

As a result, multi-criteria decision making method of AHP, this type of solution of the hierarchical model is very comfortable and has been used successfully. Comparison table for consistency in the valuation criteria, to recognize the possibility of control than other methods is the biggest advantage. This study, multiple criteria analysis method, and there are a lot of physical space of GIS, environmental, social and economic factors into consideration and can be implemented by using a variety of data can produce a result that is revealed

Similar efforts will be made in the future to be successful must be provided public data for standard data layers not necessarily. GIS environment to do multi-dimensional decision making studies of digital graphics that make up the data, different pads, disciplines, taking into account the will use a common data base of production.

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Yarding with a tethered balloon, a new start in the French Alps

P. Magaud[1]*, F. De Morogues[1], M. Chakroun[2]

Abstract
French National Forest Policy calls for an increase of wood mobilization to maintain a competitive forest-based industry in rural areas and meet the national objectives regarding energy. Expectations are high towards sustainability and protection of the environment (soils, water, bio-diversity . . .). The French Alps concentrate all these aspects: fragility of natural environment, important wood resources and difficulties in the logging process (steep terrain, limited accessibility. . . .). Cable cranes are used for yarding and considered a good technical solution, with fuel consumption perceived as a little drawback of this system.
In the early seventies yarding by balloon was tested in a few countries (never in France) but soon given up for economical reasons. Since then, many evolutions modified the context and now open new possibilities: new textiles for the envelope, synthetic ropes, electric motors and batteries, better knowledge on aerodynamics.
In order to test the feasibility of yarding with balloon, FCBA worked with a forest enterprise and a balloon manufacturer. A small model was built and tested on the field in July 2014. The principle is a tethered balloon, with 2 electric winches (top and down) piloting its movements. With a length of 20 m, 5 m high and 273 m^3 of Helium, the model can handle a payload up to 100 kg. Several measurements were done on energy consumption and cable tension, to determine the adequate dimensions of the final balloon and meet the defined expectations.
The test confirms the principle and feasibility of this new system. Many technical options are still open: numbers of cables and winches, automation of the balloon positioning. . . It corroborates that the weathervane profile is a relevant shape, since it enables quick move speed and ensures that the balloon always stands front of the wind.
A development project is on the way. The objective is to design a new balloon with a 2 tons payload in the next 2 years. The integration in the consortium of a high-tech mechanical society (for the electric winch construction) and a national aerodynamic research center shows the possibility for the forest sector to include innovation, modernity and technologies in harvesting solutions.

Keywords
steep terrain, yarding, tethered balloon, environment protection

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1. Introduction

French National Forest Policy calls for an increase of wood mobilization to maintain a competitive forest-based industry in rural areas and meet the national objectives regarding energy. Expectations are high towards sustainability and protection of the environment (soils, water, bio-diversity . . .). The French Alps concentrate all these aspects: fragility of natural environment, important wood resources and difficulties in the logging process (steep terrain, limited accessibility. . . .). Cable cranes are used for yarding and considered a good technical solution, with fuel consumption perceived as a little drawback of this system.

In the early seventies yarding by balloon was tested in a few countries such as the USA (Dykstra 1976, Olsen 1984) but never in France. Soon after, it was given up as a technic for economic reasons. Still, there are many advantages to logging by air: reduction of road construction and special mountainous trucks, protection of soil and trees and limitation of damages, reduction of fuel consumption. Since the 70s, many evolutions modified the context and now open new possibilities: new textiles for the envelope, synthetic ropes, electric motors and batteries, better knowledge on aerodynamics.

The objective of this project is to test the technical and economic feasibility of yarding with a tethered balloon, in order to identify the constraints for a real development. The logging company Echoforet initiated the creation of this experimental consortium. The entrepreneur's long experience in mountain environment grounded his desire to experiment yarding with a balloon as a solution for the forest protection and the wood mobilization. Collaboration with the French balloon manufacturer Airstar allowed the identification of aerial constraints in order to build a balloon which could meet the expectations of logging in mountainous conditions. FCBA participated to the project to identify and describe the technical specifications, organize the tests and measurements and finaly confront technical results with an economic analysis.

2. Expectations towards the balloon and subsequent technical specifications

2.1 Aerial conditions

The main constraint to use the balloon in mountains is the wind. Rain and snow are only a handicap for the access of the team on the logging site.

Airstar defined the limit of 40 km/h to allow the balloon to fly. This threshold is valid for all configurations, whether considering a tethered balloon or in free flight.

Weather data was collected from the whole alpine space and over the past year. Statistical analysis highlighted that more than 220 days per year systematically qualify as favorable for balloon flight with wind velocity below 40 km/h. After consulting the partner company, it was considered that a 200 days window for an annual workplan would be reasonably enough, provided that the company would modify its work schedules with its employees.

In order to work continuously, the balloon needs a storage area, where it can be quickly secured in case of high wind. This requirement was also dutifully recorded to be taken into account for future development.

2.2 Technical approach

The choice of developing a tethered balloon rather than an airship comes from the idea that it's more efficient to spread the elevating forces in the cables, rather than compensate with ballast. The final goal is for the balloon system to allow 2,000 m yarding distance, to reach stands otherwise out of reach by forest roads or cables crane. It also gives the opportunity to land the wood directly into the valley and to avoid the use of trucks on small mountain roads.

The productivity (and the cost) of the system is related to the speed of the balloon (the carriage in cable crane) and the carried load (Magaud 2014). But the maximum balloon's speed decreases with its size. Moreover, trees commonly considered mature for harvest in the French Alps are big, which would require high loading capacity, typically over 4 tons.

Finally, the objective of a 2 tones payload is understood to be a good compromise between all these criteria. To achieve these objectives, the following specifications have been chosen

- 50 m length and 17 m diameter balloon, full of 4000 m^3 helium;
- Average speed of the balloon, with payload: 10 m/s
- Elevation capacity: 2 tons, and payload: 1,8 tons

Moreover, the use of the lift of the balloon during yarding will reduce the energy consumption. This is currently considered as a motivation to try and use electric energy as a source, a possibility worth testing in a future development phase.

Figure 1. The prototype, 17 m length, in the test area.

3. Material and Methods

Investigations on the balloon-based system were organized in different steps:

- Specifications of the system were described
- A small-scale system was designed and built for test purposes
- Performance measurement were collected during field tests
- A preliminary economic analysis was run

3.1 Feasibility and conception of the logging system

To allow the first tests, a small balloon containing 273 m^3 Helium was built (17 m long, 6 m diameter) for a payload of about 100 kg.

Attached by synthetic ropes, the balloon can move with winches (T1 and T2 on Fig 2 and 3, fixed on anchorages) located on the ground. Several configuration have been thought and tested in the field with this small model, to identify the good solution: balloon attached directly at the winches (Fig 2.), or attached at a pulley moving on a zipline (fixed on the ground, Fig 3.).

3.2 Performance measurements during field trials

One week test was conducted in July 2014 on a ski slope (40 % slope), along a 80 m line between the 2 anchorages and winches. A small log of 80 kg was hooked to the balloon. Test sheets were prepared to assess and measure different configurations.

The main objective of the tests was to identify the best performing configuration for the balloon to move quickly,

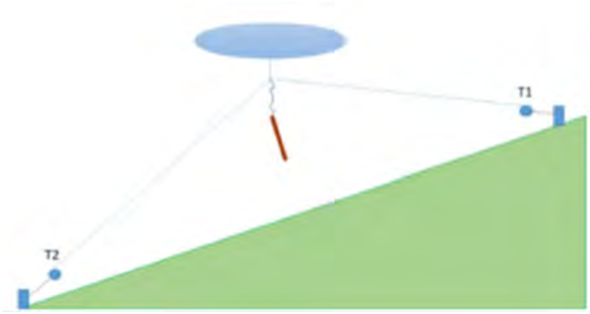

Figure 2. The balloon is attached at 2 winches.

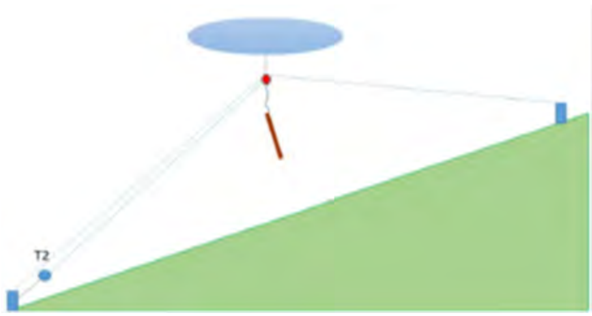

Figure 3. The balloon is attached at a pulley, moving on a zipline by a bottom winch.

while minimizing the tension in the ropes and the energy consumption. The performance of the balloon was not measured, but observed by the aerial experts of Airstar and confirmed with a camera, such as lateral moves, reaction and position to the wind, speed and aerodynamics.

For measuring tension in ropes, dynamometers were installed, allowing measurements in the various configurations of the tests.

Another objective was to determine the power required by winches enabling the movement of the balloon. Two electric winches were selected and instrumented to measure the instantaneous energy consumption. The constraint of these electric winches was their slow speed (0,17 m/s), which prevents from moving the balloon at the higher expected speed (10 m/s).

4. Results and discussion

4.1 Tensions and performances

The performance of the balloon was judged as very good, and Airstar was satisfied of the shape and the reaction of the balloon to the wind. A small test with high speed (40 km/h, without the winches, the balloon was moved by a quad) confirms the good reaction of the balloon which always comes back quickly in position in front of the wind. Afterwards and to continue the search of the optimal design, a new rigid tail shape was tested in a new trial in 2015, but the results were not so good.

Concerning the energy consumption, there was a big difference between the 2 configurations (see fig 2 and 3). The zipline installation reduced the energy consumption of the winches by close to 50 %, with or without payload (see table 4). The results confirm that the heavier the payload, the lesser the consumption, because the system is close to the static balance.

The tensions in the ropes have been measured by dynamometers. They decrease with height of the balloon, which is also coherent (see figure 5). In practice, this will mean that attention should be paid to maintain the balloon at the right altitude to minimize the tensions in the cables. The measures also show that the tensions in the ropes are pretty low (less than 500 kg, while the tension of the main line in current cable crane is about 15 tons), and allow the use of synthetic rope of small diameter (6 mm for the small prototype). Such replacement would reduce the weight of the global system.

4.2 Results from the preliminary economic simulation

The goal of the economic simulation is to see if yarding with a balloon is economically possible, particularly in comparison to the nearest operating system: the cable crane. The simulation was focussed on the 2 tons payload target balloon (4000 m^3 of Helium), with the following hypothesis:

- Cost of the balloon with all equipment: 2 000 000 €, with financial amortization of 20 years for the winches, and 10 years for the envelope.
- 180 days of annual a utilization, for a team of 2,5 operators.

The foreseen productivity is quite high (108 m3/day and 7 cycles/h), but not so far from big cable crane's usual productivities in production phase (with a 5 or 6 tons payload). Moreover, the installation of the line for the balloon is very quick, because no intermediate support needs to be built.

The economic balance depends mainly on the productivity (payload, number of cycles/h) and the operating cost of the system. Figure 6 displays these main parameters, and shows that for a specific cost of the balloon (€ 2,000,000), the yarding price depends on the number of cycles.

To be competitive with cable crane (around 35 €/m^3, without tree felling), a minimum of 8 cycles/hour is needed (14,4 m^3 h^{-1}presence). Under this productivity, we have to find other arguments (protection of biodiversity, alternative for road construction...) to use balloon for yarding, in the local forest economy. The cost of the balloon construction is also uncertain, and a significant reduction would place the balloon as an economically viable solution in many technical configurations.

5. Conclusion and perspectives

The balloon attached to a zipline with a pulley seems to be the best technical operating configuration: low tensions in the synthetic ropes, low energy consumption, good profile and performance of the balloon....

The economic model is tight and complex, but shows the possible viability of the system. A particular attention must be focused on the construction cost of the balloon, which must meet the technical requirements, especially concerning the high speed of 10 m/s.

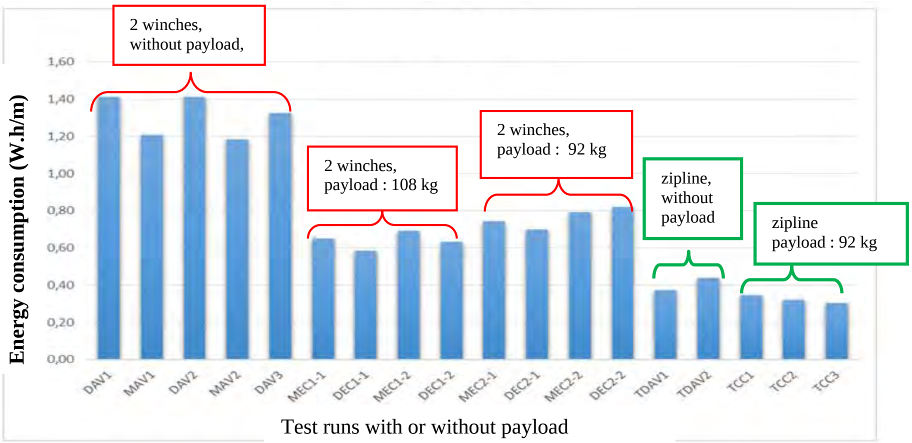

Figure 4. Energy consumption in 2 configurations, with or without payload.

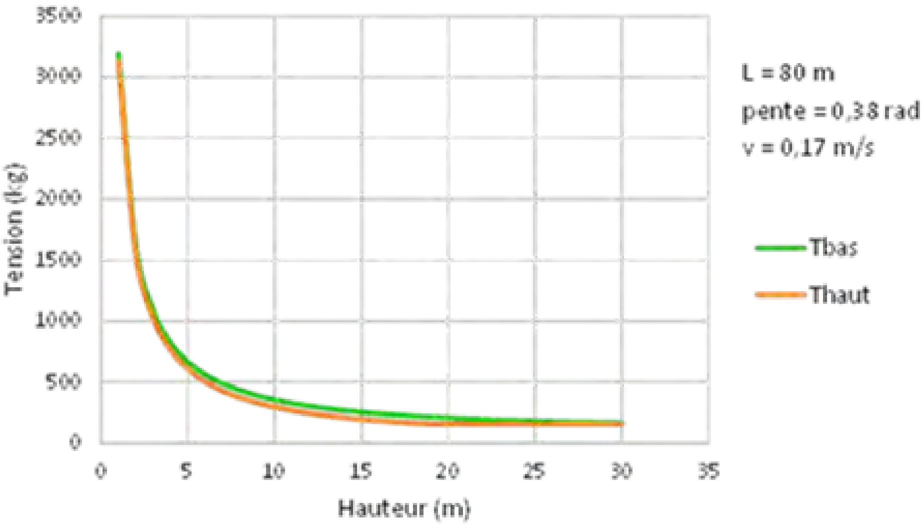

Figure 5. Tensions in the ropes depending of the high of the balloon.

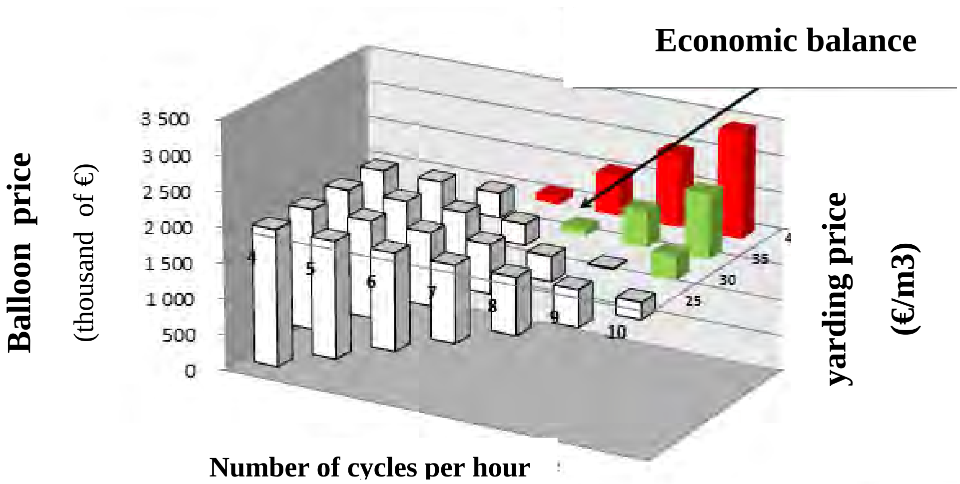

Figure 6. Economic balance depending on the productivity and the cost of the balloon.

These encouraging results have allowed the consortium to continue its investigations to increase knowledge and to consider the development of a larger balloon. A new project will start in 2016, based on national funding. Its main objective will be to build an operational balloon of 2 tons capacity by 2018.

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Steep-slope timber-harvesting research in Western Canada

D. Amishev*, J. Hunt

Abstract
In 2014 FPInnovations launched a Steep-Slope Initiative to address timber-harvesting challenges on steep terrain. The related challenges are: safety, costs, timber supply, regulatory compliance, environmental impacts, availability of skilled labour, investment in equipment, and planning. The forest industry in western Canada is shifting more of its operations into steep terrain at a time when much of the skilled labour force is retiring from the workforce. Twenty-four percent, or 18 million m^3 of the allowable annual cut in Canada's westernmost province of British Columbia is on slopes greater than 35%. The main goals of the Steep-Slope Initiative are to improve worker safety, increase the operating margin for timber harvested on steep slopes, and increase access to economical and sustainable fibre. The 5-year research program includes assessments of ground-based, cable, and helicopter harvesting systems, as well as the development of innovative trucking and road-building techniques. The introduction of European and New Zealand winch-assist equipment will be monitored and assessed. Comparisons of cut-to-length machines, hoe-forwarding, grapple processing, and six-wheeled skidders with conventional alternatives are planned. New yarders, small mobile yarders, grapple cameras, and GPS systems will be evaluated. Further work will continue on computer modelling of machine stability based on tilt-table testing. An overview of FPInnovations' Steep-Slope Initiative in western Canada and results are presented.

Keywords
steep-slopes, harvesting, steep terrain, winch-assist

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1. Introduction

Harvesting timber safely, sustainably, and economically from steep slopes is among the top priorities of the forest industry in western Canada. In response to the demand from forest companies, FPInnovations and its Forest Operations Research group are taking a lead role in finding solutions to the steep-slope challenges and in improving the overall viability of steep-slope harvesting in western Canada.

1.1 Challenges

The development, introduction, and implementation of new equipment for steep-slope harvesting will need to address the issues of safety, comfort, acceptability, and sustainability within this challenging operating environment. The public scrutiny of steep-slope harvesting is magnified because it is highly visible on the landscape and because of the perceived environmental risks (e.g., landslides, erosion). It is necessary to ensure that steep-slope operations are sustainable.

Attracting new workers into the forest industry and getting them trained on new types of equipment and systems may be one of the biggest challenges in implementing steep-slope solutions. The key components to operating equipment safely, efficiently, and productively on steep slopes are to:

- ensure proper work procedures are documented and implemented,
- ensure that workers are adequately trained, and
- ensure harvest plans are appropriate to the site conditions.

Another challenge will be the compliance to the various regulatory environments in order to get new equipment approved for operational use. Harvesting and road-building operations on steep slopes are tightly controlled under a variety of regulations to ensure maximum safety and minimize negative environmental impacts. In British Columbia, for example, regulations set a maximum slope where mechanized equipment is allowed to operate unless a manufacturer's limit for steep-slope operations is specified or a site-specific risk assessment is conducted.

1.2 Safety

According to WorkSafeBC's statistics for 2013, injury rates associated with manual falling are more than 10 times greater than those associated with mechanical falling, and half the injury rate for all forestry work (Table 1). Injury claims paid out to manual fallers were 20 times greater than for mechanized workers. Approximately one out of twelve fallers sustained serious injury that year. Although statistics specific to incidents on steep slopes are not readily available, harvesting on steep slopes is universally understood to be more dangerous than working on gentle terrain. Mechanization that removes workers from hazardous hillsides and

Table 1. Accident statistics: timber-harvesting-related incidents in British Columbia, 2013.

Work category	Person Years Worked	Injury rate (%)	Serious injury rate [a] (%)	Claims paid (millions of $)
Manual tree falling and bucking	490	26.8	8.4	9.3
Mechanized tree falling	483	1.9	0.6	0.4
All forestry work	16 215	5.2	1.3	44.3

[a] In 2013, Serious Injury was defined as >30-days lost time.
The current definition is >60 days lost time. (Source: WorkSafeBC)

Table 2. Distribution of AAC in British Columbia by slope class.

Area	Portion of AAC, by slope class				
	> 35% slope (000 m^3)	(%)	35 to 50% slope (000 m^3)	>50% slope (m^3)	All classes (000 m^3)
Entire province	18 276	24	8 972	9 304	76 990
Coastal B.C.	10 098	56	3 870	6 228	18 079
Interior B.C.	8 177	14	5 101	3 076	58 911

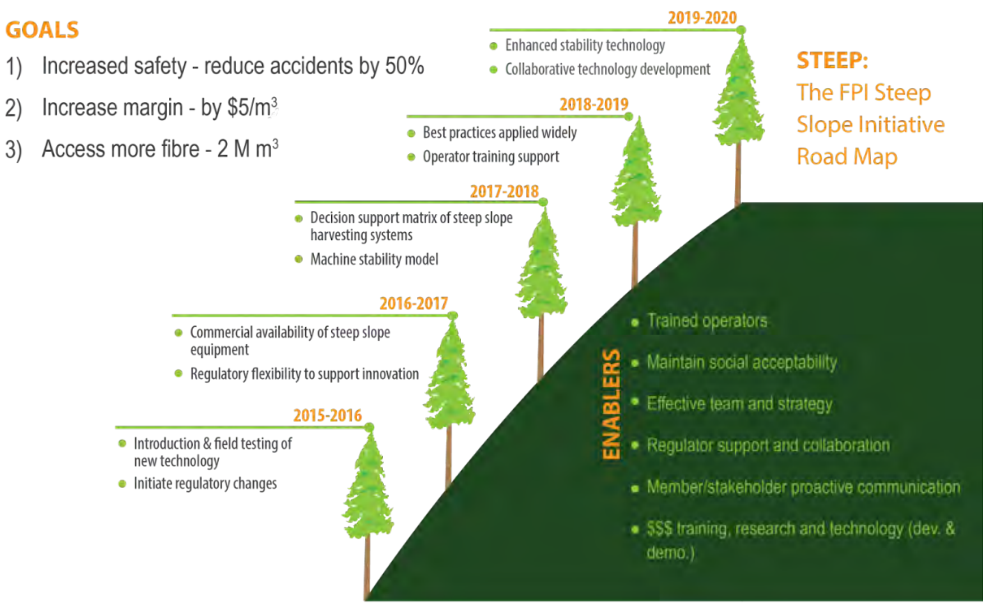

Figure 1. Representation of FPInnovations' Steep-Slope Initiative Road Map.

protects them in machine cabs is a main focus for improving safety.

1.3 Volumes/Slope Class

Steep slopes contain a significant pool of fibre in western Canada. Analysis of the British Columbia Timber Harvest Land Base by slope class indicates that 24% of the AAC occurs on slopes >35% (Table 2), most of it is on the coast and in the southern interior timber supply areas (TSAs) (Figure 1).

Harvesting costs on steep terrain are typically higher due to the use of cable yarding systems, higher fuel consumption and lower productivity relative to flat ground. In order to sustain fibre costs for mills, harvesting costs need to be reduced or the value of timber utilized should be increased to offset the additional cost of operating in steep terrain With 18 million m^3 of BC's AAC on slopes >35%, a cost saving of \$5/m^3 could yield a benefit of \$90 million in addition to lower safety claims.

1.4 Steep Slope Initiative Road Map

In response to the demand from its members, FPInnovations and its Forest Operations Research group are taking a lead role in finding solutions to the steep-slope challenges and in improving the overall the viability of steep-slope harvesting in western Canada. The Steep-Slope Initiative is a 5-year operational research and development plan that pursues transformative, innovative harvesting technologies to give the forest industry safe, economic, and sustainable access to the substantial pool of fibre on steep slopes in western Canada.

The Initiative is engaging forest industry members, equipment manufacturers and distributors, regulators, and other stakeholders in building a common vision and strategy, including high-level goals, outcomes, proposed projects, milestones, and a process to effectively communicate progress and results.

Two committees have been formed to help guide the initiative and facilitate knowledge transfer, an industry-led steering committee and a manufacturer working group..

FPInnovations will strive to attain three high-level goals through the Steep-Slope Initiative in western Canada (Figure 1).

1. Mitigate risks to worker safety on steep slopes (target – reduce accidents by 50
2. Increase and maximize operating margins of steep-slope harvesting (target – increase margins by \$5/m^3)
3. Increase the steep-slope fibre pool economically and sustainably available (target – extra 2 million m^3).

2. Research Program

A major component of the research program under FPInnovations' Steep Slope Initiative is evaluation of new equipment, both locally and internationally. Winch-assist technology for felling, bunching and extracting on steep terrain is a substantial part of these evaluations. Other projects are briefly described here.

Figure 2. Comparative LTRs at 35, 40 and 50% for tilting and non-tilting feller-bunchers for comparable test positions.

2.1 Stability Modeling

In an effort to quantify machine stability on steep slopes, tilt-table testing of two types of feller bunchers was conducted in late 2013. The goal was to develop a model to realistically assess machine stability. This would allow designers and planners to look at impacts of machine design and operation strategies on machine performance and safety. In 2011, FPInnovations developed a test procedure for evaluating stability of harvesting equipment on steep slopes (Boswell & Parker, 2011). This procedure was field-tested in 2013 using two types of feller-bunchers (Figure 2) (Boswell & Parker, 2015).

The tilt-table testing used the Load Transfer Ratio (LTR) as a measure of stability. Table 3 shows the results of the LTRs for different machine test positions at 35, 40 and 50% slope, which correspond to WorkSafeBC‘s slope limits for different types of equipment. The results showed that the tilting machine was generally able to achieve better stability than the conventional feller-buncher (Parker 2015).

Following these static tilt-table tests, FPInnovations developed a model employing Mathworks Simulink using the test results from the tilting feller buncher and machine specifications provided by manufacturer. The model was used to estimate LTR characteristics using the test data gathered from the tilt table testing. Individual motions can be prescribed to look at dynamic characteristics in the future.

Winch-Assist Technology A 2015 survey by FPInnovations of nine BC forest companies indicated a demand

Table 3. Distribution of AAC in British Columbia by slope class.

	Position descriptions								Non-tilting machine			Tilting machine		
	position	track angle	boom angle	reach	pay-load	head ht	tilt forward	tilt side	LTR @ 35% slope	LTR @ 40% slope	LTR @ 50% slope	LTR @ 35% slope	LTR @ 40% slope	LTR @ 50% slope
No payload	**5b**	0	0	max	0	low	0	0	-0.12	-0.05	0.09	-0.29	-0.22	-0.10
0 track angle, max reach	**2**	0	45	max	0	low	max	0	0.24	0.32	0.47	-0.02	0.05	0.18
No payload	**5a**	0	0	min	0	low	max	0	0.49	0.57	0.72	-0.16	-0.07	0.12
0 track angle, min reach	**1**	0	45	min	0	low	max	0	0.53	0.60	0.75	0.11	0.19	0.35
No payload	**12**	90	0	min	0	mix	0	max	0.31	0.36	0.45	0.11	0.16	0.26
0 track angle	**9**	90	90	mid	0	mix	0	0	1.00	1.00	1.00	1.00	1.00	1.00
No payload, 180 track	**13**	180	0	min	0	high	0	0	0.86	0.93	1.00	0.75	0.82	0.95
50 % payload	**5**	0	0	min	50	low	max	0	0.05	0.13	0.30	-0.22	-0.14	0.01
0 track angle	**3**	0	45	min	50	low	max	0	0.14	0.22	0.38	-0.07	0.01	0.15
rotate through the	**6**	0	90	min	50	low	max	0	0.62	0.70	0.85	0.37	0.44	0.57
boom angles	**7**	0	135	min	50	mix	max	0	1.00	1.00	1.00	0.62	0.68	0.81
	8	0	180	min	50	low	max	0	1.00	1.00	1.00	0.98	1.00	1.00
50 % payload, 45 track	**10**	45	90	min	50	high	0	max	0.70	0.74	0.81	0.67	0.71	0.77

Footnotes

red indicates the a difference between the plan and actual tests

mix indicates one machine had to be tested with the load height higher than 0.5 m

high indicates both machine had to be tested with load heights higher than 0.5 m

LTR 0.00 - 0.29	good stability
LTR 0.30 - 0.59	moderate stability
LTR 0.60 - 0.89	marginal stability
LTR 0.90 - 1.00	unstable

(LTR = load transfer ratio. Higher LTR = less stability.)

(LTR of 1 = upset condition)

for 155 winch-assist machines in the next five years. There are eight winch-assist systems from New Zealand, Europe, US and BC that have recently been introduced or are expected to start in the next year. FPInnovations will assist in adapting this technology and the development of safe procedures, benchmark studies of cost and productivity as well as assessments of safety and environmental impacts.

FPInnovations conducted a study of the Remote Operated Bulldozer (ROB) with a tethered feller-buncher (Figure 3) in Northland, New Zealand in July 2015. Mechanized falling was achieved on slopes >100%. A report is in progress and preliminary results suggest that harvesting crews achieved a productivity increase of approximately 20% with the ROB compared with conventional manual falling and yarding. One ROB is on Vancouver Island and a productivity assessment is planned.

There is a ClimbMAX machine operating in the BC Interior and a second one on the Coast. An assessment is planned.

A Ponsse cut-to-length (CTL) system with a Herzog winch is working in thinning operations in Oregon (Figure 5). An FPInnovations productivity assessment in Oregon is planned in conjunction with Oregon State University. Although wheeled harvesters and forwarders are not common in BC operations, a Ponsse forwarder and John Deere harvester with Herzog winches are reported to be starting in BC next year.

A John Deere harvester and forwarder equipped with winches manufactured by Haas (Figure 6) have just arrived in Interior BC. There are many of these machines operating in South America. An FPInnovations assessment is planned.

An HSM clam-bunk harvester/forwarder equipped with a Timber Max directional felling head and an HSM winch (Figure 7) will be arriving to the Interior BC this year. It will be used to extract long logs by first felling the trees while winch-assisted and in the second pass will skid downhill dragging logs in the clam-bunk. It would have a lower capital cost than a harvester and forwarder combination. An FPInnovations assessment is planned.

Summit Attachments and Machinery LLC, based in Castle Rock, Washington, recently designed and developed a unique prototype winch-assist felling system. FPInnovations observed the system in April 2015 while it was undergoing early operational testing at a site near Portland, Oregon (Dyson 2015). The main components of the system are a tower with winches mounted on Kobelco 350 excavator and a Tigercat LS855C shovel logger felling machine (Figure 8). The Kobelco moves the tower and powers the winches. The tower system serves two functions. It can act as a winch-assist system for the felling machine or as a yarder. The main winch is controlled from the Kobelco or remotely from the Tigercat. An FPInnovations assessment is planned.

2.2 Electronic Self-Releasing Chokers

Electronic chokers offer potential increases in productivity as they can be unhooked remotely and faster than manually unhooking. There are also safety benefits from avoiding manual unhooking. The productivity of two electronic radio-controlled choker systems - Fortronics and Ludwig

Figure 3. The ROB base bulldozer (top), cable-assisted feller-buncher (middle), slope accessibility (bottom).

Figure 4. The ClimbMAX machine in British Columbia (top), operating on steeper slope (bottom).

Figure 5. Ponsse harvester with Alpine winch (top), and forwarder with winch (bottom).

Figure 6. John Deere harvester with Haas winch (top), and forwarder with winch (bottom).

Figure 7. HSM feller-clambunk forwarder.

Figure 8. The Summit winch-assist system. Tower and Kobelco base machine (top) and Tigercat LS855C with directional felling head (bottom).

(Figure 9) - was compared to conventional chokers at a site in the southern B.C. interior. A Madill 071 yarder rigged with a scab skyline yarded the stems. Three 6.1 m long cable chokers were used in each system, set by 2 choker setters. Compared to conventional chokers, at 60 m yarding distance, productivity increased by 8% when using the Ludwig chokers and by 3.5% with the Fortronic chokers. The higher yarding productivity increase with the Ludwig chokers was due to faster hook-up and unhook times. Faster hook-up time was attributed to their lighter weight and ease in setting.

Figure 10 shows yarding productivity (m^3/PMH) of the 3 choker systems. As distance increases a greater proportion of cycle time is spent on outhaul and inhaul phases and productivity is less affected by choker hook-up and unhook time. The Fortronic chokers have been used by the contractor for 9 months and have performed reliably with only minor maintenance. This trial was the first time the contractor had used the Ludwig chokers.

2.3 Pierce Grapple Processor

FPInnovations started a stud y of the Pierce Grapple Processor in on Vancouver Island (Figure 11). The grapple processor can process, load, hoe-forward, and buck with the same head. This may decrease the landing area required on steep terrain. Early observations indicate it can effectively manage large piece sizes and log decks in spatially constrained areas. Future assessments are planned with a variety of harvesting systems.

2.4 Hoe-Forwarding

Harvesting on steep terrain in the Alberta Foothills has been reduced due to high costs, soil disturbance constraints and lack of suitable techniques to operate within the 5% maximum soil disturbance limits. FPInnovations evaluated ground-based alternatives to costly cable extraction that still met ground disturbance standards. These methods were

Figure 9. Fortronics (top) and Ludwig (bottom) choker bells.

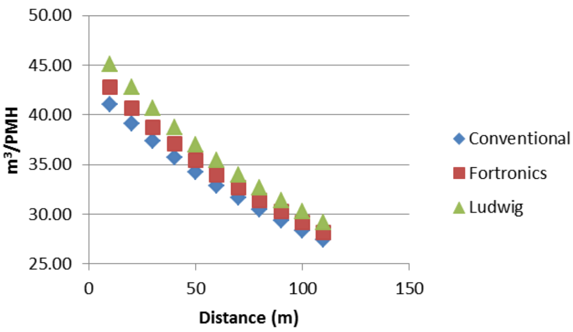

Figure 10. Yarding productivity vs distance of the three choker systems studied.

Figure 11. The Pierce Grapple Processor.

Figure 12. Yoader (top) and backspar (bottom) used in this operation.

Figure 13. Helicopter logging.

measured over a range of slope classes and the fuel intensity for each machine was also measured.

2.5 Yoaders

Yoaders are loaders that are modified to yard logs, but can also perform other tasks such as loading or hoe forwarding (Figure 12). Yoaders provide several advantages over larger conventional grapple yarders. Set up and demobilisation is faster as there are no guylines. They have lower capital and operating costs. They can reach areas not viable for grapple yarding, and they are adaptable for hoe forwarding or loading.

FPInnovations conducted a short term productivity study on a yoader operating on the B.C. coast (Dyson 2015). Productivity averaged 12.7 m^3/PMH. The average yarding distance was 52 m and average turn volume was 2.1 m^3.

2.6 Planning Tools (Heli-logging)

Helicopter logging's popularity waned during the last decade due to the market downturn when industry focused on lower cost logging methods to remain competitive. Interest in helicopter logging has increased in recent years. In the past, FERIC did extensive work developing cost and productivity information for helicopter logging but much of this information is now outdated. Industry has requested current cost and productivity information to plan and execute efficient and cost-effective helicopter logging operations as many young planners working in the industry lack heli-logging experience or background. FPInnovations is updating its helicopter logging costs database and developing a planning tool and optimization model to assist companies implement heli-logging operations more effectively (Figure 13).

2.7 Steep Slope Market Analysis and Technology Development

FPInnovations is in the process of assessing the market for steep slope innovative equipment such as winch-assist machines, grapple cameras, yarder alternatives, etc, in western Canada. This work builds on an earlier survey of nine major BC companies which showed that over the next 5 years there is demand for more than 150 winch-assist machines. FPInnovations will work with manufacturers, contractors and forest companies to analyze the issues and needs specific to western Canada, and form partnerships to assist with technology development for steep terrain harvesting.

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Topic 12

Poster session

Investigation of job satisfaction on forest logging groups: Case study North of Iran

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Abstract
In this study the degree of satisfaction of workers in one of the logging companies of forests in northern Iran was assessed using the Minnesota Satisfaction Questionnaire. The reliability of the questionnaire was confirmed using Cronbach's alpha (α= 0.95). Pearson correlation test results showed that the indices of income, career advancement, communication among staff and the physical conditions of the workplace are correlated with job satisfaction. The relative average was 3 being calculated based on Likert scale. The indices of income with an average of 2.26 and physical conditions of the workplace with an average of 1.9 had the lowest satisfaction among workers. Chainsaw operators had the lowest and the managers had the highest job satisfaction. Generally, the employees are not satisfied with their jobs. Paying attention to employees' income and providing appropriate welfare facilities in the workplace by managers have a high impact on increasing job satisfaction.

Keywords
workers, logging companies, degree of satisfaction, Minnesota Satisfaction Questionnaire

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1. Introduction

Job is one of the most important aspects of people's lives and an important part of their life is at their workplace (Bakan and Buyukbese, 2013). Job satisfaction is a frequently used construct studied in the organizational psychology, being considered to have a direct influence on the working quality of the employees' of an organization (Mihalcea, 2013). Job satisfaction has a significant impact on the tendency of people to have a job. Social relations are also affected by job satisfaction of workers (Babayi nadinloyi et al, 2013; Mohammad et al. 2011). Many scholars and unskilled people believe that a causal relationship exists between job satisfaction and worker's performance (Bowling, 2007). Various studies show that organizational, environmental, personal factors and the nature of job have some effects on job satisfaction (Tabatabaei et al, 2013). Forestry workers have lower job satisfaction, and less subjective physical symptoms and psychological complaints (Ohta et al, 1998). Activities such as timber harvesting operations are known difficult and dangerous occupations and they have a combination of natural and physical hazards for health and safety of workers (Özden et al, 2011).Topographic conditions, variable weather conditions, remote and difficult to reach areas of work, dangerous animals, nutritional status and several other factors, have caused that workforce today have less attention to the commercial forests of northern part of Iran. Large companies active in this field have problem in providing skilled and young manpower for occupations such as chainsaw operator, skidder driver, choker man and unskilled workers. Workers job satisfaction strengthens the structure of institutions active in this field, and causes higher quality of logging and reduces damage to forests. Lack of job satisfaction among forest workers reduces productivity and increase costs of operation and work accidents. Wan and Leightley (2006) their investigation they concluded that the employment income has a significant effect on job satisfaction so that people with lower incomes are less satisfied with their jobs. It is most likely that forest workers leave their job to find a higher income. Yurdakol Erol (2011) after reviewing the comments of 262 forestry workers in Turkey who 13% were woodsmen and 32% of them was technical staff, concluded that technical staff have high expectations associated with performance benchmarking and improving their equipment so as to improve motivation and work ethic by it. Despite the problems related to wage conditions, they are satisfied with their jobs. Gandaseca et al (2001) in a research on occupational health and safety on workers of cabling timber system in the forests of Turkey after questionnaires were filled out by 113 cases, concluded that 60 people were satisfied and 53 of them were dissatisfied with their jobs. The reasons for the workers dissatisfaction include wage problems, job difficulty and long distance to work. Karabiyik and Korumaz (2014) in their study examined the relationship between job satisfaction and feeling of being effective in teachers in Turkey. The results showed that there is a direct relationship between these two factors.

2. Material and Methods

The population of the research includes the staff of one of the logging companies in forests of northern Iran. A total of 504 people are working in the forestry sector which 187 of them are operational staff. Table 1 specifies the statistics of human power according to sector and employment.

The most common tool that can measure the level of job satisfaction is the questionnaire called Minnesota satisfaction (MSQ) (Eyupoglua and Saner 2009; Scarpello and Campbel, 1983). Hooman (2002) validated this questionnaire in Iran. In this questionnaire respondents rate their satisfaction by Likert scale which is usually consisted of 5 parts (Totally agree - agree - disagree - totally disagree) and options can be changed based on the purpose and method of the study. Each part is given a score of one to five, and then the score is calculated for each statement. In this study, using Minnesota Satisfaction questionnaire, a questionnaire regarding seven aspects (income, job type, career advancement, and communication among staff, management style and the physical conditions of the workplace) and consisting 21 questions was developed and distributed among the population of the study. The reliability of the questionnaire was calculated using Cronbach's alpha coefficient of determination (Equation 1) (Cronbach, 1951).

$$\alpha = \frac{k\bar{C}}{\bar{V} + (k-1)\bar{C}} \tag{1}$$

k = *Number of questions*
$\bar{C}$ = *Average covariance between questions*
$\bar{V}$ = *Questions variance*

This study investigates the employees' satisfaction regarding the different dimensions of their job such as income, job type, and welfare facilities, organizational atmosphere, physical conditions of workplace, management style and opportunities for advancement in the workplace. According to the average mean of Likert scale which is 3, for indices with higher average, there is job satisfaction and indices with lower average show lower level of job satisfaction. To examine the relationship between each of the indices of job satisfaction, Pearson correlation test was used.

3. Results

First the reliability of the questionnaire was calculated. According to Cronbach's alpha coefficient, the reliability of the questionnaire was appropriate.

$$\alpha = \frac{21\ 0.33}{0.7 + (21-1)\,0.33} = 0.95 \tag{2}$$

The 120 questionnaires were distributed which 108 of them were filled out and returned. Thus, the response rate was 90%. Information gathered through questionnaires, was analyzed by «SPSS» software. To analyze the data, descriptive statistics such as frequency, mean and standard deviation were used. In addition to questions related to staff satisfaction, there were some demographic questions in the questionnaire. Data gathered through questionnaires were then coded and analyzed. Table 2 shows the results for demographic data.

Among people who were working in forests logging, 98% were male workers and only 2% were female workers who were doing office work. Regarding age classes, the most frequent class with 55% was the class of (30-49) and the lowest frequency was the class of (18-29) with 19%. In regard to employment, 67% of people have temporary contracts and do not have enough job security. Education status of workers shows that most of the people have the least education and people with higher education are active in management and undergraduate affairs. With respect to income, 67% of staff gets paid between 175-375 Euros per month. Tables 3, 4 and 5 show the results related to questionnaire's indices. The minimum average for relative satisfaction is 3 based on Likert Scale.

The results in Table 3 shows that the average of proportion of income with ability and also the proportion with other employees is lower than average and there's no sufficient satisfaction. Among the questions related to job, lowest satisfaction is related to independence and freedom which is averaging 1.7 and only workers are satisfied with the proportion of their job and their abilities. The presence of independence in work to the borders of responsibility can lead to employees' self-esteem. Workers are not satisfied with their job's social status and 67% of them are temporarily working, they do not have a permanent contract and are not satisfied with current job security. Workers are also satisfied with the distribution of welfare facilities (3.36>3).

According to Table 4, the average for questions related to opportunities for career advancement is lower than average and workers are not satisfied. The possibility of progress in job has an important role in job motivation. The average for questions related to spirit of cooperation and a sense of integrity and trust with employees is higher than average and staff are satisfied with their relationships.

According to Table 5, Employees have little satisfaction of having a role in decision making (2.59 <3) but they are satisfied enough with the managers' style of communication with staff and obtaining the necessary information from them. The least satisfaction which is 1.6 is for physical conditions of the workplace. They also don't have satisfaction about the right equipment and heating and cooling of their workplace. Forest environments due to variable weather conditions and high temperatures in summer and cold weather in winter creates difficult conditions for working people there. In general, and according to the indices used in the questionnaire included seven questions and given answers by employees, the level of satisfaction for each of the parameters is shown in Table 6.

The Pearson correlation test results in table 7 show that while P-value for the indices of income, career advancement, communication among staff and the physical conditions of the workplace were less than 0.05.Thus, these indicators are significantly correlated with job satisfaction. Pearson coefficient is positive so the relationship is direct. The highest mean is related to the physical conditions of the workplace. In two indices job type and management style (p-value >0.05) the correlation between these two indices and job satisfaction is not significant. Factors of Job type and management style may be correlated with job satisfac-

Table 1. Staff statistics based on employment type and activity type.

Employment type	Activity type: Permanent	Temporary	Daily
Road Maintenance and Construction	1	7	6
logging	38	82	21
forestry	0	4	4
Repairs	0	0	3
Engineering and planning	15	14	2
Total	54	104	36

Table 2. Some demographic information of participants group.

Feature		Number	%
Gender	Male	106	98
	Female	2	2
Age classes	18-29	21	19
	30-49	60	55
	>50	27	26
Work status	Temporary	72	67
	Permanent	36	33
Education	≤ Diploma	60	55
	Licentiate	34	31
	>Licentiate	14	14
Income (Monthly)	≤ 175€	25	24
	176-375€	73	67
	>375	10	9

Table 3. Statistics about the income and job type.

	Strongly agree		Agree		Neither agree		Disagree		Strongly disagree		Average	SD
	N	%	N	%	N	%	N	%	N	%		
Proportionality of income and ability	5	14	17	18	10	9	45	25	30	45	2.28	0.66
Proportion of income with others	10	9	14	13	21	19	11	10	52	49	2.25	0.72
Proportion of job and ability	39	36	20	19	6	6	17	16	26	23	3.25	0.5
Feel satisfied with result of work	11	10	23	21	14	13	11	10	50	46	2.41	0.68
Enjoy working	5	5	3	3	7	6	8	7	85	79	1.47	0.14
Independence and freedom at work	4	4	8	7	8	7	20	19	68	63	1.7	0.11
Satisfaction with job social status	38	35	11	10	6	6	12	11	41	38	2.93	0.7
Job security	40	37	3	3	2	2	15	14	48	44	2.74	0.87
Justly distribution of welfare facilities	48	44	10	9	13	12	7	6	30	29	3.36	0.71

Table 4. Statistics about career advancement and communication among staff.

	Strongly agree		Agree		Neither agree		Disagree		Strongly disagree		Average	SD
	N	%	N	%	N	%	N	%	N	%		
Proportionality of Advancement and merit	2	2	3	3	5	5	8	7	90	83	1.32	0.15
Possibility of potential appearing	3	3	4	4	7	6	8	7	86	80	1.42	0.15
Equal Opportunity for advancement	22	20	10	90	6	6	10	90	60	54	2.29	0.91
spirit of cooperation	31	29	40	37	4	4	20	19	13	14	3.51	0.58
Sense of integrity and trust	17	16	34	31	18	17	5	5	32	31	3.17	0.5

Table 5. Statistics about management style and the physical conditions of the workplace.

	Strongly agree		Agree		Neither agree		Disagree		Strongly disagree		Average	SD
	N	%	N	%	N	%	N	%	N	%		
Written communication between management and staff	39	36	18	17	6	6	12	11	33	30	3.37	0.56
Role in decision making	28	26	6	6	11	10	20	19	43	39	2.59	0.59
Staff information and managers decision making	69	65	7	6	11	10	11	10	10	9	4.05	0.11
Empathy between managers and Staff	9	8	13	12	3	3	6	6	76	71	1.79	0.12
The physical conditions of the workplace	10	9	3	3	5	5	6	6	84	77	1.6	0.14
Appropriate equipment and decoration	20	19	2	2	3	3	26	24	58	52	2.1	0.9
Heating and Cooling workplace	14	13	6	6	8	7	3	3	77	61	2.01	0.1

Table 6. Average of indices according to Likert scale.

1	Income	2.26
2	Job type	2.55
3	Career Advancement	1.67
4	Communication among staff	3.34
5	Management style	3.93
6	The physical conditions of the workplace	1.9
total		2.23

Table 7. Pearson correlation test between indices of research and job satisfaction.

indices	Number of responders	Pearson coefficient	α	p-value
Income	108	0.19	0.05	0
Job type	108	0.09	0.05	0.06
Career Advancement	108	0.23	0.05	0
Communication among staff	108	0.17	0.05	0
Management style	108	0.13	0.05	0.08
Physical conditions of the workplace	108	0.26	0.05	0

Table 8. Average of job satisfaction based on Likert scale.

Job	Average based on Likert Scale
Chainsaw operators	50
Skidder drivers	57
Operational experts	63.5
Managers	65
Other	53.5
Total average	57.8

Table 9. Average of job satisfaction based on demographic indices.

Indic (comparative job satisfaction= 63)	(comparative job satisfaction= 63)		
Age classes	18-29	30-49	50≤
Average	65	60	54
Marital status	Single	Married	
Average	68	61	
Level of Education	≥ High School Diploma	Bachelor's Degree	> Bachelor's Degree
Average	59	64	68
Monthly Income	≥175€	176-375€	>375€
Average	56	59	69

tion but this correlation is not significant in this statistical population.

Table 8 shows the level of staff‘s satisfaction according to their job type. In regard to the total of 21 questions and the average mean of 3 for each question, 63 would be the average. As shown in the table, among available jobs, operational experts and managers have sufficient job satisfaction and workers in other occupations do not have enough job satisfaction. Chainsaw operators and managers have the lowest and the highest job satisfaction respectively.

Table 9 shows the relationship between job satisfaction and demographic indices. Single people have more satisfaction than married ones and the level of satisfaction increases as the level of education goes higher.

4. Discussion

The presence of women in this population is at minimum. Due to religious issues and the difficult working conditions in forests, women are not often used in forest logging and they are assigned to work in comfortable and easier jobs (Özden et al, 2011). Generally, in Iran women do not have a role in field operation (Lotfalian, 2012). The factor of income has a direct connection with job satisfaction. Job satisfaction increases with higher income (Bakan and Buyukbese, 2013; Tsioras, 2011).The average satisfaction with income is 2.26, which shows that naturally employees are dissatisfied with their income which is consistent with the results of Tsioras (2011). Factor for satisfaction of job progress has the lowest average that is only 1.26. Employees do not hope to advance in their jobs, and this reduces the incentive to work and thus reduces the job satisfaction. A person needs to feel that doing the job properly leads to the promotion of job and income. This is more evident among the forest workers. The relationship among staff and management style, are two factors which have the highest satisfaction among staff with percentages of 3.34 and 3.93 respectively. Management style also is effective in job satisfaction which is consistent with the results of Mihalcea (2013). The physical conditions of the workplace, with an average of 1.9 has a low average and based on Pearson's test is the most effective factor influencing job satisfaction of workers. Due to the difficult working conditions in forests and impassable areas of operation, this dissatisfaction can be reasonable. This dissatisfaction can be somewhat reduced by using a systematic plans and providing appropriate facilities within the forest, such as good nutrition and transportation. There is a direct relationship between job satisfaction and age factors (Eyupoglua and Saner, 2009), marital status and education (Tabatabaei et al, 2013). Results showed that job satisfaction increases with increasing postsecondary education which is consistent with the results (Eyupoglua and Saner, 2009). People in age class of 29-18 have a relative satisfaction from their job and satisfaction decreases with an increase in age. Based on demographic data, 67% of employees are working temporary. As long as an organization‘s staff are not sure of their future and their employment status, and do not have benefits such as health insurance and pensions, they always will be worried and anxious. Perhaps this anxiety affects their working lives and lowers their yield and productivity. Based on the results of this study, managers and operational experts have the highest satisfaction from their jobs and this is because of higher incomes and more appropriate physical conditions. Chainsaw operators and skidder drivers have the lowest job satisfaction due to the difficult job conditions. Managers have a lot of positive effects in creating motivations and releasing their staff‘s potentials (Mihalcea, 2013). They can take steps to renew the organization and productivity of employees by applying appropriate policies and guidelines in order to recruit specialized workforce, assigning of tasks among staff fairly, encouraging them to participate in the affairs and decisions, evaluating staff at different intervals and improving wage conditions.

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Comparison of trees biodiversity in excavation and embankment trenches of forest roads

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Abstract
The purpose of this study is to investigate the effect of forest roads on the biodiversity of trees established at a distance of 25 meters from the edge of the road. In this study of the forest, areas with the same volume per hectare and species composition was selected. To sample the total road length, a 4 transect sampling excavation trench, and a 4 transect sampling in embankment trench system was designed. Comparison of diversity indices showed that species diversity indices (Shannon - Wiener and Simpson) and Shannon index in the excavation and embankment trench are significant different at the distance of 15 meters and up to 25 meters away from the edge of the road, respectively ($p<0.05$).

Keywords
forest roads, biodiversity, transect sampling, road edge trees

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1. Introduction

Construction of roads effects on ecosystem structure, their dynamics and function and has direct effects on ecosystem components such as species composition. It is clear that construction of roads will cause direct destruction of available ecosystem and re-configuration of land's local forms. However, the roads have wide direct primary and indirect secondary ecological effects on landscapes. Roads effects on living and non-living parts of aquatic and terrestrial ecosystems can be examined (forman et al, 2003) (Torabi, 1387). Depending on the severity and extent of the effects, density and diversity of plant communities will change (Najafi et al, 1389:140). Many plants that are included in the category of public plants are present widely alongside of the roads (Worley and Tyser, 1992). in addition, there are plenty of non-native plants at the edge of the road and their seeds are dispersed by vehicles and thus can be considered as a threat to the environment (Schmidt, 1989). There are plenty of light and little competition for moisture on the road edges from bushes and established trees and quick flow of nutrients exist periodically in them. Easy access to limiting factors such as light, water and nutrients which are combined with invasive mechanisms of species in scattering, the frequent involvement of human and development and expand of the roads sides continuously up to the hundreds of kilometers have been make these areas achievable easily and properly for species (Parandes and Jones, 2000, 2003) (Torabi, 1387:3).

2. Material and Methods

Details of the study area: For this purpose, a total of 8 transect sampling perpendicular to the road path were established so that of these 8 transect sampling, the number of 4 transect sampling were designed in excavation slope and 4 were designed in embankment slopes, and these transect sampling were started from the edge of the forest road and continued to distance of 25 meters inward the forest, and the distance of next was selected 3 m plot and the first transect sampling were determined randomly and the next ones were set at a height equivalent to the tallest trees which was considered as 26 meters and for investigate, the first transect sampling at a distance of 2.5 m, the second at 7.5 m, the third at 15 m and the fourth were stationed at a distance of 25 m from the edge of the road. A total of 30 transect sampling and 120 circular sample plots were measured and the analysis of data was performed using the ecological software. For this purpose in order to mean comparison, the paired t test was used. The species diversity is calculated by the use of Simpson and Shannon - Weiner indices, and in the end the values of diversity indices were determined using the ecological software.

3. Results

3.1 Diversity indices

The results of species diversity indices comparison in the excavation slope at different distances from the edge of the road showed that the highest species diversity located in sample plots were observed at distance of 2.5 and 15 meters. But in embankment slope, the highest Shannon and Simpson biodiversity indices were observed at a distance of 15 meters. Also the lowest value of Shannon index in excavation and embankment slope was respectively observed at 2.5 and 25 meters, and the lowest Simpson index in embankment slope was observed at a distance of 25 m (Table 1).

Table 1. Comparison of trees biodiversity indices at different distances from the edge of the road in two excavation and embankment slopes.

distance from the road edge (m)	Shannon index		Simpson index	
	excavation slope	embankment slope	excavation slope	embankment slope
2.5	2.61	2.58	0.92	0.92
7.5	2.65	2.58	0.93	0.92
15	2.68	2.63	0.93	0.93
25	2.63	2.57	0.92	0.91

Table 2. Comparison of different diversity indices in both excavation and embankment slopes

diversity indices	excavation slope	embankment slope	t-statistics value	significance level
Shannon diversity	2.6	2.59	6.148*	0.008
Simpson diversity	0.93	0.92	1.73^{ns}	0.18

** the significant difference up to 95% probability level*

^{ns} represents the lack of significant difference up to 95% probability level

3.2 Comparison of different diversity indices in both excavation and embankment slope

Comparison of these two slope in the terms of biodiversity indices using paired t test showed that up to distance of 25 m from the road edge, the Shannon diversity at the excavation slope is significantly (0.05 >p) greater than that of the embankment slope while the Simpson diversity has no significant differences (Table 2).

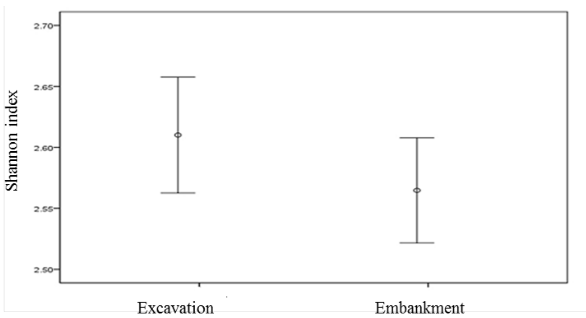

Figure 1. Mean and confidence limits of Shannon diversity index in both excavation and embankment areas.

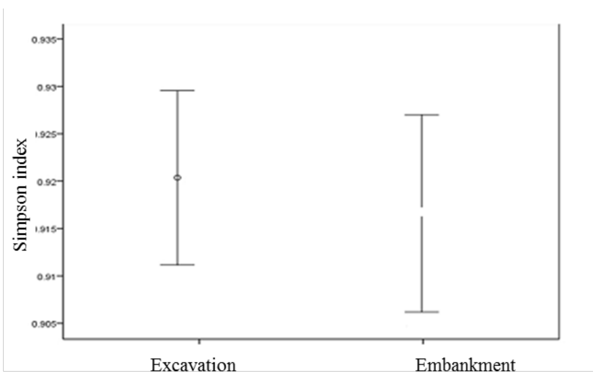

Figure 2. Mean and confidence limits of Simpson diversity index in both excavation and embankment areas.

4. Discussion

The highest biodiversity indices (Shannon and Simpson) have the greatest value in a distance of 15 meters from in embankment slope and in a distance of 25 meters the excavation slope has the highest number of seedlings and the highest amount of Shannon diversity and since the main limiting factors of trees regeneration in destroyed forest lands include food shortages, soil compaction, lack or abundance of soil moisture, direct sunlight radiation, intraspecific and interspecific competition (Nepstad et al., 1991), lack of sufficient seed and the distance of seed origin, seed feeding by seed eaters (Mcclanahana and Wolfe, 1998) and being trampled and loss by livestock (Harrey and Haber, 1999), and because in this area, all remained households livestocks intervene and grazing in entire areas of series 4, this process causes damage to natural regeneration and forest vegetation and inventory reduction in this area.

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The relation between organic matter content and CBR of road subgrade: Case study Hyrcanian forests, Iran

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Abstract
This study aims to assess the effect of organic matters on CBR of forest subgrade, and the relationship between organic matters content with engineering behaviors of forest soil. The study site is located in Kheyrud forest in the middle part of the Hyrcanian forest, Iran. Therefore to assess the effect of organic matter on the behavior of soil, a typical mineral soil was selected regarding most frequent soil type of study area. A profile was excavated and soil was sampled from 30-60 cm depth to reduce natural organic content, and then transported to the laboratory. The organic matter was collected from dead trees and litter on the forest floor. The soil was mixed with different treatments of organic matter contents artificially (0% (control), 5%, 10% and 15% by weight) and CBR tests were performed on soil samples. Results showed that organic matter decreased CBR. Results confirmed negative effects of organic matter on soil material.

Keywords
CBR, forest roads, Hyrcanian forest, organic matter content

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1. Introduction

Forest roads are one of the most important infrastructures for sustainable forest management and create communication lines in natural habitats. The most valuable services that forests provide in all over the world are; recreation, filtration drinking water, industrial use, wildlife conservation, biodiversity, and erosion control and flood prevention. In order to use these resources, construction and maintenance of forest road network is necessary. If forest roads used for a long-time, negative consequences will follow such as; rising costs, destruction of habitat, changes in the hydrology cycle and geomorphology of the area (Switalski, Bissonette, DeLuca, Luce, and Madej, 2004).

Soil types behave differently and provide varying degrees of stability when used as road material. Awareness of characteristics of soil and determination of it's technical properties is necessary for forest road operations and ensures stability. In forest road construction, natural soil also plays a role as road bed, therefore should be able to bear the weight of the gravel surfacing and also road traffic. However in the Hyrcanian forest, due to the low resistance of fine grain soils (usually CL and CH in Unified Soil Classification System), the road bed often cannot alone bear the traffic and must be stabilized with appropriate materials. According to the mechanical behavior of soil, it is the most complex material for constructing road. Study of mechanical properties of road bed soil can help to decide on how to build and maintain the road bed. One of the most important principles of constructing forest roads is to prevent the incorporation of organic materials in road constructing operation in both cut slope and fill slopes, because it may affect the road stability. Organic soils create a dense, grainy soil structure and as a result tend to hold onto moisture, which makes a material that easily changes in shape and size. Organic matter is mixed into the fill if not clearly separated in the topsoil removal phase. Organic matter in forest soils consists of; a complex mixture of plant remains decomposed to varying extents, substances synthesized by biological or chemical means from the decomposition products, and plant secretions and their decomposition products. Generally, many studies have shown that the presence of organic matter in the soil acts detrimental to the quality of engineering performance and is harmful for quality of soil (Malkawi, Alawneh and Abu-Safaqah, 1999; Yildirim and Gunaydin, 2011).

Previous studies have been conducted about the effect of organic matter on soil properties. Organic matter have been reported to have significant effects on mechanical properties of soil such as decreasing shear strength or soil resistance (Franklin, Orozco, and Semrau,1973; Davies, 1985; Ekwue, 1990; Carter, 2002; Ohu, Mamman, and Mustapha, 2009). Much of conducted researches had been done on the engineering behavior of highly organic soils, however, relatively little is known about the engineering behavior of soils with smaller amounts of organic matter (Malkawi, Alawneh and Abu-Safaqah, 1999). Therefore the aim of the present study was to investigate the effect of organic matter on the mechanical properties of soil regarding forest road construction also assessing the relationship between different organic matter contents and soil properties. Because of the high economic and environmental costs of forest roads, factors that affect the success of these operations are important.

2. Material and Methods

2.1 Study site

The study site is located in Kheyrud forest in the middle part of the Hyrcanian forest (latitude: 36°33' N, longitude: 50°33' E), Iran. The research was carried out in second district (Namkhane) with about 1083 ha area and ranging from 350 to 1350 m above sea level. The system of management is selection system and ground skidding is used to transport woods from stands to depots, then woods are loading and extracted from forest by means of trucks. The road length is 15.8 km and road density is 20 m/ha. The range of rainfall in this district is 1300-1600 mm.

2.2 Methods

Previous works in the study area had found that most of area had clay soil with high plasticity (CH in Unified classification system) (Majnounian 1990). Therefore to assess the effect of organic matter on the behavior of soil, a typical mineral soil was selected regarding most frequent soil type of study area (Majnounian, 1990) and transferred to the laboratory. The litter and plant residues on the soil surface were removed to reduce side effects and eliminate organic matter and a profile was excavated and soil was sampled from 30-60 cm depth to reduce natural organic content (Malkawi, Alawneh and Abu-Safaqah, 1999). One hundred kg of Soil sample was transported to the laboratory and were dried by spreading them out at room temperature for two weeks. The organic matter was collected from dead trees and litter on the forest floor. The organic matter were mixed and milled, then passed through No. 40 sieve to remove coarse particles (Malkawi, Alawneh and Abu-Safaqah, 1999) to have a uniform mixture of organic matter. Four artificial organic content treatments were considered for the tests, control (0% organic content) and mixing 5%, 10% and 15% (percentage by weight) of organic matter to soil. Then each mixture was placed in a plastic bag and left for a curing period of 7 days before performing the required tests (Malkawi, Alawneh and Abu-Safaqah, 1999). To assess the effect of organic matter CBR (ASTM D1883) test was conducted on different treatments.

3. Results

3.1 CBR

The resulted CBR values are displayed in table 1. As table 1 shows CBR values reduced with increasing organic matter content in the soil.

Table 1. Resulted CBR values for different treatments.

Treatment	Control	5%	OMC 10%	15%
Penetration (mm)	2.54	2.54	2.54	2.54
CBR	15.72	12.74	6.49	4.75

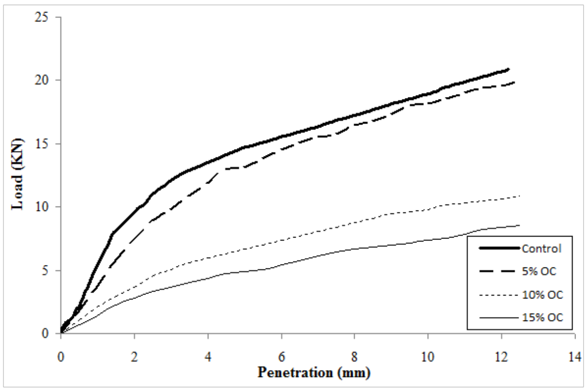

Figure 1. CBR test results for different treatments.

4. Discussion

4.1 CBR

Previous studies about influence of organic matter on soil strength have showed that organic matter reduces stability and resistance (Low, 1954; Williams and Cooke, 1961; Greenland, Rimmer, and Payne, 1975; Ohu, Raghavan, and McKynes, 1985; Ohu, Mamman, and Mustapha, 2009; Ekwue, 1990; Carter, 2002; Mitchell and Soga, 2005). The results of CBR showed that CBR values as index of bearing capacity of soil reduced by increasing organic matter content. Strength decrease with increasing organic content is attributed to the reduction in the maximum dry density of compaction by increasing organic matter. Also organic particles are stiff when compressed and act as rigid particles when dry, but when they absorb water they become soft (Malkawi, Alawneh and Abu-Safaqah, 1999). Also Thiyyakkandi and Annex (2001) found that Angle of internal friction (as one factor of soil strength) was decreased linearly with increase in organic content.

5. Conclusion

The effect of organic content on CBR of clay soils has been investigated. The tests results indicate that the organic content significantly alter the geotechnical properties of clay. CBR values reduced with increasing organic matter content. It can be concluded from the results that organic matter have negative effect on engineering properties of soil for road construction purposes even in small amounts. Therefore it is very important to remove organic materials from soil and avoid mixing it into the fills to ensure road sustainability.

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Comparing of two GPS models in urban forests and green spaces management

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Abstract

The goal of this study was to evaluate the precision of consumer grade GPS units in urban green spaces by using ground control point coordinates (GCP). To assess the effect of crown canopy and daytime, data was recorded three times (eight, 11, and 12) using the GARMIN-Rino 130 and GARMIN-Colorado 300 in the Faculty of Natural Resources, University of Tehran, Iran. Points were located in a place consisting of large sized Platanus orientalis trees. Five replications were recorded to make averaging possible. Therefore, effect of daytime and point averaging on precision can be evaluated. Results showed that daytime with three and five points averaging errors, did not have any differences for both receivers. The range of mean errors (three points) is 2.2-4.9 and 5.1-18.1 for the Colorado and Rino respectively and means of error (five points) for Colorado and Rino is 1.1-4.0 and 6.5-25.3. According to the results, Colorado receiver generally has lower error and therefore better precision.

Keywords

consumer grade GPS, green spaces, platanus orientalis, precision

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1. Introduction

GPS is one of the most important tools for data collection in environmental studies. The urban forest may be defined as the assemblage of woody and other vegetation that lies within an urban area, or that forest structure which is regularly subjected to influences of an urban nature (Sanders, 1984). Management of urban forests can be challenging and requires availability of current and comprehensive information, which geospatial tools such as GPS may work extremely well for gathering this kind of information, especially where conditions change rapidly (Ward and Johnson, 2007). Nowadays free and easy use of GPS allows it to be used in all aspects of environment management.

A GPS device receives signals from at least four satellites to calculate the location. Typically by receiving signals from more satellites, calculating the position would be more accurate. However, GPS has several sources of error including; interference signals of satellite with the atmosphere, the time difference between satellite and GPS, earth's rotation, pattern of satellites rotation (Ginsburg, 2002), orbital error, satellite clock error, ionosphere error, tropospheric error, multipath and receiver noise (Olynic, 2002). Moreover, the main concerns of using GPS receivers in woody environments are availability and characteristics of satellite signal under canopy. Branches, trunks, and needles/leaves attenuate, distort, or break GPS signals, so that precision in location are markedly lower than in areas with unobstructed sky conditions (Wings, Eklund and Kellogg, 2005). Previous studies showed a strong variation in results according to the equipment used, vegetation covers, as their effect would be very different depending on tree density (Piedallu and Gegout, 2005).

Wing and Eklund (2007) assessed the accuracy and precision of six GPS devices in three different canopy densities. They showed that averaging and canopy cover had positive and negative effect on accuracy respectively. They reported accuracies of 5 and 10 meters for leaf-off and leaf-on conditions. Serr, Windholz and Weber (2006) measured accuracy and precision of fifteen points using the coordinate of five GPS type. The results showed that the stated accuracy by the manufacturers is within the range of estimated accuracy. Rodriguez-Perez, Alvarez and Sanz-Ablanedo (2007) assessed the accuracy and precision of low-cost receiver in forest environments. In this study they took eighteen points using four types of GPS. Five positional replications were recorded for each single point. Exact coordinate of points were taken by using a DGPS. The results showed significant difference in precision between GPS receivers and negative effect of the canopy cover on precision.

The aim of this research was to assess the precision of two consumer grade GPS receivers at different hours of the day in an urban forest. Also effect of point averaging (three and five points) was assessed on resulted precision. It was aimed to determine the most suitable method and receiver in terms of easiness of use, accuracy, reliability regarding urban forestry applications

2. Material and Methods

2.1 Study area

The field tests were conducted in the faculty of Natural Resources, University of Tehran, Karaj, Iran. Measurements were taken at eleven GCPs. Intervals between points were 42-130 m, with 785 m overall length. The corridor where points were located in it contained multipath environment consisting of large sized Platanus orientalis trees (a deciduous tree) with approximately 15 m height. Platanus orientalis is the most frequent species in urban green spaces of Iran.

2.2 Data collection

The positions of eleven GCPs that had been recorded using an Ashtech-ProMark 2 DGPS were obtained from Karaj subway project as exact coordinates. Two types of consumer grade GPS receivers, the GARMIN-Rino 130 and GARMIN-Colorado 300 were selected for precision assessment because of their widespread availability and usage in environmental management. The coordinate of sample points were recorded on March and July of 2012 at three times of day (8, 11 and 12) to assess the effect of daytime. Five replications were recorded to make averaging possible. Therefore the effect of daytime, and point averaging on precision can be assessed. To ensure that data can be obtained from satellites the devices were turned on about 10-15 minutes before use (Rodriguez-Perez, Alvarez and Sanz-Ablanedo, 2007; Wing and Eklund, 2007). All data was collected at a standard height of 1.8 m above ground surface (Owari, Kasahara, Oikawa and Fukuoka, 2009).

Statistical analysis

In order to calculate precision, the following equation was used (Rodriguez-Perez, Alvarez and Sanz-Ablanedo, 2007).

Precision:

$$\partial_{H-pre} = \sqrt{\partial_E^2 + \partial_N^2} \tag{1}$$

$$\partial_E = \sqrt{\frac{\sum_{i=1}^{n}(E_i - \bar{E})^2}{n-1}} \tag{2}$$

$$\partial_E = \sqrt{\frac{\sum_{i=1}^{n}(N_i - \bar{N})^2}{n-1}} \tag{3}$$

Where N is number of replications, N_i and E_i is location of i^{th} epoch along easting and northing directions, respectively, $\bar{E}$ and $\bar{N}$ sample mean of the measurements along easting and northing directions, respectively.

A Kolmogorov–Smirnov test was used to check the normality of the data before proceeding analysis of covariance and where this assumption was violated; data was log transformed prior to analysis to ensure homogeneous residual variance and normality. To determine whether there were any differences in precision (error) due to GPS receiver or daytime, the test results were subjected to two way analysis of variance. ANOVA was carried out using completely block randomized design which each station considered as a block. As each treatment has five replications we assess the effect of averaging on resulted precisions. Therefore the data is analysed three times, single point (first record), three points (average of first, third and fifth records) and five points (average of all five records).

3. Results

The results of ANOVA for precision showed that there were significant differences between precision of seasons for 3 points ($P<0.05$) in both GPS models, but difference in season precision ($p<0.05$) of 5 points averaging were only significant for Colorado GPS model (Table 1).

Table 1. Summary of ANOVA for precision.

Variable	3 points ave.		5 points ave.	
	F	P	F	P
Rino				
Season	4.212	0.013	1.864	0.157
daytime	1.253	0.291	0.956	0.389
Season x daytime	1.247	0.291	1.384	0.231
Colorado				
Season	7.604	0.001	5.239	0.005
daytime	2.159	0.122	1.33	0.27
Season x daytime	1.531	0.179	0.498	0.808

SNK test was used to compare means of precision for both GPS receivers (figures 1). Figure 1 shows mean±SD error (precision) of 3 points averaging of two receivers in two seasons.

As figure 1 shows errors are not significant due to daytime for both receivers. The effect of season is significant and summer error levels are lower. The range of mean errors is 2.2-4.9 and 5.1-18.1 for Colorado and Rino respectively. As figure 1 shows Colorado receiver generally has lower errors and therefore better precisions. Figure 2 shows Mean±SD of errors for 5 points averaging of two receivers in two seasons.

Generally daytime and season had not any significant effect on error level for both receivers. The range of mean errors is 1.1-4.0 and 6.5-25.3 for Colorado and Rino, respectively. Again the Colorado receiver generally has better precisions with lower error levels.

4. Discussion

When precision is considered the results have more variety. The Colorado receiver point averaging had positive effect on precision while Rino receiver precisions indicate the contrary. Figure 3 shows the descriptive statistics for precision.

With regard to precision the Colorado receiver is better than Rino model. Also we observed during our data collection that the Colorado GPS receiver was able to begin data collection faster than the Rino receiver. Using Colorado in the leaf-off period to provide positions is the most suitable regarding ease of use and precision. More research is suggested to test other position averaging methods to find suitable one. In this study we did not use an external antenna but Wing and Eklund (2007) findings encouraged the use of an external antenna. They suggested an extending antenna upward to reduce errors. Also D'eon (1996) found that PDOP decreased as antenna height increased

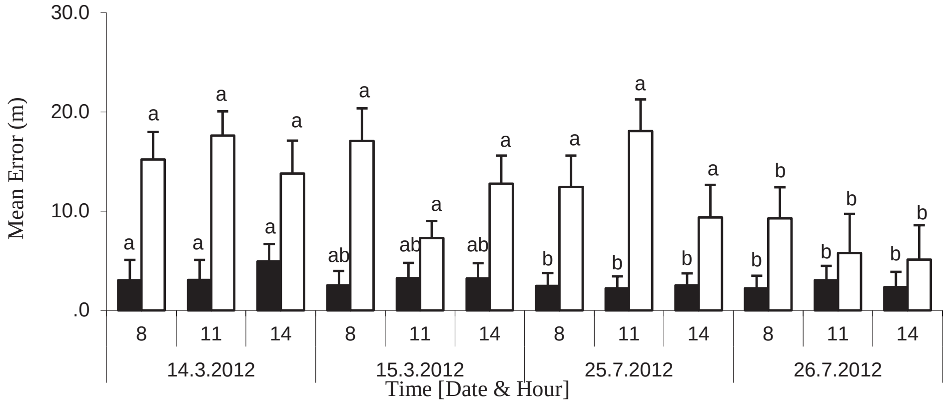

Figure 1. GPS error (precision) with 3 points averaging (Mean±SD) Colorado (black) and Rino (white). For columns with the same color, means with different letters are statistically different ($p<0.05$).

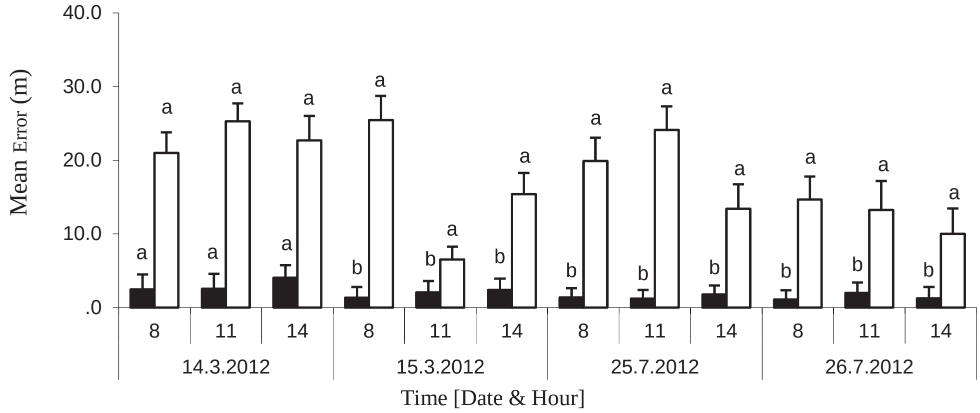

Figure 2. GPS error (precision) with 5 points averaging (Mean±SD) Colorado (black) and Rino (white). For columns with the same color, means with different letters are statistically different ($p<0.05$).

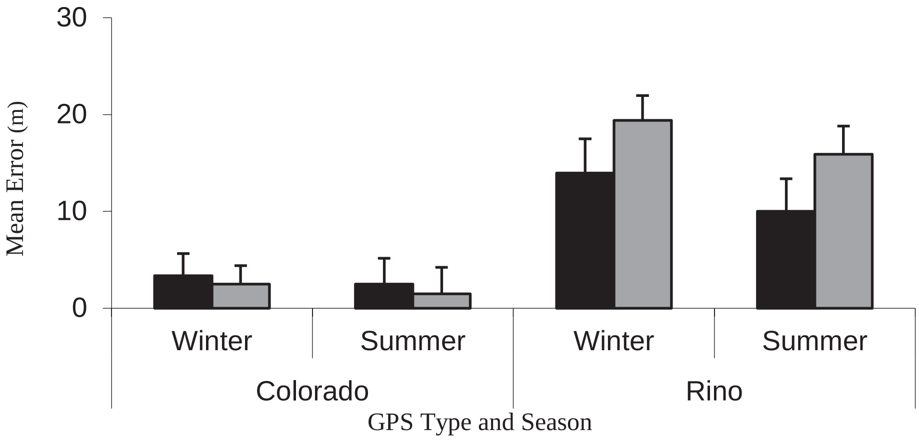

Figure 3. GPS positioning error (precision) (Mean±SD) three points (black) and five points averaging (grey).

from 2 to 4 m. In addition our experiences during data collection encourage this. As Ward and Johnson (2007) stated in an urban forest where conditions change rapidly GPS may provide timely and low cost data for management purposes. Our results showed that selecting proper GPS receiver can provide precise data for environment and urban forest management.

5. Conclusions

This study assessed two GPS receivers and determined both precision and accuracy for leaf-off and leaf-on period and different daytimes. While selection of the optimal GPS receiver is a project-dependent consideration, the data we present showed that even low-cost consumer grade receivers can provide acceptable precision for environment and urban forest management while they are easy to use. Also this study shows that noticeable differences in precision exist for two low-cost GPS receivers tested due to season, model, daytime and point averaging methods. If accuracy requirements are moderate–low, Colorado receiver may provide valuable positional data even under the canopy of urban green space but best results may obtained in leaf-off period.

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Logging and transportation by John Deere 1110D forwarder in Bulgaria - productivity and impact on soil

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Abstract
Forwarders are perfect machines for transportation of log assortments in Bulgaria. This study deals with the productivity of a John Deere 1100 D forwarder; the first and only machine of this kind for the time being used in our country. A regression model for predicting the time of forwarding has been developed over 105 working cycles of the forwarder and the distances of transportation have been summed in the course of its work in the Eastern Balkans region. Mathematical models have been developed for distances from 800 to 1400 m. The productivity depends on the distance of transportation and the size of the load. What is interesting to note is that the operator‘s work progress in a year. In the course of the observations conducted on the forwarder, for the first six months the average daily productivity reached 44 m^3 and, in a years' time, 57 m^3. The comparison has been made in the same forest-exploitation conditions, with the same terrain characteristics and the same 800 m distance of transportation on steep (right) slopes.
A series of studies has been conducted on the impact exerted by the forwarder on the soil. A number of soil indices have been examined: volume density, soil structural aggregates permeability to water, micro-aggregate structural analysis, soil hardness, moisture content, soil-hydrological constants, quantity of dead forest cover. By increasing the road's density both the number and the depth of the wheel tracks decrease in the cutting area, thus reducing the risk of severe damage to the soil. The findings reported in this study are supported by a series of measurements carried out on the terrain and by statistical calculations. Taking into consideration the variety of the forestry conditions in Bulgaria and the fact that all the variations are not included in our studies, significant differences may occur, especially, on even terrains where such differences tend to be positive while in highly pronounced terrain the differences tend to result in negative.
A comparative analysis of the characteristics has been made between the forwarder and the assortment tractor of MCI-100 hydro-manipulator constructed in Bulgaria, considering that the latter one could not find any application therein.

Keywords
logging, forwarder, productivity, soil studies, Eastern Balkans region

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1. Introduction

A significant experience in the use of multi-operational machines as processors, harvesters and forwarders, has been gained in the countries which have been developing logging. The use of such types of machines makes possible a total elimination of manual operations and leads to achievement of a comparatively high labor productivity.

The use of the animal traction, i.e. the haulage of wood by horse, is widely spread in Bulgaria. As we consider, that same method can also be applied further to a small-scale logging, thinning and ecologically sensitive forests, considering the cheap labour force, as well. According to Zimbalatti and Proto (2010), the forwarder productivity in a cut-to-length forest harvesting system has a tighter correlation with the volume of the payload size and the average extraction distance, and it is expected to increase with the rise in the payload but to drop with the increase in the average extraction distances. The average production (based on free delay hours) was estimated at 14.41 m^3/h - 15.11 m^3/h.

The productivity of the forwarder is strongly correlated with the stand type (final felling/ thinning), the average haulage distance, the timber density on the strip road and the load volume (the size of wood bunk) (Kellogg and Bettinger, 1994) . Besides, at least in theory, the increase of average tree size should reduce the loading time. The number of the wood assortments also has an influence on the forwarding productivity since it affects the timber density on the strip road. In certain conditions, for example, it may be more appropriate to haul mixed loads (two or several wood assortments in the load) although it increases the time consumption during the unloading phase. (Kuitto et al.1994). According to Tiernan et al. (2004), the productivity is evaluated as the volume of the timber payload during the corresponding productive system time (PST) in

m^3 h [PST]$^{-1}$, delays excluded. A significant drop in the forwarder productivity has been evidenced with the increase of the distance of timber extraction and independently of the payload.

From the operational viewpoint, one should explore the possibility of increasing the road density in order to reduce the extraction distance (Spinelli et al., 2004). Overall, the productivity of timber extraction may vary from 6 to15 fresh tons/SMH and that does not differ too much from what has been documented by other studies of the Standard Scandinavian forwarders, if the long extraction distance is taken into account.

Factors of the time consumption in forwarding operations could be more complicated than in harvesting ones: volume of harvested timber per 1 ha, spacing of skidding trails, mean volume and length of particular assortments, skidding distance etc. (Neruda and Valenta, 2003) With regard to the impact on soils, the influence of the distance on the forwarding productivity could be viewed through its interaction with the classes of soil-bearing capacity and the classes of forwarders. Likewise, with the increase of forwarding distance, the load volume becomes more significant (Stankič et al, 2012).

Poršinsky et al. (2012) have proved that equipping the forwarder with semi-tracks on wide tires results additionally suitable for the environmental soundness of timber forwarding, due to a further drop of the nominal ground pressure which is lower, ranging from 61% (unloaded vehicle) to 12% (loaded vehicle), in comparison with the allowed contact pressure of the soil of limited bearing capacity. And it is also important that the environmental suitability of the researched vehicle under the above indicated work conditions could be improved by using semi-tracks or limiting vehicles travel to skid-trail network where an additional soil protection is provided by covering skid roads with brushmates or limiting the load volume (Porsinsky et al., 2007).

The decrease of the loaded timber volume severely affects the forwarder efficiency (especially by the increase of the forwarding distance), and hence, from the economic point of view, it results that the method of providing forwarder mobility in conditions of limited soil strength of the Croatian lowland forests is absolutely unacceptable (Poršinsky et al., 2011).

The relocation of soil layers, caused by vehicle movement, is manifested through ground hollowing (rut), upper soil layers removal and surfacing of the materials from deeper soil horizons (Arnup, 1999). Susceptibility of forest soils to compaction is primarily determined by the following factors: size of vehicle's tyres or tracks, soil texture, soil moisture during the timber extraction, portion of skeletal and sand particles within the soil, soil structure, bulk density and porosity of the soil, natural soil compaction (depending on the geological origin), thickness and origin of humus-accumulative layer.

2. Material and Methods

Which method is better to be applied, according to Ghaffarian and Stampfer (2009), to gain more accurate results? No comparison has been made in the previous studies among the different methods for the purpose to choose the most appropriate one of studying the optimum road spacing. The observations carried out in the course of a 3-year period have been reported in this paper, with some intermittences, due to adverse meteorological conditions and certain minor repairs on one of the first forwarders used for logging in Bulgaria, i.e. John Deere 1110 D, second hand purchased (s.Fig.1).

Figure 1. John Deere 1110 D forwarder in operation.

The study has been conducted in the black (Pinus nigra Arn.) and white pine (Pinus silvestris L.) cultures grown on terrains of a hilly and up to a mountain character.

The plantations are in a status after windthrow; yet, they are considered usable for conducting operations therein by the above described machine, taking into account the set objectives. The forestry requirements include a preparation of "liberated areas" for a reforestation, i.e. for clear cuttings. The haulage distance is an important factor for cutting planning. The regression method usable for the haulage time forecasting has been developed by performing 105 working cycles during the operations by the above said forwarder in the State Forestry of Kotel, located in the Balkan mountains. The observations on the forwarder have been conducted in several cutting areas situated in succession, depending on the terrain slope and the forwarding direction. Usually, in order to analyze the technological process of the machine, one need to be familiar with some concrete stages of the working process, as following below: travelling empty, moving in the cutting area for loading, setting in order, rearranging of the assortments in the cutting area, loading, travelling full, unloading and ordering, rearranging the assortments in stock. Along with time consumption, there have also been controlled the number and the length of the loaded assortments, the covered transportation distance of the load, as well as the road surface and the slope.

All the time-related data have been reported by means of a chronometer. The distances have been measured by a preliminary marking of all the routes and a measuring of the respective distances. The road slope has been measured at each 20 m by a slope meter. The load size has been determined by the type and the counting of the numbers of assortments available in it. An additional measurement has been made of the whole load by a metric tape; and applying the respective coefficient to, the load cubic meters have been converted from bank cubic meters to the solid ones.

Both regression and correlation analyses by Pearson' correlation coefficient have been used for the determination of the force (robustness) and the direction of relations between the total time consumption and the forwarding distance of the wood. Along with that, Fisher's F criterion, Sy standard error, Student's t criterion have been used in order to select the most appropriate model and a test has been performed by a mono-factorial dispersion analysis (ANOVA).

In the course of the studies on the impact exerted by the technological schemes on the soil, the soil physical properties have been predominantly examined, as it is supposed that these ones could be subject to alterations, to the greatest extent, under the mechanical impact. The wood material hauling machines exert mainly pressure on the soil. The soil capacity to with stand against such a pressure depends on its properties and on the type of the used machines.

A range of soil indices have been subject to examination as following ones: voluminous density, structural aggregates water resistance, micro aggregate structural analysis, soil hardness, moisture content, soil-hydrological constants, dead forest cover quantity. It should be noted that when the soil structure is examined as a factor for soil fertility, there are not only the structural aggregates shape and size of a significant importance but first of all, their mechanical resistance and, in particular, their water resistance. For that reason, the most important part of the studied soil indices has been analyzed as the total quantity of the aggregates in the soil, by using Savinov's method, the structural aggregates water resistance by Savinov's wet sifting method, the soil voluminous density applying Kachinski's method to, and the quantity of the dead forest cover, by a weight analysis.

In the course of the performed analyses, the soil samples have been subdivided into fractions as following: structural aggregates of size below: > 10 mm, 10-5 mm, 5-2 mm, 2-1 mm, 1-0,5 mm, 0,5-0,25 mm and < 0,25 mm. Each fraction can contain aggregates of different size, yet, within the same determined fraction.

Soils have been studied in control areas, (i.e. in stands where forwarders have no access to), on haulage roads and in experimental (cutting) areas immediately after the cutting. The above described study has been made for the purpose of determining the forwarder possibilities for work in Bulgaria, taking into consideration its productivity when wood materials are hauled away and the problems which arise from and are allied to the introduction of that new technology. The results obtained from that study should be used for an efficient introduction of the above said machines, depending on the concrete conditions available in our country.

3. Results and discussion

The forwarding operations by John Deere 1110 D forwarder include: travel empty, loading when assortments type is taken into consideration, travel full, unloading, sorting of materials. Some of the most important indices are shown in Table 1: both regard to the plantations and the work performed by the forwarder.

Table 1. Some indices of the plantation characteristics and the work performed by the forwarder.

State Forestry of Kotel:: SFB composition-bpc 7, wpc 3 Age–55 y., DBH–26 cm, H–21,0 m, complex valuation–2 completeness–0,8, storage–480 m^3*/ha, relief terrain plain slope at the lower edge 150; SFB composition bpc 10, age–55 y., DBH–26 cm, H–22,0 m, completeness–0,7 storage–250* m^3*/ha, relief terrain – plain slope at the lower edge 170*

Indices	Values
Machine made dating: year	2006
Cost of the machine, €	75 000
Insurance, €/y	18 000
Working days	78
Quantities obtained in m^3	4 052
Average productivity in m^3/d	51,95
Costs, €:	11 329
Fuel, €	5 604
Salaries, €	3 061
Repairs, €	2 664
Security, €	1 000
Incomes, €:	27 523
Profit, €:	16 194
Profit, €/monthly	4 376
Profit, €/daily	207,62

Note: Assortments - d cm - logs, at the thin end - 30(15%) 18-29(40%), for beams - 16-18(10%) and for cellulose.

State Forestry of Kotel:: SFB composition-bpc 7, wpc 3, age–55 y., DBH–26 cm, H–21,0 m, complex valuation–2, completeness–0,8, storage–480 m^3/ha, relief terrain – plain slope at the lower edge 150; SFB composition- bpc 10, age–55 y., DBH–26 cm, H–22,0 m, completeness–0,7, storage–250 m^3/ha, relief terrain – plain slope at the lower edge 170

The productivity of the forwarder depends on the forestry conditions as following: tree species, plantation composition, standing mass, type of cutting, types of assortments, terrain type: its macro- and micro-relief, bearing capacity, obstacles etc. There are also other influences: seasonal ones or due to the way of the assortments arranging in the cutting area and, especially, along the haulage road. The schemes of the work during forwarding and of the operational costs are shown in Fig. 2 and Table 2, respectively. In 2013 a general standing rule was laid down of the statistically significant correlation between the operating time consumption in travelling and the forwarding distance but the level of significance was low. The reason for that lies in the unsteady precision in performing the operations by the operator. Due to that, it was impossible to find out other sig-

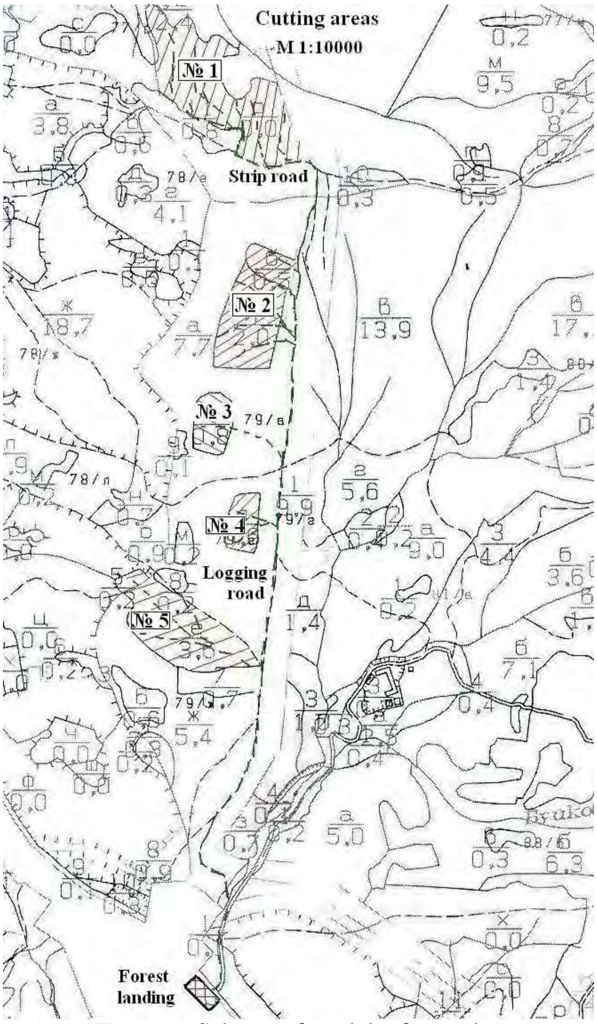

Figure 2. Scheme of work by forwarder.

nificant relationships in the processes in examination. For that same reason, it was in 2014 when observations were conducted after becoming convinced in the adequate experience gained by the operator. Table 2 illustrates the operating time consumptions in forwarding operations during the first six month and in a year. As it is evidenced by the conducted observations, time varies from 80 to 117 min/ cycle in the very first months and from 65 to 99 min/cycle after a year of work, at the same distance of 800 m. The highest shares have been found out of loading and unloading time, travel time and time for moving within the cutting area, which ones expressed in percentages, are of 33%, 12%, 28% and 13%, respectively, in the first six months, and of 31%, 11%, 25% and 19%, respectively, in a year (See Fig. 3). The progress achieved by the operator is evident after a year of work: in travel and loading-unloading operations performing by the forwarder where time has been reduced by 18% in loading and 25% in unloading, respectively.

It is obvious, the work accomplished by the operator has advanced in a year, in comparison with that one performed by him in the very first six month which period can be considered as his first year of work. In the course of the observations carried out on the forwarding operations, in

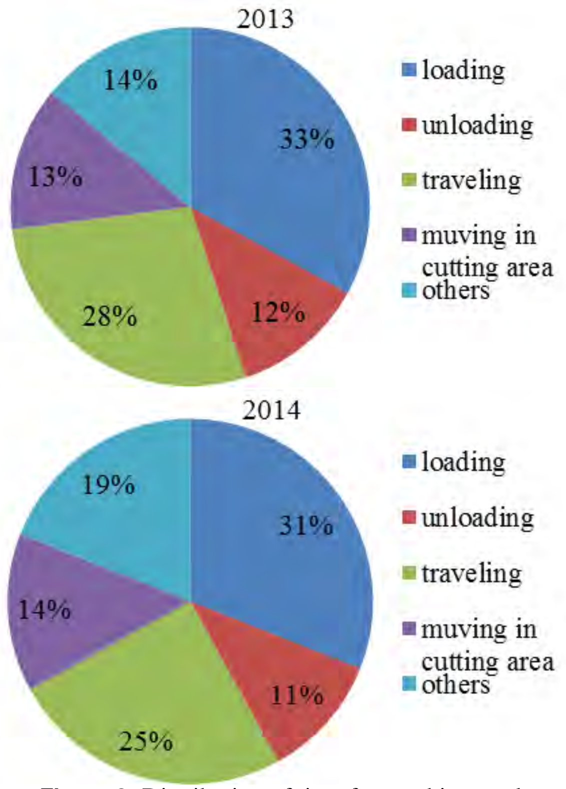

Figure 3. Distribution of time for machine work.

the first six month its daily productivity has achieved 44 m^3 and in a year 53 m^3 , at the same forwarding distance of 800 m. It may be important to point out that in the course of the observations conducted in the first six months the average volume of the load has reached 9,3 m^3 and in a year, 9,7 m^3. What also makes an impression is a comparatively higher productivity of John Deere 1110 D forwarder compared to that one of MSI 100 Bulgarian assortment haulage tractor (28 m^3/day). The productivity of John Deer 1110 D forwarder in haulage by a winch-equipped tractor is of 55 m^3/day while in a joint work with John Deere 1270 D harvester it is of 68 m^3/day). The reason is that the forwarder is of a higher passability, being able to access to the assortments in the cutting area without any risk of affecting the stand.

One of the most important factors of production related to the forwarder is the forwarding distance. Table 3 shows the obtained models of relationship between the total time of forwarding and the forwarding distance when the latter one is from 800 to 1400 m. The increase of the distance is associated to an intense increase of the forwarder operation time.

In case of competing functions, the most appropriate model should be selected for an adequate description of the relationship and a minimum error. For that purpose we use the standard error *Sy* (as it is shown in Table 3). If such a situation occurs when two or more models indicate signs of adequacy, an important question arises: "Which is the best one?" In order to make a precise selection, we should be led by the object and the objectives of the study. Keeping to

Table 2. Operational time consumption in forwarding of a load at a distance of 800 m by John Deere 1110 D forwarder.

Nr in order	Operation	Time - in min. 2013	2014
1	Traveling empty	8-12	7-11
2	Moving in cutting area for loading	10-15	9-14
3	Stacking of the assortments in the cutting area	12-17	10-14
4	Loading	27-38	20-31
5	Traveling full	12-16	10-14
6	Unloading	11-13	8-10
7	Stacking of the assortments in store	0-6	1-5
	Total	80-117	65-99

Table 3. Theoretical models, correlation coefficient and standard error of estimation between empirical and theoretical values.

Theoretical model	Equation	Correlation coefficient	Standard value
Rectilinear function	$y = 0.0636x + 29.0825$	R = 0.558	Sy = 19.0899
Logarithmic function	$y = 67.05ln(x) - 369.34$	R = 0.549	Sy = 19.2284
Second degree polynomial (parabolic) function	$y = -2.2756\ 10^{5x^2} + 0.1159x + 8.7045\ 10^{-07}$	R = 0.552	Sy = 19.1994
Exponential function	$y = 48.052\ 10^{0.000649x}$	R = 0.562	Sy = 19.5906

Occam‘s principle, we will be able to select a model which should be as simple as possible, with the minimum number of variables. That is why the rectilinear model should be selected by us: in fact, it is the most appropriate one taking into consideration the standard error of the estimate Sy = 19.0899. That means, the least deflections from the straight line is produced.

Controls as following below should be performed in order to evaluate the extent to what the constructed model reflects the objective reality and can be adequate for use in practice: on the one hand, it is necessary to provide a control on significance of the correlation and regression parameters of the model by using Student‘s t-criterion for, as these parameters serve as means of measurement of the relationship between the distance and the total time for haulage; on the other hand, a control should be performed on the model adequacy taking into consideration the dispersion relation (by using Fisher‘s F criterion for comparison of dispersions). After analyzing the data, the following results have been obtained by us (see Table 4).

A proof for the significant influence exerted by the “distance” factor is a test which has been conducted by using the mono-factorial dispersion analysis (ANOVA). The obtained value of the index Sign.$F = 6.07\ 10^{-10}$ is much lower than α=0.05 level of significance and that means, the examined “distance” factor significantly influences on the resultative index of “total time for haulage”, hence, that model is adequate. It is evident, from the above enclosed table, that the parameters of the linear function are statistically significant, as the P-value for both of them has a significantly lower value than the level of significance α = 0.05.

The coefficient of determination R^2 = 0.312 of the rectilinear function shows that 31.2% of the changes in operating time are due to changes in the haulage distance while the rest ones 68.8% are due to other factors which are not included in that analysis (they may be the object of further studies instead). The regression coefficient of the linear model $y = 0.0636x + 29.0825$ indicates that the operating time increases by 0.0636 min at each successive meter of distance.

In the course of the observations, it has been found out that the loading of the forwarder is inversely proportional to the haulage distance. That means, if we intend to rise the productivity by increasing the loads, we should decrease the haulage distance, especially, when there are steeper slopes of the terrain.

Potential users get an opportunity to calculate their proper costs in different conditions, by using forwarders, and to evaluate the competiveness of the alternative variants. That same particularly goes for companies which have been implementing conventional technologies in haulage by tractors where the cheap labour force is really considered a hindrance for investments for specialized forestry machinery. The technical state of the machinery is extremely important for a timely utilization of wood, especially in case the works are performed in calamities (see Table 5).

The results from the analysis carried out for determining the impact caused by the haulage on the soil during the use of John Deere 1110 D forwarder are shown in Table 6-8. Note: The roads in the Cutting area Nr 2 are at every 50-60 m while in the Cutting area Nr 5 there is a haulage road in the middle part of the area.

It is evident from the structural aggregates grouping in the cutting area Nr 2 that there is a predominance of the “coarse granular” to the “crumb-grainy” fraction; the same is the situation in the cutting area Nr 5, the control excluded; that means, as a whole, in all of the experimental areas of both the cutting areas, the structure is of a “coarse granular” type (see Fig. 2).

Taking into account the importance of the soil structure

Table 4. Verification of parameters significance and model adequacy.

ANOVA	df	SS	MS	F	Significance F
Regression	1	17330.62	17330.62	4.665.024	$6.07\ 10^{-10}$
Residual	103	38264.63	3.715.013		
Total	104	55595.26			
	Coefficients	Standard Error	t Stat	P-value	
Intercept	2.908.245	1.033.827	2.813.088	0.005877	
Distance, m	0.063616	0.009314	6.830.098	$6.07\ 10^{-10}$	

Table 5. Repairs on John Deere 1110 D forwarder.

2013	2014
Sealers, valves, brake system etc. 2325.0 €	Rolls, thermostat, seals, brake chambers etc. 2664.0 €

Figure 4

Figure 5

as a significant factor for soil fertility, an ascertainment can be suddenly drawn that none of the essential soil indices has been breached. A change has been found in the soil structure, compared to the control, in the cutting areas and on the haulage roads, as it is considered essential on the haulage roads. Regardless of the fact that the soil structure remains unchanged, as a whole, if it is examined in details, some substantial changes may be found out of its aggregates quantity in the single fractions. Such changes indicate a decrease of the aggregates of the "crumb-grainy" fraction while there is an increase in the quantity of the aggregates in the dusty fraction, even a more substantial increase found in soil along the haulage roads.

It is not only the type of the soil structure, which is considered essentially important From the point of view of the soil fertility; the water resistance of the soil aggregates is also significant, as it can be seen in Table 6. Besides, the data on the soil voluminous density are shown in that same table. There is an increase of density caused by the mechanical pressure on the soil: that increase is more significant on the haulage road along the cutting area Nr 5. It is also ascertained by the studies on soil hardness. As regard to the soil-hydrological constants, no differences have been found out, compared to the control. No data about such constants are enclosed hereto, as a logical inference can be made about the influence by the forwarder on the constants and that inference also results from the above said ascertainments. As an example of influence exerted by the implemented technology on the soil can be mentioned the decrease of the dead forest cover – more significant on the haulage roads. Such type of influence may be determined as limited in area and inevitable.

It is evident from what exposed to that point that changes occur in the soil layers in wood material forwarding: such changes are less significant in the cutting areas (if a frequent penetration of the forwarder in the stands is avoided) and more significant on the haulage roads. The delineation of the haulage road is important not only for the improvement of the forwarding operations but for avoiding damages, too; and in that way, less injuries would occur in the stand.

It is interesting to note that by increasing the roads density at each 50-60 m the number of the wheel-tracks in the cutting areas and their depth decrease, i.e. there are less severe damages on the soil (Fig.4). But the situation is quite different on main haulage roads, instead, because not only changes in soil structure occur there but the soil

Table 6. Structural analysis of the soil samples - Physical-chemical analysis.

Physical-chemical analysis				
Cutting area	Location	Moment humidity, %	Volume density g/cm^3	Limited field moisture capacity %
Nr 2	Control	37.81	1.18	27.74
	Cutting area	38.3	1.21	31.78
	Strip (forwarding) road	33.35	1.32	30.14
Nr 5	Control	31.6	1.23	31.59
	Cutting area	25.98	1.34	28.56
	Strip (forwarding) road	30.73	1.31	30.21

	Humus, %	Dead cover, g/m2	Hardness, kg/cm2	
			0 cm	10 cm
Nr 2	4,856	303,73	16,9	22,2
	3,800	256,71	18,7	25,0
	3,631	127,38	23,8	30,3
Nr 5	3,589	228,32	20,8	23,2
	3,420	196,13	25,0	34,5
	3,378	83,86	33,3	58,8

Table 7. Structural analysis of the soil samples - Macro-aggregate analysis.

Macro-aggregate analysis							
	Fractions size, mm	>10	5-10	5 - 2,5	2,5 - 1	1 – 0,25	<0,25
Nr 2	Control	51.08	21.47	10.47	16.82	0.09	0.06
	Cutting area	55.05	19.87	9.63	9.3	4.91	1.25
	Strip (forwarding road)	77.85	11.45	8.49	0.13	0.04	2.05
Nr 5	Control	32.98	21.95	15.62	17.44	10.73	1.26
	Cutting area	60.14	20.82	12.77	2.55	1.39	2.33
	Strip (forwarding road)	74.08	11.9	4.29	3.61	2.52	3.59

Table 8. Structural analysis of the soil samples - Water resistance of the structural aggregates.

Water resistance of the structural aggregates					
	>5	5 - 2,5	2,5 - 1	1 – 0,25	<0,25
Nr 2	66.38	4.62	5.78	13.51	9.7
	35.39	8.82	13.45	27.99	14.29
	21.1	15.36	22.03	27.58	13.92
Nr 5	15.42	12.07	17.13	29.76	25.61
	11.12	10.68	33.33	30.27	14.64
	5.58	13.94	23.63	42.82	14.03

structure is strongly compacted where deep tracks remains of the maximum depth even to 600 mm are (Fig. 5).

It is obvious that in soils of a high moisture content where reiterated cycles are performed by the forwarder, it is better to use chains on the rear wheels – and that same was done by us. Using of chains in conditions as the above described ones ensures the mobility of the forwarder and leads to a drop in the nominal pressure on soil and consequently, to a lower extent of damages and injuries in the stands.

4. Conclusion

That comparatively higher daily productivity of 28 m^3gained in the past by MSI 100 assortment haulage tractor, made in Bulgaria, was considered unable to impose the above said machine because of its comparatively low productivity and significant technical imperfections. When John Deere 1110 D forwarder is used, its productivity results 1,9 times higher compared to Bulgarian assortment tractor one and 6,8 times higher compared to the animal-powered haulage which is being used in a large scale now, in our country.

The forwarder operator‘s experience is of a great importance for a rise in the rate of productivity. Just to make a comparison: after six month of work there is an increase of productivity by 4,3%, in a year time its rise arrives at 20,1%, and no further changes will follow in it. The experienced operator is a good observer of the entire system, being skilled and able to demonstrate a prompt and reliable motor sensory reaction, especially in loading-unloading operations.

Four equations have been made, based on the empirical data: and the linear model $y = 0.0636x + 29.0825$ has resulted as the most appropriate one. A proof of that is the standard error of the estimate $Sy = 19.0899$ and of the index Sign.$F = 6.07\ 10^{-10}$. The obtained values of the correlation coefficient R=0.558 and the determination one indicate a direct relationship and give a proof that 31.2% of the changes in the working time depend on the changes in the haulage distance while the rest ones: 68.8% are due to other factors non included in the present analysis (factors which can be objects of further studies). Hence, the haulage distance exerts a significant influence on the time consumption for the forwarding of wood materials by John Deere 1110 D.

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Evaluation of skidding system by MB Trac 900 forest tractors on steep slopes in thinning operations

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Abstract
The aim of this paper is to determine the productivity of skidding with a MB Trac 900 forest tractor using a cut-to-length system in a spruce forest on steep terrain in Northern Turkey. The cut-to-length system is one of the most widely used harvesting methods in Turkish forestry. In steep slope areas, uphill extraction activities are mostly performed by skidding with forest tractors. The elements of the skidding work phase were identified and 34 working cycles were recorded for the study. The models for effective time consumption, total productivity and work phase models are calculated. The average total time of cycle was measured as 7.490 min for uphill logging. The average load per cycle and the average skidding distance were 1.066 m³ and 94.706 m, respectively. The results also indicated that the productivity of cable skidding by forest tractor is 8.467 m³/h.

Keywords
MB Trac 900, cut-to-length, uphill yarding, steep slope, thinning operations

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1. Introduction

It is produced in Turkey forest approximately 13 to 13,5 million m³/h timber and 5-5,5 million m³/h firewood (Cilan, 2013). Ensuring optimum efficiency from the forest in order to meet the needs of the community has gained a great importance especially in countries where have imbalance between production and consumption of wood raw material.

Timber extracting activities are difficult, expensive, high risk of accidents and harmful activities (Johns et al., 1996; Pereira et al., 2002; Ünver and Acar, 2009). Timber procurement (made up of timber harvesting and transport) is one of the most costly operations within the forestry value chain, accounting for up to 70% of the total expenses (Warkotsch, 1994). Especially, timber harvesting takes place under difficult conditions in the mountains.

Efforts to design more efficient timber harvesting systems on steep terrain have led to mechanization of working systems. Technology improvements were driving forces for economic improvements and therefore provide a significant contribution to sustaining the competitiveness of forest enterprises (Stampfer and Steinmüller, 2001).

The productivity of MB Trac 900 tractor for 50 m skidding distance was calculated 6,300m³/h in Artvin Region (Acar, 1997). The productivity of the wheeled skidder in Caspian forests having below 30% slope was found 8,6 m³/h (Barari et al., 2011). Increasing the average skidding distance during the forest operations decreases the efficiency of machines. In the other study, it was found the transportation time for ground-based skidding by MB Trac 900 tractor on gentle slopes for average 600m and 300m were 33 min. and 21 min., respectively. Amount of load for each time was 3,49 8m³ and 3,315 m³ (Öztürk and Demir, 2005). The objectives of this study are to find the production rates (m³/h) of ground-based skidding by forest tractor operations and to develop a regression model of the work phases.

2. Material and Methods

This study was carried out on compartment 27 in Trabzon forests in the northeast of Turkey. The slope, area and stand type of the compartment are 60%, 13,6 ha and Lcd3/KnLcd3, respectively. Dominant canopy species include Picea orientalis (L.) Link. and Fagus orientalis Lipsky. Total 140 trees were cut in this compartment and the total volume of production was 318 m3. During ground-based skidding in uphill yarding, the forest tractor type used MB Trac 900 Turbo, with the power of 63 KW and the weight was 6360 kg (Figure 1-a). Average length and weight of the skidding route are 130m and 1,5 m, respectively (Figure 1-b).

Operational variables for cable skidding with forest tractor measured in the field include number, diameter and length of logs per turn, skidding distance (m) and ground slope (%).The volume per log (m³) was computed by Huber volume formula in Equ. (1).

$$v = (\frac{\pi}{4}) * d^2 * L \tag{1}$$

Where; V, volume of log (m³); d, diameter of log (m) and L, length of log (m) Times and operational variables were measured by using a stopwatch and recorded. Time measurement phases in a skidding cycle were composed

(a)

(b)

Figure 1. MB Trac 900 Turbo (a) and cable skidding on the ground (b).

six stages. Work phases were determined; unloaded tractor travel (f1), pulling out of cable (f2), hookup (f3), winching (f4), loaded tractor travel (f5) and unhook (f6). It also measured that the time lost when carrying the log (f7), rest breaks (f8), tractor maintenance breaks (f9), average cycle time (f10) and total time free delay (f11).

The total skidding cycle time was not included delay time. The delay times and the reasons of them were also recorded to survey form during the field study. There are three categories of delay time: personal (resting, other breaks for personal needs), mechanical (breaking and replacing, oil or gas supplement) and operational delay time (waiting of the operator because the log was not ready for skidding). SPSS 13.0 software was used for data analysis. Productivity of forest tractor was computed by Equ. (2).

$$P = \frac{V}{T} \tag{2}$$

Where P, productivity (m³/h); V, volume of log (m³) and T, time (h).

3. Results and Discussion

In this study it is aimed to find the production rates (m³/h) of ground-based skidding by forest tractor operations and to develop a regression model of the work phases.

34 timbers winched from average 94,71 m distances and time measurements were carried out. The average diameter and the length of timbers were 54,88 cm and 4,5 m, respectively. One timber skidded with the forest tractor in each cycle and the average amount of timber in each cycle was 0,1248 m³/cycle. Cable skidding by MB Trac 900 tractor took a long time about 4,24 h. Average load volume and average hourly yield were calculated 1,066 m3 / cycle and 8,4670 m³/h respectively. Similarly Najafi (2008) found that the productivity of the skidder was 6,53 m³/h. The statistics of operational variables of cable skidding with forest tractor are given in Table 1 and distribution of time consumption in each work phase is shown in Figure 2.

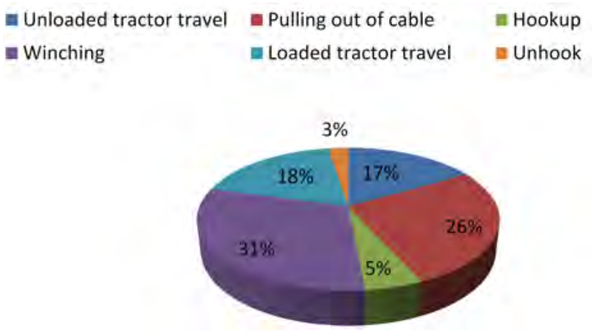

Figure 2. Distribution of time consumption in work phases.

Operational delay time, mechanical delay time and personal delay time were determined 14,087 min, 33,31 min and 20,00 min, respectively. Average delay time in this study was computed 0,54 min/cycle (Figure 3).

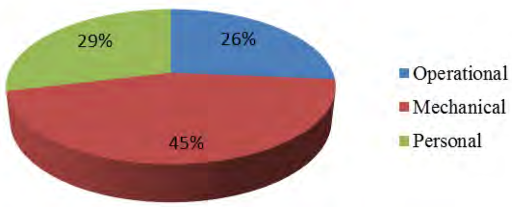

Figure 3. Distribution of delay times.

The independent variables are work phases and the dependent variable is cycle time free delay time (T). The stepwise regression analysis was applied to determine fixed coefficient and R square (R²) has been found 0,978 (98%). The regression model equation was Equ (2).

$$\begin{aligned} T = 4,568 + (18,450f1) + (10,490f2) \\ + (4,660f3) + (22,768f4) \end{aligned} \tag{3}$$

R^2 = 0,978; F = 324,060 and p-value < 0,000
Where: f1: unloaded tractor travel, f2: pulling out of cable, f3: hookup and f4: winching.

Table 1. The statistics of operational variables of cable skidding by forest tractor.

Parameter	N	Min.	Max.	Sum.	Mean	Std. Error	Std.
Skidding distance (m)	34	20,00	135,00	3220,00	947,059	528,148	3,079,603
Cycle time (min)	34	4,76	10,30	254,65	74,898	0,24687	143,950
Log volume per turn (m3)	34	0,29	2,37	36,25	10,661	0,09566	0,55778
Productivity (m³/h)	34	2,75	18,01	287,88	84,670	0,67764	395,126
Log diameter (cm)	34	30,00	84,00	1866,00	548,824	262,062	1,528,074
Unloaded travel (f1)	34	34,03	140,01	2565,70	754,618	391,893	2,285,108
Pulling out of cable (f2)	34	49,01	179,50	4074,89	1,198,496	526,374	3,069,262
Hookup (f3)	34	8,63	78,27	809,63	238,126	269,635	1,572,227
Winching (f4)	34	51,20	381,33	4712,94	1,386,159	1,155,053	6,735,060
Loaded tractor travel (f5)	34	40,38	142,08	2794,52	821,918	403,693	2,353,914
Unhook (f6)	34	8,00	23,42	399,45	117,485	0,49616	289,311

According to the significance level of ANOVA, the model is significant at 0,01. The multiple correlation coefficients are interpreted as 0,978% of total variability.

4. Conclusions

The goal of this paper was to develop a model for cable skidding with forest tractor on the steep terrain involved in cut-to-length silvicultural method. The log winching by forest tractor was carried out uphill. Length, diameter and slope of skid trail were 1,80 m, 135 m and 60%, respectively. In this study, the average total time of cycle was measured as 7,490 min for uphill logging. The average load per cycle and the average skidding distance were 1,066m3 and 94,706 m, respectively. The results also indicated that the productivity of cable skidding by forest tractor 8,467 m³/h.

The highest time consumption for uphill skidding with forest tractor was occurred during winching operation which was 31% of the total time consumption similar to Nikoyy et al. (2013) and Jourgholami (2005). It was determined that skidding distance and volume per turn was the main factors affecting the skidder productivity important.

In this study, it was found that time consumptions on work elements could generally be affected from steep slope, roughness of the surface and timber distribution over the harvesting area.

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An investigation of effects of physical damage arising from logging by man power on price of the fir log [*Abies nordmanniana* (stew.) Spach.]

H. Eroğlu[1]*, A. Öztürk[2], U. Demirci[2], R. Yilmaz[2]

Abstract
This study is aimed to determine the effects of physical damages arising from logging by man power on the selling price of fir logs in Artvin. For this purpose, end damages in fir log stacks which are exposed for sale in Hamamlı and Ormanlı forest storages in Artvin Regional Forest Directorate were determined. Then changes in estimated price and selling price of these parties due to physical damage ratio were statistically evaluated. As a result of the study, it was ascertained that there is 29.06% end damage in fir log stacks that are produced in Artvin, which is located in highlands which have high slopes with rocky and steep land. At the same time, it is found that increase in the damage ratio in fir log stacks has a negative effect on the selling price of these products. Based on these results, suggestions intended to decrease the physical damages and potential revenue loss for state forest enterprises have been made.

Keywords
logging, physical damage, revenue loss, stack, Artvin

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1. Introduction

Quality and quantity losses occur in wood products depending on non-use of appropriate techniques during logging (Eroğlu et al., 2009a; Eroğlu et al., 2009b; Holmes et al., 2002; Sist and Ferreira, 2007; Erdaş, 1986; Gürtan, 1975). Also, it is stated that as a result of unplanned production processes; insurance, amends and transportation costs increase and damage occurs in forest soil of stand (Dykstra and Heinrich, 1996; Horn et al., 2007; Jackson et al., 2002; McDonald et al., 2008; Pereira et al., 2002; Putz et al., 2008). It is important to analyze types, levels and reasons of physical damages occurring in all stages of wood raw material production in terms of determining precautions for reducing these damages. In this study it is aimed to determine economic effects of end damages occurring in log which is the most important revenue source for state forest enterprises in Turkey.

2. Material and Methods

In the study, economic effects of physical damages occurring in the production process are determined for log stacks. For this reason, economic effects of end damages arising mostly from ground skidding and occurring in the ends of the logs are determined for each log stack. In the study, based on number of logs having end damage and total number of logs in stacks, damage ratio (density) for each stack is determined. Then relationship among damage ratio, estimated price increment rate and selling price of these stacks is revealed. For this, 133 third class normal length fir log stacks having varied damage ratio are examined.

To figure out damage ratio for each stack, log end damages are based on and number of damaged (Figure 1-a) and undamaged (Figure 1-b) logs are determined. Then, based on the ratio of damaged logs to total number of logs in the stack three groups are formed as below:

1. Group: Slightly damaged stack (damage ratio is less than 10%), 2. Group: Damaged stack (damage ratio is between 10% - 50%) 3. Group: Heavily damaged stack (damage ratio is more than 50%)

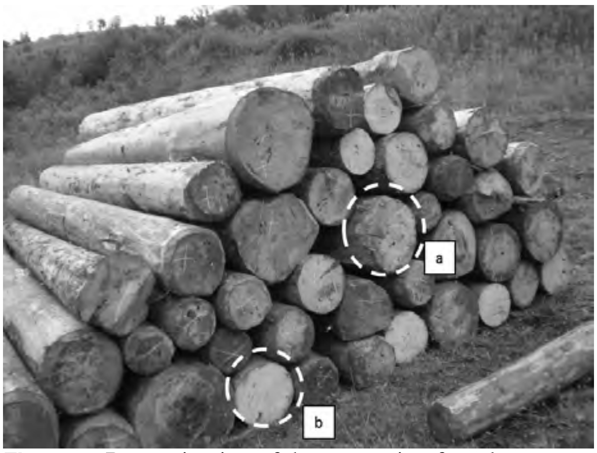

Figure 1. Determination of damage ratio of stacks (a-damaged log, b-undamaged log).

Data such as average selling price, estimated price, stack volume, number of logs etc. for each stack was obtained from sales result information tables prepared by Artvin Regional Directorate of Forestry Division of Forest Production and Marketing.

In order to present the effect of product damages on economic value of the logs, it was aimed to reveal that if there is a statistical relationship between damage ratio and estimated price increment rate and selling price of these stacks. In developed model, selling price (P) was deemed as a function of damage ratio of stacks (DaR), estimated price increment rate (EPIR) and unit product volume (UPV). As UPV increases, diameter of logs increases and usage area of the logs expands, it was estimated that there is a linear relationship between UPV and selling price. The relationship between selling price and mentioned variables is showed as below:

$$P = f(EPIR, DaR, UPV) \tag{1}$$

Where, P stands for selling price, EPIR for estimated price increment rate, DaR for the damage ratio of stacks and UPV for unit product volume.

Statistical relationship was determined by "One-Way Analysis of Variance".

3. Results and discussion

As a result of linear price model considering the relationship between fir log stacks sales price and other variables, model appears to be able to explain, statistically significantly, almost 88% of the variation in sales price of fir log stacks (Table 1).

In the model, relation between EPIR, UPV and DaR variables and sales price have the expected signs. While there is a positive correlation between EPIR and UPV variables and sales price, a negative correlation is valid for DaR variable and sales price. Relation between DaR and EPIR variables and sales price is statistically significant, but relation between UPV and sales price is not statistically significant (Table 2).

A negative correlation was found between end damage ratio arising from production process and sales price of fir log stacks. Ceteris paribus, 1 unit increase in damage ratio results is 1.37 € m^{-3}decrease in sales price. In other words, as damage ratio of stacks increases, customers bid less for these stacks. As a result, sales price of these stacks is relatively low.

With reference to sales price formed as a result of auction of third class normal length fir log stacks, average estimated price increment rate for each damage group is shown in Figure 2.

For slightly damaged stacks, sales price was 16% more than estimated price. In other words, there was a 16% value increase in sales price after auction for the stacks having a damage ratio less than 10%. On the other hand, EPIR value was 12% for damaged stacks which have a damage ratio between 10% - 50%. For the heavily damaged stacks (damage ratio is more than 50%), EPIR was 11%. This means that, EPIR value of slightly damaged stacks was 4%

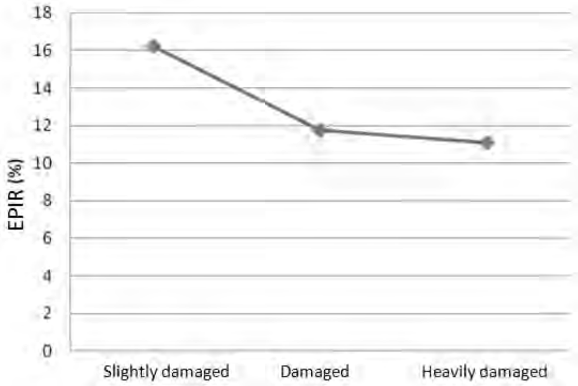

Figure 2. Average estimated price increment rate for each damage group.

and 5% more than damaged and heavily damaged stacks respectively.

When we analyze third class normal length fir log stacks based on damage groups, it can be said that as damage ratio increases, EPIR decreases. However, EPIR difference is not statistically significant. Average sales price of third class normal length fir log stacks is shown in Figure 3. Average sales price of slightly damaged stacks is more than other damage groups. While average sales price of slightly damaged stacks is 87.83 € m^{-3}, these values are 84.03 € m^{-3} and 82.51 € m^{-3} for damaged and heavily damaged stacks respectively.

When we analyze third class normal length fir log stacks based on damage groups, it can be said that as damage ratio increases, sales price decreases. However, sales price difference is not statistically significant.

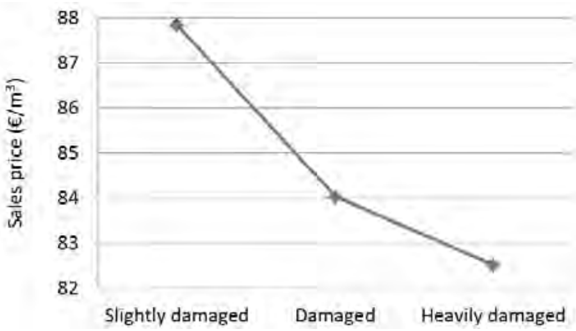

Figure 3. Average sales price for each damage group.

4. Conclusions

Physical damages arising from transportation of wood products and increase in damage ratio in these products in the forest storages have a negative effect on sales price of the wood product. This negative effect leads to potential revenue loss for state forest enterprises as most of the revenue of forest enterprises comes from wood products sales revenue. In order to prevent sales price decreases in auctions, while stacking logs in forest storages, damaged logs should not be take part in the stacks, or damage ratio should be less than 10%.

Table 1. Multiple linear regression analysis model summaries.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	
1	0.938[a]	0.879	0.875	759.718	
Change Statistics					
R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
0.879	225.199	3	93	0	1.938

[a] *Predictors: (Constant), UPV, EPIR, DaR*
[b] *Dependent Variable: Sales price*

Table 2. Multiple linear regression analysis coefficients table

	Model	Unst. Coeff. B	Std. Error	St. Beta	t	Sig.
1	(Const.)	203.558	5.875		34.651	0
	DaR	-3.599	1.755	-0.076	-2.051	0.043
	EPIR	1.472	0.058	0.926	25.538	0
	UPV	13.539	9.950	0.05	1.361	0.177

95.0% Confidence Interval for B Lower Bound	Upper Bound	Correlations Zero-order	Partial	Part	Collinearity Statistics Tolerance	VIF
191.892	215.223					
-7.084	-0.114	-0.135	-0.208	-0.074	0.945	1.059
1.358	1.587	0.934	0.936	0.921	0.99	1.010
-6.220	33.297	0.078	0.14	0.049	0.948	1.055

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Effects of experimental excavator traffic on forest floor vegetation in an *Abies sachalinensis* plantation in Hokkaido, Northern Japan

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Abstract
Hokkaido in northern Japan is ideal for cut-to-length (CTL; harvester-forwarder) systems because of its gently sloping topography, contrasting with the other regions of Japan. CTL systems have high productivity and occupational safety, however the heavy machinery might affect forest environments, such as the soil structure or vegetation. Excavator-based CTL systems, which are popular in Japan, use a number of machines that result in heavy traffic in forests compared to wheeled CTL systems that are used in Europe. However, little is known about the effects of machine traffic on forest floor vegetation in excavator-based CTL systems in Japan.
In order to examine the effects of machine traffic on forest floor vegetation, we conducted a field experiment in a 40 year old plantation of Abies sachalinensis, which is a native and popular plantation tree in Hokkaido. Within a flat 1-ha plantation, two 45m long and 7m wide experimental lanes between planted trees were used for experimental excavator runs in July 2012. The two lanes were created by thinning one line of planted trees with a spacing of approximately 3.5 m prior to the experiment. Thinning was conducted manually in March 2012 with thick snow deposit in order to not disturb the forest floor. A Komatsu PC-120, which is a 14-ton excavator with feller-buncher attachments, was used in each lane. The excavator ran four times in one lane and ten times in the other in order to pass through the same crawler footprint every time with the same speed.
Quadrats (4 m²) along each lane with 5-m intervals were used for the vegetation surveys that were conducted in; August 2011 prior to the thinning, in the experiment, and in August 2013 one year after the experiment. In the post experimental vegetation surveys, we divided each quadrat into 50-cm-wide crawler footprint areas and adjacent undisturbed areas.
The floristic composition was poor and differed greatly among the quadrats before thinning. After thinning, the species number and coverage increased. The floristic compositions became similar in the crawler footprints, although the undisturbed areas varied substantially among quadrats. The floristic convergence in the crawler footprints derived from the increase or emergence of several herbaceous species.

Keywords
traffic effect, ground flora, line thinning, mechanized logging, strip road

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1. Introduction

One of the main problems in plantation forest management in Japan is significant delay and avoidance of thinning. The delay and avoidance of thinning results poor vegetation development, which leads the decrease of forest biodiversity and that of forest productivity via topsoil runoff. The delay and avoidance of thinning in Japan is mainly due to the low profitable and high laboring nature of thinning operation. In order to reduce the cost and to increase work productivity, mechanized thinning is expected to introduce. Especially vehicle based system is effective in flat and gentle sloping terrains. Although a significant portion of land area is covered with steep slopes in Japan, Hokkaido northern part of Japan is covered with flat and gentle slopes, suitable for vehicle based mechanized thinning.

Although its effectiveness, vehicle-based mechanized thinning might provide impact on forest soil and ground vegetation. Therefore, there is a risk of falling into conflict, that thinning is effective for mediating vegetation development and soil conservation, while ground-based mechanized operation could suppress and affect ground vegetation and soil. In Japan, excavator is utilized in ground-based thinning system in current. Excavator-based thinning in Japan might have a lot of traffics of machine, since it uses grapple loader in addition to harvester and forwarder and each machine passes a forest lot of times because of their dealing capacity. Therefore it is expected that excavator-based thinning provide a substantial impact to forest soil and ground vegetation. While, any studies did not verify the effect of machine traffics on forest soil and ground vegetation in the system in Japan. In our study, we manipulate number of excavator passes experimentally, thus verify the effect of excavator traffics on ground vegetation in a plantation of *Abies sachalinensis* (Fr. Schmidt) Master, a common tree species in Hokkaido, northern part of Japan.

2. Material and Methods

2.1 Study site

The study site is a plantation of *Abies sachalinensis*, located in the experiment forest of Hokkaido Research Center of Forestry and Forest Products Research Institute in Sapporo city (42°59' N, 141°23' E., 180m a.s.l.). The climate of Sapporo city is a humid continental climate, with warm summers (mean August temperature 22.3 °C), quite cold winters (mean June temperature -3.6 °C), around 1,107 mm annual precipitation and an average snowfall of 597 cm (averages of 1981 2010). The age of the plantation was 40 years in 2012, the year of experiment. The plantation was conducted line thinning at 1997 by manually. The study site was approximate 4° flat slope, a northerly aspect and soil type was moderately moist black soil (BlD) with classification of forest soils in Japan (Forest soil division, 1975).

2.2 Excavator traffic experiment

We set 10 lanes paralleled with a contour line between planted trees. In these 10 lanes, we used 2 lanes with 7 m width (Lane No.4 and 7) in this study. The other 8 lanes with 3 m width were used in the excavator traffic for other studies. 2 wide lanes were created by thinning of one planted trees in line, originally was on border to two 3m-wide lanes as same as other 8 lanes. Thinning were conducted by manually in winter prior to the experiment to avoid the direct disturbance of logging on soil and vegetation. In July 2012, an excavator (PC 120, Komatsu Industry) which normally used for mechanized thinning in Hokkaido, ran experimentally on 2 lanes (Figure 1). Experiment was conducted in a day at 24 July, with no continuous and heavy rain during previous week. In the experiment, the excavator with a feller-buncher attachment ran same location in the lane as to trace the same tracks every run (Figure 2). The excavator ran without any logging work, with same speed. Weight of the excavator with attachment was 13, 800 kg and ground contact area of crawler was 2.88 m².

2.3 Vegetation survey and analysis

In each lane, we established two survey lines for vegetation survey prior to the experiment in 2011. Each line started from a border of natural forest to another border of larch plantation (Figure3). Along each line, we set vegetation survey quadrats with 5m interval. Vegetation survey quadrat was 2m by 2m for each, composed of four 1m² compartment. In the run experiment, excavator moved along one of survey lines, as to pass through vegetation survey quadrats. Therefore, in the post-experiment survey in 2013, we divided the area inside of quadrat into on-track and off-track

Figure 1. Excavator traffic in study site.

Figure 2. Track formation by excavator traffics.

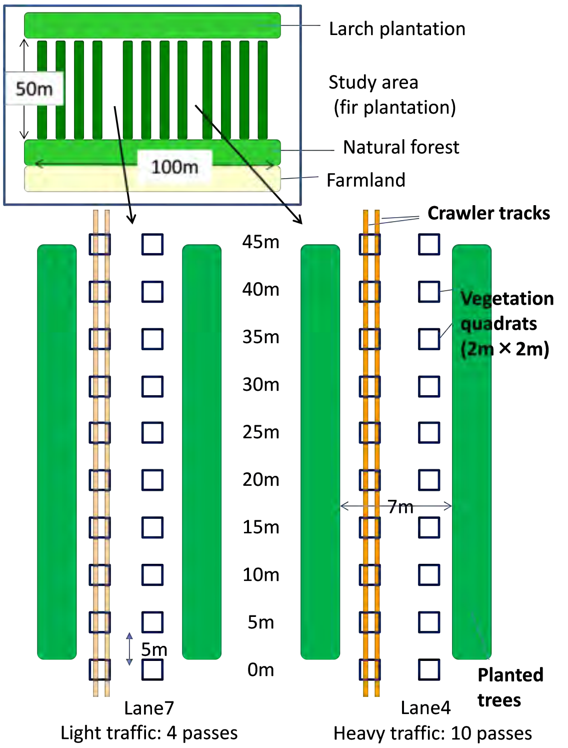

Figure 3. Arrangement of excavator traffic and vegetation survey.

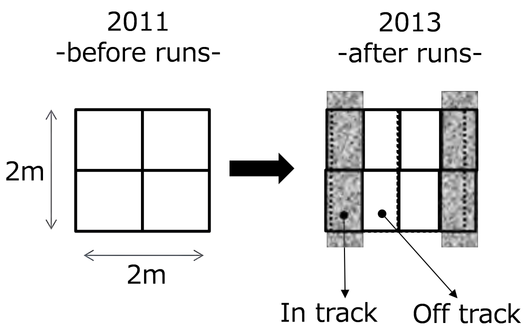

Figure 4. Divisions of vegetation survey quadrat.

area, and conducted the vegetation survey for each area (Figure4). In vegetation survey (prior experiment in 2011 and post experiment in 2013), we recorded all of vascular plant species less than 130cm high with their coverage and number of plants (except liana) ,for each area and compartment of quadrat. Coverage, occurrence and density of each plant species (releve data), were calculated b for each area (track and off-track) and quadrat compartment-based data. Total coverage was also calculated for each area (track and off-track) and quadrat.

Based on track and off-track area and quadrat calculation, we conducted multivariate analysis to ordinate and classify vegetation composition of releve data. Non-metric multivaliate scaling (MDS) was performed for plotting the compositional relationship among releve data on two-dimensional plane, with the relation of environmental factors. As environmental factors in the analysis we adopted lane and line position, distance from the edge, impact of machine traffic (expressed as number of excavator passes in the lane for each survey period), presence of track (track or off-tack), slash and log cover index. Cluster analysis was also performed for classifying the groups of releve data, which have similar or related composition. To focus on the effect of direct passage of machine, classification and regression tree models were applied to representative species, which have frequent occurrence and substantial coverage in the forest.

3. Results

3.1 Total vegetation coverage

Total vegetation cover in the quadrats showed substantial variation along edge-interior gradient for both lanes, usually was higher in edge than interior. Vegetation cover showed obvious increase after the manual thinning in off-track area in 2013 (Figure 5). Between on-track and off-track area in 2013, vegetation cover showed no significant difference for both lane (Figure 6).

3.2 Species diversity and composition

Number of species increased after thinning (in 2013) compared as before thinning (in 2011) (Figure 7).Increase of number of species was mostly due to the increase of herbaceous species. On track area, total number of species was not significantly different with off-track area. On track area, number of tree species was slightly less than off-track area. Oppositely, number of herbaceous species was slightly more than off-track area. This increase of herbaceous species on track area included the emergence of non-forest species and alien weed species.

MDS ordination of species composition and coverage of each species showed substantial variation among quadrats within and between lanes prior to thinning and machine traffic. After thinning and machine run experiment, variation among quadrats was retained in off track area of quadrats, while in track area variation was decreased and increased similarity among quadrats. MDS main axis 1 was strongly related the distance of quadrat from forest edge.

3.3 Effects of track formation and other factors on distribution of species

For main species which were frequently appeared in many quadrats and abundant both or which of track and off-track, effects of machine traffic especially of track formation and number of machine passes and other related factors were explored by classification and regression tree models. We select four species (sedge; *Carex breviculmis R. Brown (CB)*, marsh pennywort; *Hydrocotyle ramiflola Maximowicz (HR)*, poison ivy; *Rhus ambigua Lavall (RA)* and fir *A.sachalinens (AS)*) for analysis. Of four species, CB and HR were abundant in track area, whereas RA was abundant before thinning and machine traffic. Naturally regenerated seedlings of SA were included analysis.

Tree model of CB abundance showed that their distribution in the plantation was explained by the presence of track primary and by the distance from the edge secondary, in the

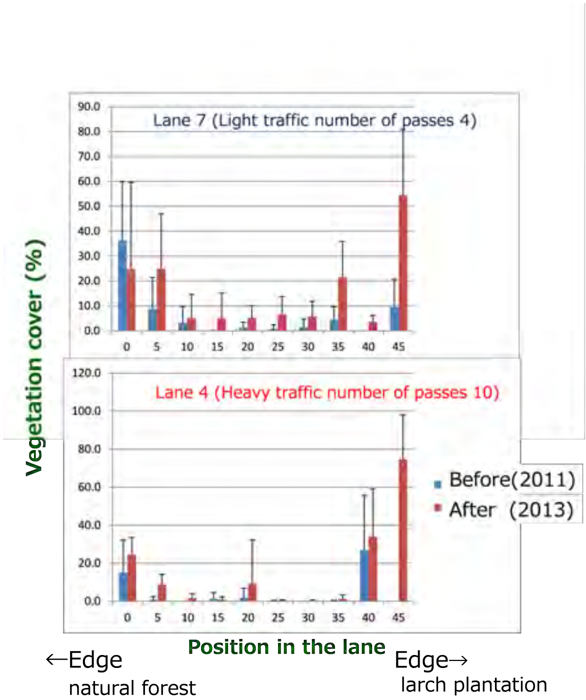

Figure 5. Total vegetation coverage before and after thinning.

Type of plants	Before(2011) Non-track	After(2013) Off-track	Track
Tree	19	18	11
Shrub	0	3	5
Liana	5	6	5
Bamboo	1	1	1
Fern	1	1	1
Herb	11	22	25
Total	37	51	48

Table 1. Species composition of quadrats before the experiment and track and off-track area after the experiment.

traffic line in lane4 with heavy traffic (Figure6). In overall model included all of lines of both lane, "track" was the dominant factor also. Presence of HR was also primary explained by "track". Thinning and distance from edge were partly explained their presence in the heaviest condition (Figure6) and the case, which all the lines and lanes were considered. In models of RA and AS, "track" was not a significant factor.

4. Discussion

In recent studies conducted in Europe and North America revealed the impact of road settlement and machine traffic (Avon et al., 2013; Wei et al., 2015; Zenner et al., 2007). Our study demonstrated the effects of machine traffic in excavator-based thinning in Japan. In our study, the case of excavator-based thinning in Japan, the number of excavator passes till 10 times mediate no obvious decrease of vegeta-

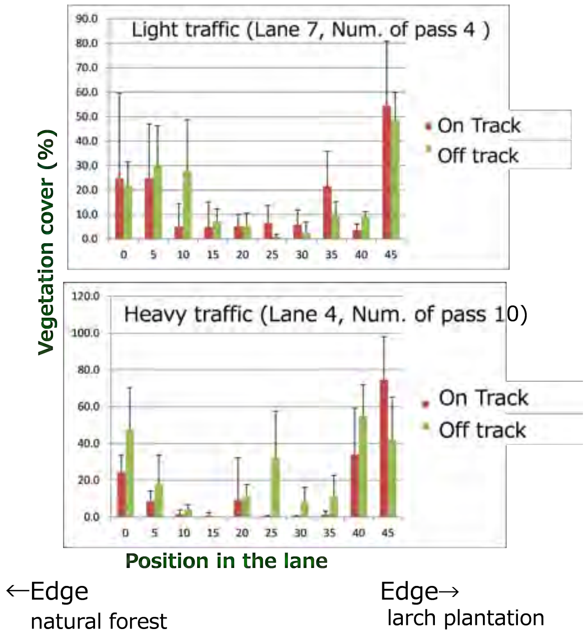

Figure 6. Total vegetation coverage between track and off-track area after thinning and machine passage.

tion cover. For the soil impacts, several studies reported that impact occurs in the first few machine passes (e.g. Han et al., 2006). In our study on vegetation impact, effect of first passes was not detected. Before thinning overstory canopy was closured, it caused poor vegetation development. Those situations might make the destructive effect of first machine passes unclear.

Kon et al. (2007) reported that in *A. sachalinensis* plantations in Hokkaido, number of species in ground flora was increased by manual thinning. They also reported that manual thinning promoted the vegetation development, especially for herbs and shrubs. Those changes were mainly due to increase of light penetration. In our study, number of species was increased by thinning, it was suggested that the increase of light penetration. Our results showed that the decrease of tree regeneration and the increase of herbaceous species on track area, which was directly affected by machine passes. Alteration of soil property mainly represented as soil compaction, direct destruction of established seedling by crawler, are possible factors to suppress tree regeneration on track area. The increase of herbaceous species on track included, obvious increase of several species mainly on track (e.g. CB), emergence of species along the tracks (e.g. HR). Emergence of herbaceous species and the decrease of tree regeneration on track might result the some simplification of flora on track. These changes were supported by the convergence of MDS plot.

Most of emergent species were non-forest species, which were not present inside the forest before thinning, while aggregated along tracks after thinning with machine traffic. Therefore, not only light increase, soil disturbance caused by machine traffic was also a possible factor of the increase of herbaceous species. Among emerged species on track after the machine passes, more than 10 were weed species

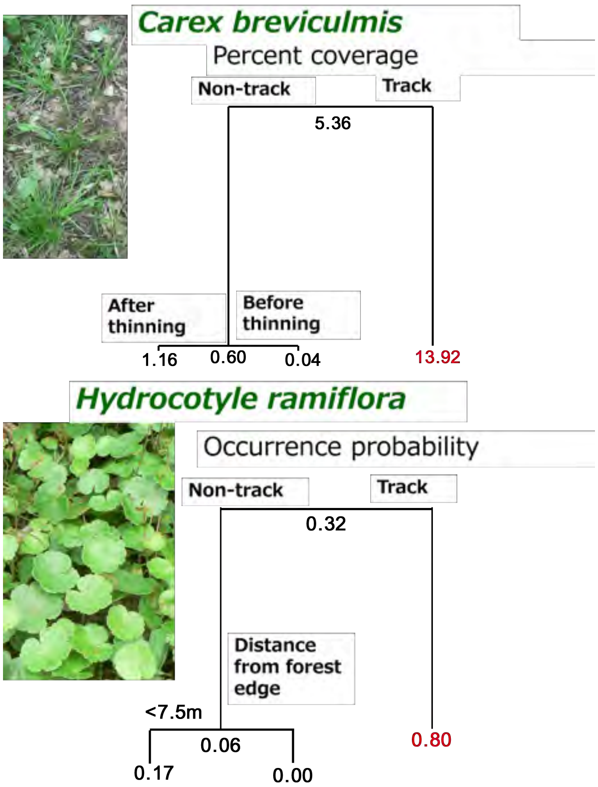

Figure 7. Tree model of CB abundance (upper: regression) and HR presence (lower: classification) in a line of traffic in lane 4, with heavy traffic.

of pasture and farmland, some of which are alien weed species such as white clover (*Trifolium repens*) and native weed species (e.g. HR) or deserted cultivars. Some of these species are fast-growing, which become strong suppressors of tree regeneration. We should monitor if these invasive species increase and colonize in forest interior in future.

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The current state and approaches to evaluation of investment attractiveness of timber industry of the Russian Federation

E. Tikhomirow*, M. Bykovskiy

Abstract
The Russian Federation forest sector adapted recently to the market relations and the requirements of global markets with a number of difficulties. Russia has more than 20% of the world's forests, but its share of the world trade in timber is not more than 4%. Of this, more than half of the exports go to the round wood and lumber (55%).
Forests cover more than half of the country, but the proportion of the forest sector of the Gross Domestic Product (GDP) is only 1.3%, of industrial production 3.7%, of employment 1% and in the country of export currency revenues 2.4%. All these facts indicate that the countries forest use is incomplete. Opportunities and prospects of the forest sector is clearly underestimated by the economic policy of the state and private investors.
The substitution of imported forestry products is a key area which offers market growth for the Russian forestry industry.
It is possible only with high investment activity in this sector of the economy. In the presence of positive factors that enhance investment processes in the timber industry complex, such as: extensive raw material base of quality forest stands, growing domestic market, formation of forest legislative, government availability of the priority strategy in forestry industry, WTO requirements, etc. There are difficulties: outdated technical base of enterprises, low density of transport networks, low attractiveness of the industry for workforce, the current state of demand for forest products necessitates, export orientation, underdeveloped legal and regulatory framework forest use, absence (for lack of) of forestry industry development in some regions, absence of a specialized engineering base, and administrative restrictions, etc.

Keywords
Russian Federation forest sector, Russian forestry industry

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1. Introduction

The forest sector of the Russian Federation recently adapted to the market economy and the requirements of global markets with a number of complications. Russia has over 20% of the world's forests, but its share in world-wide timber trade is not more than 5%.

Status of forest resource potential of the Russian Federation
Percentage of the forestland in Russia is 46%, but the spread of forests are very unevenly from the regions with 70 or more percent of the forest cover (Perm territory, the Republic of Komi) to subjects with less than 1% - Stavropol territory and others. Overall data is presented in Figure 1.

Russian forests are mainly represented by the boreal forest type. The main forest forming species are larch, pine, spruce, fir, cedar, birch, aspen. They occupy more than 98% of the land covered with forest vegetation. The stands of larch occupy 35.8%, pine - 15.6%, birch - 15.0% of forestland. Subboreal and Nemoral types of forests that contain the broad-leaved species of oak, beech, elm, linden, maple, occupy only 2% of forests.

Forest forming species of Coniferous tree groups make up 68.4%, hardwood - 2.4%, softwood - 19.3%. Other tree species (pear, chestnut, walnut, Manchurian walnut and others) occupy less than 1% of the land, the rest area - shrubs (creeping cedar, birch scrub and others.) - about 9%.

Forest area with the main forest forming species is quite stable over the past decades. Reducing the spruce area from 1988 relates to deforestation, fires and slower regeneration of spruce. Increasing area of softwood stands is explained by natural replace of conifers with the deciduous (succession) on broad slash and burnt areas, as well as by weak demand for wood of these species.

In the hardwood group, the stone birch occupies about half the area, five species of which grow in Eastern Siberia and the Far East. The most valuable species – long-boled oak and beech - occupy about a quarter of the area of the group. The area of hardwood trees remains constant due to the selected categories of protection.

Distribution of the main tree species by the following

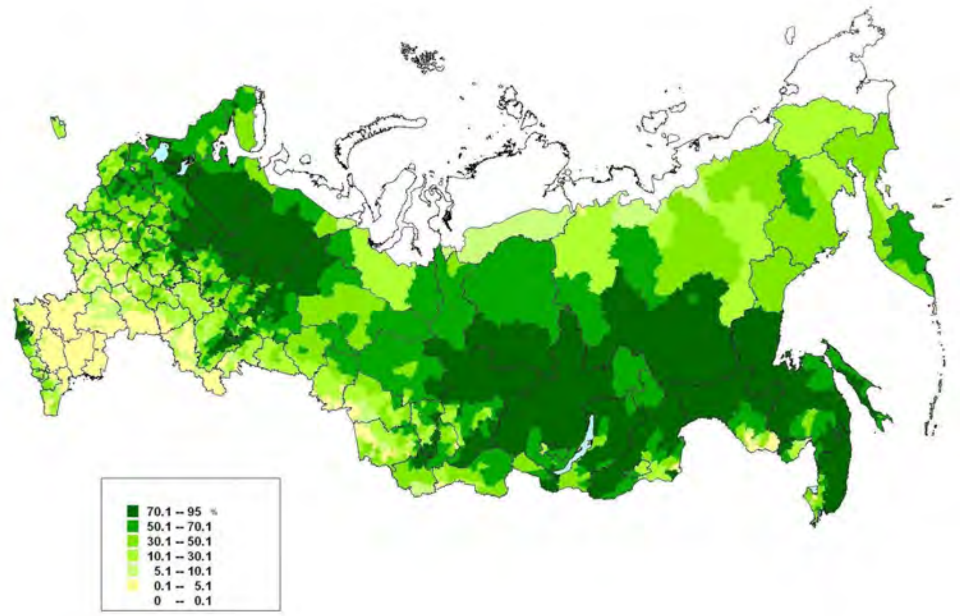

Figure 1. The percentage of the forestland in Russia (%).

age groups: young forests occupy 17.1% of middle aged - 28,5%, ripening - 10.7%, full ripe and overripe - 43.8%. About 50% of the conifer includes full ripe and overripe stands. Their accumulation occurs mainly in remote and inaccessible forest areas on lands with abundant moisture of the soil.

2. Material and Methods

The total stock of wood in the forests of the Russian Federation is equal to 83.4 billion m³, including in forests located on forestry fund lands - 80 billion m³, on the lands of the former rural forests - 3.4 billion m³. Countrywide, the average timber stock is equal to 105 m³/ha in full ripe and overripe stands (without shrubs) - 132 m³/ha, in the woods that can be used for timber harvesting, - 165 m³/ha. The annual average increase in the stock of wood in the forests of the Russian Federation is rather low and does not exceed 1.27 m³ per 1 ha of land covered with forest vegetation.

Since 2010, there have been positive changes in gross margin and growth of timber. The increase in stock occurs due to the overgrown wooded areas of forestry fund, previously owned by agricultural organizations, as well as due to increase in the area of low value stands of soft-wooded broadleaved species. There is a substantial accumulation of coniferous forest stands having low productivity on lands with abundant moisture.

More than half of the forests of the Russian Federation grow on permafrost soils (Siberia and the Far East) in a harsh climate, which determines their low productivity and fragmentation of forest stands. Only 45% of the forest area is available for use. The majority of them - in the European North, the Urals and along the Trans-Siberian Railway – are depleted because of intensive use. Economical affordability of full ripe forests is lower. Thus, the share of productive full ripe and overripe coniferous stands of I-III productivity class does not exceed 16%.

The overall average increase of stand on forestland is equal to 1 016 million m³/year, of which 853 million m³/year - in the forest legally available for logging. In accordance with the silvicultural rules, allowable capacity of timber harvesting shall not exceed the average annual growth of stands in forests, available for logging.

According to figures from experts of VNIILM (Russian National Research Institute for Silviculture and Forestry Mechanization), more than 200 million m³ of hardwood can be harvested each year without loss of country's forests. However, due to low demand for hardwood timber, in a number of regions the softwood forests are in the process of aging, increase of the part of the stands, which has the debris and decays. The forests become debris-strewn with reducing of their growth and deteriorating in the general sanitation conditions. We have the critical situation with aspen forests. They consist predominately of overripe stands, which are largely exposed to stem rot, lose their technical qualities, making them difficult to sell well.

In 2011, 196.8 million m³ of wood was harvested on forestland of FFA (Federal Forestry Agency). (Tab. 1).

Harvesting of predominantly softwood inevitably leads to changing of species and depletion of coniferous stands. Established volume of annual outturn of timber in 2010 amounted to 634 million m³, including 61 million m³ in protective forests and 573 million m³ - in merchantable forest. The largest volume of annual allowable timber harvesting in the pine wood sector amounted to 128 million m³. The share of use of the established annual amount of timber outturn does not reach 30%.

The potential of the forest resources of the Russian Federation in federal districts is presented in Table 2. In regions, the situation is similar to forest management in

Table 1. Dynamics of timber harvesting and utilization of annual allowable cutting rate in the Russian Federation in 2003-2011.

Year	Calculated cut hm³	Volume of timber hm³	%
2003	515.9	152.3	29.5
2004	519.4	158.8	30.7
2005	526.5	160.1	30.4
2006	531.7	161.8	30.4
2007	536.6	187.5	34.9
2008	597.0	167.4	28.6
2009	626.1	158.9	25.3
2010	633.4	173.6	27.4
2011	668.7	196.8	29.4

Russia.

Production and consumption of forest products in the Russian Federation

Volumes of production of forest products for the years 1980-2012 are given on the basis of statistics in Table 3. It should be noted that these data of Rosstat (Federal State Statistics Service) may underestimate the small business. For example, according to expert estimates the lumber production in 2012 amounted to 24.7 million m³, compared with 20.3 million m³ of Rosstat estimates.

In 2012, the domestic market consumed nearly two-thirds of timber produced in the Russian Federation (61%). The rest (39%) of the products were exported. The export duties for transportation of round timber abroad, increased in 2008, significantly reduced the volume of exports of round wood. In 2010, gross revenue from exports of forest products totaled $ 9.5 billion USD and distributed by markets as follows: European countries - 37%; Asian countries - 49%; other countries - 14%.

Consumption of forest products in the domestic market is limited to the government and consumer demand. The budget funds allocated for the purchase of forest products for government needs (defense, education, healthcare, etc.) are the limiters of the government and consumer demand. Demand is determined by the consumer's purchasing power, which depends on actual revenues. According to statistics, in 2010, the actual monthly income per capita was 16,857 rubles. The share of forest products accounted for 435 rubles. per month, which is 2.6% of income.

The Russian Federation is characterized by a high degree of personal income differentiation. People with high income, who can buy wooden products, mainly live in large cities. Incomes of the population in rural areas and small provincial towns and settlements, as a rule, do not allow to generate strong demand for construction of wooden houses, purchase of furniture, books and other timber products.

Branches of chemical and chemi-mechanical processing of wood consumed 21.3% of the volume of timber harvested. This is considerably less than in countries with a highly developed forestry sector. For comparison: in the US the share of chemical and chemi-mechanical processing is 76.2%, in Finland - 84.0%, in Canada - 69.0% of the total timber-harvesting.

A large part of domestic demand for forest products in Russia is satisfied by imports. In 2010, the Russian Federation has imported 1534 thousand tons of paper. Import of paper and cardboard amounted to 2 130 million USD, paper products - 1823 million USD, furniture - 2372 million USD. The total value of import of forest products amounted to 8055 million USD. Thus, the question of import substitution should take an important place in the predictive estimates for the forest sector. The lag of Russia in per capita consumption of timber forest products behind the leading countries, particularly noticeable in such species as: timber, paper and cardboard, testifies to the possibility of increasing domestic demand for forest products.

The share of timber industry in the national and world economy at the beginning of 2011 is characterized by the following indicators: gross domestic product - 1.3%; in the volume of shipped products - 4.7%; in foreign exchange earnings from exports - 3.2%; in the number of employees in the industry - 3.2%; in investments in fixed assets - 1.5%; in the volume of world trade in wood products - 2.9%.

Investment attractiveness of the Russian timber industry

Expansion of the domestic market of timber products and the establishment of import-substituting industries are the key factors in the development of the Russian timber industry. It is possible to implement only with high investment activity in the sector. The volume of investments into development of the timber industry increases every year, despite the global financial crisis.

At the same time 80% of investments in timber industry accounts for Northwest and Central federal districts and only about 15% for the Siberia and Far East. Moreover, half of the total investments in the timber industry invested in the development of woodworking industries due to relatively low capital intensity of production and a rapid return on investment, and tariff regulation measures adopted by the Government of the Russian Federation to limit the export of unprocessed round timber.

The total volume of investment in recent years shows a positive trend of increasing the share of borrowed funds. The latter will lead to sharp reduction of round wood exports and the need to process about 35 million m³ of saw logs within Russia, which requires about 100 billion rubles of investment in lumbering only. Taking into account the production of sawmill waste, the volume of necessary investments will increase.

This will amplify the impact of such negative factors as: the weak development of the domestic market and the problem of waste production.

Therefore, in the presence of such positive factors of enhancement of investment processes in timber industry, such as: extensive forest raw material base of high-quality forest stands; growing domestic market; the formation of the legislative base of forest management; the understanding of the priority development of forestry by the public authorities and others.

There are considerable difficulties: insufficient infrastructure development on forestry fund lands; the current

Table 2. Potential of forest resources of the Russian Federation in federal districts, million cubic meters.

Russian Federation	Total stock	Ripe And overripe	Softwood	Yearly growth	Cutting rate
Central Federal District	82130	44320	34222	994	635
Northwestern Federal District	3828	876	259	78	40.4
Southern Federal District	10093	5966	4565	133	117.5
Volga Federal District	784	387	119	10	3.5
Urals Federal District	5546	2021	971	110	69.9
Siberian Federal District	7959	4056	2785	100	81.9
Far Eastern Federal District	33346	19166	15467	353	227.4

Table 3. Dynamics of production of the main types of wood and paper-based products of Russian Forestry enterprises.

Name of product	1990	1995	2000	2007	2008	2009	2010	2011	2012
timber harvesting bln.m³	304	150	165.9	207	167.4	158.8	175.5	196.7	202.2
Lumber, bln.m³	75	26.5	20	24.3	21.6	17.2	19.1	20.3	20.5
plywood, k.m³	1597	939	1484	2776.8	2592	2127.6	2686.5	3002.7	3216
Particleboard, k.m³	5568.3	2206	2334.8	5500.8	5750.7	4598.9	5465.9	6634	7164
DVP, bln..m2	418.2	234	292.2	480.6	479.2	372.5	397.7	441.6	466
Cellulose , tsd. tn.	2770	1801	2036	2420.6	2285.3	2176	2221.5	2300	2392
Paper and paperboard tsd.t	8325	4074	5312	7581.4	7699.7	7307.6	7582.8	7604	7765
Furniture, tsd bln. rub.	5.8	12.2	18.2	83.6	104.9	78.4	89.5	107.2	117

state of demand for forest products necessitates export orientation; underdeveloped legal framework of forest management; the absence of forestry development programs in some regions; lack of a reliable legal protection of property; lack of specialized engineering base; administrative restrictions; low levels of funding of industrial R & D and others.

Whereby, we should focus on the assessment of the economic efficiency of resource use in investment projects.,

Professor Balov A.V. has proposed one of approaches. Its essence is as follows. Economic evaluation of any natural resources shall be determined in terms of its sustainable use. Such an approach can be ensured by the wide application of methods of optimal planning in the field of environmental management, the use of which opens up great possibilities for the reasonable calculation of socially justifiable limits of expenditures connected with increase in output of this type of product, i.e. marginal costs.

Let us assume that there is a multitude $I = 1,...,I,...,M$ of initial recoverable resource options. After certain economic transformations, the latter may be used in other ways (in some capacity), which is denoted $J = l,...,j,...,m$. Next, we identify the kind of resource with the option of its use, and assumed to be given:

$R = 1,...,i,...,n$ a variety of products resulting from the development of the resource under consideration;

$S0_i$ initial supply of i - resource quality;

Π_2^0 the need for the r- product in year t;

a_{ir} the productivity of the resource unit of i-quality for production of the r-product;

c_{ir} current costs for development of the resource unit of i-quality for production of r-product;

c_{ij} operating costs for change-over of resource unit from the i-th category into the j-th; category

k_{ir} the cost of capital investments for the development of the resource unit of the i- quality for production of r-product;

k_{ij} specific capital intensity for resource unit change-over from i-quality into j-quality;

The unknown quantities are:

X_{ir}^t resource utilization capacity of i-quality for production of r-products in year t;

X_{ij}^t the amount of the transfer of resources from i- quality to j-quality in year t;

Y_i^t the required amount of capital investment for the development and transformation of resources in year t;

With the assumptions and notation, the problem of the rational resource management consists in minimization of cost of development and transformation of resource:

$$\sum_{t=1}^{T} g_{t-1} \sum_{i=1}^{m} \sum_{r=1}^{n} (c_{ir} x_{ir}^t + \sum_{j=1}^{m} c_{ij} x_{ji}^t + y_i^t) \rightarrow min \qquad (1)$$

under the following conditions:

$$\sum_{i=1}^{m} a_{ir} x_{ir}^t \geq \Pi_r^t \qquad t = \overline{1,T}; r = \overline{1,n} \qquad (2)$$

conditions to ensure the planned target Π_{tr} as required in the production of r-type product in year t;

$$\sum_{u=1}^{n} x_{ir}^{t} \leq S_{i}^{O} + \sum_{i=1,j\neq 1}^{m} \sum_{r=1}^{t-1} x_{ji}^{r} - \sum_{j=1,i\neq 1}^{m} \sum_{r=1}^{t} x_{ij}^{r} \qquad t=\overline{1,T}; r=\overline{1,n} \tag{3}$$

Based on restrictions, we obtain:

$$a_{ir-k_{jr}} \sum_{\tau=t+1}^{T} w_{\tau} - k_{ir} g^{t} - c_{ir} \sum_{\tau=t+1}^{T} g^{(\tau-11)} [a_{jr} \sum_{\tau=t}^{T} w_{i}^{r} - c_{jr} \sum_{\Psi=t+1}^{T} g^{\tau-1}] \leq k_{ji} u_{i}^{t} + g^{(}t-1)c_{ji} \tag{4}$$

The latter expression means that the feasibility of transferring resources from the i-category into the j-category in the t-year is conditioned by the ratio of the difference of the cumulative effects from the use of resource unit of i-category in the period $[t+1,T]$ and the j-category in the period $[t,T]$, and construction and operating costs for the transfer of resources from the i-category into the j-category in the t-year. In this case, we mean the transfer of resources from the i-category into the j- category in order to use it for production of r-products.

Marginal costs (dual assessment of production unit) for the production of r-product under the terms of t-year are determined on the basis of the restrictions. And, if we indicate resource category as i_0 for which the expression reaches its maximum, we find that:

$$\overline{w_{r}^{t}} = \frac{\overline{v_{i0}^{t}} + k_{i_0 r}\overline{u_{i}^{t} + g^{t-1} c_{i_0 r}}}{a_{i_o r}} \tag{5}$$

Where marginal costs under the terms of t-year consist of discounted costs for the development of i_0 resource category for production of r- product plus standard of efficiency of i_0-resource (i_0-dual assessment of the resource), taking into account the possible transfers it from one category to another.

Evaluation of the resource of i-category under the terms of the t-year is determined by taking into account the future effects from the transfer of resource unit of the i-quality into the j-quality, discounted costs for the implementation of this transition, as well as the effect of the use of the transferred units in the j-quality until the end of the scheduled period, i.e.

$$v_{i}^{t} \leq \sum_{r=t+1}^{\tau} v_{j}^{r} + k_{ji} u_{i}^{t} + g^{t-1} c_{ji} - \sum_{r=t+1}^{\tau} v_{i}^{r} \qquad j=\overline{1,m} \tag{6}$$

The effect of the use of the resource unit of i-quality in the production is also conditioned both by the development costs of such unit for production of r-products $(r=1,n)$, and by resource productivity for certain products.

Thus, the peculiarity of the economic valuation of reproducible resources consists in the need for its calculation in terms of each separate year, in addition, the unlimited use of their stocks also depends on the their reproduction by the quantity. At the same time, the assessment of non-renewable resources, as will be shown below, under the conditions of the scheduled period and the trajectory of their consumption have the estimate as a whole for the period rather than in terms of annual period.

3. Results

Professor N.P. Kozhemyako suggested a somewhat different method of valuation of investment attractiveness. In order to assess the readiness of the implementation of the investment project in forest development, he developed a system of indicators, taking into account the economic, budgetary and socialand technological readiness of the project (Tab. 4).

It is worth noting that the indicators system has the necessary properties of versatility and flexibility and can be used to evaluate all types of investment projects in forest development.

This indicators system allows the evaluation of the effectiveness of the investment project both at the stage of consideration of the application, and at the stage of enterprise's progress in a targeted capacity.

4. Discussion

Overall Summary and Conclusions

Russia has over 20% of the world's forests, but its share in world trade of timber accounts for 4% only. At the same time, more than half of exports accounts for the logs and lumber (54%). Forests cover more than half of the country, but the share of the forest sector in gross domestic product (GDP) was only 1.3%. This suggests that the huge potential of the country's forest is significantly underutilized. Opportunities and prospects of the forest sector are clearly underestimated by the economic policy of the state.

Expansion of the internal market of timber products and the establishment of import-substituting industries are the key factors in the development of the Russian timber industry. That is possible only with high investment activity in the sector. The volume of investments into development of the timber industry increases every year, despite the global financial crisis.

The investment attractiveness of the Russian timber industry is significant in spite of a variety of positive and negative factors. In this case, the evaluation of investment attractiveness is advantageously carried out either by evaluating the economic efficiency of resource use in investment projects or by analysis of the indicators system and availability of socio-economic efficiency of the investment project.

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Table 4. The system of indicators to assess the readiness of the implementation of the investment project.

Index name	Calculation methods
The ratio of investment activity of the enterprise ($И_{вл}$ - the volume of investments, $И_{заявл}$ - the amount declared for the project investment)	$K_{и.а} = \frac{И_{вл}}{И_{заявл}}$
The ratio of readiness of creating production facilities ($ПМ_{i.созд}$ - created production capacity for processing of raw materials, $ПМ_{i.заявл}$ - declared production capacity for processing of raw materials)	$K_{пр.мощ.} = \frac{\sum_{i=1}^{n} ПМ_{i.создан.}}{\sum_{i=1}^{n} ПМ_{i/заявл.}}$
The ratio of the level of fulfillment of social obligations on new job formation ($K_{р.м. созд}$. - the number of jobs created, the $K_{рм. заявл}$.- the number of reported jobs)	$K_{р.м.} = \frac{K_{рм.созд}}{K_{рм.заявл.}}$
The ratio of the level of fulfillment of social obligations on creation of social infrastructure ($И^{соц}_{вл}$ – the amount of investments in development of social infrastructure $И^{соц}_{заявл}$ - the amount of declared investments for the establishment of a social infrastructure under the investment project)	$K^{соц}_{и.а} = \frac{И^{соц}_{вл}}{И^{соц}_{заявл}}$
The ratio of development of the annual allowable timber harvest of leased forestry fund ($Q_{заг.древ}$.- volume of harvested wood, $Q_{ежег. доп}$ - the annual allowable timber harvest on selected woodlots)	$K_{осв.лес.рес.} = \frac{Q_{заг.древ.}}{Q_{ежег.доп.}}$
The ratio of availability of forestry fund for the lease ($Q_{арендов}$.- annual allowable timber harvest on leased forest land)	$K_{аренды.} = \frac{Q_{арендов}}{Q_{ежег.доп.}}$
Integral indicator of the readiness of the implementation of the investment project.	$K_{интегр.пр.} = K_{и.а.} * K_{пр.мощ.} * * K_{р.м.} * K^{соц.}_{и.а.} * K_{аренды}$

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Soil preparation machinery and deception of the consumers

T. Blija*

Abstract
Many different mechanisms are used in the preparation of forest soils. The biggest problem is that the tillage mechanisms names do not possible to determine their operating principles. This leads to the consumer - reforestation specialist's deception.

Keywords
mechanism of forest soil preparation, deception of the consumer

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1. Introduction

Forest soil preparation for reforestation in cleared areas is well known and recognized (Upītis H.,1931). In ancient times soil preparation was done by mechanisms powered by humans or horses. More powerful and complex mechanisms for soil preparation were invented through technological development. Designers of the new technology drifted apart from end users which led to dissonance among technical thought and forestry needs. Over the years more young mechanical engineers are involved in development process of new technology for forest soil preparation. The issue is that these specialists lack knowledge in forestry specifically in forest soil preparation process. This is not a regional but global issue that leads to inadequate usage of technology and incorrect titles.

2. Material and Methods

Firstly mechanism operational principles and application opportunities will be determined. Every mechanism or tool has theoretical justification for its operation (Gasiņš L. 1975). Secondly forest soil processing mechanism application opportunities and necessity will be determined. The evaluation will be based on particular forest growth and embossing circumstances (Mangalis I. 1980, 1989, 2004). Forest soil preparations mechanisms are based on four principles of soil:

- excavations,
- drilling,
- ploughing,
- soil milling

2.1 Operational theory of Forest soil preparation mechanisms

Excavation - soil digging and relocation (Gasiņš L. 1975)
It is the simplest form of soil preparation that is based on shovel operational principle. Shovel is inserted in the soil then removed with a piece of soil that is put next to the pit. Three favorable places for tree planting have been created:

- pit,
- side of the pit,
- on the soil that has been taken out of the pit.

Drilling–drilling of the soil with large soil drills (Gasiņš L. 1975)
A pit is drilled in the soil where the plant later on is inserted.

Ploughing – soil transformation using three wedge theory (Gasiņš L. 1975)
Three wedge theory has been further discussed in Formec Graca (Blija.T 2011).

Soil milling – soil crushing with several types of chisels or knifes (Gasiņš L. 1975)
Soil milling is the process of crushing soil together with plant parts that are located on it. A margin of crushed soil with plant parts is created after soil mill has been used.

3. Results

Unpleasant situations occurred in fieldwork. Several forestry specialists have asked me to explain the title and usage possibilities of diverse forest soil preparation mechanisms. Often usage possibilities of a mechanism are explained as principles of operation (Czech Republic, Sweden and Finland). This tendency is incorrect and leads to consumer misleading. Some forest soil preparations mechanism producers are mistakenly naming ploughs as mills or scarifiers. This phenomena is occurring in Europe e.g. Czech Republic (TPF-1,TPF-2 (Diskinėfreza TPF-2)).

Issue with incorrect titles is occurring also in Nordic countries e.g. Latvia, Sweden and Finland. Disc trenchersT21.b, Bracke T26.a - Disc trencher, Bracke T35.a - 3- Row Disc Trencher.

These all are disc ploughs that can carry out scarification as it is stated in internet advertisement: "Trencher

Figure 1. Diskinėfreza TPF-2.

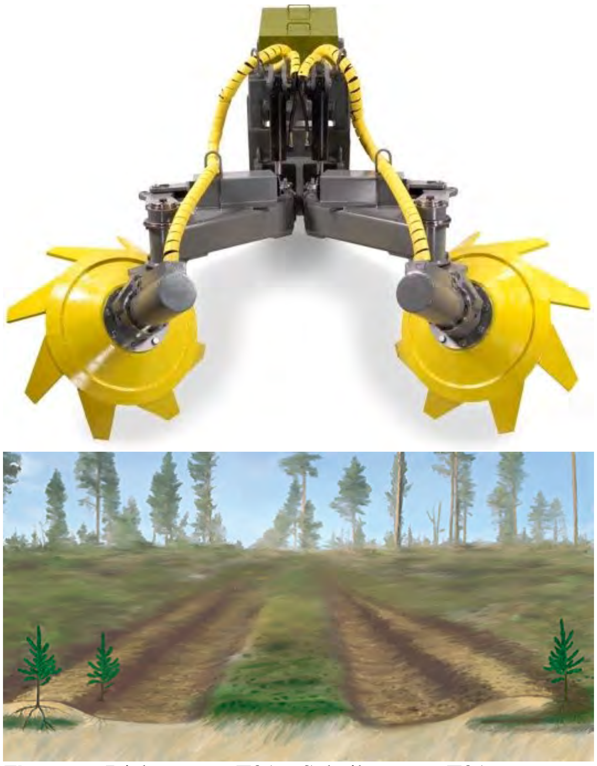

Figure 2. Disk trencer T21.a Scheibenegge T21.a (www.brackeforest.com)

Scarification with the T21.b gives plants and seeds a good start for growth and survival." As mentioned disc ploughs can carry out not only scarification in rich soul of Finland and Sweden where the soil is fruitful 10-25 cm but also other soil preparation activities. In other soils T21.b can create furrows that differ in depth (up to 40 cm deep). This process is not called scarification.

Soil mill with natural elements for comparison
When looking at Picture 2 it is clear how to not mix disc ploughs with mills.

Figure 3. Soil milling mechanisms.

4. Discussion

I have been asked by my former students about incongruity among forest soil processing machinery titles. The answer is quite simple. Soil processing machinery is developed by highly trained mechanical engineers. Forestry specialists are in most of the cases not involved in the development process of new machinery. Moreover the mechanical engineers are lacking basic knowledge in theory of soil processing. One example:

How to distinguish ploughs from mills? It can be done easily if previously developed forest plough classification is used (T.Blija FORMEC 2013, 2011). An overview of classification is available in figure 4.

Forest ploughs and mills cannot be mixed if the mentioned classification is used. Thereby the discussion about plough and mill disparities should be concluded. Correct

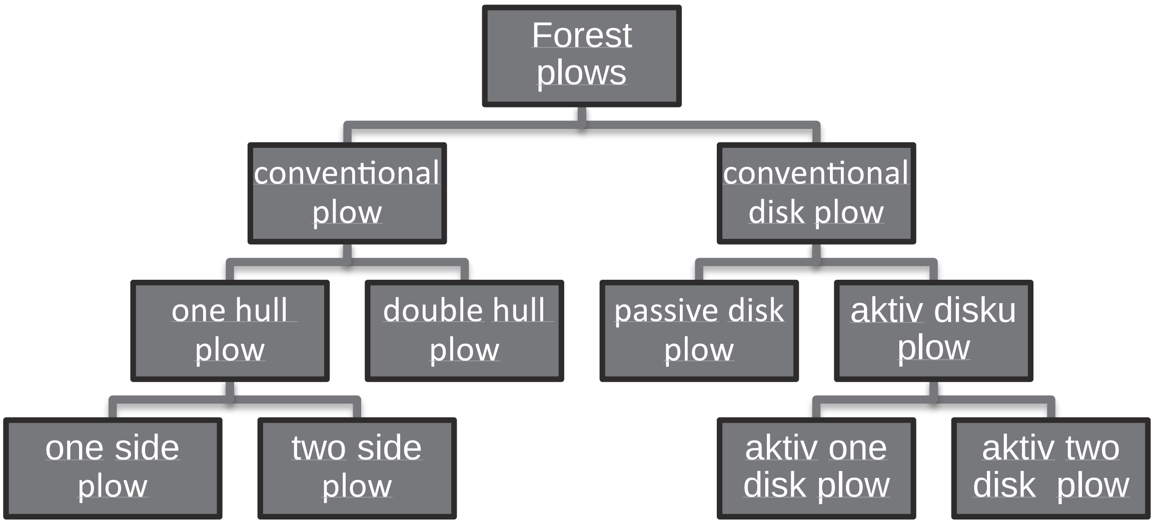

Figure 4. Forest plough classification by T.Blija.

titles should be given to the new machinery to avoid consumer misleading.

5. Conclusion

1. United forest soil machinery classification should be implemented in Europe to avoid consumer misleading
2. Greater attention should be directed to the operational theory of forest soil processing mechanisms and the actual operational possibilities of mentioned mechanisms.
3. Following change should be implemented in Forestry University programs: *Chapters about forest soil machinery operational principles and actual operational possibilities should be included in reforestation study module.*
4. Seminars regarding operational principles of forest soil processing machinery and the actual operational possibilities should be led to machinery producers and contractors.

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Feasibility study of timber harvesting systems on steep terrain in Thailand

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Abstract
Timber harvesting on steep terrain is perceived to be more expensive and complicated than conventional timber harvesting. In addition, the role of environmental effects in timber harvesting on highlands has high importance in decision making and planning logging operations. It requires several aspects of knowledge to select an optimal method of operation. The selection of suitable harvesting systems aims to identify individually compatible and environmentally sound solutions for the area of interest.
This research was conducted at Royal Agricultural Station Angkhang, which is located in the Chiang Mai Province, Thailand. Research methodology can be classified into 5 main steps: 1) define study area, 2) study feasibility, 3) select the suitable harvesting system, 4) design, introduce and install the best suitable system into area, and 5) evaluate the system performance. This research is based on GIS analysis. GIS helps to compare harvesting systems and determines the suitable harvesting system with consideration of the local circumstances and conditions.
This paper presents only a result from a feasibility study, the result indicated direction of extraction has significant impact on extraction method and potential harvesting area of each logging system. Felling with chainsaw and extracting with iron horse had the highest potential harvesting area among other logging systems.

Keywords
feasibilities, timber harvesting, logging systems, steep terrain

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1. Introduction

A timber harvesting system is one of several combinations of equipment used for felling and extracting timber. Every system requires (1) a mechanism for felling trees and (2) a mechanism for removing felled trees to a roadside log landing for transportation to a mill. Matching the equipment to the site, implementing proper harvest layout, and hiring a skilled operator all contribute to successful logging. Timber harvesting systems vary from place to place, depending on the available resources, technology, labor costs, and other circumstances. Many levels of technology have been implemented globally from manual work to full mechanization. When considering a "best suitable harvesting system" is often misunderstood that the cheapest harvesting method is the best practice. Costs, are in many cases, an important factor, often the most important factor, however they are not the only factor. A "best suitable harvesting system" can also be understood as being the most optimal procedure under consideration of certain basic conditions. Principle of harvesting system selection could be carried out taking into account the basic conditions. The first step is the choice of timber harvesting procedure taking into account the basic conditions: topography, soil, access, stand, planned operation, proposed technique, workers, risks for the stand and damage to the soil, and weather. In a follow up step the technically possible procedures are then considered from an economic and environment point of view. The timber harvesting costs are then calculated. Profits are estimated using actual market prices. Timber harvesting on steep terrain is perceived to be more expensive and complicated than conventional timber harvesting. In addition, the role of environmental effects in timber harvesting on highland has great importance in decision making and planning logging operations. Consequently, more emphasis should be put on a planning system so that environmentally sensitive sites for a certain harvesting system can be recognized and the most suitable machinery selected for given terrain conditions. The specific objectives of this research are:

- to identify a suitable harvesting system into studied area (simple, economical, and environmental friendly).
- to test the harvesting system in area of interest.
- to distribute the knowledge as a prototype to whom who may interested i.e. small scale forest plantation on highland.

2. Material and Methods

This research was conducted at Royal Agricultural Station Angk-hang, which located in Ban Khum Village, Mae ngon Sub district, Amphure Fang, Chiang Mai Province. This station located at average point above sea level of 1400 meters. Total area covers 1,989 rai (318.24 hectare).

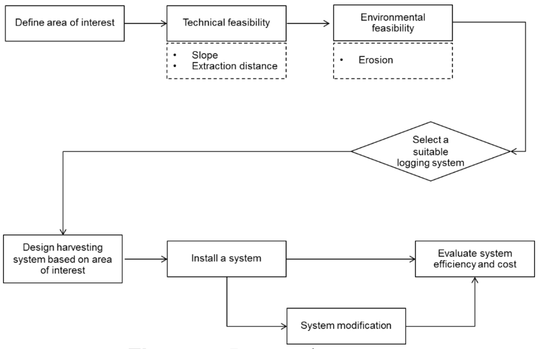

Figure 1. Research process.

Research methodology can classify into 5 main steps: 1) define study area, 2) study feasibility, 3) select the suitable harvesting system, 4) design, introduce and install the best suitable system into area, and 5) evaluate the system performance (Figure 1). First, the area of interested is defined. Then, feasibility study of timber harvesting determines their compatibility with location factors. The utility analysis of environment aspect is also including in feasibility analysis as well. In this feasibility study step, a GIS based evaluation is designed to support the forest operations decision making process. It helps to compare harvesting systems and determines the best suitable harvesting systems in consideration of local circumstances and conditions. Afterwards, the most important step is to design and implement the best harvesting system that obtained from model into the area of interest. Last, evaluation of introduced system is needed in order to assess system efficiency and operating cost.

Five different logging systems have been taken into consideration for technical feasibility test (Table 1). All are semi-mechanization timber harvesting with cut to length (CTL) method. Limitations of each logging system are described in Table 1.

3. Results

Timber extraction direction (downhill and uphill) has significant impact on extraction method and potential harvesting area of each logging system. The distribution of logging systems in studied area showed in Figure 2. Perhaps, one area may have more than one logging systems that can be applied.

Felling with chainsaw and extracting with iron horse given the highest potential harvesting area among other logging systems. The possibility of extracting timber with iron horse is greater than 80% of area in both cases of downhill and uphill extraction. While, the potential of extracting timber with small tower yarder is just 5 and 16% of the studies area, for downhill and uphill extraction, respectively (Table 2). Shifting from downhill to uphill extraction, most of extraction methods decline the potential harvesting area, but the possibility of extracting timber with small tower yarder is three times increasing. In addition, extracting timber with animal power decreased the potential area of harvesting dramatically when shifting from downhill to uphill, from 82% harvesting area to 25%.

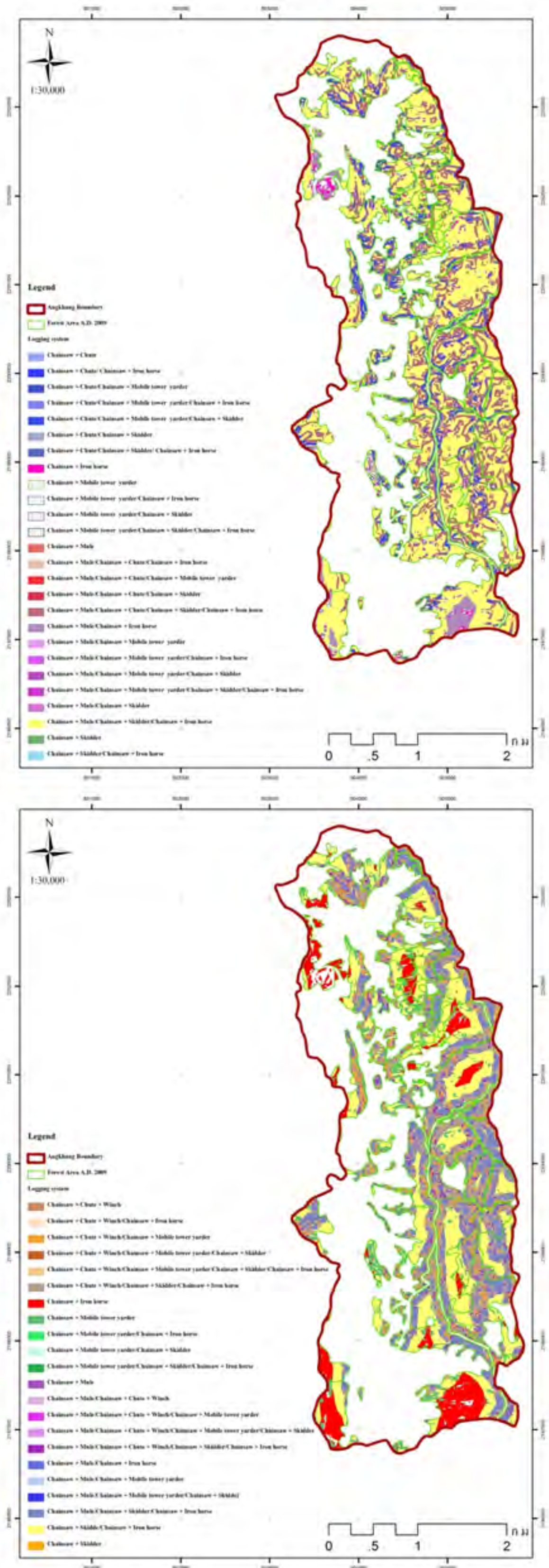

Figure 2. Map showing distribution of feasible logging systems in the studied area (top) downhill extraction (below) uphill extraction

Table 1. Logging systems and equipment subject to terrain data.

	Logging system	Downhill	Uphill
1	Chainsaw & Mule	Slope < 30% Extraction dist. < 200 m	Slope < 20% Extraction dist. < 100 m
2	Chainsaw & Iron horse	Slope < 40% Extraction dist. < 500 m	Slope < 30% Extraction dist. < 500 m
3	Chainsaw & Log chute	Slope 20-50% Extraction dist. < 150 m	Slope 15-45% Extraction dist. < 100 m
4	Chainsaw & Small tower yarder	Slope 40-100% Extraction dist. < 250 m	Slope 30-100% Extraction dist. < 250 m
5	Chainsaw & Skidder	Slope < 35% Extraction dist. < 300 m	Slope < 30% Extraction dist. < 200 m

Table 2. Potential harvesting areas based on technical evaluation.

	Potential harvesting area			
Logging system	Downhill		Uphill	
	ha	%	ha	%
Chainsaw & Iron horse	652.31	0.9432	572.51	0.8345
Chainsaw & Skidder	572.02	0.8271	501.49	0.731
Chainsaw & Mule	572.24	0.8274	174.1	0.2538
Chainsaw & Log chute	291.06	0.4064	229.69	0.3348
Chainsaw & Small tower yarder	38.38	0.0555	113.7	0.1657

4. Discussion

Note that result of this paper is presented only results of technical feasibility study, had not include the environmental factor into consideration yet. Thus the initial results showed some areas where more than one logging systems are possible to be implemented. Next step is to weight other related concerns into account, for instance, erosion risk, operating cost and work safety. Potential harvesting area of Kühmaier and Stampfer (2010) showed that helicopter and cable logging were the most favorable extraction operation, on the contrary, this study extracting timber with small tower yarder is not preferred. The lack of road network might be a cause for this reason. Extracting timber with mule is dramatically decrease the potential harvesting area of 82% downhill to 25% of studied area uphill extraction that because animal is more sensitive to tough conditions compared to machine. To conclude, direction of extraction has significant impact on extraction method and potential harvesting area of each logging system.

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Dendromass production technology on woody energy plantations

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Abstract
A much more renewable energy utilized green based economy needs to be built in Hungary, this method would avoid economic dependence. Biomass as a "green energy" could be the long-term solution. The majority of the biomass is wood-based (i.e. dendromass). One alternative for producing large quantities of wood in a short time are woody energy plantations. This research examines the past and present situation of woody energy plantations. The energy plantations examination looks back more than a decade, but their area is not significant yet. The biggest area is producing poplars including AF2 and Monviso clones.
The results of examinations have proven that with stump diameters between 8-112 mm or 2-90 mm diameters at breast height, the tree mass can be estimated, thus the plantation yield can be determined. As such we can value the plantation yield without cutting the trees down.
We analysed that problems which influence the plantations yield and survival. There are problems of woody energy plantations mechanization (planting, cultivation, harvesting) were also examined. For example a new harvesting machine prototype was prepared.
Finally we examined the relation between the plantations and markets. We established that the dendromass quantity from the plantations is only minimally sufficient to the needs of power stations.

Keywords
dendromass, energy plantations, tree mass estimation, yield of the plantations, machine development

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1. Introduction

In 2013 the primary energy consumption was 960,5 PJ (KSH, 2015) in Hungary. It had about 9,8% (∼94 PJ) came from renewable energy sources, the fossil energy dependence is significant. It would be wiser to build our future on a green economy basing on local renewable resources instead of depending on import-based and incalculable energies.

Our country renewable energy potential would enables that we could meet almost the half of our energy demand. In view of the country ability our possibility long distance is the „green energy". Not only has biomass a significant role in energetics but is an important factor to rural and agricultural development too. The majority of this biomass is wood-based (Gőgös, 2005; Czupy et al., 2012.). One of the possibility the fast and large biomass production is energy plantation.

2. Situation of energy plantation in our country

Energy plantations examination look back more decade equally in abroad and our country. Before 2005 had been energy plantations examinations on 50-60 ha. If we had started the energy plantations deployment in 2005-2006 on 5-10000 ha the energy plantation area should grow 60000 ha by 2010. 1 million t/year biomass were produced on this area. (counting 16 t/ha/year) (Giber et al., 2005).

The first data of energy plantations area we traceable in 2009: 1505 ha. (Szajkó et al., 2009). By data of Forest management NÉBIH the announced energy plantations area are in year 2012 2080 ha (NÉBIH, 2012), in 2013: 2338 ha, in 2015: 3268 ha (NÉBIH, 2015).

Analyse the area distrain we can visible (Fig. 1.) that the region South Transdanubia is prominent, where is found important outlet. (Pannonpower group).

Energy plantations should be installed in a location where the markets are available. Three species territorial control are significant in our country: poplar, willow, and locust. This species deployment authorized by relevant law. The poplar species have got the most significant area (76%), followed by willows (15%) and standing of the line the locust (9%) (details tab year 2015).

Two Italian varieties territorial control are significant out of poplars: AF2 clone 1699 ha and Monviso clone 459 ha. In one respect these varieties adulterant stand by the market and the other hand the yield these clones are greater 10% than the remaining clones.

3. Yield estimation on woody energy plantation

Because of the lack of yield estimation functions in Hungary, and in order to develop a tool to predict yield we made a suite of own measurements in 36 separate plantations by

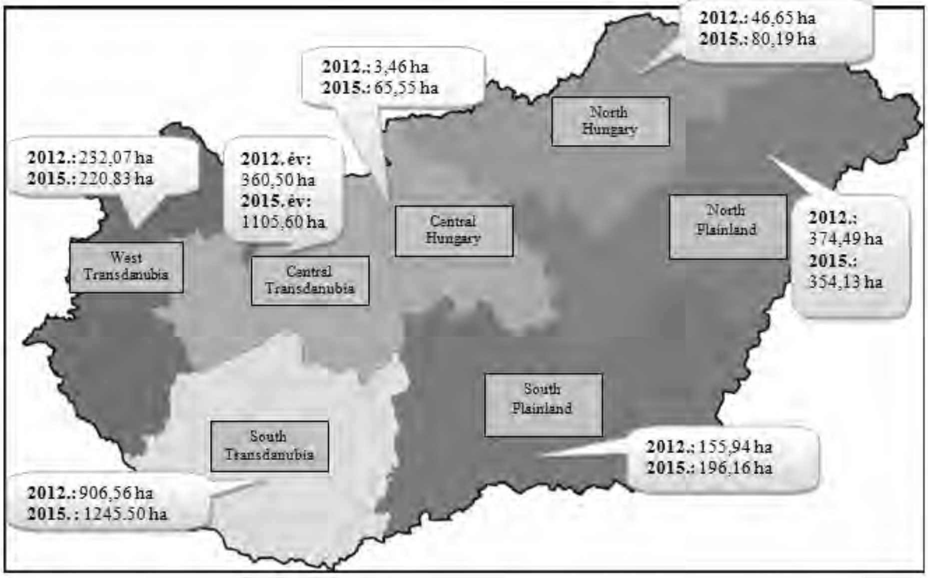

Figure 1. Regional distribution of woody energy plantations in Hungary 2012 and 2015 (based on data of the National Food Chain Safety Office, NÉBIH).

19 settlements. Our aim was to collect data for various site conditions. Yield measurements were carried out in each case outside the vegetation period, in AF2, AF6, Monviso, Kopecky, Pannonia, I214 poplar plantations 1-7 years of age. Predominantly AF2, Kopecky and Monviso plantations were surveyed. Measured were 10 m long sections with three replicates for each plot respectively. Taking in account shoot and row space, we measured the diameter at soil surface and breast height (1.3 m) level with mm accuracy, afterwards felling trees on 3x10 m sections and weighing them with an accuracy of 10 g for each.

After ordering data along age and clone type we produced yield graphs. Our measurements were carried out for a range of 8-112 mm diameter at soil surface and 2-90 mm breast height diameter, and they resulted in high correlation yield estimation functions (Fig. 2,3; Vágvölgyi et al., 2014; Vágvölgyi, 2013).

Results of the yield estimation method were compared with the total biomass measured after harvesting a 2 years old Kopecky poplar plantation (Table 1.).

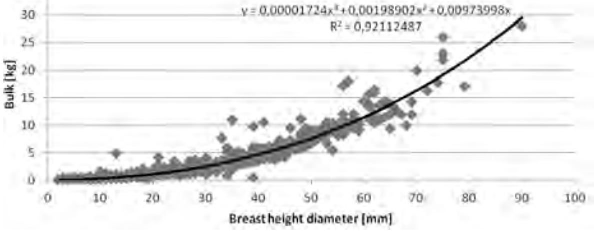

Figure 2. Estimated bulk weight as a function of shoot diameter 1,3 m above ground (Vágvölgyi, 2013).

Table 1 clearly indicates, that there is no significant difference between the estimates and the measured data (maximum deviation 12%), so it was stated that all our yield estimation functions can be used to predict the amount of dendromass. In case of the plantations of this measurement, with an age ranging from 1-7 years (later already after 3 harvesting), yield estimation functions predict 2 t/ha to 50 lutro-t/ha yearly biomass production (6.600 shoots/ha, 90% planting success).

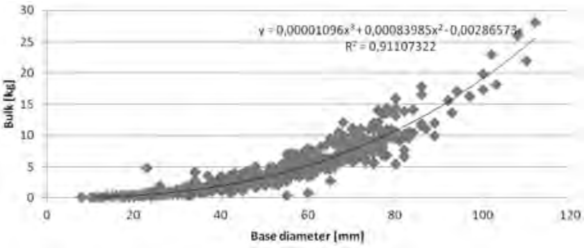

Figure 3. Estimated bulk weight as a function of soil surface level (base) shoot diameter (Vágvölgyi, 2013).

4. Location matrix of energy power plant and woody energy plantation

Conventional power generation in our country is still largely under central control, the innovative (electrical) power generation is characterized by decentralization, which is running in a smaller scale, at multiple sites, closer to the end-users. As nowadays the decentralized energy production has only a small proportion in Hungary, biomass has often to be transported to big (30 MW) power plants, the profitability of the plantations is limited. We examined the location of power plants and plantations creating a matrix, from which the different input-output of them can be determined.

We can ascertainable that biomass demand of active power plants in Hungary are (Fig. 4.) 1.500.000 t/year, on the woody energy plantation produced biomass satisfy of this 1,3% (in year 2013).

Table 1. Comparison of yield estimation results with measured biomass from harvesting in a Kopecky poplar clone plantation by Kiskunlacháza (Vágvölgyi, 2013).

Yield	[t/ha/2year]	difference to measure-ment
base diameter by „Kiskunlacháza”	19.03	-3%
breast height diameter by „Kiskunlacháza”	20.52	4%
base diameter by „Kopecky”	18.7	-5%
breast height diameter by „Kopecky”	20.02	2%
base diameter by „global”	22.08	12%
breast height diameter by „global”	19.7	-0,5%
Measure after harvesting	19.6	-

Figure 4. Biomass power plants in Hungary (blue dots=running; red dots=planned) (Vágvölgyi, 2013).

5. Technologies, difficulties, reasons and consequences in woody energy plantations

The laws gives a large control above the woody energy plantations. It is important to simplify or discontinue the laws. Based on the experiences in Hungary, the economic efficiency of woody energy plantations largely depends on the attitude of the farmers. The law doesn't make obligatory the preliminary site. Therefore many case was not the right species/clones for the specific site so we can find several plantations with low productivity or even total failure and the area was ploughed.

Weed control has a crucial role in plantations in Hungary. On sites with limited water supply of the plants, strong weed concurrence can effect tree growth dramatically in a negative sense, even leading to total failure of planting.

In Hungarian energy plantations there is no irrigation, and fertilization activity is low. Rust is the most important disease caused by various fungi of the Melampsora spp., and energy plantation is in some cases effected by the red poplar leaf beetle (Chrysomela populi L.), while pest control is virtually unknown to private farmers. Significant damage occurs only in the first year, from the second growing season stocks are not appreciably effected unless yield is partly decreasing.

In Hungary the significant number of wild game is important for woody energy plantations, red deer and roe deer can cause the highest damage to them. In some registered cases game damage made up to 100%. Fencing can extremely increase the cost of establishment (Vágvölgyi et al., 2014).

Further problems can arise in terms of harvesting, as indeed only few proper machines are available. In the future expected additional investigation and machinery technology adaptation which we can take care of the harvesting optimal and economically. Difficulties, reasons and consequences in energy plantation are summarized in Fig. 5.

6. Machinery development on woody energy plantation

Fig. 6 summarizes the cultivation technology of energy tree-planting.

We can see that it is necessary to shape an optimal mechanization the woody energy plantations planting, cultivating, harvesting and winding up. To this we made machinery development in recent years. This developments including but not limited to present the Table 2.

7. Conclusion

We can establish the result of research that increase of woody energy plantations area would be needed in coming years in our country. So can the wood energy plantations signify dendromass base for energy plants. Area increase promote a deliberate economic and legal regulation besides would be needed the supporting incentive and the continuation of the results home machinery development. Knowledge with woody energy plantation of farmers would be needed enlarge so they can eliminate the problems and

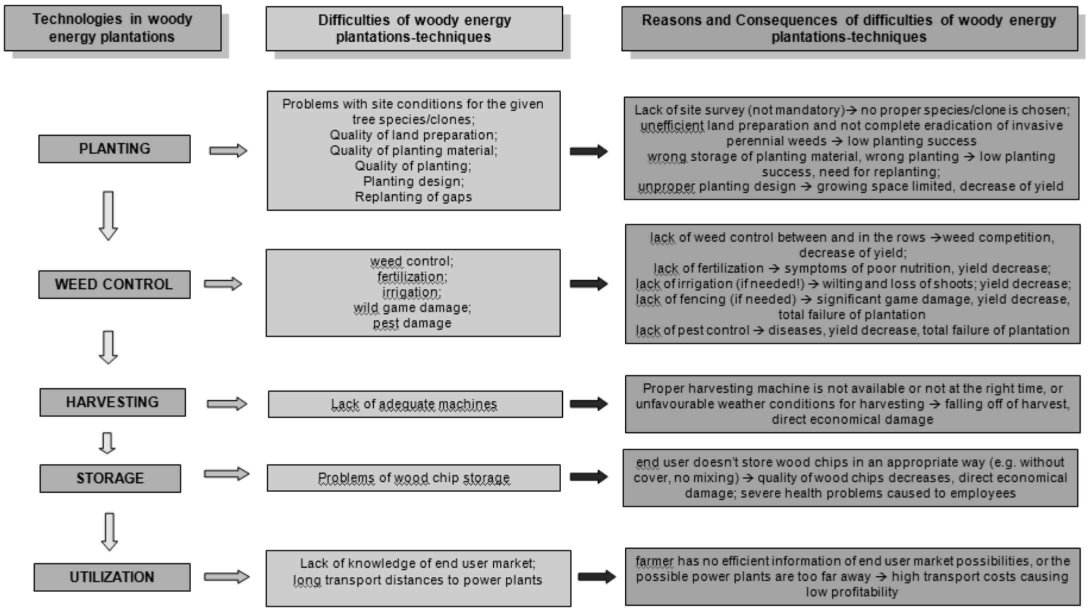

Figure 5. Technologies, difficulties, reasons and consequences in energy plantation (Vágvölgyi, 2013).

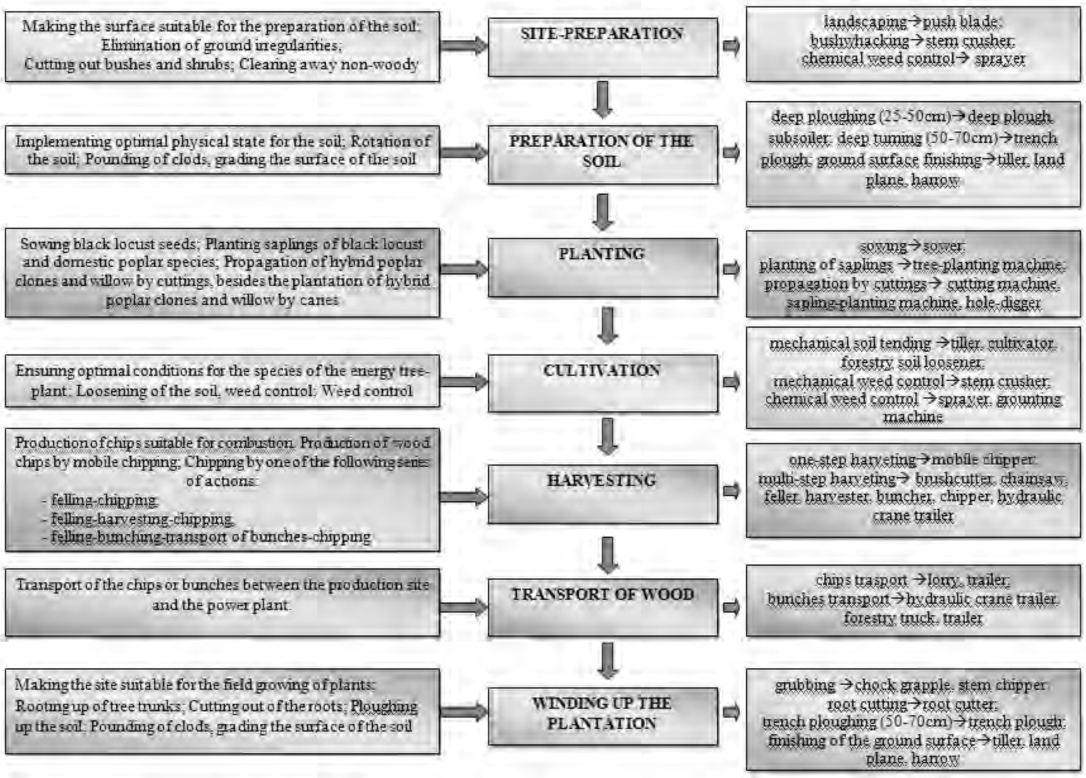

Figure 6. The actions and the corresponding machinery required in the cultivation technology of energy tree-planting.

Table 2. Machinery developments in recent years.

Name of machine	Aim of machine development	Cooperative partners	Picture
Machines for planting energy tree plantations	An ideal planting machinery and to develop an optimal planting technology for it	Bagodi Mezőgép Kft., University of West Hungary - Institute of Forest and Environmental Techniques, Ministry of Rural Development - Hungarian Institute of Agricultural Engineering	
Machinery for tending energy tree plantations	Afforestations against grub damage- Injecting machine	University of West - Hungary Institute of Forest and Environmental Techniques, Huniper Kft.	
Machinery for plantation harvesting	Planting harvesting OG-FD type felling machine; OPTI-VFA type felling and chipping machine	Optigép Kft.	 
Machinery for harvesting the underwood level of flood plain forests	The proper treatment of the underwood level of flood plain forests	Bagodi Mezőgép Kft., University of West Hungary - Institute of Forest and Environmental Techniques, Ministry of Rural Development - Hungarian Institute of Agricultural Engineering	
Wood chipper	This part of our research focused on the development of a machine with low power consumption which is primarily suitable for handling the amounts of fuel wood generally processed in small farms.	Metripond M. 93 Kft., University of West Hungary - Institute of Forest and Environmental Techniques	
Bunching machine	The aim of this development was to create the prototype of an equipment which is primarily suitable to handle the branch material left back at the felling site.	KEFAG Ltd., private companies	

deficiency and extend the yield and age of energy plantations, improve the sanitary status.

Acknowledgements

Research is supported by the project "Complex assessment of climate change impacts - preparing international R&D projects in the University of West Hungary (TÁMOP-4.2.2.D-15/1/KONV-2015-0023)". The project has been supported by the European Union, co-financed by the European Social Fund.

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Spreading of harvesters in Hungary

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Abstract
Today harvesters are the most efficient logging machines in hardwood and softwood stands. The first harvesters have worked in Hungary since the 1970's. Then political changes stopped the technical developments. Harvesters appeared again in Hungarian forests from 2006. As a result of new developments in technology, harvesters are no longer be confined to softwood forests only. Using a questionnaire we surveyed the harvesters working in the state forests. Today the number of the harvesters are continuously working hardwood and softwood stands are above 20.

Keywords
harvester, survey, questionnaire, logging

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1. Introduction

The leading machines of highly mechanized logging work systems, multioperation or multipurpose logging machines, better known as harvesters went through continuous evolution since their appearance in the 60's. Today they became the most effective representatives of logging in both conifer and deciduous stands.

2. Material and Methods

In Hungary the first demand for the use of multioperation logging machines arose in the mid 1970's. The reason for this demand could be found among the directives of the timber management development concept in the 5th Fiveyear Plan. They wanted to raise the volume of logging from 6,85 million gross m^3 in 1975 to 7,4 million m^3 by 1980 (Andor, 1977). To reach this goal, adequate levels of technical development were needed. The lack of workforce was also a problem back then and worksystems were considered outdated in order to reach an increase of 500 thousand m^3 in felled timber.

Szepesi imagined one of the methods to increase the level of productivity by using multipurpose logging machines in conifer, noble poplar and black locust stands. According to the concept of introducing multipurpose machines, the productivity of logging works could be doubled or tripled and the productivity of works on cutting areas could be raised by five-ten times of their former scales. Processors (delimbing and slashing machines), harvesters (felling, delimbing and slashing machines) and woodchip production machinery lines were the options coming most into question (Szepesi, 1976). That is why it was important to examine the opportunities of using multioperation logging machines. These examinations were done with the cooperation of ERTI (Scientific Forestry Institue) and thanks to the Hungarian-Yugoslavian cellulose industrial cooperation coming into operation at that time they were focusing on mechanizing the process of polpar felling (Csontos, 1977). The machines back then were not totally similar to the ones we now call harvesters neither in their structure nor in the complexity of their operations. During the research they got to the conclusion that productivity can be raised ten-fifteen times by using these machines but from the side of costs they are not yet competitive with traditional methods (Walter, 1978).

In 1976 and '77 the first Timberjack TJ-30 feller-delimber machines arrived to the State Forestries of Devecser and Kiskunhalas (Csontos, 1977). Work with them could have been started. At the Kiskunhalas State Forestry and neighbouring agricultural facilities about 4.000 hectares of noble poplar were available where the traditional „at the stem" chainsaw techniques were not providing satisfying results upon the beginning of thinning. Workslike felling started on the 1st of April 1977 with the machine which was forerun by a 30 days training period. Selection thinning seemed only to be finished on time with the machine which was aided by the planting network and the use of conventional selection thinning methods. However totally new technologies had to be worked out for this lead machine with special aspects taken into consideration such as determining the timber sortiments produced at thinning, the use of machinery in the technology already present at the forestry and what elements could be used from previously used logging techniques. The method used was the following. The Timberjack Tj-30 did the felling, delimbing, forwarding and bunching. A T 150-K TNP winch skidder did the skidding. Slashing, classification and decking was done at the edge of the cutting area. For this they used Stihl 030 AV chainsaws. Processing (debarking) was done on the workbench with a KR-2 debarker and loading was done with IFA trucks and KCR-3000 cranes. After one year of operation they found out that the Timberjack TJ-30 designed to be used in conifer stands can also work in noble poplar stands and with some slight modifications even in final cuts. All in all considered

	Brand	Model	Year of manufacture	Owner	Status	Place of purchase	Buy year	Purchase price (M HUF)	Telephone number	Company	Address
1	Doosan 255 NLC + LogMax 7000B		2013	Pendli István Attila	new	n.a.	2013	n.a.	30/566-06-68	vállakozó	8790 Zalaszentgrót, Erzsébet királyné u. 4.
2	CAT	550 ???	n.a.	Rafaj József	n.a.	n.a.	n.a.	n.a.	n.a.	vállakozó	n.a.
3	John Deere	1470D	2005	Virág Tibor	used	Ausztria	2005	n.a.	30/303-60-04	Hercules Bt.	3235 Mátraszentistván, Petőfi út 46.
4	Komatsu	911.5	2012	Jákli Csaba	new	Kuhn Kft.	2012	n.a.	30/217-81-05	6x6 Trans Kft.	8868 Letenye, Szabadság tér 11.
5	Königstiger	n.a.	2003	Balla Gábor	used	Ausztria	2013	18	20/468-70-04	vállakozó	Ipoly környéke
6	Ponsse	Buffalo Dual 8WD	2007	Varga István	used	USA	n.a.	n.a.	30/237-56-80	vállakozó	8109 Tés-Csőszpuszta 9.
7	Ponsse	Buffalo Dual 8WD	2013		new		2013	n.a.			
8	Ponsse	Buffalo Dual 8WD	2004	Tóbi István	used	Forest power Kft.	2010	n.a.	30/338-15-53	Robusta Kft.	6033 Nyárlőrinc, II. kerület 162.
9	Ponsse	Ergo 8WD	2012		new		2012	125,56			
10	Ponsse	Ergo 6WD	2005	Mátyás Csaba	used	Forest power Kft.	2013	n.a.	20/579-68-33	Mátyás Kft.	7356 Kismányok, 072 hrsz
11	Ponsse	Beaver	n.a.	Hamvasi Ferenc	n.a.	n.a.	n.a.	n.a.	30/458-38-46	Hamvasi és Fiai Erdészeti és Szolgáltató Kft.	8421 Zirc, Köves János utca 32.
12	Ponsse	HS 16 Ergo	1999		used	Csehország	2008	31,3			
13	Sampo-Rosenlew	1046 Pro	2012	Zalaerdő Zrt.	new	Készenlét Zrt.	2012	n.a.	30/227-32-40	Zalaerdő Zrt.	8800 Nagykanizsa, Múzeum tér 6.
14	Silvatec	896 TH-H	2002	Vescan Kft.	n.a.	n.a.	2010	40	88/44-22-22	Vescan Kft.	8200 Veszprém, Házgyári út 16.
15	Skogsjan Caterpillar	695	1998	Ékes Zoltán	used	Ausztria	n.a.	n.a.	30/927-40-02	vállakozó	n.a.
16	Timberjack	1270B	1999	Ruzsics József	used	Ausztria	2006	22	30/969-33-48	gépi és kézi fakitermelés	8960 Lenti, Kápolnai út 81.
17	Timberjack	1270B	1999				n.a.	n.a.			
18	Timberjack	1270B	2002	Hoffer Ákos	used	Ausztria	2011	21	70/374-12-23	vállakozó	8428 Borzavár, Fő út 24.
19	Timberjack	1270B	2000	Kiss Olivér	used	Ausztria	2014	17	20/828-99-99	vállakozó	8472 Nemeshany, Petőfi u. 41.
20	Timberjack	1070	n.a.	Csapó ????	used	n.a.	n.a.	12,5	20/573-97-67	vállakozó	Zirc környéke
21	Timberjack	1470D	n.a.	Fábian Árpád	used	n.a.	n.a.	n.a.	20/973-47-36	Bioenergia - Massza Kft	9081 Győrújbarát Pándzsa út 1.
22	Timberjack	870	n.a.	Pilise Zsolt	used	n.a.	2014	n.a.	30/252-40-88	vállakozó	Zirc környéke
23	Valmet	911.3	2005	Bodor Károly	used	Németország	2010	60	30/956-86-77	Ihartü-2000 Erdészeti és Faipari Kft.	8444 Szentgál, Vörösmarty u.38.
24	Valmet	911	2000	Honcsorov Attila	used	Ausztria	n.a.	n.a.	30/937-87-81	Bakony - Forgács Kft.	8444 Szentgál, Nyírőkert ltp. 58.
25	Valmet	911	n.a.	Palásti-Kovács Imre	used	n.a.	n.a.	n.a.	20/328-89-35	HEPIK Bt.	7626 Pécs, Katalin u. 23.
26	Valmet	901	n.a.	Dobos Mihály	used	n.a.	n.a.	n.a.	70/229-82-68	vállakozó	Kecskemét környéke ???
27	Valmet	901 II.	n.a.	Németh Szabolcs	used	n.a.	n.a.	n.a.	20/464-80-48	vállakozó	Gyepükaján Kossuth u. 37
28	n.a.	n.a.	n.a.	Orbán József	n.a.	n.a.	n.a.	n.a.	30/939-40-84	vállakozó	8286 Gyulakeszi, Kossuth u. 64.
29	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Holzhacker Kft.	6421 Kisszállás Tanya IV. körzet 47.
30	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Stem	Bonyhád környéke

Figure 1. Hungarian harvesters.

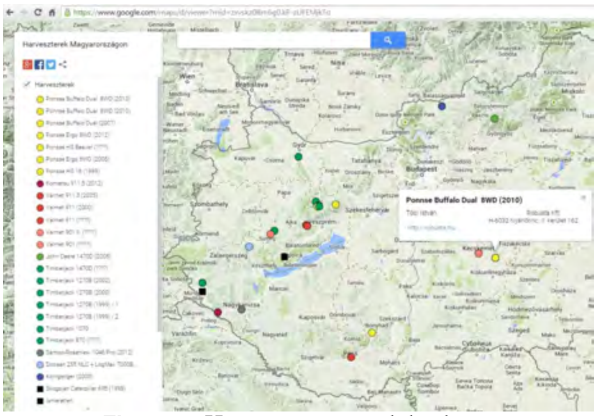

Figure 2. Harvester map and database.

they found the machine to be reliable and productive since the time loss per work hour was only 0,1 and the annual logging capacity was 13-14 thousand net m^3 at one-shift operation (Csordás és Farkas, 1979; Sovány 2013). However the spread of multipurpose machines did not come to reality at such an extent and pace as domestic professionals thought earlier.

Because of the political changes the swing of technical development broke and with the appearance and spread of entrepreneurs it went out of mind for a long time. After the political change only fowarders were used furthermore among multipurpose machines beacuse with them gentle methods could be used productively. After the end of the 2000's an innovative group appeared among entrepreneurs with new perspectives, who were willing and being able to use modern technology and machinery and thanks to them, multioperation logging machines appeared besides forwarders in hungarian silviculture again in the last 5-6 years.

Today there are more than 30 harvesters which are working non-stop. Most of the machines are bought used but there are several new machines purchased as well. Most of the used machines come from Austria and Germany, but equipment was also purchased from the USA or the Czeh Republic. In Hungary the three most popular harvester brands are Ponsse, Timberjack and Valmet. Among the machines there is one which is considered a milestone: the harvester of Zalaerdő Plc. This is the first machine purchased by a state forestry company. The database of harvesters being in the possession of hungarian logging entrepreneurs and companies is shown in Table 1. Information gathering was done via personal contact and phone. Based on the table database a map database was also done with Google Maps. A dot marks the stations (company stations) of different machine types on the map of Hungary, different colors are used for each manufacturer. Clicking on a dot opens a smaller window which shows the known data of the machine and company (type, year of manufacture, owner, company name, address) (Figure 2.). The map is available under the following link: www.google.com/maps/d/edit?mid=zxvskz0Bm6g0.kP-zUFEMjkTo.

In the last few years in Hungary logging with multipurpose machines was done in black locust, alder, noble poplar, turkey oak, hornbeam-oak, beech, hornbeam-scots pine and of course in norway spruce, scots pine and black pine stands. In point of intervention type they were used in clearcuts, thinnings, regeneration cuts and sanitation cuts.

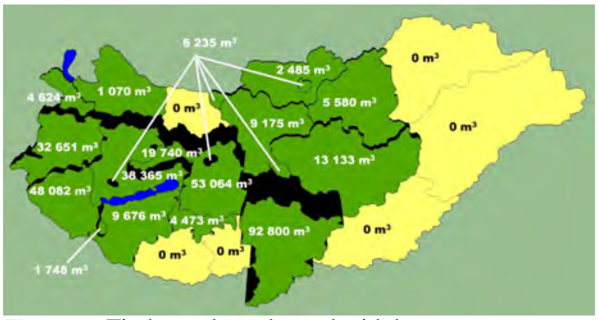

Figure 3. Timber volume logged with harvesters at state forestry companies between 2008 and 2014.

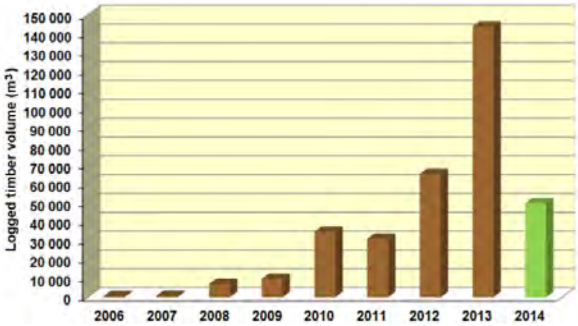

Figure 4. Annual logged timber volume between 2006 and 2014.

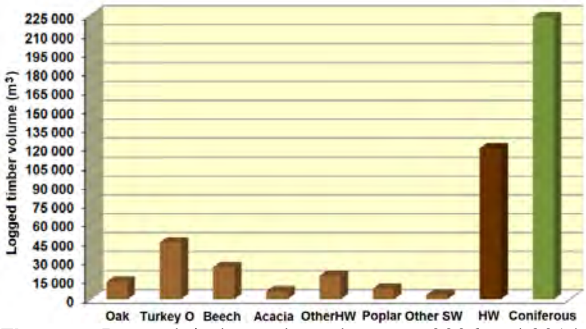

Figure 5. Logged timber volume between 2006 and 2014 per tree species.

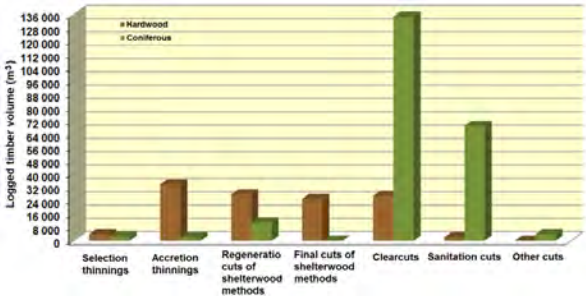

Figure 6. Logged volume between 2006 and 2014 per logging method.

3. Results

With the help of a questionnaire the work of harvesters at state forestry companies was mapped. From the evaluation of the data provided by the 22 state forestry companies it is visible that 342.901 m^3 of timber was logged with harvesters between 2006 and 2014. We have to mention that the data of 2014 is not complete because it took more than a year to get the needed information from all forestry companies. Because of this the first data series could not contain the logging information for 2014, but the last already did. In Figure 2. logging data per company is displayed. In the point of logged timber the list is lead by KEFAG cPlc. (92.800 m^3), VADEX cPlc. (53.064 m^3) and Zalaerdő cPlc. (48.082 m^3).

Annual distribution of logged timber is shown on Figure 4. The increase is clearly visible which is in connection with the number of imported machines and their more intensive and efficient use.

If we examine the given data on a tree species level, we can see that 65% of logged timber are conifers and 35% are deciduous. Among deciduous species the most usual are turkey oak, then beech, other hardwoords, noble poplar and oak (Figure 5.).

There is a more interesting correlation between the data if we examine them not only on a species level, but also per logging method. In Figure 6. and Table 1. it is clearly visible that harvesters in deciduous stands are mostly used in thinnings, as well as in regeneration and final cuts of shelterwood methods. In conifer stands the most typical use is in clearcuts and sanitation cuts because of the large-scale pine disease.

By examining the 119.520 m^3 of logged deciduous timber (Figure 7.) it is visible that the percentage of turkey oak, beech, and other hardwoods is outstanding. These species are primarily felled in thinnings and sheltewood cuttings with harvesters. The reason for this lies among the parameters of the machines as well as among the characteristics of hungarian silviculture methods and forest sites. These species fall between the optimal dimension levels of used harvester heads at their age of thinning and shelterwood cutting. Stem diameters in beech and other hardwood stands usually do not allow the use of multioperation logging machines at final cuts. Furthermore these stands give the most valuable sortiments at this age. Felling, delimbing and slashing of trees can be done more precisely with a chainsaw. By cutting away the tapers lower stem heights can be achieved than with a harvester. Turkey oak stands at final cut age are suitable for harvester logging in both stem diamater and timber quality. Clearcuts were mainly made in turkey oak, noble poplar, black locust and oak stands with these machines. The outstanding data at sanitation cuts shows – among others – the averting of damaged wood in beech stands caused by heavy winds in 2010 in Transdanubia.

4. Discussion

The number of harvesters shows a rising tendency in the recent years just like the volume of logged timber. The rise of logged timber volume is also in connection with the experience of operators and with the fact that professionals are also starting to recognize the legitimacy of harvesters in hungarian forests. It remains a question however what the destiny of harvesters will be which were purchased directly

Table 1. Logging data (m^3).

Method	Oak	Turkey Oak	Beech	Acacia	Other HW	Poplar	Other SW	HW	Conifer.	∑
Sel.thi.	688	928	0	68	169	1878	172	3903	2756	6659
Acc.thi.	1850	8749	11953	190	9095	702	1245	33785	2047	35832
Reg.cut	3654	13924	6775	149	3082	0	194	27775	11030	38805
Fin.cut	1835	14670	4909	31	3523	0	93	25060	99	25159
Clearc.	5320	6222	482	5607	2349	5610	1293	26883	134654	161537
Sani.cut	307	291	1198	59	166	0	15	2036	68986	71023
Otherc.	0	0	0	0	0	0	78	78	3808	3886
Sum	13654	44784	25317	6104	18384	8190	3090	119520	223380	342901

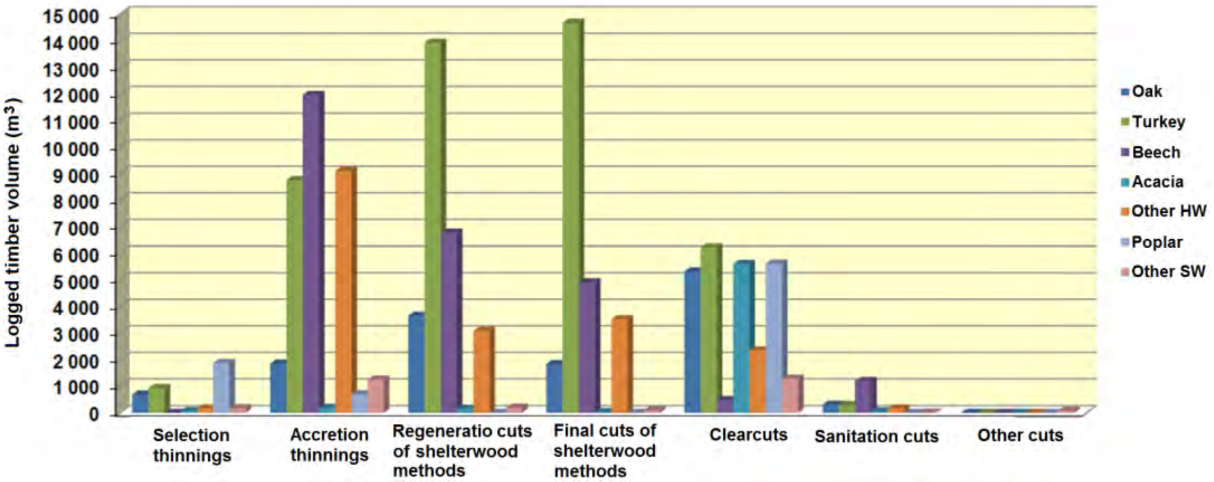

Figure 7. Deciduous timber volume logged between 2006 and 2014 per logging method.

to log the dying pine stands, but hopefully these machines will have their place in hungarian forests as well.

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Development of a forest road network extraction method using a high-resolution DTM

M. Saito*, K. Imasaka, K. Moriguchi, T. Ueki

Abstract
This study develops a new method for determining road networks by extraction of data from high-resolution digital terrain models (DTM), for purposes such as determining the state of forest stands and identifying landslide scars. The target area was Terasawayama Research Forest at Shinshu University in Nagano Prefecture. By applying simple algorithms and existing GIS tools, it was possible to semi-automatically create road network data that reproduced the actual shape of the network. Although some deviations and erroneous extractions and un-extracted areas were found, these could be edited easily and quickly, as compared to the time needed for surveys and reconnaissance by GPS. Also, all of the work was carried out by using free software and an open source GIS. Therefore, this method is considered useful for preparing road network data over wide areas in the early stages of GIS introduction, when no existing road network data exists.

Keywords
road network, DTM, LiDAR, GIS

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1. Introduction

1.1 Background and objectives

In recent years, the forestry industry in Japan has been driven by vehicles traveling on dense networks of roads, and it is expected that new routes will increase. Therefore, management of new and existing road network information using a geographic information system (GIS) is needed, and positional data on road networks is important. However, most of this positional data is currently managed by drawings, and there is no centralized management of the information as digital data. This means that attempts to provide information on existing and new road networks as digital data are expensive because surveys and site reconnaissance using global positioning system (GPS) must be carried out, and then the data must be organized by a GIS. Therefore, in this study, a new method is developed for determining road networks by extraction the information from high-resolution digital terrain models (DTMs) used for purposes such as determining the state of forest stands and identifying landslide scars.

Research into automatic extraction of road areas in Japan has been underway for some time, but the majority has focused on urban areas or plains (Kim et al., 1993; Kato et al., 1996; Itonaga et al., 1999). Some of this research has involved extracting road areas by using a combination of data such as aerial images, high-resolution satellite data, and digital surface models (DSM). Extraction of road areas using digital ortho aerial imagery has been done by using the differences in reflectance properties of road areas and other areas and then matching the differences with an intersection model to construct a road model (Kotaki et al., 2005). Research using high-resolution satellite data includes a method of extracting edges of road areas and other areas by near infrared (NIR) in addition to reflectance properties (Oba et al., 2006). Research using DSM includes a method that makes use of the differences in elevation between road areas and building areas (Uemura et al., 2009), and this has achieved some good results. However, research on road extraction of the kind mentioned above has not been carried out in Japan's mountainous regions. Therefore, this study attempts to develop a method capable of extracting networks of forest roads with widths of about 3 m in Japan.

1.2 Research procedure

In this study, road networks were extracted as raster data using a DTM generated from Light Detection and Ranging (LiDAR) data, then converted to line vector data to produce the final road network data. This was then evaluated by comparison with the actual road network data. Figure 1 shows a flowchart of this process.

2. Summary of study area and data used

The study was carried out in Terasawayama Research Forest at Shinshu University in Ina, Nagano Prefecture. Terasawayama Research Forest is located at a height between 970 m and 1,400 m above sea level and covers an area of 219.9 ha. There is a dense road network in the forest with a total length of 21,394.9 m, a road density of 97.3 m/ha, and a road width of 2 to 5 m. This study used 0.5 m grid DTM data generated from the LiDAR data. The LiDAR data was measured in 2012, and the mean density of measurement points in the study range was 9.8 points/m² (Figure 2).

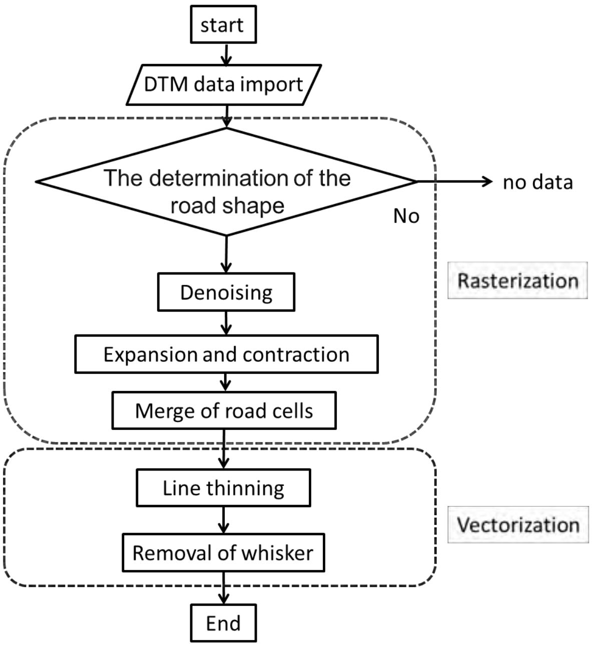

Figure 1. Flowchart for creating road network data.

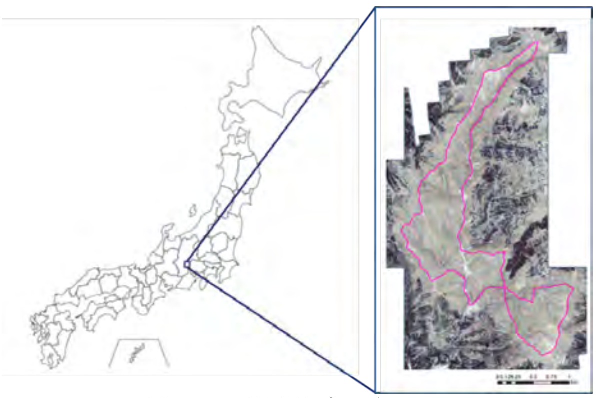

Figure 2. DTM of study area.

3. Creation of road network raster data

The raster data of the road network was created by the following procedure: 1) Classification using a model of road network geometry that identifies slopes and road surfaces from the DTM to determine the rough shape of the road network; 2) Removal of noise from classified data; 3) Merging of road network cells to create continuous data.

3.1 Road network geometry model

The model of the road network geometry is shown in Figure 3. The model assumes that Section A–B is a slope on the mountain side of the road network, Section C–D is the road surface, and Section E–F is a slope on the valley side of the road network. Although attempts were made to extract the road network by using various parameters, extraction was often difficult at points where the road shoulder was rounded, because the elevation differences did not fit within the set values.

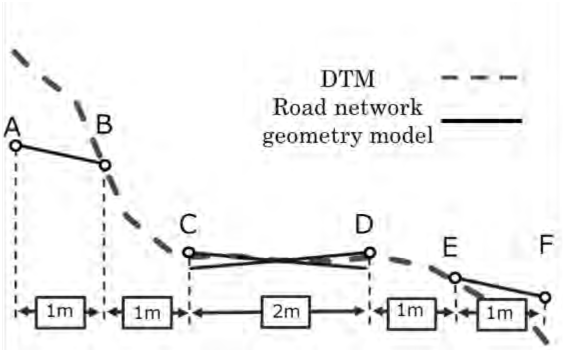

Figure 3. Road network geometry model.

Based on the number of cells extracted as a result, a model was adopted that extracts the road network under the conditions that the elevation difference of Section A–B and Section E–F (slopes) is 0.25 m or more, and the elevation difference of Section C–D (road surface) does not exceed 0.2 m. A distance of 1 m was left to avoid rounded sections caused by the collapse of cuttings and embankments, and this made it possible to extract the boundaries between the slopes and the road surface more reliably. The model was rotated in increments between 0° and 45° in the transverse direction centered on one cell of the DTM, and when there was a direction in which the model was compatible, the center cell was judged to be road surface. Figure 4 shows data extracted by the above method. Falsely detected points are observed throughout the figure and give it a granulated appearance. This is because some sections of natural slope also match the model. Noise processing must be carried out to remove these points.

3.2 Noise processing

In the extracted data, most parts of the road network are connected and form clusters that exceed a certain number of cells. In contrast, the erroneously extracted parts form small clusters that are not connected to the road network. Therefore, it is possible to remove the erroneously extracted parts by sieve filtering. The number of cells that can pass through the sieve can be set freely, but if the number is too small, noise will remain; if the number is too large, parts of the road network will also be removed. In this study, the sieve size was varied between 10 cells and 160 cells, and the parameter was reviewed. After comparing the number of extracted cells, it was decided that a 90-cell sieve was suitable, and clusters below that size were eliminated. The actual processing was done by using the sieve tool in Qgis.

Next, even after sieve filtering, points that were not extracted as road network remained within the parts considered to be road network (hereafter, “isolated points”). If vectorization is carried out with these isolated points left as they are, circles will be generated to enclose the isolated points. Expansion and contraction were carried out to prevent this. In principle, one cell is added on the outside of the contours of a region extracted as road network. The isolated point inside the part considered to be road network is removed. The contraction process is the opposite of the expansion process, and the cell on the contours is removed. This processing was carried out on the binarized road network data after sieve filtering in order to remove isolated points.

3.3 Merging of road network

Even after completing this two-step processing, there will be many places where the road network is unconnected because data is not judged to be road. This is influenced by the fact that, where the road surface is wide, the cells comprising the road form a smooth plane with little difference in height between adjacent cells. Therefore, after noise processing, the continuity of the road surface was reproduced by using a method of connecting points with little difference in elevation. Specifically, points in the vicinity of 8 cells from a point determined to be road network were newly judged to be a road network when the slope did not exceed 2.0° and the elevation difference was -0.05 m or more. By processing the data multiple times with this method, the parts of the road network were gradually extended from the extracted road network cells and linked to other disconnected parts of the road network. Subsequently, holes were observed within the road network parts, and so expansion/contraction was performed again to complete the merging of the road network (Figure 5).

However, with this model, flat terrain was extracted regardless of area. Therefore, where the road network ran alongside a mountain stream, there were places where many parts of the stream were extracted.

The creation of raster data was completed as described above, but there were still parts that were not connected (Figure 6). This is because the DTM data was not acquired properly due to problems such as obstruction by the tree canopy, and so the geometry was not like the cutting–road surface–embankment in the model. In such cases, the road was not extracted even at the stage of network merging.

Also, because the height difference of the road surface in the road network geometry model (Section C–D) was set to a width of 2 m, there were places in narrow sections of road that were difficult to extract. Therefore, the width of Section C–D in the road network geometry model (Figure 3) was set to 1 m and extraction was performed again, but terrain on mountainside terraces was erroneously extracted, and noise processing was not used on this occasion.

4. Creation of road network vector data

The road information must be converted into vector line data to manage it with a GIS. Therefore, two processes were carried out on the road network raster data: thinning and line conversion. GRASS GIS tools were used for both processes. The GRASS "r.thin" tool was used for thinning and the "r.to.vect.line" tool for line conversion. In thinning of linear drawings, line segments of one cell (pixel) in width comprising center lines are extracted. The method involves searching the image from top left to lower right for cells that are candidates for removal. The same search is then carried out from the opposite direction. This process is repeated and cells are gradually removed until the line segments in the image are one cell in width. In addition to the central lines found as a result of thinning, there are other lines called "dangles" (Figure 7). These line segments are clearly extracted as short line segments when linearization is performed. Dangles were removed using the GRASS "v.clean.rmdangles" tool. The removed dangle length was set at 25 m or less based on the maximum length of the dangles for removal. The tool removed short line segments that occurred partway along a line segment. However, when a dangle occurred close to the end of a line segment, it was found that the tool sometimes removed the end of the line segment rather than the dangle.

Following the abovementioned processing, the GRASS "v.clean.snap" tool was used to simplify and smooth the line segments to create the final road network data (Figure 8).

5. Results and discussion

5.1 Evaluation

The road network extraction rate was evaluated by comparing the vector data extracted from the DTM with the shape data of the road network generated from existing survey results. In consideration of the amount of correction required when actually managing the data as road network information, this evaluation method involved first evaluating connectivity by counting the number of fragmented road networks. Road networks are essentially entirely continuous, and so the number of networks is unity if the whole road network has been extracted. Specifically, a 10 m wide buffer was created around the existing road network data, and line vector data within that range was extracted and classified as erroneously extracted data. Then, polygon data were created with respect to the extracted line vector data, and the number of polygons was counted. As a result, the data in the range where extraction was performed were divided into 12. This showed that the road network was divided and required data correction in 12 places.

5.2 Heipke method

Next, the Heipke method (1997) was used to evaluate the data. This method evaluates three items: completeness, correctness, and quality. The evaluation is normally performed

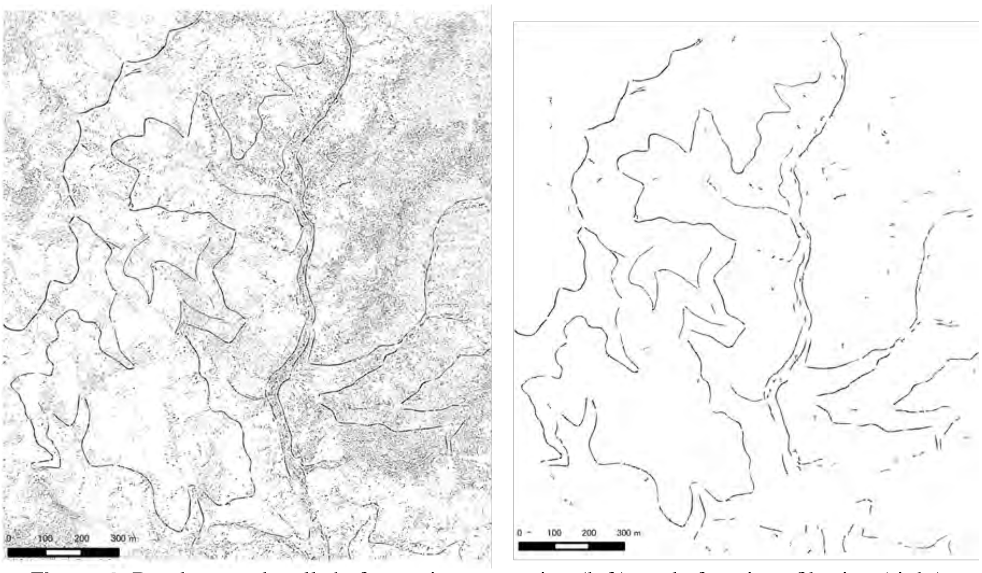

Figure 4. Road network cells before noise processing (left), and after sieve filtering (right).

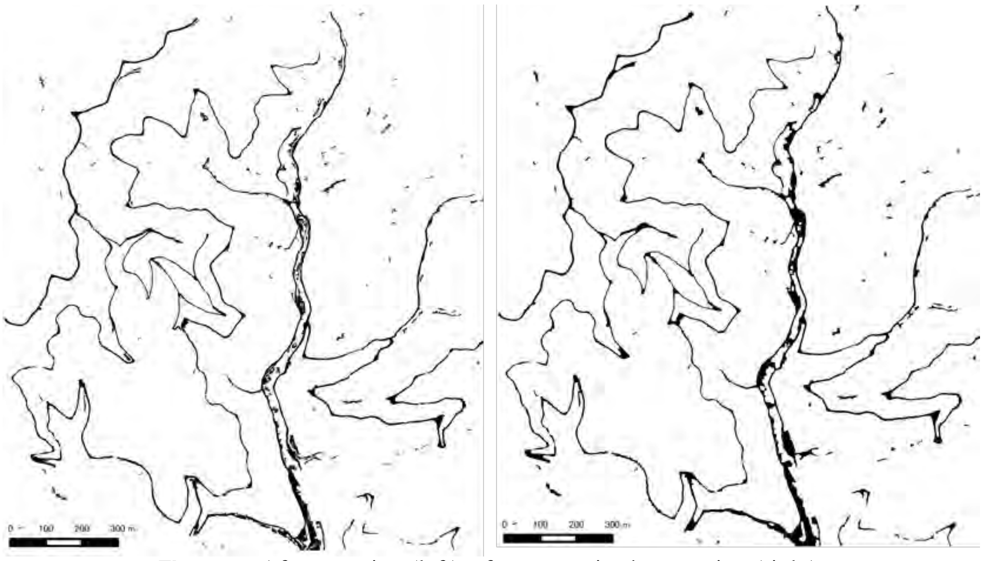

Figure 5. After merging (left), after expansion/contraction (right).

Figure 6. Part where data is missing. Black: Part determined as road network after processing.

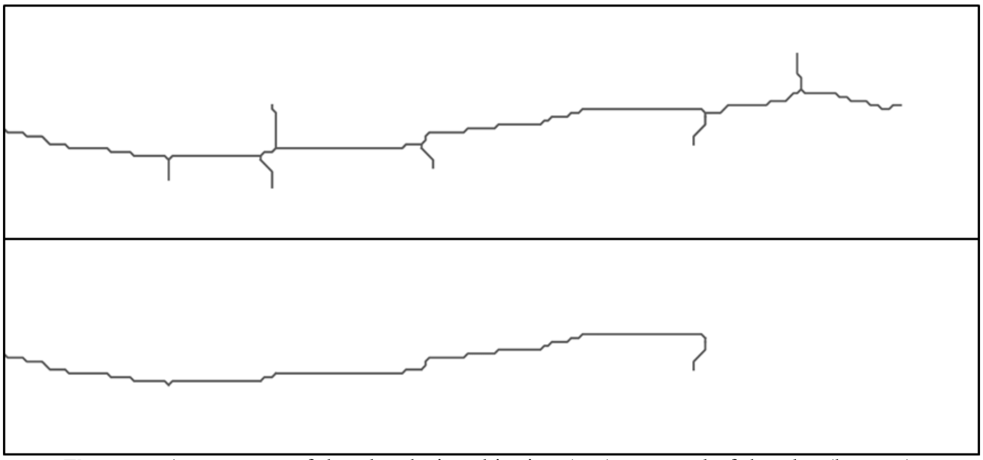

Figure 7. Appearance of dangles during thinning (top), removal of dangles (bottom).

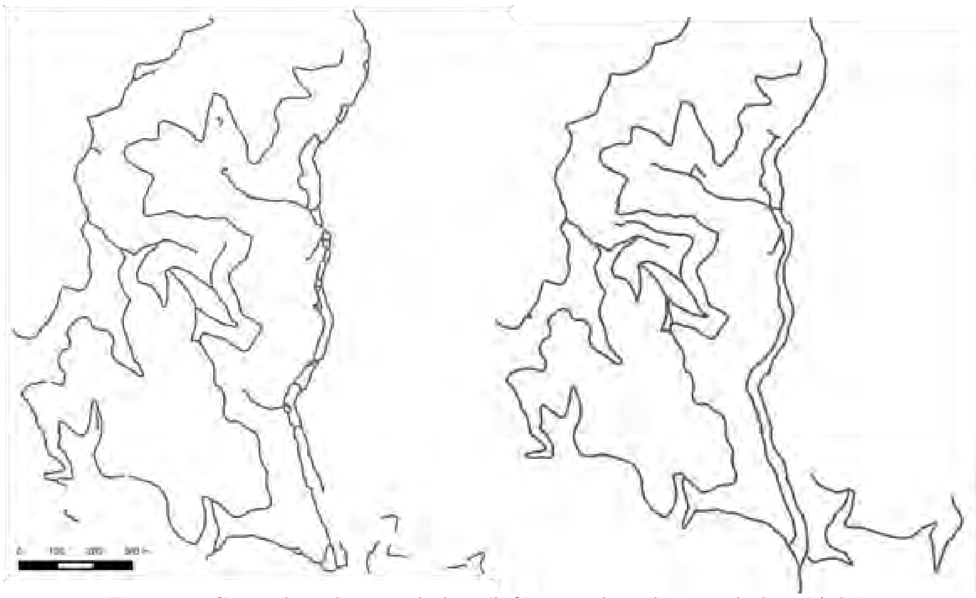

Figure 8. Created road network data (left), actual road network data (right).

based on the number of pixels, but in this study it was performed based on line length. Three values—TP, FP, and FN—were used to evaluate the three items. TP indicates a correctly extracted line length, FP indicates an erroneously extracted line length, and FN indicates an unextracted line length. Classification using these three values was determined according to whether a line segment was contained within a 3 m wide buffer around the actual data. First, a 3 m wide buffer was produced around the actual correct road network. When an extracted line segment was contained within the buffer, it was classified as TP, and when a line segment was not contained within the buffer, it was classified as FP (Figure 9).

Conversely, a 3 m buffer was also produced around the extracted line segments. When the actual correct road network was not contained within that area, it was labeled FN (Figure 10).

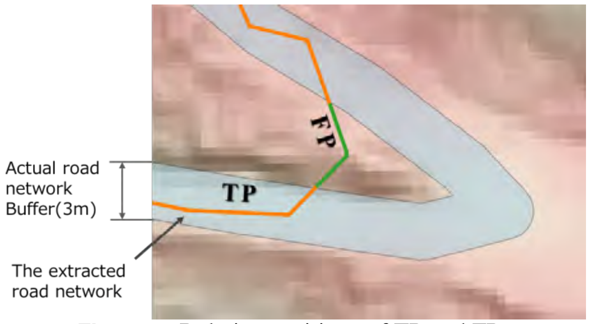

Figure 9. Relative positions of TP and FP.

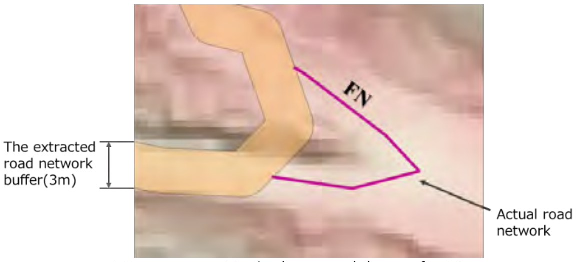

Figure 10. Relative position of FN.

Completeness, correctness, and quality were evaluated by the three values of TP, FP, and FN, classified as described above. The equations for the three evaluation items are shown below.

$$Completeness \ldots \frac{TP}{TP+FN} * 100 \quad (1)$$

$$Correctness \ldots \frac{TP}{TP+FP} * 100 \quad (2)$$

$$Quality \ldots \frac{TP}{TP+FP+FN} * 100 \quad (3)$$

Completeness indicates the number of unextracted line segments, correctness indicates whether deviation from the actual data is small, and quality comprehensively evaluates both completeness and correctness. Each item is expressed as a percentage, and the higher the percentage, the better.

The results of this study were completeness 70.4%, correctness 69.3%, and quality 53.7%. In research in urban areas, a study by Hasegawa et al. (2006) examined data extracted by separating road areas and other areas based on small height differences by using DSM with building areas removed, and data extracted by separating road areas and other areas based on differences in RGB reflectance values. Data were also extracted by a combination of both methods. Also, a study by Uemura et al. (2009) extracted data by separating buildings and roads based on height differences by using DSM. No great difference was found when comparing the extraction results in urban areas with these methods and the results obtained from this study (Table 1).

6. Discussion

Factors causing reduction in completeness and correctness were examined. The primary factor was deviation towards the inside of curves that occurred when thinning was performed. This happens when expansion/contraction is carried out multiple times, and consequently the widened portions of curves, which are not actually part of the road, are extracted as road network cells (Figure 11).

The second factor was the occurrence of circles along mountain streams (Figure 12). This happens when flat areas that are not related to the road network are judged to be road during the merging process, and then the two opposite shores are merged by the subsequent expansion/contraction process.

The two phenomena mentioned above are caused by problems in the algorithms for processes such as expansion/contraction. Therefore, possible solutions include construction of an algorithm that does not perform expansion/contraction, but pinpoints and buries holes judged to be a road network in the data. Another possibility is a process that eliminates circles in vector data.

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7. Summary

- This study examined a method of extracting a forest road network in the Terasawayama Research Forest by a DTM. By applying simple algorithms and existing GIS tools, it was possible to semi-automatically create road network data that reproduced the shape of the network to a certain extent. Evaluation using the Heipke method gave results of 70.4% completeness and 69.3% correctness. Such values were obtained because there were many large deviations at curved sections and erroneous extractions in places such as mountain streams. However, it is considered possible to generate basic information on road network shape because these deviations and erroneous extractions

Table 1. Extraction results for this study and studies in urban areas.

	This Study	Hasagawa et.al(2006)			Uemura et.al(2009)
		DSM	RGB	DSM+RGB	DSM
Completeness (%)	70.4	74.6	70.5	66.3	72.5
Correctness (%)	69.3	39.9	34.8	47.1	51.5
Quality (%)	53.7	35.1	30.4	38	42.8

Figure 11. Extraction of widened portion of curve (left), deviation of the curve developed during thinning (right).

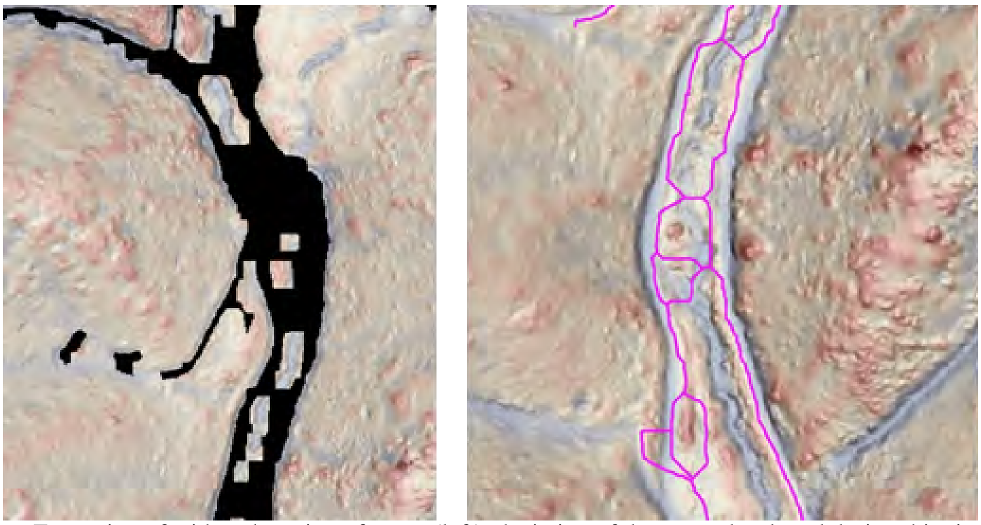

Figure 12. Extraction of widened portion of curve (left), deviation of the curve developed during thinning (right).

can be edited using a GIS, and unextracted sections can also be easily edited.

- The time taken to create the road network data was approximately 1.5 hours. This is short compared to the time taken to carry out surveys and reconnaissance by GPS. However, multiple tools were used to create the final road network data, and managing the many intermediate files created was complicated. Therefore, automation using Python would be helpful in the future.

The road network data created by the method examined in this study is characterized by the short length of time taken to create it. Also, all of the work can be carried out using free software and an open source GIS. Therefore, this method is considered useful for preparing road network data over wide areas in the early stages of GIS introduction, when there is no existing road network data.

Further investigation is required into a model/algorithm for road network geometry that can accommodate various road widths, as well as prevention of circles along mountain streams, automatic removal of circles.

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CARTOMOB: an integrative GIS tool for forest management and logging operations based on LiDAR data

T. Carrette*, A. Thivolle-Cazat

Abstract
In the FORESEE research project, a GIS based solution called CARTOMOB has been developed. It integrates such input, handles its processing in an analytical tool and delivers results in decision support system. Information provided by LiDAR is combined with other geographic layers. Hence, a technical and economic study of the forest resource is carried out. The objectives are to characterize and spatialize wood availability, as well as to analyze the physical and economical feasibility of its logging. To achieve this, three modules based on mathematical models are run alternately to estimate: available volumes by product type (silviculture regimes), technical accessibility and economical aspects (financial balance of the operation). At the end of the process, it is possible to easily visualize and estimate wood volume available, inaccessible plots, economical interest for owners, contractors and public body.

Keywords
analytic tool, forest management, decision support

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1. Introduction

Recent evolution of remote sensing technologies such as LiDAR and development of new geomatic tools opens up a new scope of applications in the field of forest management and logging.

The main advantages brought by such technologies and computational models are precise topographical information, quantification of the resource, continuous forest mapping and forest road networks detection. Never the less, such information is not easily exploited to its full potential. In the FORESEE research project, a GIS based solution called CARTOMOB has been developed. It integrates such input, handles it's processing in an analytical tool and delivers results in a decision support system.

2. Methods

Information provided by LiDAR is combined with other geographic layers. This integrative tool matches LiDAR information with public databases or information layers regarding species distribution or cadaster... Hence, a technical and economic study of the forest resource is carried out. The objectives are to characterize and spatialize wood availability, as well as to analyse the physical and economic feasibility of its logging.

To achieve this, three modules based on mathematical models are run alternately to estimate; i) volumes available by product type (silvicultural regimes), ii) technical accessibility and iii) economic aspects such as financial balance of the operation. The silvicultural module is based on wood rate scaling available in the area. This analysis can be drilled down to as many species as desired, but in this first version of the software only four main species were detailed. Regarding technical accessibility, the SYLV'ACCESS software developed by IRSTEA has been directly encapsulated in CARTOMOB. This module enables the creation of "smart buffer" to identify the area accessible by a skidder and the distance the machine will have to travel.

At the end of the process, it is possible to easily visualize and estimate available wood volume, inaccessible plots, and economical interest for owners, contractors and the public body. This service can answer many needs expressed by forest managers, logging contractors, timber industries, forest owners and natural conservators. CARTOMOB can be used in many practices by professional or institutions.

- For professional companies: commercial exploration (location of the volume by species and type of wood: sawn timber or pulp wood...), support decision for logging operation (cost, aggregation of site operation...) and detection of under-exploited areas (inactive owners).
- For institutions: support decisions when planning the creation of new forest roads (Area with high unreachable volume or high cost of mobilization...), sub-plot analysis of the resource, inventory and statistics for an area selected or a type of proprieties (see Table 1).

3. Implementation

CARTOMOB has been tested in over 900 square kilometers of forests in the northeast of France on the Vosges area.

Table 1. Type of results available for forest management purpose.

Area and nature of the plot	Volume Sawn Timber	Volume Pulpwood	Global Volume Available	Volume unreachable wood
<= 4 ha				
Private owner	68 076	46 243	114 305	23 982
Public owner	65 727	43 023	108 730	20 712
>= 20 ha				
Private owner	21 491	58 960	80 450	14 127
Public owner	769 341	575 627	1 344 914	156 598
4 < s < 20 ha				
Private owner	26 882	27 093	53 972	23 737
Public owner	811 822	500 230	1 312 069	190 019
Total	1 763 339	1 251 175	3 014 440	429 175

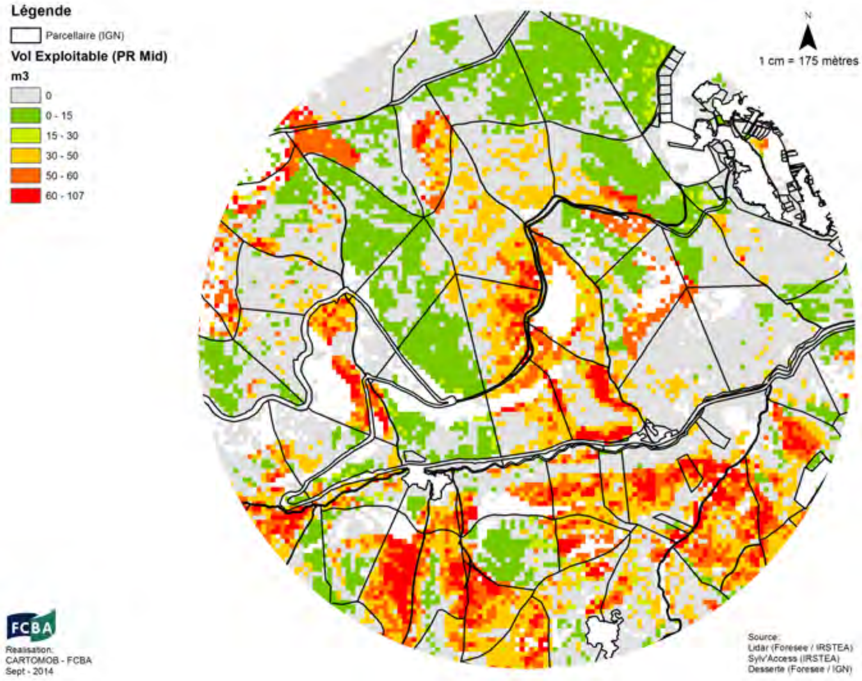

Figure 1. Output map on volume available in a sub-area of the north-east test site.

Feedback was collected from private and public forest managers. According to them, analyses enabled by the tool clearly show its relevance. CARTOMOB is very evolutional and simple, on purpose, with a calculation time of 45 minutes for all this area. The maps provided by the tool were simple to use in the field and the information layers were easily integrated in practitioners' own GIS software. (See figure 1 for an example of output map).

4. Discussion

This tool has been developed in the ARCGIS environment. Based on a python script, the structure of the tools has been conceived in a way to allows implementation and evolution on each part of the three modules. The major advantage of this tool is still its ability to integrate. In the near future more information will be integrated such as hydrographic network or fertility. Hence, all developments in connection with the LiDAR mapping and forest mapping can be provided to forest-based practitioners who are not in the habit of handling such data.

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Contributions of traffic frequency and ground pressure to soil disturbance

R. Naghdi*, A. Solgi

Abstract

Vehicle imposed soil compaction is one of the serious concerns in forestry and one of the environmental problems that requires accurate studies. The aim of this paper was to assess the impact of front and rear tyres of an agricultural tractor with different tyres size and axle loads on bulk density, total porosity and on the rut depth, for three levels of traffic intensity. Traffic levels were 1, 3 and 7 passes of a conventional 2WD tractor, using two different tyres as front tyres (750-18) and rear tyres (18.4-30). Rut depth after traffic and soil bulk density and total porosity in a 0–10 cm profile were measured before and after traffic.

For the different tyres, the topsoil compaction increased from increasing of passes independently from the ground pressure. The results showed that tyre size is an important factor of disturbance produced in the soil for different number of passes. When the tyre-soil contact area increased, ground pressure and soil disturbance decreased. Results showed that topsoil compaction depends directly on ground pressure.

Our results show that the use of wide and large tyres with low ground pressure has a real effect on decreasing the topsoil disturbance.

Keywords

bulk density, compaction, contact area, porosity, rutting

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1. Introduction

In forest stands, the increase in size, power and weight of forest machinery is one of the main causes of soil disturbance (Rohand, Al Kalb, Herbauts and Verbrugge, 2004). The most significant changes have been shown to occur in soil surface layers which can restrict the movement of air and water into soil layers (Rab, 1994, Botta, Jorajuria, Rosatto and Ferrero, 2006). Compaction is perceived as one of the leading causes of forest soil disturbance resulting from forest operations (Brais, 2001). Compaction involves a rearrangement and packing of the solid particles of the soil closer together, resulting in an increase in the bulk density (Solgi and Najafi, 2014).

Machinery-induced soil compaction strongly reduces porosity and pore connectivity, and increases soil density and shear strength (Williamson and Neilsen, 2000; Solgi, Naghdi and Nikooy, 2015a). When forest soils are compacted, pores volumes are reduced and consequently aggregates crumble and smaller inter-aggregate pores with non-accommodating faces are formed (Pagliai and Vignozzi, 2002). The major loss of the largest pores caused by soil compaction changes the pore size distribution and reduces water retention (Dexter, 2004). Compacted soil impedes root growth and thereby limits water of plants. Botta et al. (2009) reported that highly compacted soil, particularly in the surface layers, generates inadequate soil physical conditions for seedling emergence.

The most obvious visual indicator of topsoil compaction is rut depth affected by tractor and machinery's traffic on the soil (Botta, Tolon Becerra, Bellora Tourn, 2009; Najafi, Solgi and Sadeghi, 2009). Rutting often occurs when traffic is applied to soil when it is in a compactable condition. Ruts may also become channels for superficial water flow and thus cause erosion since the infiltration of rainwater is reduced (Startsev and McNabb, 2000; Solgi, Najafi and Sadeghi, 2014).

Compaction that a machine tyre imposes on the soil is a function of four factors of axle weight, forward speed, tyre inflation pressure and number of passes (Afzali, Ghezelbash and Loveimi, 2014). The number of machine passes is a factor that significantly influences the degree of soil damage. Several authors (eg. Jamshidi, Jaeger, Raafatnia and Tabari, 2008; Naghdi and Solgi, 2014; Solgi, Naghdi, Tsioras and Nikooy, 2015b) have studied the impacts of the frequency of vehicle passes on soil compaction. These studies showed that most compaction occurs during the first few passes of a vehicle. Subsequent passes have less, but may increase density levels and reduce non-capillary porosity to critical levels for tree growth (McNabb, Miller, Lockaby, Stokes, Clawson, Stanturf and Silva, 1997). Arvidsson and Keller (2007) studying the effect of wheel loads (11, 15 and 33 kN) at inflation pressures of 50, 70 and 150 kPa on soil stress, found that the tyre inflation pressure has a large influence on soil compaction measured at 10 cm depth. Abu-Hamdeh and Al-Widyan (2000) evaluated the effects of different tyre inflation pressures and different axle loads on soil compaction and concluded that these factors affected the density of soil layers beyond 20 cm depth. Sharifi-Malvajerdi et al. (2013) found that the increase in the axle load mostly affected the subsoil whereas the effects of increase in the inflation pressure mostly appeared in the upper layers of soil. Botta et al. (2002) found that topsoil compaction depends, directly, on ground pressure. By increasing ground pressure, the soil disturbance increased. Smith and Dickson (1992) and Botta et al. (2008) found that compaction on the surface layer is determined by the ground pressure. The low ground pressure exerted by wide tyres on soil produces a decrease in topsoil compaction (Botta, Tolon-Becerra, Tourn, Lastra-Bravo and Rivero, 2012). The objective of this work was to quantify topsoil compaction caused by ground contact pressure of front and rear tyres of an agricultural tractor.

2. Material and Methods

2.1 Study area

The study was conducted during the period August -September 2014 in compartment 41 of third district of Shenrood forest, Guilan Province, northern Iran (between 36°31'56" N and 36°32'11" N latitude and 51°47'49" E and 51°47'56" E longitude). The forest comprised predominantly of oriental beech (Fagus orientalis Lipsky) that grew on a clay loamy soil. Canopy cover, mean diameter, mean height and stand density were 80%, 29.72 cm, 22.94 m and 170 trees ha-1, respectively. Elevation is approximately 800 m above sea level and the study area has a northern aspect. The average annual rainfall recorded at the closest national weather station, located 20 km far from research area, was 860 mm. The maximum mean monthly rainfall of 120 mm usually occurs in October, while the minimum rainfall of 25 mm occurs in August. The mean annual temperature is 15 °C, with the lowest values in February. At the time of skidding, weather conditions were wet with an average soil moisture content of 28%. The soil had not been driven on before the experiment.

Ground-based skidding operations were performed with a rubber an agricultural tractor (Massey Ferguson 285). In the experiment tractor was driven unloaded. The main technical characteristics of this machine type are given in Table 1.

Table 1. Technical details of the agricultural tractor Massey Ferguson 285.

Specifications	Massey Ferguson 285
Engine power (ps)	83
Front tyres	750-18
Rear tyres	18.04.1930
Total weight (kg)	3114
Front weight (kg)	1420
Rear weight (kg)	1694
Front tyre–soil contact area (m²)	0.0484
Rear tyre–soil contact area (m²)	0.1771
Ground pressure front tyre (kPa)	146.7
Ground pressure rear tyre (kPa)	47.823

2.2 Experimental treatments

In this study, the impacts of different ground pressures on the surface soil layer (0 to 10 cm depth) of skid trail was quantified using dry bulk density, total porosity, and rut depth and compared to the undisturbed area at different levels of traffic intensity.

For this reason, a trail was selected with a longitudinal slope lower than 5% and without any lateral slope. Treatment plots included the combination of three levels of tractor passes and two dimensions of the ground pressure (front and rear tyres). The levels of tractor passes were 0, 1, 3, and 7 tractor passes in same tracks.

Prior to the trial, the tractor was weighed to obtain their total and individual axle loads. The tyre/soil contact area was measured on the experimental field by reversing or driving the machines into the field and spraying the area around the tyre with paint. A hydraulic lift was then used to raise the machine and the tyre impression outlined on a sheet of glass by placing the glass on the soil surface. The observed area free of paint was then transferred to paper and measured with a planimeter. Average ground pressure was estimated as the total axle load divided by the tyre–soil contact area for both tyres on the axle (Botta, Tolon Becerra, Bellora Tourn, 2009).

Ten treatments were imposed on plots 10 m long × 5 m wide (50 m²) each one, with 10 m wide buffer zones between plots to avoid interactions. Plots were in completely randomized blocks having three replications. In each sampling plot, 5 lines, of which three lines were chosen at random for sampling, were set up perpendicular to the movement direction with a minimum 2 m buffer zone between lines to avoid interactions. Soil samples were then taken from a depth interval of 0–10 cm at two different points on each line: the left wheel track (LWT), and the right wheel track (RWT) (Fig. 1).

The soil samples were collected with a soil hammer and rings (diameter 5 cm, length 10 cm), put in polyethylene bags, labeled, and transported to the laboratory where they were promptly weighed. Soil samples were dried in an oven under 105° C for 24 h. The moisture content in the soil samples was measured gravimetrically after drying in the oven (Kalra and Maynard, 1991).

Soil bulk density was calculated as Equation (1):

$$Db = \frac{Wd}{VC} \tag{1}$$

Where Db is the dry bulk density (g cm^{-3}), Wd is the weight of the dry soil (g), and VC is the volume of the soil cores (196.25 cm³).

Total soil porosity was calculated as Equation (2):

$$AP = \frac{1 - \frac{Db}{2.65}}{VC} \tag{2}$$

Where AP is the total porosity (%), i.e., the proportion occupied by pores larger than 50 µm, Db is the dry bulk density (g cm^{-3}), and 2.65 (g cm^{-3}) is the particle density.

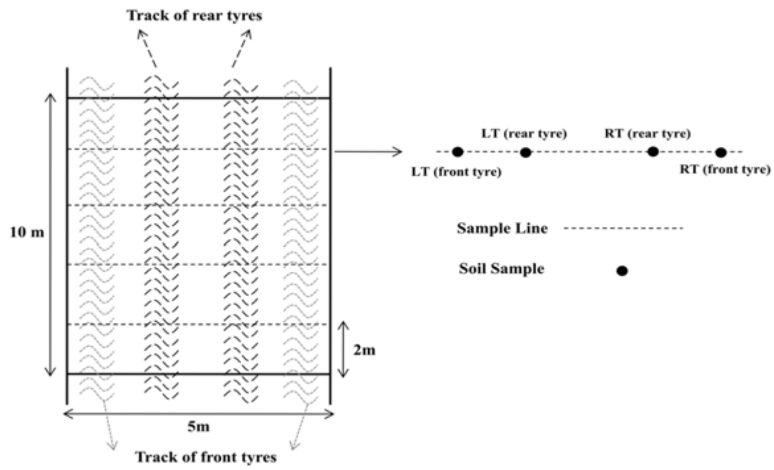

Figure 1. Sketch of the treatment set-up with the location of the sample lines within the plot.

Ruts at least 5 cm deep from the top of the mineral soil surface and 2 m long were sampled. Rut depth was measured using a profile meter consisting of a set of vertical metal rods (length 500 mm and diameter 5 mm), spaced at 25 mm horizontal intervals that slid through holes in a 1 m long iron bar. The bar was placed across the wheel tracks perpendicular to the direction of travel and rods were positioned to conform to the shape of the depression (Nugent, Kanali, Owende, Nieuwenhuis and Ward, 2003). Rut depth was calculated as the average depth of 40 reads on the 1 mbar (Fig. 2).

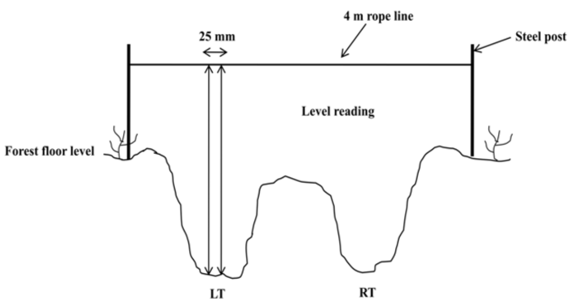

Figure 2. Illustration of the technique used for rut depth measurement. LT, left rack trail; RT, right rack trail.

2.3 Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS 11.5). An analysis of variance (ANOVA) was performed on the data, and Duncan's multiple range test was used to analyze the means. Paired t-tests were used to analyze soil properties data in two axles of tractor (front and rear) at an alpha level of 0.05.

3. Results and Discussion

Measurements of bulk density, total porosity and rut depth that were done immediately after traffic in the tractor tyre tracks lanes are shown in Tables 2, 3 and 4 respectively. These data confirm that the front and rear tractor tyres significantly ($P < 0.01$) increased both bulk density and rut depth an also decreased total porosity in respect to the control plot which had no traffic.

Table 2. Effect of ground pressure on soil bulk density (g cm^{-3}). Different letters indicate statistically significant differences ($\alpha \leq 0.05$) among group means based on Duncan's multiple range test.

	Traffic intensity			
Tractor	0*	1	3	7
Front tyres	0.68^a	0.97^a	1.18^a	1.44^a
Rear tyres	0.68^a	0.85^b	1.01^b	1.19^b

*0 passes denotes undisturbed soil

Table 3. Effect of ground pressure on soil total porosity (%). Different letters indicate statistically significant differences ($\alpha \leq 0.05$) among group means based on Duncan's multiple range test.

	Traffic intensity			
Tractor	0*	1	3	7
Front tyres	70.05^a	61.18^a	53.42^a	46.39^a
Rear tyres	70.05^a	66.73^b	59.86^b	54.15^b

*0 passes denotes undisturbed soil

The front axle used narrower tyres than the rear axle, which caused a higher pressure on the soil of the front axle compared with the rear axle (wider tyres and having greatest soil/tyre contact area). Indeed soil compaction increased as ground pressure increased from 47 to 146 kPa.

Figure 3 is shown that the relationship between bulk density and ground pressure is strongly positive. These results agree with those quoted by Smith and Dickson (1992), confirming the direct relationship between topsoil compaction and ground pressure. Raghavan and McKyes (1978) com-

Table 4. Effect of ground pressure on rut depth (cm). Different letters indicate statistically significant differences ($\alpha \leq 0.05$) among group means based on Duncan's multiple range test.

	Traffic intensity		
Tractor	1	3	7
Front tyres	0^a	5.3^a	13.8^a
Rear tyres	0^a	2.4^b	7.1^b

pared the compaction produced by the number of passes for different size of tyres with an approximate load of 14 kN. The 16.9–28 tyres produced an increase of the soil bulk density even after the fifth pass, exceeding this, the increase was lower.

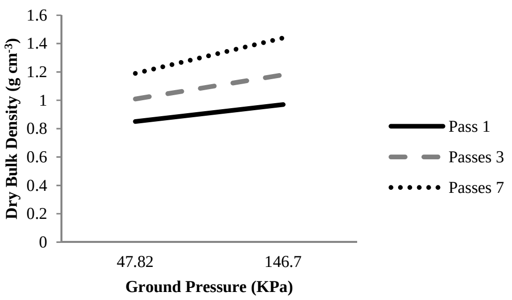

Figure 3. Relationship between bulk density and ground pressure for front and rear tyres of agricultural tractor.

The majority of the soil compaction along the trail occurred during the first few passes: the bulk density of the soil after the first tractor passes was substantially greater than in control plots, regardless of ground pressure (Table 5). For the number of passes is known that the second and next passes of the tyre causes less compaction than the first one. However, this response to traffic is related to the initial level of soil compaction and the distribution in deep layers (Soane, 1980).

Table 5. Dry bulk density increase (%) per axel load and ground pressure class compared to the previous traffic intensity level.

	Traffic intensity		
Tractor	1	3	7
Front tyres	42.6	21.6	22.1
Rear tyres	25	18.8	17.8

Total porosity decreased to 66.7–46.4% and was significantly affected by ground pressure and traffic intensity (Table 3). The traffic of rear axel tractor caused a mean reduction in total soil porosity of 22.6%, 14.5% and 4.7% with 7, 3 and 1 passes, respectively. Whereas reduction in total soil porosity for front axel was 33.8%, 23.7% and 12.6% for 7, 3 and 1 passes, respectively. This corroborates other research suggesting that one pass of a tractor with different ground pressure can result in extensive topsoil compaction and severe reduction in total soil porosity (Tolon-Becerra, Botta, Lastra Bravo, Tourn, BelloraMelcon, Vazquez, Rivero, Linares and Nardon, 2010). The reduction of total porosity after trafficking typically occurs at the expense of the large air-filled pores in the soil surface layers due to a conversion of soil macropores to micropores (Williamson and Neilsen, 2000).

The rut depth measured results, are shown in Table 4. No significant ($p < 0.01$) differences were found in rut depths between front tyres and rear tyres when they passed one time, but there was a difference when traffic raised up to three passes. All the rut depth values measured in soil under front axel were higher than the ones measured in soil under rear axel. The results showed that the mean rut depth increased with increasing ground pressure and with increasing traffic intensity. The positive relation between rut depth and traffic intensity observed in this study has been observed elsewhere (Eliasson 2005; Botta, Jorajuria, Rosatto and Ferrero, 2006; Najafi, Solgi and Sadeghi, 2009).

The front axle in spit of having lower weight has the higher bulk density. This is explained by the fact that the area of pressure distribution is small, as such, the tyre pressure is acting on a small area thereby increasing the point pressure on the soil.

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Monitoring the changes of flood discharge caused by harvesting operations in a mountainous Hyrcanian forest

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Abstract
Most of the mountainous forest areas in northern Iran are located on medium slopes and steep terrain. These areas are very sensitive to erosion and runoff caused by various harvesting operations. Excessive and inappropriate harvesting operations and consequently loss of forest areas have caused floods in the region. The aim of the present research was to link the volume of stock and the number of harvested trees as independent variables to maximum flood discharge, as a depending variable, and to evaluate the interactive effects of the independent variables on flooding within an assumed period, before and after harvest. Accuracy of the hydrological data was measured with using the “Test Run” test. Fitting the data using different statistical distributions (with use of software Hyfa) was performed and the maximum precipitation and flood flows with return periods of probability were extracted. The required digital maps were prepared using GIS (in ILWIS environment) and physiographic parameters were calculated. Using the obtained diagrams, comparing maps and flood zoning and vegetation produced correlation of each independent variable, exploitation of forest lands and rainfall with discharge values were studied. Finally, the relationship between these correlations and the amount of peak flood flow was studied. Results showed that, despite climate change unreduced rainfall in recent years, the number of flood sand river flow rate was greatly increased in the years after the harvest. The surveyed flood discharge data showed that the daily flood discharge in the years before harvesting had been monotonous and had a maximum of four m^3/s. This amount increased at the years after harvesting, was variable and had a maximum of nine m^3/s. Since the strip cutting was performed in the region, according to uneven-aged forest structure, it is essential to apply the close to nature forestry practices single selection harvesting methods for sustainable forest management.

Keywords
harvest, flood, regression, distribution, Landsat-TM

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1. Introduction

Guilan province in the northern Iran has been recognized as the area with high precipitation. One of the important factors for protection of soil, water and resistance drought is conservation and proper utilization of natural resources and forest cover. Today, protection of natural resources with the development of human society has become extremely important. Scientific document and empirical evidence has proven that incorrect and excessive exploitation of natural resource, it is extinct. As Iran is one of the poorest countries, conservation of this source is very important. Reduction of forest cover and terms of utilization non commensurate with the potential of this region and some other factors, including loss of soil and flood coming through the recent decades. Therefore, it is required a proper planning and management of the macro-structures for preservation of this valuable resource. For example, mountainous forests of northern Iran, is supply water source for agricultural land. Forest with its humus production, which is the spongy tissue, cause water retention and disposal it for gradual that this would also prevent flooding and act as a natural barrier and prepared water needed in the dry season. One of the main causes of flooding in the northern Iran is the indiscriminate exploitation of forests in the mountainous areas. Research showed that the parameters of area, mean annual precipitation, elevation basins and drainage density have a pivotal role in the calculation of maximum discharges (Khojyni 1999). The impact of floods could be as much the result of exposure due to population pressures as changes in climate or the environmental impact of human activity. The infrequency of extreme floods, and the effort required to properly instrument watershed studies, has severely limited reliable scientific information about extreme events (Eisenbies et al., 2007). As a result, hydrologic modeling has been used to estimate flood characteristics, but results have not always been satisfactory. Modeling these interactions is a difficult problem due to very complex interactions among site attributes (Hibbert, 1967; Phillips, 2004). Climate, geology, and watershed geometry are all essentially fixed (Benda et al., 2004). Soils, topography, and vegetation can all be influenced by management practices and land-use. Antecedent moisture conditions also greatly affect watershed responses (Findell and Eltahir, 1997). This Study to investigate the relationship between forest harvesting and runoff in Shafarood basin is done that source of raw materials for pulp and paper is Chuka factory that the land use was further changed.

2. Material and Methods

2.1 Study Area

The study was conducted in Shafarood forest, Guilan Province, northern Iran (between 37°25'11" N and 37°34'30" N latitude and 48°6'30" E and 48°41'56" E longitude). Elevation is approximately 900 m above sea level (minimum 60 m and maximum 2903 m) (Fig. 1).

Geological structure of the second period and expand layers sensitive to erosion can be seen in most parts of Shafarood basin. Sediment production in this area is 149,880 tons per year. This area has humid climate with annual precipitation 1431.76 mm and containing water regimen in autumn. Maximum rainfall in the area Shafarood in autumn (October) is 240.5 mm and minimum rainfall in summer (July) 60.9 mm. The average annual temperature is 5.16 mm and the maximum evapotranspiration occur in summer (July). The maximum debi discharge to be in March 9.22 in August and the least 2.99 cubic meter per second. 100.7 km is the basin environment and has a slope between 30- 50%, textured soil is heavy to very heavy (Fig. 2).

2.2 Study of Vegetation

The number and volume of wood harvested in the study area were taken from Guilan natural resource management office. Land use basin area was determined using satellite image processing (Fig. 3). The images changed format to the ILWIS program. Preprocessing (atmospheric and geometric corrections) was performed on them. The correlation between the spectral bands, reviews, and index OIF calculated and determined spectral bands was to choose the best combination. False color image was produced. NDVI index was used for the classification and visual interpretation. Finally, the adaptation of the points taken with GPS, the type and quality class was determined (Fig. 4).

2.3 Hydrology Investigation

The peak instantaneous data rate and annual data collected in the study area. The base period was selected. Theoretical data and the extent permit determined by SCS method were to extend the length of the statistical year. The hydrological data based on regression, reconstruction and complete. Analysis of statistics of maximum instantaneous flow rate from year's different periods, based on current distributions in hydrology (normal, log-normal, two and three-variable regression, Pearson, log Pearson, gamma and Gamble) was performed using the software HYFA. Based on the distribution, the maximum instantaneous flow rate was determined for different return periods. Estimation The flooding intensity in the basin and providing appropriate methods for the control and mitigation of floods and flood mitigation of the impact of the proposed operations (using the proposed model) is as follows:

Basin area and river length of data are obtained through physiography studies. Because the routing basin SCS method is more suitable (select this method, due to greater use of physical data of the basin and its global credibility) the map of soil retention factor (CN) was prepared. The map of soil hydrological groups (based on the permeability of the soil texture using SCS) and watershed land use map was obtained. The number of floods in the basin for model calibration and accuracy evaluation determined with Run Test method. In calibration phase, due importance of peak flood events, the maximum discharge was considered as an indicator calibration. For identifying the relationship between risk factors and their impact on basin flooding in flood discharge, sensitivity analysis (Sensitivity Analysis) was used. In order this, for determine the flood hydrograph outlet, the factors that control is to its for management, are entered into the model.

2.4 Factors flood in the basin

By using graphs Obtained and with compare the flood zoning maps and vegetation, and regression method, correlation coefficients of each independent variables, volume and number of trees, decrease forest area and precipitation was associated with discharges. The above equations, analyze and harvesting effect on the increase or decrease in peak flow and flow rates were determined. Finally, factors contributing to the changes and its compliance with other scientific and practical experience to find solutions for optimal operation were performed.

3. Results

Land use area according to maps from satellite image interpretation is according to table 1.

Table 1. Land use of shafarood Basin.

Land use	Area (km²)	Percent (%)
Dense Forest	15.5	4.4
Moderate dense Forest	198.66	56.8
Destroyed Forest	43.2	12.4
Agriculture	73.74	21.1
Urban & Bare land	18.76	5.6
Water resource	0.02	xxx.yy

Curve moving average precipitation 2, 3 and 5 years shows that amount of precipitation in several decades has been decreased (Fig. 5).

Overall, 38 percent of the rainfall in this area falls in autumn, and then summer and winter are the highest seasonal rainfall. Spring rainfall, with 16 percent allocated to the lowest percentage of annual precipitation. Compare weather charts show, in the first six months of water (October to March), with a decrease rainfall, runoff and temperatures are decreased. But in the second half (April to September), the process flow is inverse. Based on in-depth Shafarood permeability soils (120-20) cm, with a low permeability coefficient of about 9.0 - 6.0 cm per hours and is part of the hydrological D (Fig. 6).

Peak period of runoff before the harvest indicates that the range of its rate is low and only in one case was found that only affect high peak with the intense rainfall. But

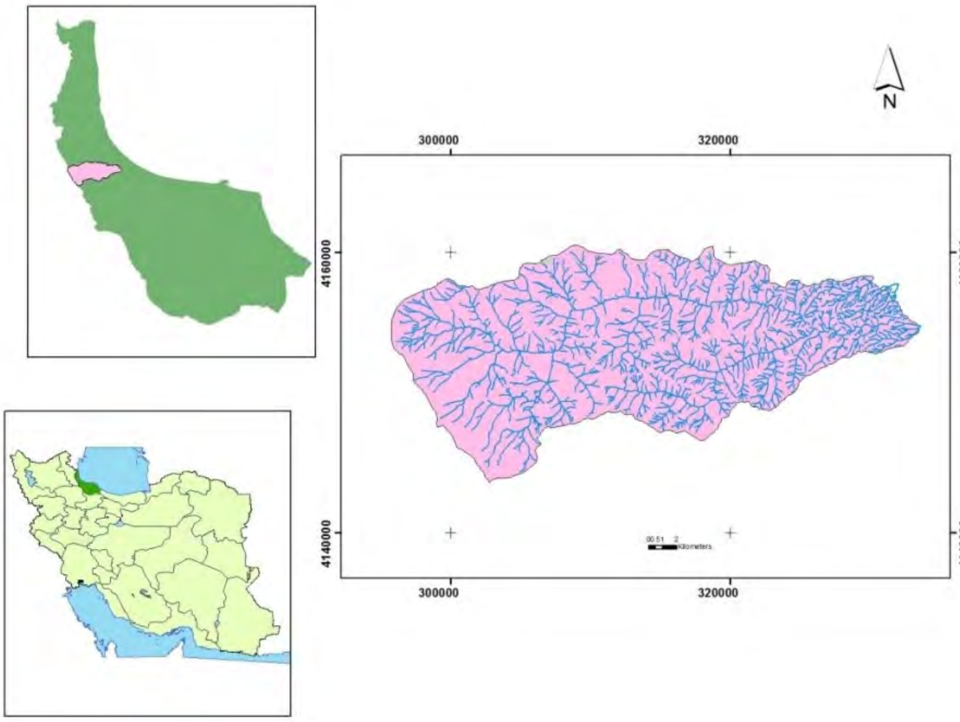

Figure 1. Shafarood Watershed, Guilan Province and Hydro Map.

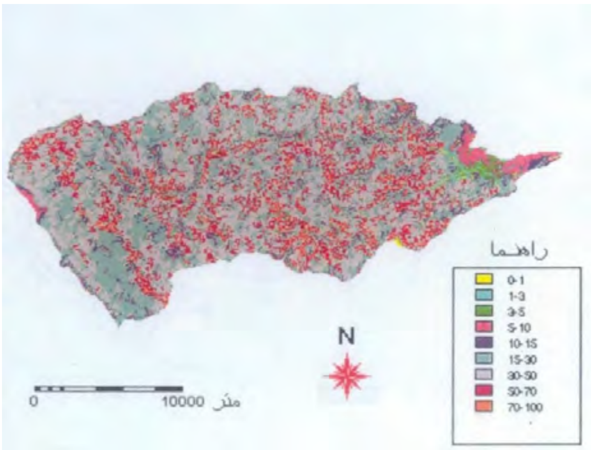

Figure 2. Slope map of Shafarood Watershed.

Figure 4. Vegetation map of Shafarood.

Figure 3. Satellite image of Shafarood.

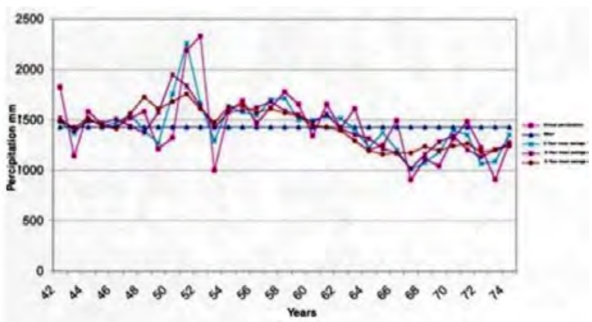

Figure 5. Moving average rainfall of 2, 3 and 5 years.

Figure 6. Soil map of Shafarood basin.

since the start of the operation, can see much more change in the general trend of maximum flood discharge. Moreover, along with the sediment load in the upstream and destroyed fat, it gives extra charge (Fig. 7).

Figure 7. Flood with sediment in Shafarood basin.

Flood potential Basin map shows that most of basin area has high and very high-risk (Fig. 8).

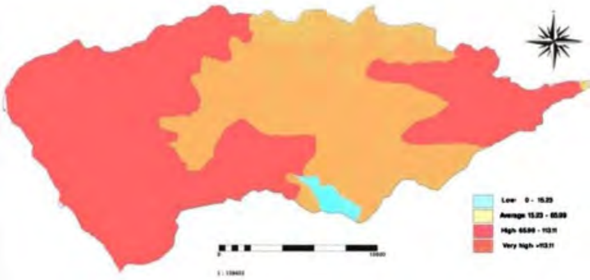

Figure 8. Zoning potential flood map of Shafarood.

There is an inverse relationship between the volumes of wood harvested with minimal runoff basin each year. The relationship is between the volumes harvested and average annual flow volume as well (Fig. 10).

There is a direct relationship between the destruction or utilization of forest and runoff the maximum moment (Fig. 11).

4. Discussion

Several factors are influenced on a basin runoff, in most cases because of constant parameters, only independent

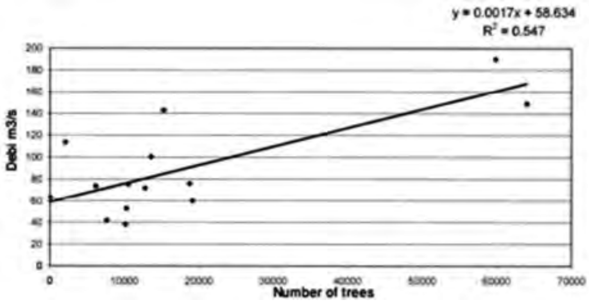

Figure 9. Relationship between the number of tree harvested with maximum moment discharge.

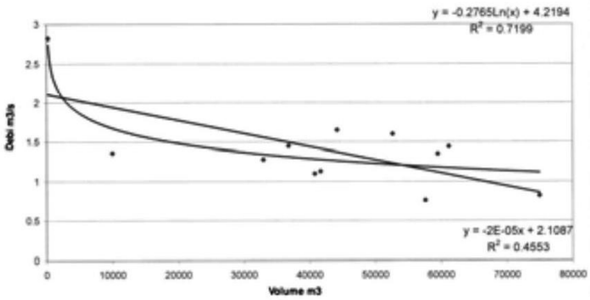

Figure 10. Relationship between the minimum discharge and volume harvested.

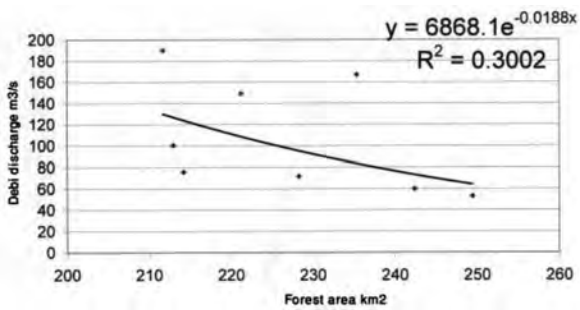

Figure 11. Relationship between the minimum discharge and volume harvested.

variable of raining used to create runoff and discharge areas are involved. The study area is fixed and the only factor that changes occurs, harvesting of forests, i.e. reducing the level of cover and rainfall, which is under the control of human. Thus coverage of area is only management factor which could help ours to proper management for control runoff. While, according to the report of Meteorology department, in recent years the temperature has risen 1.5 degrees, and the amount of rainfall has decreased, but increased the amount of runoff and flooding. Reduced coverage caused hydrograph modified and the coefficient of water retention reduced, delay time and area focus to reach the peak discharge and flood has changed and for this area from about 14 to 9.6 hours. these factors plus climate change and dispersion erratic rainfall caused to , despite the impression, in some years, the people, especially farmers be experienced drought or like few years recent, forest very early lose leaves in September. Research of Sobh zahedi and et al (2012) and Alidoust and et al (2012) also confirm this. In the past, the river flow volume according to the amount of rainfall, the process is almost regular. So that over the year, river's water was flowing. But today, with deforestation and destroy soil by human activities, with a rainfall of less, because of the lack of cover and reduce the permeability of soil water, drain water done quickly and changed to flood. The study of Engler (1919) also reveals that the average maximum water flow surface area of sparse forest and non-forest area was more than 2 times from forest area.

Compare the peak discharge before harvest years with moving averages 2, 3 and 5 years old, shows that more than 70 percent rainfall ia above average 1431 millimeter. But since the start of the operation, more than 67 percent less rainfall than average, whereas if you have seen peak discharge, observed that much more changes to show in the general trend of maximum flood discharge .Such can say, according to the soil conditions and other parameters proved normal, and rainfall decline compared to previous years, the only factor that plays an important role in increasing the peak discharge operation is harvesting inappropriate.

Considering the harmful effects of forest harvest conditions at the same time, the strip or clear cutting entirely methods were used, suggested that forestry management methods close to nature or uneven aged to be used.

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Forecasting the degree of error in trees falling direction using cascade-forward artificial neural network

I. Ghajar, R.Naghdi*

Abstract
Safety of workers is one of the top priorities in forest activities. The felling operation is a dangerous activity that more people are killed in than during any other harvesting activity. Although logging workers can usually control the direction of tree falling by cutting first notch on the side of the tree that faces the desired direction, the tree does not fall in the expected direction in many cases, particularly in mountainous conditions. The aim of present research was to develop a reliable model for predicting the amount of error in falling direction using cascade-forward artificial neural network (CF-ANN). To do that, a number of 95 trees of three species; Fagus Orientalis Lipsky, Carpinus Betulus, and Acer Platanoides were felled in a mountain forest in northern Iran. For each tree, the difference between the expert predicted and actual fall directions were measured as felling error. The elements of terrain slope, tree's height, diameter at the breast height (DBH), and tendency of the trunk were used as input variables of the models. Results showed that CF-ANN could generate models with high performance to predict the amount of felling error. Among the collection of obtained results, the determination coefficient of one of the robust models was 0.9998 and the root mean square error was 0.0001. Results indicated that models with the same transfer functions in the hidden layers had high generalization power for estimation and forecasting of probable error in prediction of falling direction.

Keywords
backpropagation, tangent, logaritmic, sigmoid, purelin

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1. Introduction

Felling error is defined as the deviation of real falling direction of the trees from expert predicted direction. Modeling this error could be very useful in safety and health in forest operations. Felling is one of the logging components that can result in serious damage to residual stand if it is not accomplished properly. In order to maintain residual trees and sustainable wood production, proper felling techniques should be applied. If these are not used, or in fact, if a tree is cut without proper undercut and backcut or maintaining hinge wood, it falls in a random direction and this can cause severe damage to the cut tree or the residual stand (FAO 2004). A correct felling operation could not be happened always due to various influential factors. One of the most important factors in directional felling is to put logs in a proper direction, however effort must be made to select a direction in which felling operation imposes less damage than other ones, although the damage resulted from felling is unavoidable (Cedergren, et al. 2002). Shourmij (2009) showed that felling operation as the first step in wood production, damaged residual trees about 17 to 20% (on average) and about 33% of these trees were of 50 to 70 cm of diameter and could form the future product of the forest. In addition, the severity of damage was to the extent that 13% of those trees with damaged crown finally died. The investigation of conducting trees toward skid trails showed that, the time required for skidding is decreased if logs are positioned in the correct direction, and also log rotation and damage to residual stand and regeneration is avoided (Naghdi et al. 2007). Undoubtedly, trees must be cut in all logging systems. Although decreasing harvest intensity lowers resulted damage, but ignoring the fact that marked trees should fall in a predetermined direction may have irreparable subsequent damage (Appanah and Weinland 1990).

A number of studies, specifying valuable residual trees, provided the required guidelines for the felling group to maintain those trees (e.g. Krueger 2004).

In order to find out whether trees fall on the proper trail according to predetermined planning, it is necessary to estimate the difference between this route and the actual direction (FE). Krueger, 2004, studied the ability of felling group in directional cutting in Bolivia. Results of the study showed that, on average, there is a 35.2° difference between the intended and the actual direction of the trees' fall. According to the obtained results from this research, increasing the diameter of the log enhanced the FE and this increase was different for various species. It was also observed that the FE varied between work groups (Krueger 2004). Many tools have been developed to fell trees in the desired direction (Lindroos et al. 2007). Although using these tools can effectively facilitate directional felling, identifying the most important components of an exact felling operation can help felling groups to perform the operation more accurately and in safe and controlled conditions.

Apart from the ability of felling groups in performing a directional cutting, there are also other effective factors on FE. The purpose of this research was to study and model FE and to identify the influential factors impact on the amount of FE. The factors such as trees' height and diameter, foot slope at the harvesting site, undercut and backcut angles and the spout of undercut were considered as possible independent variables influencing FE. By identifying the effective factors on the directional error, the felling groups could perform the operation more accurately with less damage to the vegetation and soil.

1.1 Artificial Neural Network

Artificial neural network is one of the subsystems of artificial intelligence that mainly uses the processing units called "Neuron". ANN's discover the innate and fundamental relationships among variables during a learning process. In fact, it creates a mapping between input space (input layer) and target space (output layer). Hidden layers process the input data from input layer and create response(s) in output layer. Training is a procedure, which leads to learning process. Each network was trained using the represented patterns. In this study, the deviation of 95 trees falling direction from predetermined direction (felling error (FE)), and some effective factors for each case, were measured and used as training patterns

Samples with known inputs, consecutively were fed to the network and responses taken from, were compared with known outputs. During the learning process this comparison propagated at the rear of the network. As a result, the connection weights among layers changed so that the difference between predicted value and target (FE data) decreased again as located in the acceptable domain. As the training process goes forth, the given responses in the network increasingly will be more accurate. The trained neural network can be used to predict unknown composition of input variables. The benefits of using ANN can be briefly described as high rate of calculation learn ability from experimental inputs and prediction of unknown patterns. Among all kinds of Neural Multi-Layer Perception (MLP), Cascade-Forward Back Propagation (CFBP), was used for modeling. Besides, to evaluate the power of training algorithms, Bayesian Regulation (BR) and Levenberg-Marquardt algorithms were used as training algorithms.

2. Material and Methods

2.1 Study area and data collection

The study was conducted in the compartment 207 of 7th district of Nav watershed in the northern Iran. The longitude was between 48° 44' 36" and 48° 49' 58" and the latitude was between 37° 37' 23" and 37° 42' 31". The whole area of the parcel was 54 hectares, with harvestable area of 41 hectares and protected area of 13 hectares. The minimum of altitude from sea level was 540 (m) and the maximum was 850 (m) and the average altitude of most parts was 750 (m). The general direction of the parcel was northern. Around 22 hectares of this parcel had the slope of 30 to 31%, 18 hectares had slope of 61 to 80%, 10 hectares had slope of 81 to 100%, and about 3 hectares had slope of higher than 100%. There were 232 trees per each hectare with of 273 (m^3) volume of stock per hectare. The measured variables for each tree before and after felling operation were felling error, tree's height (m), leaning (degree), tree's diameter (cm), foot slope (%), undercut spout angle (degree), Undercut surface horizontal angle (degree), Undercut surface vertical angle (degree), Backcut surface horizontal angle (degree), Backcut surface vertical angle (degree), Undercut area (cm^2), Backcut area (cm^2), Decayed area (cm^2).

2.2 Designing of Artificial Neural Network for skidding time modeling

Assuming some effective variables in felling error, 12 inputs in all samples were the determining factors for FE. Networks were designed with two hidden layers including 2 to 20 neurons in both first and second hidden layer and one neuron in output layer. Neural network toolbox of MATLAB 2011a was used for design, implementation, visualization, and simulation of modeling process and CFBP network was adopted for FE modeling. Simultaneously with network training, errors between real data and predicting values were minimized and training process moved to stability. In order to select the number of layers and neurons for evaluating different typologies, the increasing method was used. By implementing this method, when network trap in local optimum, new neurons gradually are added and the optimum size of network is obtained. To obtain the optimal network, the threshold functions LOGSIG and TANSIG were used with various compositions with the number of neurons and layers.

To obtain the optimal network, the threshold functions LOGSIG (Eq. 1) and TANSIG (Eq. 2) were used with various compositions with the number of neurons and layers.

$$Y_j = \frac{1}{1+exp(-X_j)} \tag{1}$$

$$Y_j = \frac{2}{(1+exp(-2X_j))-1} \tag{2}$$

Where X_j is the sum of weighted input for each neuron in layer J. X_j can be calculated using the following formula:

$$X_j = \sum_{i=1}^{m} W_{ij} Y_i + b_j \tag{3}$$

Where m is the number of neuron in the output layer, W_{ij} is the weight between ith and jth layer, Y_i is ith output neuron, b_j and is the bias of jth neuron for a FFBP network. About 60% of data were used for training the network with various topologies, LM and BR training algorithms. Training data were feed to the network through the training process and network was adjusted according to its error. About 20% of data were used as validation data and the rest were used to test the model. The validation data utilized to control the power of network generalization and to stop the training in order to prevent the overfitting. Testing data have no effect on training and provide an independent measure of network performance during and after the training.

Network performance was evaluated by sum of square error RMSE (Eq. 4) and determination coefficient (Eq.s 5 and 6) between output and input. The training process were repeated twenty times and the greatest result of each setting parameters were recorded.

$$RMSE = \sqrt{\frac{1}{T}\sum_{K=1}^{T}(S_K - T_K)^2} \quad (4)$$

$$R^2 = 1 - \frac{\sum_{K=1}^{T}(S_K - T_K))^2}{\sum_{K=1}^{T}(S_K - T_m))^2} \quad (5)$$

$$T_m = \frac{\sum_{K=1}^{T} S_K}{T} \quad (6)$$

Where T is the number of the data patterns, S_K is the output of kth network pattern (ANN predicted FE), and TK is the target output of k^{th} network pattern (the real FE).

Due to different scale of the input factors which effect on FE, increasing in network, input and output data were normalized in a boundary of (0,1) before using in the network.

$$X_n = \frac{X_j - X_{min}}{X_{max} - X_{min}} \quad (7)$$

3. Results

Two types of training algorithms and two types of threshold functions were adopted to test their effects on the optimization of the network. All settings were tested in CFBP network with LM and BR training algorithms. The best results for using the LM training algorithm were related to the topologies 6-9-1 and 6-18-1 which were used the TANSIG and LOGSIG threshold functions respectively (Table 1). The amount of R^2 was 0.9972 and 1 and RMSE was 0.0495 and 0.0001, respectively. These result indicates that for the first adopted training algorithm (i.e. LM), both threshold functions had great performance, however, LOGSIG was better than TANSIG. The training process of CF-ANN with Levenberg-Marquardt algorithm and tangent-sigmoid threshold function illustrated in the Fig. 1. Also the training process of CF-ANN with Levenberg-Marquardt algorithm and logaritmic-sigmoid threshold function are shown in the Fig. 2.

The best result for second training algorithm (i.e. BR) was related to the topology 6-2-1 with threshold Function TANSIG and the topology 6-8-1 with threshold function LOGSIG that their R^2 were 0.9866 and 0.7903 and their corresponding RMSEs were 0.0317 and 0.2309, respectively. The training process of CF-ANN with Bayesian-Regularization algorithm and tangent-sigmoid threshold function illustrated in the Fig. 3; and The training process of CF-ANN with Bayesian-Regularization algorithm and logaritmic-sigmoid threshold function are shown in the Fig. 4.

Therefore, according to the results, LM training algorithm showed a greater performance than BR in this research.

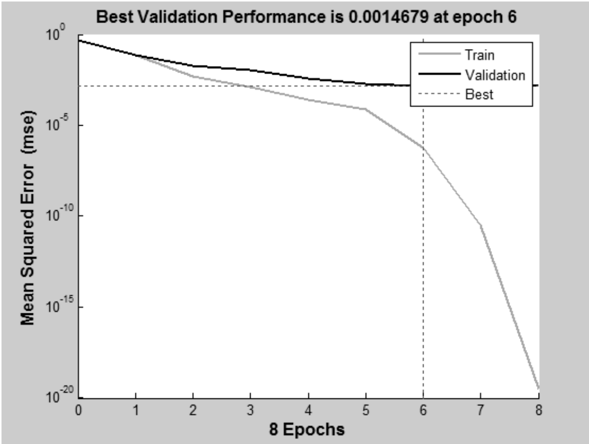

Figure 1. Training process of CF-ANN with Levenberg-Marquardt algorithm and tangent-sigmoid threshold function.

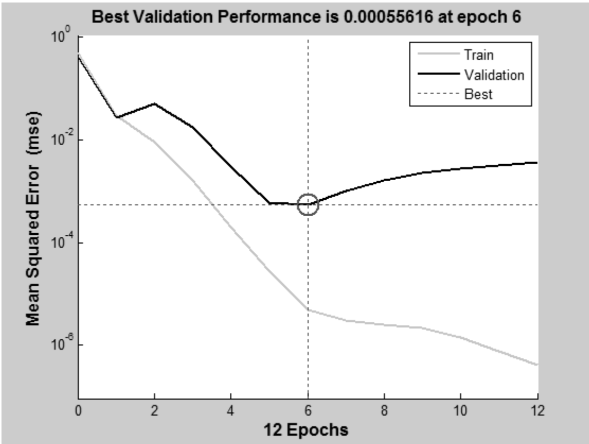

Figure 2. Training process of CF-ANN with Levenberg-Marquardt algorithm and logaritmic-sigmoid threshold function.

4. Discussion

According to the results, the LM training algorithm showed a greater performance than BR. Naghdi and Ghajar (2012) used the BR training algorithm to model the time of skidding operation. They reported a relatively high performance of using the BR training algorithm. Results of the present study, however indicated that the LM training algorithm could generate more robust models with higher generalization power. A high performance of the present models is not due to overfitting because of the use validation data that prevent models to just learn the pattern of the training data. Figures 1 to 4 illustrated that the results were obtained in a few iterations. A more iterations in the figure 4 could be due to the compostion of training, validation, and test data that randomly have been selected for each setting of the ANN.

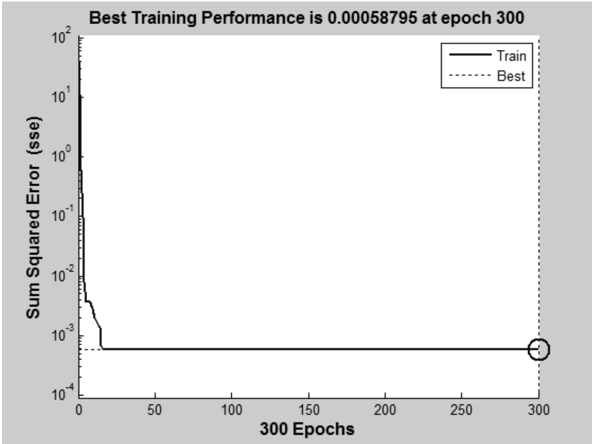

Figure 3. Training process of CF-ANN with Bayesian-Regularization algorithm and tangent-sigmoid threshold function.

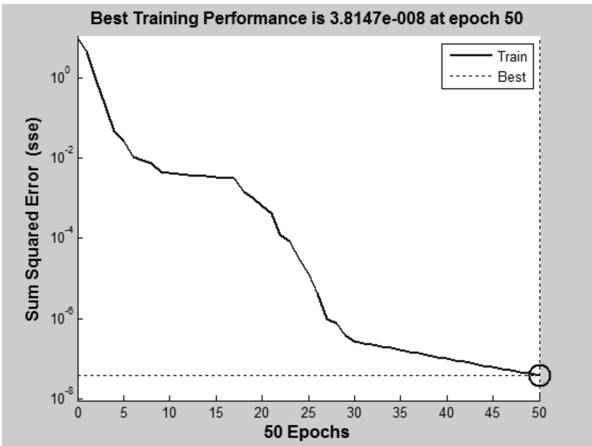

Figure 4. Training process of CF-ANN with Bayesian-Regularization algorithm and logaritmic-sigmoid threshold function.

Table 1. The greatest result of LM training algorithm with the same and different threshold functions for various topologies of CF-ANN.

Network	**Cascade Forward Back Propagation**	
Training algorithm	**Levenberg-Marquardt**	
Threshold function	**Logsig**	**Tansig**
Topology	6-18-1	06.09.2001
R^2	0.9998	0.9972
RMSE	0.0001	0.0495
Epoch	6	10

Table 2. The greatest result of BR training algorithm with the same and different threshold functions for various topologies of CF-ANN.

Network	**Cascade Forward Back Propagation**	
Training algorithm	**Bayesian-Regularization**	
Threshold function	**Logsig**	**Tansig**
Topology	06.08.2001	06.02.2001
R^2	0.7903	0.9866
RMSE	0.2309	0.0317
Epoch	50	19

It could be concluded that ANN could generate reliable models for prediction of trees felling error. Although ANFIS method is not so easy to handle for many practitioners and even researchers, however, is important not to stop the investigation of new methods, more powerful in terms of various aspects of forest operation to predict the required parameters especially the parameters related to safety and health of workers in forest.

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Determining of work efficiency zones for a multiprocessor harvesting machine with grapple

A. Laptev, A. Makarenko, M. Bykovskiy*

Abstract
The article is devoted to the determination of optimal harvesting in the machine work area, taking into account the production constraints affecting the performance. Indicators of the geometric parameters of the zone indicate the availability of an efficient work zone.

Keywords
efficiency zones, multiprocessor harvesting machine

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1. Introduction

The main requirements of cutting and processing for modern technological multiprocessors are; cutting directionality, felling without damaging a trunk and high performance of works while shragging and shortening. The effectiveness of the use of harvesting grapple machines depends on many factors, including grapple working area which can be implemented in cutting, felling and bunching, felling and delimbing - shortening and other process modes. Geometric parameters implemented by the working area are defined by the machine working position in the correct operating mode, i.e., the machine installation location with respect to the tree or group of trees to be harvested (Abol , 1981).

2. Material and Methods

Geometric parameters of the working area are strongly influenced by a number of factors that could be divided, under certain assumptions, into three groups.

The first group consists of factors related to the subject of labor - a tree. On the one hand it is necessary to consider the subject of work in terms of the forest. Such factors are enumeration indicators of stand as a whole, geometrical arrangement of trees with respect to the harvesting machine and each other. On the other hand it is necessary to take into account factors that relate to the individual characteristics of a separate tree: shape, size, weight, physical and mechanical properties of the basal part of the stem, positioning of separate parts of a tree in space.

The second group combines environmental factors: air temperature; precipitation; wind load; air environment resistance of falling trees; terrain; soil and groundwater conditions. In arriving at technological calculations some of these factors are of a very clear determination (e.g. relief), other - such as atmospheric conditions, can be considered with a certain degree of probability. The third group includes factors determined by technical parameters of harvesting machinery and machine performing this complex technological operations. These factors are type of the base machine, its geometric and weight characteristics, equipment configuration and its specifications, technology chosen for work in afforestation, operation procedure for harvesting and processing technology of individual trees.

These are just that factors of the third group that have the most significant effect on the performance of the main equipment, namely grapple and working mechanism (claw-like felling unit, harvesting head etc., and accordingly multiprocessor as a whole. Optimization of the grapple working area formed by multiprocessor machine is one of the ways of improving its performance. On the one hand increasing grapple overhang leads to enlarging the number of trees, reachable from one working position, thus increasing productivity by reducing the time required to moving and other off-cycle amount of time. On the other hand grapple overhang increasing is limited by stability of the machine (Gerz 2004). Lateral stability restrictions lead to reduction in the coefficient of grappler use in a transverse position and as a consequence a decrease in the width of the developed swath. Longitudinal stability is higher than transverse and the value of grapple overhang in longitudinal direction is limited by its load moment, which determines value of the utilization coefficient of grapple in longitudinal direction. Thus, the dimensional load characteristics of the multiprocessor working area are based on a combination of stability of the machine and load moment of grapple.

Stability of the machine is a variable parameter that is dependent on the angle of grapple rotation and its overhang. The ability to resist roll-over depends on the design parameters of the machine, as well as actions of the operator to handling the machine. Conditionally native and managed stability of the machine can be distinguished: the first depends on the design parameters of the machine; the second - on the operator's actions in critical situations (tripping over or down an obstacle, cornering the slope, etc.) by a corresponding change in speed or position of the machine and its operating equipment. Elements of the ma-

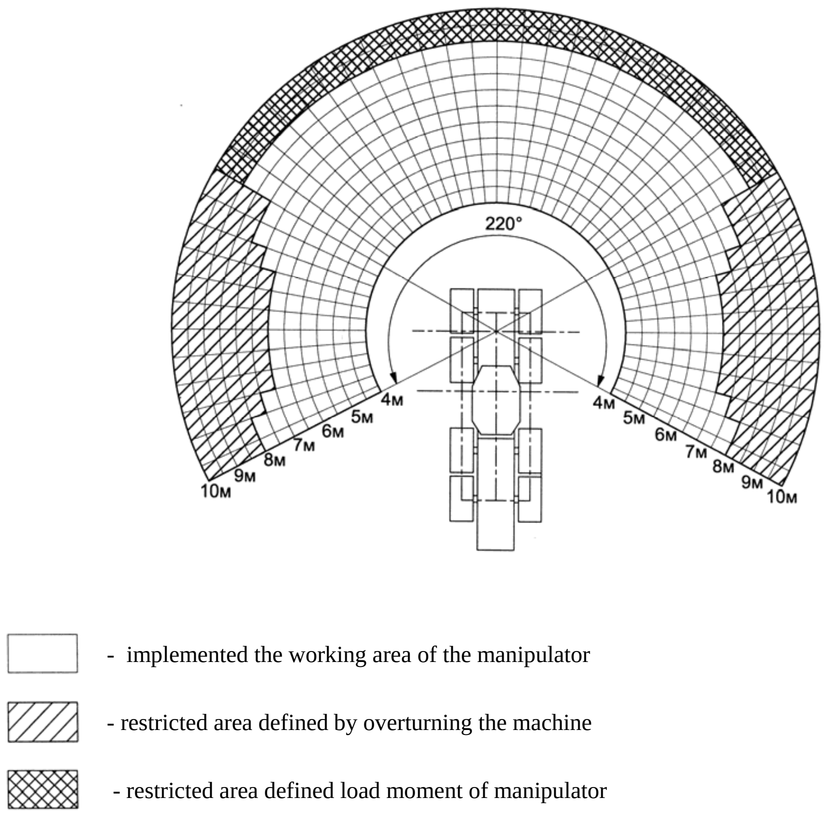

Figure 1. General view of the working area multistage the machine because of its stability and capacity manipulative equipment.

chine through which the operator controls the resistance, characterize "active" safety of the machine, as it is realized through the active actions of the operator. There are static and dynamic stability against roll-over (Bykovskiy & Redkin 2011). Static stability is characterized by the equilibrium state of the machine under the influence of external loads, standing by value and direction. Dynamic stability characterizes the ability of the machine to maintain a predetermined state after it is exposed to the disturbing forces and moments (Barinov 1988). Depending on roll-over direction lateral and longitudinal axes are distinguished, which together form the reference contour of the machine.

Determination of the load moment in different positions of grapple and for different value of its extension allows to found the maximum load that can raise grapple, and on the basis of this bearing capacity chart is prepared based on the machine stability.

Having calculated stability of the harvester and knowing the factory specifications of the load moment of grapple, we can construct an overall stability diagram using the received data. The diagram is based on the rotation angles of grapple, lengths of extension and load value. Load value is taken as the smallest of the resulting calculations of roll-over or nominal data, established by the manufacturer for the load-carrying capacity of grapple. The harvester of 15 tons equipped with a grapple with a maximum overhang of 10 m and load moment 188 kNm was adopted for the calculations.

3. Results

As the analysis of the diagram shows that having lifted the load at a certain angle of rotation and overhang, the harvester cannot roll over, but the load moment can damage grapple. On the assumption of it the working area of the multiprocessor grapple can be divided into two zones in which there are restrictions on the harvesting possibilities by weight characteristics. The first zone is located on the left and right side of the machine and is formed by the restrictions imposed by transverse roll-over in relation to the longitudinal axis of the support contour

4. Discussion

The second zone covers a part of the sector formed by a line of a maximum grapple overhang in which harvesting head can handle trees of the forest stand, and lines emanating from the attachment point of grapple and passing through point of intersection of the front transverse and longitudinal axes of the supporting contour. The size and configuration of the two zones influence parameters of stand defined by its enumeration data. Thus we can conclude that the utilization coefficient of grapple in the area of the central angle in the working area k_{ca} is defined by the weight characteristics of trees and the load moment value of grapple. This coefficient determines the distance of the machine movement between working position in the development of the cutting area. The utilization coefficient of grapple in the side angles k_{sa} is determined by taking into account weight and geometrical characteristics of grapple, harvesting head, the machine base, the stand and cutting area developed, stability of the machine. Coefficient k_{sa} shall be considered in determining the width of the apiary developed by multiprocessor.

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B

Abstracts

Topic 13

Presentation abstracts

Expanding ground-based harvesting onto steep terrain: A review

R. Visser[1], K. Stampfer[2]*

Abstract
Timber harvesting on steep terrain has always been, and will remain, a challenge in terms of economic viability, safety and environmental performance. For almost a century motor-manual felling coupled with cable yarding has been the most appropriate harvesting system, but new technologies and innovations have led to machines and systems being developed that are modernising the way we operate on steep terrain. Specifically, they provide the opportunity for the mechanisation of operations with proven improvements in both safety and cost-effectiveness. The additional development of cable-assist machines is potentially making a real step-change by expanding the operating range onto very steep slopes. This paper reviews these developments, the main engineering considerations of how cable-assist works, as well as the advances being made in terms of how such equipment is integrated into harvesting systems. The review also includes analyses of the operating guidelines that are either in place or being developed to help implement the systems.

Keywords
timber harvesting, steep terrain, cable assist, harvester, forwarder

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Remarks

Full paper has been published in the FORMEC CROJFE Special Issue:

Visser, R., Stampfer, K., 2015: Expanding Ground-based Harvesting onto Steep Terrain: A Review. Croatian Journal of Forest Engineering 36(2): 321–331.

Stock and state of forest machines in Germany

J. Hittenbeck*

Abstract
Economical harvesting of forests in countries with a high wage level depends on the utilization of machines and mechanized operations. Somewhat differently from the earlier years when forest operations were mainly done by their own workers, today mechanized operations (in particular) are carried out by forest service enterprises of different (predominantly small) sizes. According to the request of forest certification labels like PEFC and FSC most of these companies are holding specialized (forest service) certificates for their offered fields of operation. As a lot of technical information has to be checked within the certification process and is recorded, the certification bodies hold rich data on the current stock and also on the state of forest machines in Germany. Gratefully the RAL certification label allowed some insights to their data on forest service enterprises working with forest machines. Together with additional information on technical properties of the machines according to manufacturer information, the data permitted the answering of some questions on the stock and the structures of forest service enterprises in Germany. Although the RAL certification label is more popular in the north and the middle of Germany it can be assumed that the tendencies in the machine market and the structures of entrepreneurs are similar in other regions that are underrepresented in the data. Generally forest machines in Germany are used with a rather long lifespan, this holds true especially for skidders and forwarders. The average working hours per year allow the assumption that machines, apart from few harvesters and forwarders, are used in one shift duty only and that the average hours per year are considerably lower than assumed in common machine cost calculations. Altogether Forest service enterprises are often working with older machines and in addition often do not reach full utilization of their machines around the year. Together with the knowledge of dominating state forest enterprises as purchasers, and the service enterprises being predominantly small (up to even just one-man businesses), the impression of a tough market for forest services in Germany is created.

Keywords
machine categories, machine sizes, forest entrepreneurs, machine stock, Germany

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High resolution forwarding data and evaluation of operator differences by use of Timberlink data

J. Manner, T. Nordfjell, O. Lindroos*

Abstract
That fact that operators have a large influence on productivity in mechanized forest operations is well known, especially for harvester operators. However, for forwarder operations the collection of data has not been as simple as for harvesters. Notably, forwarder computerization has been slower and time studies yield few observations since every forwarded load takes about an hour. Consequently, there is a shortage of representative forwarding data in general, and especially with a resolution higher than stand averages. Similarly, relatively little is known about forwarder operator performances. Forwarding might be considered simple and to be conducted in a relaxed pace compared to harvester work. However, in addition of machine handling skills, forwarding requires the capacity to solve complex planning problems to minimise time and fuel consumption. In this study, we extracted high resolution data from forwarding in order to contribute to the lack of representative forwarding data and also to evaluate operator differences. The automatically collected TimberLink databases in two John Deere 1910E were used in the study. The forwarders' empty mass was 22 tonnes and had a payload capacity of 19 tonnes. In total the data contained circa 9000 forwarded loads, which were the result of a combined work time of circa 3 years. The forwarders had been operated in total by nine people, and only in final felling stands in mid-Sweden. All data was available per load. The data provided representative averages and dispersion values of; distances driven, time consumptions, fuel consumptions and average speeds per load, during forwarding in mid-Swedish conditions. Moreover, the data also revealed significant differences between operators with respect to these parameters. For instance, the differences in total driven distance per load were mainly due to operator variations, while the machine (i.e. stand conditions) had only a minor effect. The median driven distance varied from 579 to 909 m between the operators, while the over-all median was 670 m. The study gives good examples of the possible use and benefits from data readily available from everyday operations through John Deere's TimberLink system, and also highlights the variation in performance between forwarder operators.

Keywords
forwarder, performance, operator effects, distance, fuel consumption

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Management of outsourced forest harvesting operations for better customer-contractor alignment

M. Eriksson*, L. LeBel, O. Lindroos

Abstract
The performance of harvesting operations is vital for wood supply chains to enable delivery of the right product to the right market at the right price. Consequently, the performance of harvesting contractors has been the topic of many studies over the years, but few of these have investigated the critical issue of whether contractor performance is in alignment with downstream needs. Furthermore, no previous study has suggested a clear route that forest companies can take to promote alignment of their employed contractors. Here, we present a framework specifically designed to help managers measure and foster contractor alignment within their wood supply chain. The framework was tested on a large sample of harvesting contractors operating in Sweden, for which a performance survey and a statistical procedure was utilized to segment contractors into groups of varying levels of alignment with their customer company. Results from the test were then used to suggest to the customer's managers the most viable blend of four generic alignment approaches for each contractor group: active sourcing, adapted incentives, active use of power advantage, and tailored contractor development programmes. If implemented, such a structured but differentiated approach to contractor alignment should lead to the most beneficial response from each contractor, and eventually to improved performance of the wood supply chain. Consequently, forest companies need to use, and be proficient in the use of, a variety of approaches to contractor alignment to make the most of their contractor force.

Keywords
forest harvesting contractor, service attributes, supplier relations, customer-perceived value, wood supply chain

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LIDAR-based forest warehouse concept

M. Opferkuch[1]*, G. Becker[2], T. Smaltschinski[1], D. Jaeger[1]

Abstract

Moving the process of identifying the right raw material for specific products upstream to an earlier stage in the wood supply chain has long been described as a key element for efficiency increase in the wood industry. Realization of such a pre-harvest log allocation requires information on quantity and quality of the trees to be harvested. Forest inventories typically do not fulfil this requirement. The problem is of larger importance in selective-cutting regimes is that it needs to be known which trees will be cut. The combination of airborne and terrestrial LiDAR (ALS, TLS) data can provide consistent information on the growing stock and allows the calculation of utilization volume and possible assortments of a forest enterprise. Tree height (h) and crown parameters from ALS data and the diameter at breast height (dbh) from TLS on a sample plot level allows estimating dbh by linear regression with ALS crown parameters as independent variables. This regression can then be used for upscaling to the enterprise level for which ALS-crown and tree height data are available. The stem diameter at a 7 m height (d7) can also be estimated by linear regression with dbh as the independent variable. With these three variables (dbh, d7, h) single-tree volumes can be estimated accurately for Central Europe with the software BDATpro. Each tree's relation to a stand is given by its coordinates, which in turn allows modelling stand-specific volume distributions. This includes the Weibull function and the modification of its parameters which allows modelling utilization covering the full range from 'thinnings from below' to 'thinnings from above'. The utilization rates can then be modelled for each stand in the same way and the assortments can be calculated by bucking simulation. Quality information is derived from TLS data (taper, sweep). This pre-harvest information for the whole forest enterprise is the necessary pre-requisite towards the idea of a forest warehouse with the required flexibility regarding the log products to be produced.

Keywords

log quality, wood supply, forest warehouse, pre-harvest quality assessment, laser scanning

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Evaluation of the educational influence on forwarding planning capacity

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Abstract
The existing large differences in productivity between operators in mechanized forest operations can partly be attributed to machine handling shills and partly to work planning. In normal work it is difficult to isolate those two factors, but in a virtual environment it is possible. For instance, in the Ponsse Forwarding Game, different types of forwarding scenarios can be simulated to train and evaluate work planning. After a finalized game, the work is summarized in terms of reports of various performance variables. In this study, the game was used to investigate possible differences in planning capacity between two schools that educate forwarder operators. At least 14 students per school participated in the study. After a warm up game, each student played two games, with different levels of difficulty. Students and teachers were also interviewed about perceptions about the game and about their education practices regarding forwarding planning. Based on the game results, there were significant differences in planning capacity between the two schools' students. The average productivity of the best school was 7-12% higher compared to the other school. The productivity values were also more homogeneous for the better school, whereas values varied more between students of the other school. Productivity differences were the result of shorter distances driven, which in turn was influenced by differences in how assortments were selected and loaded in individual round trips. The students of the better school loaded on average more assortments per load, and managed obviously to do so in a more efficient way. Based on the interviews, the main difference between the two schools' education seem to be in supervision of practical forwarding. The better school engaged in a higher amount of active feedback from a teacher during forwarding work, according to the interviews. How to improve forwarder planning education has to be investigated further, but this study gives a valuable insight in possibilities to evaluate the planning capacities, and in how differences in education can influence the planning capacity.

Keywords
forwarder, operational planning, game, education, vocational training

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Survival test of RFID UHF tags in timber harvesting operations

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Abstract
Traceability of wood products is more and more relying on high technology systems. Among them the Radio-Frequency IDentification with Ultra High Frequency (RFID UHF) tags are probably the most flexible and promising tools. Several studies address their use in timber logistics, but the possibility to mark standing trees and maintain intact the information along a whole-tree extraction system is still not explored. Under this perspective one of the main challenges is the capacity of UHF RFID tags to survive the harsh conditions of timber harvesting. Different tag models and different placement positions on the tree may lead to diverse ratio of tags arriving intact up to the landing. Particularly extracting operations may play a major role in damaging or removing the tags from the trees. In the present study, two tag models and two fixing modalities were compared during three commercial hauling and one transport operation in mountain conditions. Over a total of 239 tracked tags, just 5 were lost, proving a good reliability for this traceability system. This preliminary result will serve for addressing the electronic tree/log marking method in the frame of the project SLOPE, cofunded by the EC.

Keywords
RFID UHF, tree marking, hauling, survival test, cable yarder

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Remarks

Full paper has been published in the FORMEC CROJFE Special Issue:

Picchi, G., Kühmaier, M., de Dios Diaz Marques, J., 2015: Survival Test of RFID UHF Tags in Timber Harvesting Operations. Croatian Journal of Forest Engineering 36(2): 165–174.

Assessing the ability of hardwood and softwood brush mats to distribute applied loads

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Abstract
In cut-to-length mechanized forest harvest operations, trees are cut, delimbed, and bucked to standard lengths directly in the harvest block. This in-stand processing, generates harvesting residue composed of tree limbs, tops, and foliage, which is frequently placed on machine operating trails to prolong trail trafficability and protect forest soils against heavy loadings. These so-called brush mats vary both in quantity and quality based on harvested wood and stand characteristics. The objectives of this study were to determine, quantify, and compare the load distributing capabilities of hardwood and softwood brush mats of different amounts (10, 20, 30, and 40 $kg\ m^{-2}$) compared to no brush (0 $kg\ m^{-2}$). This was done by laboratory tests analyzing the difference in strain recorded below brush mats at small scale when exposed to single and repetitive loadings. Brush mats (approx. 37 cm x 37 cm in area) were placed inside a test structure including a top open box with the bottom filled with a 15 cm thick layer of sand, below which strain gauges were installed. The entire test structure was positioned on a load frame programmed to lower a loading disk directly over the brush mat, thereby applying increasing loads up to 10 kN on the mat. Results suggest that for specific brush amounts and loadings, softwood brush showed a slightly better capacity to laterally distribute exerted loads than hardwood brush, especially at brush amounts of 10 and 20 $kg\ m^{-2}$. At higher brush amounts, the differences of recorded loadings (strains) between the tested softwood and hardwood brush were reduced and at 40 $kg\ m^{-2}$ hardwood brush contributed to a lower response of the strain gauges than softwood brush when subjected to 5 and 10 kN loadings.

Keywords
brush mat, brush compressibility, strain, load distribution, soil protection, forest operations

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Remarks

Full paper has been published in the FORMEC CROJFE Special Issue:

Labelle, E.R., Jaeger, D., Poltorak, B.J., 2015: Assessing the Ability of Hardwood and Softwood Brush Mats to Distribute Applied Loads. Croatian Journal of Forest Engineering 36(2): 227–242.

Forwarding on soft soils, comparison of rutting with and without wooden bridge sections

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Abstract
Soil damages and rutting is a general problem with heavy machines on soft forest ground. This is especially emphasized in the extraction of logs from a harvesting site to the forest road. As an example, a standard midsized forwarder (15 m³ load, and a kerb weight of 14 tonnes) passes 13 times on the path to landing for transportation of 200 m³ of logs from a site. This means 13 times passing with and 13 times without load, and in total 500 – 550 tonnes (machine and load) has been transported on the same path from a small harvesting operation. It is not difficult to understand that if the forest soil is soft at this path, the result will be deep ruts. However, many times it is only a short part (10-40m) of the extraction distance that passes really weak ground. It might also be a situation when the shortest path includes passing a small creek, and because of environmental reasons this path impossible, just because a weak section of 5-10m. If it was possible to overcome short but weak parts of the extraction distance without causing severe damages, the extraction would be more environmentally gently and often also more productive. A technique to achieve this is to use purpose built wooden bridge sections (0.9m wide, 4.5m long and manufactured of 0.2m square building timber, bolted together with 1m long screw bolts) and place them directly on the ground on weak parts of the extraction path. A load of 16-20 sections transported on a forwarder and placed in front of the machine with the grapple loader, creates a “wooden bridge” with a length of 36-45m. After transporting all harvested logs from the site, the bridge sections will be loaded back on the forwarder on its last pass from the site. Results will be presented from a field study with an experimental design where both rut depths and soil compaction are compared with and without the use of wooden bridge sections and with an increasing number of passes using a loaded mid-sized forwarder on very soft ground. Significant differences are promised.

Keywords
gentle logging, CTL, soil protection

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Effects on soil physical characteristics after forwarder passes for logging operations

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Abstract
The most important problem of the forest sector is to minimize the ground damage caused by heavy forestry machines during forest operations. Generally, harvesting effects include changes in; vegetation, nutrient availability, soil microclimate and structure, and litter quantity and quality. Several studies were carried out on the impacts of heavy machinery on soil. However, only a few studies took into consideration the effect of bogie tracks on soil impact. The aim of this research was intended to investigate how a bogie track can influence the soil compaction through changes of the soil physical parameters (bulk density, porosity shear and penetration resistance). The study was carried out in a conifer stand of Larix decidua and Picea abies in one forest in north-eastern Italy during logging with a forwarder. In this site 3 tracks (of 20 m) were identified, 2 influenced by loaded forwarder passes and 1 control (no passes). The tracks were: (i) track A, with 31% of slope and influenced by 2 passes, and (ii) track B, with 3% of slope and influenced by 10 passes. Soil samples after forwarder passes were collected on all tracks in order to directly determine how the forest operations influenced the various soil physical properties. The results showed different impact of logging operations on soil between tracks.

Keywords
forest machine, boggie track, soil compaction

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Ground pressure is a poor indicator for ecological and technical compatibility

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Abstract
People believe that ground pressure (in kPa) is a perfect indicator for ecological and technological compatibility of forest machines on forest floors. Consequently when the machines turn to become larger and heavier, the number and dimension of wheels have to be enlarged in order to keep the ground pressure in a comparable range. By means of a linear model three hypotheses are discussed: 1^{st} hypothesis: While the capacity of soils to recover any disturbance is limited, beyond the limit the soils turn to be permanently unfertile. For calculation this natural capacity is set to 50 kPa. Only very light machines with very large wheels or caterpillars are able to stay under this limit, in practical forestry most machines are too heavy to let the soils recover themselves by means of biological processes. This has two consequences: The quantitative consequence is that the absolute volume of degraded soil should be minimized. Concerning wheels this leads to the 2^{nd} hypothesis: The volume of compacted soil in the sensible organic layer decreases with bigger wheels. It can be shown, that under the condition, that the load per wheel is less than 25 kN, the volume of degraded soil under a larger wheel is less than under a smaller one. But as soon as the machine turns heavier, the wider contact area counteracts this positive effect. So for ecological reasons the load of the wheel is more important than the ground pressure. The other consequence deals with the quality of degradation: While the soil is biologically degraded its use for technical purposes should be ensured. This correlates with the depth of ruts and leads to the 3^{rd} hypothesis: The disturbed zones under large wheels are smaller than under small wheels. The model detects the depth where the load per wheel is equal to the stress ratio of the soil. Surprisingly the positive influence of a large wheel can only be confirmed with light machines, but it turns to the opposite when the load per wheel runs over 40 kN. Decisions that are only based on the soil pressure of a machine tend to be wrong. In order to observe ecological needs as well as technical limits, the total mass of the machine or the load of each wheel respectively should be considered, too.

Keywords
ground pressure, soil compaction, machine weight

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Automatic wheel load control system as a contribution to improve soil protection and technical trafficability

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Abstract
For ergonomic and economic reasons harvesting and extraction of timber requires the use of modern forest machines, resulting in off-road traffic in forest stands. The effects are often soil disturbance, such as compaction and deep ruts from soil displacement. To limit these damages, off-road traffic is restricted to so-called skid trails spaced at distances of 20 to 40 m. By this at least 80% of the forest floor is protected from machine passes and related disturbances. This shows that systematically and permanently applied skid trail networks are an essential requirement for an ecologically and economically sustainable harvest of wood. It is a top priority for the permanent use of skid trails to maintain the technical trafficability. Studies show that reduction of the wheel load is most effective in maintaining and prolonging technical trafficability. Therefore machines with mostly six or eight wheels are used in connections with bogie axles. Equal load distribution on all wheels is an important pre-requisite for low-impact use of skid trails by forest machines in timber harvesting and skidding operations. In addition, increasing the contact area by using bogie axles helps to reduce ground pressure. However, forest machines with bogie axles show an unequal load distribution between the two wheels of a bogie during acceleration: the loading of the rear wheel is increased while the loading of the front wheel is reduced. The opposite effect occurs during deceleration of the machine. Because of these effects, the intended reduction of ground pressure by applying bogie axles is not implemented, at least not during acceleration. The main objectives of our study were, a) to assess loading differences of bogie wheels during acceleration and b) to design machine features for equalizing these loadings. Therefore, firstly a load monitoring system for a full scale skidder was designed using strain gauges. This method revealed the magnitude of load differences between bogie wheels during acceleration. Secondly, an electro-hydraulic wheel load control system was designed for balancing the wheel loads. This system was tested under semi-laboratory and practical conditions to analyse potential effects of equalized loading with respect to actual wheel load distribution and soil compaction.

Keywords
soil protection, technical trafficability, dynamic wheel loads, boggie axles

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Management and evaluation on team logging operation by GPS - efficiency and process improvement

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Abstract
Field logging operations were examined by utilizing GPS records. More than one, usually three or four work points were available for one team operation a day. A tower yarder logging field was examined in the study. The data processing was conducted through a developed integrated package of software for convenience and rapidity. The history of the operation was cut into processes by the locations and the moving directions. Sequences of operation process were analysed to discuss the efficiency and adequacy of them. A logging business firm utilized this data and analysed the management. The system efficiency was analysed using different operational conditions of mountainous terrains and road availabilities. The system was useful to direct operations and to have same understanding on operation status.

Keywords
logging, operation, GPS, process, efficiency

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Estimating harvester productivities in pine stands of different ages and thinning intensities

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Abstract
Estimating the productivity of a harvester is essential for calculating the unit costs of machine use in various stands. In economic terms, the main limiting factors of harvester application in thinning operations are the stand age and thinning intensity, which itself further depends predominantly on tree size, but also on the number of trees extracted per hectare. The objective of the research was to estimate the impact of stand age (class) and thinning intensity on harvester productivity. The research was carried out in 60 different, pure pine stands grown in the same soil and weather conditions (the same site index and the same forest district). 18, 20 and 22 sample plots were established within 3rd, 4th and 5th age classes, respectively (age groups (AG): 3, 4 and 5). In each age class, a different number of trees per hectare was recorded: 563÷1573, 323÷868 and 476÷822 trees ha^{-1}, in 3rd, 4th and 5th age class, respectively. Eventually, in each AG, the stands were divided according to different thinning intensity groups (TIG): A: 60 m^3 ha^{-1}, respectively. Each stand group was marked with AG (3, 4 or 5) and TIG (A, B or C). In each sample plot the same pattern of strip roads was designed, with a maximum of up to 4 m and a distance between them of 20 m (from axis to axis of a strip road). The trees for thinning were marked by a forester according to silvicultural prerequisites and stand conditions. A Valmet 931.1 harvester was used for the thinning operation in each stand. Considering the division of stands into AGs, the lowest mean productivity was observed in AG 3 (18.57 m^3 h^{-1}) and it was statistically different to AG 4 and 5 (22.24 and 22.60 m^3 h^{-1}, respectively). In relation to the TIGs, the lowest mean productivity was obtained in TIG A (16.19 m^3 h^{-1}) and this was statistically different to TIG B and C (21.44 and 21.98 m^3 h^{-1}, respectively). Therefore, from the research results it can be concluded that the application of the Valmet 931.1 harvester in younger age class pine stands (41-60-y.o.) was less profitable than in older stands (61-100-y.o.), as well as when thinning intensity was below 30 m^3 ha^{-1}. These findings should be considered when calculating the costs of thinning operations provided by a harvester.

Keywords
harvester, productivity, thinning intensity, pine stands

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Comparing the effectiveness of harvester use for thinning operations in beech and birch stands of 4th age class

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Abstract
An increase in the number of harvesters and in the share of mixed stands in Poland has led to the expansion of mechanized forest operations in broadleaved stands. However, the morphological features and branches of broadleaved trees can obstruct efficient log processing, especially of older trees which have thicker branches. Eventually, excessively thick branches are a limiting factor for effective harvester use. The objective of the research was to compare the effectiveness of the use of a Timberjack 1070D harvester in beech and birch stands of the 4th age class. The effectiveness was measured according to: 1) operational productivity, 2) time consumption for delimbing and cross-cutting, as well as 3) trunk use for logs. The operational productivity was understood as pure working time with no breaks. The operational productivity was 15.75 and 17.54 $m^3\ h^{-1}$ for beech and birch stands respectively. The delimbing and cross-cutting of a single tree took on average 6 seconds less time for beech compared to birch. For both species, the utilization of the trunk amounted to 63% of the tree height. At the same time, the average minimum top diameter of the thinnest (top) log was 10 and 11 cm for beech and birch, respectively. However, the harvester was able to process logs from 35% of the beech crown length but only 13% of the birch crown. The bigger average volume of the birch trees (compared to beech) had a significant impact on harvester productivity. However, the birch branches were more problematic for delimbing, and eventually a bigger volume of the birch tree tops was left after harvesting.

Keywords
harvester thinning operation, broadleaved species, beech, birch

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Long log harvesting by harvesters and combination forwarders

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Abstract
A 6-week logging experiment in the Aeule district (Breisgau-Hochschwarzwald County) was carried out from mid-July to late August 2014. Time studies based on the continuous timing method were conducted on the procedures of; fully mechanized timber harvesting and processing, skidding, and motor-manual felling. Four variants were investigated. The primary focus was on the comparison of the labour productivity and the impact on the residual stand, between a system of long logs logging (ST (B / C, 10 - 21 m) and one of short logs logging (FL (B/ C, 5 m). This comparison was combined with a comparison of a wheel harvester (John Deere 1470 E) with a crawler harvester on an excavator-base (Königstiger Kern 30 TSS). The long logs were skidded only by the combination forwarder that was upgraded with a hydraulic bundler (HSM 208 F), the short logs were skidded by a forwarder (Valmet 860.4) and by the combination forwarder (HSM 208 F), which had a modified stanchion system. The felling was conducted by a lumberjack and a second-year apprentice. The investigation took place in an 87-year-old spruce forest that covered 27.2 hectares. The cutting intensity (excluding directional felling on the extraction lines) was about 81 solid m³ / ha with the average diameter at breast height of 33.3 cm. The results of the labour productivity showed that the fully mechanized harvesting and processing is more efficient in the long logging. Compared to the short log variants, the long log variants provided between 4.1 solid m³/PMH (+ 15% productivity) (wheel harvester) and 6.1 solid m³/ PMH (+ 29% productivity) (crawler harvester) additionally. These results were superimposed by surface effects and the differences would possibly be smaller in more comparable areas. In the direct technical comparison the wheel harvester in combination with the skills of the machine operator proved to be more efficient with a 29% higher level of productivity for short logs and a 15% higher level of productivity in the long logs. In the short wood areas the effects of the location were decisive too, however in regard to long logs the effects of the working method of the machine operators determined the results. The skidding of the long logs with 5.3 solid m³/PMH (+34% productivity) (wheeled harvester) and additional 7.4 solid m³/ PMH (+42% productivity) (crawler harvester) was significantly more efficient than the skidding of the short logs. The reason for this is that the short logs had to be moved in broken haulage on travel-sensitive soils and also a lot of work had to be invested on the restoration of the technical soil trafficability.

Keywords
long log harvesting, harvester types, combination forwarder, productivity, stand damages

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1. Extended Abstract

In the technical comparison, skidding was more efficient in the areas of the crawler harvester, with a 13% higher level of productivity in short logs and a 20% increased productivity in long logs. The reason for this is mainly based on the working method of the machine operators. The operator of the crawler harvester spent more time threading the logs downhill, butts-ahead in the extraction lines, then putting the short logs in respective loose stacks at one side. This method considerably reduced the loading times of the forwarders.

Because there are no differences between the variants according to the motor manual felling, a differentiation in regard to working productivity was considered not relevant. For the cost calculation a labour productivity level of 9 solid m³/h was used.

For the calculation of costs, the yield also plays an important role as well as labour productivity. The ratio of the industrial laminated timber (IS-K (3 m), IS-NF (2 m)) across all areas was comparable to at least 3% and at most 5% of the total volume of timber harvested. Within the long log variants the quality class D-ratio (FL (D, 4m) was significantly lower, representing 6% to 10% compared to the short log variants with 16% to 17%.

This can only be explained as a result of past timber harvesting in short log areas (bark-and root damages) and because of the more unstable and wetter locations for spruce. Accordingly the yield of B/C quality within the long timber variants was higher and consequently the proceeds of the timber sale. This distribution cannot be generalized and must be considered while interpreting the results of this study.

Also relevant for a benchmarking of different variants of harvesting systems, was the impact in the residual stand for the allocation of the logs. In this study total damage percentages were observed in the short log variants between 16% and 19% and within long timber variants between 23% and 26%. A higher damage level within long log logging compared to the common damage rate of short log logging has already been discovered on frequent occasions and was reaffirmed in this investigation.

The technical comparison could not find clear differences related to the amount of the observed total damage percentages despite slightly different work methods and different machines.

Current practices and efficiency gaps in logging operations from European mountain forests

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Abstract
Timber production is an important ecosystem service of European mountain forests. The aim of this paper was to assess the current practices in logging operations and to identify the efficiency gaps in timber production. The study was located in seven case study areas from representative European mountain ranges, where 632 logging operations were analysed. The focus was on road infrastructure, transport systems, harvesting methods and extraction technologies. Often inappropriate technology was used in steep terrain; there was no correlation between the average slope and the selection of harvesting systems. Skidding was the most common extraction method (75%), while cable yarding and forwarding had shares of 15% and 8%. The mean road density was 18.5 m ha^{-1}. The mean extraction distance was 501 m. The mean harvesting and extraction productivity were 9.0 m^3 h^{-1} and 10.2 m^3 h^{-1}; the mean costs were 11.1 € m^{-3} and 11.7 € m^{-3}, respectively. Non-mechanized and obsolete harvesting systems reported the lowest efficiency and the highest environmental footprint, while fully mechanized systems reported the highest efficiency, the lowest number of accidents and the lowest stand damage. Cable yarders are the appropriate extraction technology in steep terrain, but they require a well-developed road network. Higher mechanization degree, improved quality of the road networks, knowledge transfer to practice and training of forest workers are some of the necessary measures to overcome the efficiency gaps in timber production in European mountain forests.

Keywords
forest roads, harvesting method, mechanization, productivity, steep terrain, timber extraction

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Effects of sieve size and assortment on wood fuel quality during chipping operations

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Abstract
Primary residual forest biomass is an important source of energy in Sweden. The fuel quality of this biomass depends on several factors including it's; moisture content, ash content, and particle size distribution. For optimal combustion, the fuel should have a low content of fine particles. The objective of this study was to compare these quality metrics for five common fuel assortments produced with a drum chipper operated using two different sieve sizes (standard & large). Sieve size had no significant effect on any of the studied fuel quality metrics. On average, 37–63% of the fuel's dry mass was distributed in particles of 16–31.5 mm. Because logging residues (tops and branches) contain relatively little stem wood, the average fine particle (<3.15 mm) content of the fuel produced by their chipping was around 10% greater than that of the other studied assortments. Moreover, the ash content of these fines was 2–3 times greater than that of the fines from other assortments. For all assortments, the ash content decreased rapidly with increasing particle size, levelling out at 1.14% for particles of 16–31.5 mm. The average ash contents of the five assortments ranged from 0.84–2.98%. For all assortments, and logging residues in particular, the fuel quality could be significantly increased by screening out fine particles. However, the economic value of such screening depends heavily on the costs of the refining process and the value/utility of the separated fine particles, which should therefore be investigated further.

Keywords
particle size distribution, ash content, fuel wood, screening, terminal

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Remarks

This study was published on-line August 14th 2015 in the International Journal of Forest Engineering.

Effects of moisture content on supply costs and CO_2 emissions for an optimized supply network

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Abstract
The replacement of fossil fuels with forest biomass should help mitigate Green House Gas (GHG) emissions. However the supply of energy wood is challenging because of high supply costs and rapidly increasing demand. A multi-criteria optimization problem (MOP) has been formulated, whereby the profit must be maximized and the GHG emissions have to be minimized. The objective function includes decisions about chipping location, transport mode and volume and terminals used. To solve the MOP, the weighted sum scalarization approach was used to derive Pareto optimal points by stepwise changing weights from maximum profit to minimal GHG emissions. The MOP was applied to a large-scale network of approximately 10,000 sources, 356 storage locations, 119 freight stations and 228 sinks with a demand of 700,000 dry tons per year. In an effort to minimize GHG emissions, 30% of the woody biomass should be delivered chipped from the terminals and more than 50% chipped directly from forest. This results in emissions of 24.3 kg CO_2 t^{-1} and a profit of 3.0 EUR t^{-1}. The rest has to be transported in solid form directly from forest to plant. By changing the weight to maximize the profit, GHG emissions will only increase by 4.5%, whereas the profit more than doubles from 3.0 to 7.4 EUR t^{-1}. The average transport distance increases from 45.7 to 48.0 km and 73% of all terminals are used. Looking at the profit a decreasing moisture content (MC) will increase the profit noticeably. A decrease of 10% MC from 40% to 30% will double the profit from 5.10 EUR t^{-1} to 12.00 EUR t^{-1}. To rule out the effect of changing revenues and to show how transport cost are affected, another simulation with fixed revenue was done. In this case the sensitivity of the model is lower, but clearly visible, with a profit increase from 6.00 EUR t^{-1} at a MC of 40% to 10.00 EUR t^{-1} at a MC 30%. The emission will decrease with a decreasing MC as expect and there seems to be no dependency on the revenue. However the effect of the decreasing MC is less prominent compared to the profit. 10% less MC from 40% to 30% will save approximately 4% of the CO_2 emissions per dry ton.

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Remarks

Full paper will be published in Croatian Journal of Forest Engineering (CROJFE), Issue 37(1) (2016).

A trial to evaluate three harvesting methods in a conifer first thinning in Ireland: cut to length harvesting, integrated harvesting, and whole tree harvesting

E. Coates*, B. Cronin, T. Kent

Abstract
A trial took place in a 19 year old Sitka spruce (Picea sitchensis (Bong.) Carr) plantation in the South East of Ireland where three methods of harvesting were performed using the same machine system: cut to length harvesting (CTL), integrated harvesting (INT), and whole tree harvesting (WT). The objectives of the trial were to evaluate the log volume and biomass mobilised from each of the methods, the productivity of the machines, and quality parameters of the biomass as a fuel. Using the CTL method, 56.5 m^3 of pulpwood per hectare was harvested, and an average of 6.4 m^3 of small sawlog per hectare was harvested. This equated to 23.6 odt of roundwood material. A significantly greater amount of biomass was mobilised using the INT and WT harvesting methods. On average, a total of 42.9 odt (40.5 odt of biomass, 6.5 m^3 of small sawlog) was harvested using the INT method, and 45.7 odt using the WT method. Biomass supply chain cost ex-forest was highest for CTL at 96.31€ odt^{-1}. Costs were 23% lower for INT (74.21€ odt^{-1}) and 33% lower for WT (64.15€ odt^{-1}).

Keywords
thinning, biomass, whole tree, integrated, cut to length

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Remarks

This paper will be published in the *Irish Forestry* journal.

The efficiency of the logistics of energy wood procurement chain in the North-East Poland

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Abstract
The energy wood harvest from forests in Poland is estimated to be around 4 million cubic meters. So far, the harvesting is carried out mainly by small businesses. In this paper we have tried to assess the effectiveness of the logistics of one of the new emerging larger companies that have produced chips from wood harvested in the northern and eastern parts of Poland. The harvesting area is very large, its extent is about 300 km from north to south and 500 km from east to west. The company is located about 80 km northeast of Warsaw, and is located near the southern edge of the area of operation. This location is the reason for the difficulty in ensuring high efficiency logistics, since located here are the; central repository of wood and chips, production and repair bases and garages of trucks and machinery. For this reason, the company organizes temporary depots and bases for machinery. The company supplies most of the manufactured chip to four heat and power plants. Two medium-sized and two large-sized plants are located in Białystok and Łódź. This last is located outside of the timber harvesting area, in the central part of Poland. The source of wood raw material is mainly branches and tops of trees remaining after wood harvesting and a small percent of defective round wood and uncontaminated wood waste from the wood industry. The Company's production capacity has exceeded 100 thousand cubic meters per year. Machinery consists of 6 large capacity chippers and one bundler. Four chippers are mounted on forwarder chassis' and operate both on the road and directly in the harvesting areas. One chipper is mounted on a truck chassis and the latest stationary machine is located at the company's headquarters. Chips are transported by means of 15 to 18 trucks. These are road tractors with walking floor trailers with a capacity of 90 m^3 each. We have online access to a sophisticated GPS based monitoring system of vehicles and machine operations. The analysis indicated the existence of operational reserves resulting from improved work planning, improved reliability and from the acquisition of return loads.

Keywords
energy wood, procurement, logistics, efficiency

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Validation of prediction models for estimating the moisture content of small diameter stem wood

J. Routa[1]*, M. Kolström[2], J. Ruotsalainen[3], L. Sikanen[1]

Abstract
Moisture is the most important factor influencing the quality and calorific value of fuel wood. Drying models for estimating the optimal storage time based on average moisture change in fuel wood stacks stored outdoors have been developed for different stem wood piles. Models are an easy option for making an estimate of the moisture content of an energy wood pile if compared with sampling and measuring the moisture of samples. In this study, stem wood models were validated against data from forest companies. Fourteen reference piles of covered pine stem wood and 8 piles of uncovered pine stem wood were studied. The results of the validation are promising. The difference between the measured and modelled moisture was on average only 0.3% with covered piles and 2.5% with uncovered piles. The models presented can be implemented in every location in Finland, because the Finnish Meteorological Institute has a database for interpolated meteorological observations covering the whole country in a 10 km x 10 km grid. For international use, model parameters need to be estimated case by case, but it should also be possible to implement the approach itself worldwide.

Keywords
energy wood, quality, storing, natural drying, model validation

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Remarks

Full paper has been published in the FORMEC CROJFE Special Issue:

Routa, J., Kolström, M., Ruotsalainen, J., Sikanen, L., 2015: Validation of Prediction Models for Estimating the Moisture Content of Small Diameter Stem Wood. Croatian Journal of Forest Engineering 36(2): 283–291.

ForstInVoice - Optimizing logistics service pattern in fully mechanized harvesting procedure

B. Urbanke*, H.-U. Dietz, U. Seeling

Abstract
Data management in tailor made wood supply chains (WSC) is decisive for efficient wood procurement in the forest industry. In German forest industry the logistics process from forest to mill is characterized by a large number of participants and interfaces. Harvest operation is nearly totally settled by small-sized contractors and forest entrepreneurs. To optimize information flow along the WSC data management of assignment; confirmation, performance, permanent reporting and accounting have to be improved. In close collaboration with forest owners, contractors associations and manufacturers, and funded by the Federal Ministry for Economic Affairs and Energy, the KWF conducted a R&D project evaluating and building up an adapted data management chain to provide harvesting and logistics procedures for medium-sized forest owners and entrepreneurs. The process routine is shaped by cloud computing and on-board communication for modern forest machines according to StanForD 2010. The agreed work order will be sent to a web-based platform by the applicant, i.e. the forest owner or manager, picked up and processed by the forest contractor on-board the machine. Finally the delivery note and invoice will be sent from the machine to the platform. The KWF will report general considerations and conclusions of process evaluation as well as steps of realization and the results of field studies of implementing the utility model.

Keywords
wood supply chain, data management, harvesting and logistics procedures, on-board communication

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Real-time managing of timber and biomass procurement, harvesting and supply based on multiple end-users demands in mountain forests

S. Huurinainen*

Abstract
The Mountain Forest Information System (FIS) under construction, works for near real time control of operations that integrates the information about the timber materials; origin, quality and quantities being processed along the supply chain, in order to; track origin, optimize procedures, fit with end-users demand, and avoid delay times in operations. The FIS is interfaced with easy-to-use mobile apps enabling efficient documentation and communication between all stakeholders. The online purchasing, sales and invoicing service of FIS is a powerful tool to mobilize "green gold" in the mountains, matching profiled demands of end-users of the value chain. MHG Biomass Manager Service, a part of FIS is available as a separate service, enabling easy documentation of timber and biomass storages through new business practices, like data input done by tractor drivers. A Lite version of Biomass Manager Service is designed for SMEs daily routine management in timber and wood energy procurement and supply.

Keywords
forest information system, forest mobile apps, real-time management of value chains

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An assessment of the logistics, cost and life cycle of supplying wood products in Tennessee

D. Abbas*

Abstract
The presentation focuses on a study developed in Tennessee from 2011 – 2015, that focuses on developing an integrated analysis of forest harvesting machine operations, cost and life cycle assessment of supplying wood in Tennessee, from site to end use. Key production factors are identified that have not been looked into before in the state. The study also highlights work conditions and operational factors that need to be considered to improve the workforce operating conditions and promote a more sustainable and growing forest products industry.

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1. Introduction

The presentation focuses on a study developed in Tennessee from 2011 – 2015, that focuses on developing an integrated analysis of forest harvesting machine operations, cost and life cycle assessment of supplying wood in Tennessee, from site to end use. Key production factors are identified that have not been looked into before in the state. The study also highlights work conditions and operational factors that need to be considered to improve the workforce operating conditions and promote a more sustainable and growing forest products industry.

2. Material and Methods

The study follows three types of assessments:

1. The logistics of forest operations in Tennessee. This section investigates the following questions:
    - What are the work force characteristics and conditions? (location, owner or operator, annual number of employees on the crew, and production in acres and tons)
    - What is the logging capacity? (equipment owned or subcontracted, type of equipment used, logging configuration and percentage and potential production capacity of the state)
    - What are the production rates per harvest conditions and prescriptions? (% of operations per cut types, skidding distances, operations per terrain types, shift hours, time of repairs and stand size).
2. The cost of the supply of timber in Tennessee. This section investigates the total cost of harvesting wood. It researched available stumpage prices, hauling, harvesting, and delivery variables. This section compares and contrasts operations in relation to their cost effectiveness.
3. A life cycle assessment of the supply of wood in Tennessee. Life cycle assessment is used to quantify environmental impacts of the supply of lumber. System boundaries of the study start at the stand and end at points of delivery of variable distances. The study analyses, using SimaPro, Greenhouse Gas emissions and the Fossil Energy Demand per extracted tonne of green wood, harvesting and transportation. It also offers a sensitivity analysis to identify areas and supply chains of greatest environmental impact.

3. Conclusion (preliminary)

- Most harvested wood volumes are from non-industrial private lands and delivered to pulp mills and hardwood sawmills.
- Equipment of highest use are fellerbuncher and chainsaw tree length systems in TN.
- Most operations are carried out in partial cut treatments, especially in 30% - 50% selected cut treatment types.
- Residue removal and chipping operations are minimal.
- Most of the reported equipment types used are beyond depreciated equipment life time.
- Most products combined were removed were removed within 48 KM (30 miles) from sites. However, most of the pulpwood was delivered slighted further within 96 KM (60 miles) from site.
- Highest supply cost in the harvesting portion. However, transportation cost becomes higher after a certain number of miles.
- Emissions from the supply of wood are predominantly from fuel and lubricant uses in there operations.

Maintenance of Macadam forest road in mountainous relief - Case study for management unit Belevine

I. Papa*, T. Pentek, H. Nevečerel, K. Lepoglavec, T. Poršinsky, Ž. Tomašić

Abstract

Forest roads, constructed so that motor vehicles can travel all year round, need regular maintenance to be able to fulfil during their lifetime all tasks specified by management plans. High-quality and timely maintenance will extend the lifetime of the forest road, reduce the operating costs of motor vehicles and frequency of their repair, make the forest road trafficable throughout the year and increase the safety of all traffic participants. The knowledge of the actual state of the primary forest road infrastructure is of key importance for the development of the study on regular maintenance of forest roads. The research was carried out on 7.031 km of macadam forest roads in selected mountainous forests in the management unit Belevine of the Training and Research Forest Center Zalesina. A cadastral survey was made of the primary forest road and a register was established of all road facilities (drainage ditches, soakaways, dykes, draining holes, bridges, supporting and coating walls, turns, passing places, turnarounds, etc.). All forest road damages were classified, quantified and photo-documented. The most frequent types and degrees of damage to forest roads in mountainous relief were defined, the methodology was developed and proposal was given for the intensity of collecting the field data. The methods were specified and the costs of forest road repair/rehabilitation were calculated with the aim of bringing them into an optimal state. The research results can be applied in operational forestry, and they are recommendable considering the share of maintenance costs in the total costs related to forest roads (for the depreciation period of 23 to 30 years, the maintenance costs are 2 to 4% a year compared to the total construction costs). By developing high-quality, methodologically uniform studies of forest road maintenance, the most adequate technology can be chosen and the dynamics of maintenance services can be planned, along with the control and rationalization of the relative costs.

Keywords

forest road, maintenance of forest roads, type of damage, degree of damage, method of repair, mountainous area

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Remarks

Full paper has been published in Forestry Journal (Šumarski list) issue 7/8 (2015).

Fly ash in forest road rehabilitation

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Abstract
Finnish forestry and bioenergy production is seeking novel uses for the fly ash deriving from biomass conversion. There are various possibilities for using fly ash in civil engineering including road construction. The increase in bioenergy production has created more interest for using ash in forest roads. However, no established methods for the rehabilitation of forest roads exist yet. Hence, this research aims to find a suitable construction method that involves using ash which provides adequate bearing capacity. It involved building ten test road sections: two of them were reference sections without fly ash. The study examined the effect of four different rehabilitation methods on the bearing capacity of roads. Measurements were made once before and four times after the rehabilitation. The measuring devices included a light falling weight deflectometer (LFWD), a dynamic cone penetrometer (DCP) and a conventional falling weight deflectometer (FWD). Two of the rehabilitation structures were 50 and 25 cm thick fly ash layers. The other two were 15 and 20 cm thick layers made of fly ash and aggregate in different mixing ratios. In all cases, the constructed layers were paved with aggregate. Statistical comparison showed that the bearing capacity of the rehabilitated road sections had improved compared to the reference sections. The recorded bearing capacities after rehabilitation (during spring thaw in 2012, 2013 and 2014) were about the same as before rehabilitation in summer 2011. Based on this study, fly ash can be recommended as an option for forest road rehabilitation.

Keywords
bearing capacity, fly ash, rehabilitation, forest road, t-test

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Forest road network planning: a GIS-based evaluation in Italy

A. Laschi*, C. Foderi, E. Marchi

Abstract
A well-developed road network permits sustainable management according to economic and productive rules. Moreover a good road network significantly reduces the impact on nature in forest operations. Forest operations need an efficient road network, in particular it has to satisfy the requirements to apply the best possible work method. Forest road building, management and maintenance requires a huge amount of resources, for this reason a forest road network plan has a key role in forest management in order to maximize the efficiency and the costs related to the roads. A field survey is the classical method to start developing a road network plan. Availability of terrestrial and dendrometric data, included in a GIS permits the calculation of different models such as Decision Support Systems (DSS). The aim of this study is to develop a model based on remotely sensed and field collected data, which estimates timber volumes moved on each forest road in a given period. It permits the estimation of timber flows on the road network. The study has been carried out in a public forest property located in Province of Trento, northern Italy. Thanks to a new methodology of data inventory a huge amount of dendrometric georeferenced information was available for homogeneous management units. Starting from Airborne Laser Scanner (ALS) data the Digital Terrain Model (DTM) and the slope map have been calculated. An up to date forest road network map has been generated with an arc-node representation, including a database containing all the structural information. A model able to allocate the expected timber volume to be harvested for each forest management unit on the best forest road has been developed. The model calculates the timber volumes transported for each node in each road, the movement according to transport direction, and accumulates these at arrival in correspondence with a node in a public road. Thanks to this model is possible to evaluate for the period of interest which roads much more used in terms of transit. This information facilitates the management during the planning of new roads, enhancement of the existing ones, and maintenance.

Keywords
forest road, forest geodatabase, timber flows, forest management

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Reengineering of forest road networks: Integrated harvest and road network planning including road up- and downgrading

L. G. Bont*

Abstract
A high percentage of the forest road networks in Switzerland were built between the 1950s and 1980s. They have a life expectancy of about 50 years, reaching the end of life in the present or the next years. Usually the road density is rather high, but the standard (weight limits) does not fulfill the state of the art requirements. A current question is now, how to redesign or reengineer these forest road networks and make them fit for the future (e.g: detect road segments that need an upgrade, identify the optimal upgrade standard or identify road segments for shutting down). We present an optimization model that concurrently minimizes the cost for the [1] road network (incl. maintenance and upgrade), [2] harvesting and [3] hauling over an entire life cycle. It detects road segments that need an upgrade, assigns them the optimal upgrade standard and identifies roads to shut down. Even the construction of new road segments can be considered. We present a case study in a mountainous area in the Swiss Alps. The model is the first spatial explicit optimization approach that solves this kind of reengineering problems and detects the mathematically optimal solution.

Keywords
road network layout planning, reengineering

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Modular portable composite bridge systems for forest industry applications – review of a research program

R. Lacis[1],K. Gode[1], E. Rudzitis[2]

Abstract
This article presents the latest research initiative in the field of forest industry infrastructure. Core of the research program is the development and testing of a modular portable bridge system which is able to carry typical forest truck loads and is characterized by relatively fast construction methods, reusability in multiple logging spots and would be considered as an economically viable alternative to permanent bridge structures. The proposed bridge system utilizes concrete and wood composite elements, which sizes and weights are designed for portability and modularity as a prerequisite. The use of glulam material adds to the lightweight character of the bridge system, as well as demonstrating to some extent; sustainability, awareness and ambition to expand usage of renewable materials in forest infrastructure applications. The experimental bridge in focus covers a nominal span of 6m and is intended for one lane heavy vehicle traffic with overall width of 3.86m. The bridge consists of two panels each having a concrete deck that is supported by three glulam beams with diaphragms. In order to examine structural and functional effectiveness of the bridge system a number of static and dynamic load tests were carried out in different seasons encompassing diverse environmental conditions, which were monitored by a permanent moisture measurement system.

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Influence of wheel load and wheel slip on rutting in forest operations

S. Pasemann[1]*, J. Erler[2], J. Hittenbeck[3]

Abstract
In most discussions about soil protection in context with forest operations, the wheel loads exerted by the harvesters and forwarders are indicated as the main reason for negative modification in soil characteristics. The loads cause soil compaction with increased bulk density and reduced pore volume. The second effect, although often underestimated, is soil displacement caused by high wheel slip. Regardless the driveline, the topmost soil becomes loose due to wheel slip and rutting starts.
Both effects, not described conclusively yet, occur simultaneously and it is difficult to understand to what extent rutting in forest operations is caused either by wheel load or slip. Studies at three different locations in Thueringen (Germany) were accomplished to describe the influence of wheel load and wheel slip on rutting in forest operations.
Conducting tests with a forwarder gives answers to that question. Variation of wheel load is simulated by weights placed on the log bunk of a forwarder, while the changes in wheel slip result from a dynamometer winch with a specified control system. Variation in machine traction types (tracked and wheeled component) were also studied. The tests were completed on different test areas with three distinct soil types and within natural fluctuation of soil water contents.
The results of this project show that the soil water content is the most important variable for rutting, while the numbers of machine passes determine the depth of ruts. The properties and formation of ruts can be described as a mathematic function, where the points of soil compaction and viscose flow, characterize this function. At a steady demand of tractive force, the wheel slip increases with increasing soil water content. On the other hand an increasing demand of tractive force through increasing terrain gradient also raises the wheel slip. Lower wheel slip and rutting processes were measured from the wheeled compared to the tracked forwarder. When comparing different traction types, soft tires exhibited earlier wheel slip and associated rut formation compared to results obtained from tracks.

Keywords
wheel slip, rutting, forwarding operations, machine operating trail, trafficability

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Noise and vibration exposure in full-tree logging systems in the Southeastern U.S.A.

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Abstract
In the Southeastern United States, logging equipment operators often work shifts in excess of 10 hours. Evidence suggests that exposure to noise and vibration may have adverse impacts on both worker health and productivity (Jack and Oliver 2008, Stansfeld and Matheson 2003). We monitored logging equipment operators at eight sites in the southeastern United States to better quantify the exposure to occupational noise and whole body vibration. Twenty-seven logging equipment operators were measured for exposure to noise and whole body vibration. Personal noise dosimeters were used to collect noise exposures while seat pad accelerometers were used to capture vibration exposures. Both sets of data were collected during at least four hours of representative machine operation. The data were collected from eleven wheeled skidder operators, eight wheeled feller buncher operators, and eight loader operators from seven different logging crews. Wheeled skidders had the highest average whole body vibration exposure at 1.58 $\mathrm{m\,s^{-2}}$ Aeq(8), wheeled feller bunchers followed at 1.04 $\mathrm{m\,s^{-2}}$ Aeq(8), and finally loaders at 0.64 $\mathrm{m\,s^{-2}}$ Aeq(8), all of which exceed the ISO 2631 recommended action limit. The value for skidders exceeded both the ISO 2631 exposure limit value and the European Union Directive exposure limit value (1.15 $\mathrm{m\,s^{-2}}$). The majority of the noise exposures were below the OSHA Action Limit of 85 dBA, but due to the long hours, almost all operators received more than the ISO EU recommended daily noise dose.

Keywords
logging, vibration, noise

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Skidding performance in reduced accessibility conditions - productivity and time consumption

S. A. Borz*

Abstract

For the time being, the forest transportation infrastructure is poorly developed in Romania. With only 6.0 to 6.5 meters of forest roads per hectare, the existing situation frequently causes instances in which timber has to be extracted over distances exceeding 1.0 to 1.5 km, and there are also situations in which the skidding distance exceeds 2.0 km. These facts have implications on skidding performance in terms of time consumption and productivity, but given the reduced labour costs in Romania, skidding operations are still conducted in such conditions. The Romanian forest provides the strategy that the forest road network should be developed in the near future and that it is likely for the new constructed roads to be developed on mountain slopes, instead of those currently existing, which are generally developed in the main valleys. In these conditions, the Romanian forestry needs decision support systems aiming to correctly design in terms of location the new forest roads. One of the major tasks in the design stage consists of estimations made of the harvesting and road-building costs in order to optimize the entire system costs. Such tasks usually require information on performance of currently used harvesting systems, with focus on the performance indicators of equipment mainly used to extract timber. At the same time, harvesting operations in Romania rely on motor-manual felling and processing, respectively skidders are used to extract the timber to the roadside. Unfortunately, no extensive skidding performance modelling studies were available for the Romanian conditions, a context that justified the present work.

Data was collected in the period ranging from 2012 to 2014 with the most commonly used skidders in Romania (TAF 657 and TAF 690 OP), it sourced six independent time studies (5 studies conducted under mountainous conditions and 1 study conducted under hilly conditions) and was further used to estimate the skidding productivity and to build time consumption and productivity models for extraction distances ranging from 150 to more than 2500 m. Each of the time studies was carried out in a traditional manner that used the application of snap-back chronometry and data collection on paper sheets. Statistical design was shaped around a modelling study and backward stepwise multiple linear regression procedures were used to develop the needed models.

Following the necessity to exclude some of the measured variables, the results indicate that the most relevant remaining predictors that explained the variation of time consumption for skidding operations (α=0.01, p<0.01) were the winching distance, number of logs forming a load and the on-trail skidding distance. The operational conditions indicated a mean winching distance of about 19 m, a mean number of skidded logs per turn of 5, a mean load volume per turn of 5.84 m^3 and a mean on-trail skidding distance of about 1357 m. Under these circumstances, the net production rate was strongly affected by the on-trail skidding distance and it yielded a value of 6.19 $m^3\ h^{-1}$, meaning that about 0.16 hours were required to skid one cubic meter of timber. The gross production rate was even smaller and it yielded a value of 3.25 $m^3\ h^{-1}$ indicating an increased proportion of the time expenditure that consisted of delays. In average, winching operations took about 0.2 hours while the on-trail skidding operations took about 0.7 hours.

Given the concept of this study, that proposed the elimination of time expenditure for landing operations, as well as the developed models that were shaped both around all the skidding operations as well as only around the on-trail skidding operations, the results of this study may be used for operational costing, and forest road infrastructure planning.

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Sensor based data collecting on motormanual wood harvesting operations

O. Thees*, F. Frutig, R. Lemm

Abstract
High mechanized wood harvesting processes can be monitored by on board computers to get data for developing productivity models. In case of motormanual wood harvesting processes the question arises if working time could be measured by means of modern information technology to avoid expensive manual time studies. In Switzerland, models for estimating performances of motormanual harvesting systems are of special interest. In future as well, the chainsaw will be an important harvesting tool in mountain areas due to terrain difficulties.
The goal of the study was to analyse the feasibility of a sensor based collecting of working times of tree felling and processing with the chainsaw. A method for automated data collecting and analyzing should be developed, tested and described. The investigation proceeded in three steps: (i) definition of requirements, (ii) development of the time measurement system, (iii) field testing. A sensor based measurement system has been developed, consisting of a measurement device for data collecting and storing and a software for data analyzing. The measurement device on the chainsaw records the movements and the operating status of the engine. After work these data can be transferred to a personal computer. There the sensor data and the tree numbers and volumes are synchronized by the software and displayed in an Excel sheet.
It could be demonstrated that automated data collecting of chainsaw work is possible. The working time of the whole tree processing as well as for the phases of felling and debranching/bucking can be measured with little differences compared to manual time studies. Productive and non productive working time can be separated. The measurement system has been tested in a one day operation of felling and processing and has been running failure free. The sensor based collecting of data which are relevant for productivity and ergonomics in motormanual harvesting is a new promising time study method.
The project has been conducted in collaboration of the Swiss Federal Research Institute WSL with the HSR Hochschule für Technik Rapperswil. Here, IMA Institute for Mechatronics and Automation Technology has been responsible for the technical realization. The project was supported by the Wald- und Holzforschungsfond of the Federal Office for the Environment FOEN.

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"Lowland cable yarder" in four different process variants

B. Engler, C. Förster*, J. Erler

Abstract
Impassable and therefore not used, flat and wet forest sites make up about 12% of the forest area of Germany. In these locations any hauling and forwarding of timber with wheeled or tracked machines cannot be done without soil compaction or soil destruction. So in most cases the forest owner abstains from harvesting operations and from income too. On these sites skidding with cable yarders (CY) offers an alternative for a compatible timber extraction that conserves stand and soil, but cable yarders are rarely used because of their costs. At the TU Dresden, the given technology, which is developed for steep terrain has been adopted to flat terrain by adding some technical innovations (Knobloch). As a result a powerful, ecologically soft, cable yarder for lowlands was created. This yarder was tested under various field conditions in four different process variants, but all of them were on wet to very wet stands. Time studies gave detailed information on productivity and costs, showing that the factors; skidding distance, load volume, and number of choker-men have a prominent influence. The stress and strain of the choker-men are assessed by means of the Ovako Working Posture Analysing System (OWAS) and heartrate measurement. For the ecological compatibility of the different process variants, visible damage in the stand and in the soil has been detected by standard methods. Based on these economic, environmental, and social criteria the range of applications and its limitations are worked out for every machine and process model.

Keywords
lowland cable yarder, time studies, OWAS

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Efficiency of topping trees in cable yarding operations

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Abstract
The extraction of biomass and nutrients out of the forest is implicit to every harvest operation. In cable yarding, whole-tree harvesting (WTH) has become more prevalent in the last few decades and processing takes place at the roadside. There is a concern that WTH impairs site productivity due to nutrient removal. One option to increase the amount of biomass remaining in the stand is to top the trees before extraction. In order to estimate the influence of topping on system productivity, time studies on a medium-sized tower yarder were carried out in three spruce dominated stands. Heart rate monitoring of the chainsaw operator was performed to examine the physiological workload. The analysis showed that topping only impacts system productivity if it takes place during the inhaul of the load as it leads to interruptions of the extraction progress. These interruptions took on average 13 seconds per turn. In addition, if topping was performed on already lifted trees, a reduction of line-speed during the lateral yarding of the loads was observed. This led to a reduction in productivity between 5 and 11%, assuming that all trees would have been topped during the lateral yarding process. Analyses of the physical workload of the chainsaw operator showed that the workload of topping trees is significantly lower than that of the felling process. Relative heart rate of the subject was lower at the cable corridors where topping was ordered. This confounding result may be a consequence of many additional factors like slope gradient or cycle time. Under both scenarios, the worker never surpassed the limit of a sustainable cardio-vascular workload for an 8 hour working day. Hence, recovery time for the chainsaw operator can be considered as adequate when topping is performed in a three-man crew.

Keywords
topping, cable yarding, productivity, workload

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Remarks

Full paper has been published in the FORMEC CROJFE Special Issue:

Huber, C., Stampfer, C., 2015: Efficiency of Topping Trees in Cable Yarding Operations. Croatian Journal of Forest Engineering 36(2): 185–194.

Terrain-going cable yarders: Systems alternatives and conditions for application

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Abstract
In this study, the performance of two terrain-going cable yarders was studied and used in a system analysis which included processing then forwarding to roadside, or whole-tree skidding and processing at roadside. The potential application for such systems was evaluated in GIS, and the investment costs in appropriate machinery was compared with the cost of extending the road network for access to conventional yarders.

Keywords
cable-yarding, steep terrain, productivity studies, systems analysis

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1. Extended Abstract

On the Norwegian west coast, an area characterized by steep and difficult terrain, just over 50% of the mature timber volume lies between 500-999 m from a forest road, and around 23% at distances beyond 1000 m. Modern European tower yarders have an economically optimal extraction distance of 2-400 m, depending on factors like slope and volume of timber per setup, while long distance yarders are not a realistic option given the excessive demands on rigging and operation. Terrain-going yarders are therefore an option where road densities are too low to allow timber to be reached from the forest road, and where individual volumes are too low to justify the heavy investments needed in extending the road network. Cable yarders that are constructed on terrain-going base machines – typically forwarders or tracked excavators – can access skid roads, or even operate from a position deep in the terrain (fig. 1), while conventional tower yarders are restricted to operating from a forest road.

Yarding from a position not accessible to timber trucks means that the timber must be processed at the yarder with a harvester/processor, and extracted with a forwarder, or skidded as whole trees to the roadside and processed and stacked there. In this study, the productivity and cost of a terrain-going tower yarder, working together with a clam-bunk skidder fitted with a processing head, was assessed and compared with existing models for processing at the yarder and forwarding in the terrain. Capital investments, operational costs, performance, and utilisation levels are provided on both systems, and the potential application of these machines in various international settings is discussed.

Figure 1. Illustration of terrain-going yarder and clam-bunk skidder.

Cable logging contract rates in the Alps: The effect of regional variability and technical constraints

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Abstract
A survey of cable logging contracts was conducted in 5 of the 8 Alpine countries, namely: France, Germany, Italy, Slovenia and Switzerland. The goals of the survey were to set a general reference for cable logging rates, to identify eventual differences between countries and to determine the effect of technical work parameters (i.e. piece size, removal per hectare, line length) on actual contract rates. With a total sample size of 566 units, the mean removal and rate were 165 $m^3\,ha^{-1}$ and 42.9 € m^{-3}, respectively. Both removal per hectare and contract logging rates varied considerably and the study found significant differences between countries. Switzerland stood out from the group with the highest removal (345 $m^3\,ha^{-1}$), but also the highest contract rate (79.5 € m^{-3}). Removal per hectare was lowest in Italy with just 58.3 m, and logging rate lowest in Slovenia at 29.3 € m^{-3}. Logging rates were highly correlated with the average labour rate of each country. Technical factors such as tree size, line length and tract size explained about 40% of the variability in logging rates. Therefore, 60% of the variability is explained by other technical factors not included in our data and by non-technical factors, such as local market dynamics.

Keywords
harvesting, mountain, wood, forestry, yarder

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Remarks

Full paper has been published in the FORMEC CROJFE Special Issue:

Spinelli, R., Visser, R., Thees, O., Sauter, U.H., Krajnc, N., Riond, C., Magagnotti, N., 2015: Cable Logging Contract Rates in the Alps: the Effect of Regional Variability and Technical Constraints. Croatian Journal of Forest Engineering 36(2): 195–203.

Self-charging wireless module for remote monitoring of forest machines

S. Grigolato*, F. Marinello, A. Pezzuolo, S. Forigo, L. Sartori, R. Cavalli

Abstract
Global Navigation Satellite Systems (GNSS) have become in recent years a useful tool. Indeed several devices have been proposed both at a research and market level, allowing tracking of machine positions but also for monitoring the status and working time distribution. A innovative low-cost self-charging wireless module integrated with a GNSS system, created with the goal to monitor functional data such as as; oil temperature and pressure, orientation and vibrations of agricultural machines and equipment, will be investigated specifically for forest machines. The device is equipped with a solar cell and and energy-harvesting systems, in order to minimize its maintenance cost and to allow continuous functioning. Data can be transmitted via Bluetooth or WiFi, to any smartphone or tablet and also stored in cloud system, where it will be possible to check status and the recorded parameters. In particula, experimental studies will focus on adapting the module to monitor forest machines and equipment. The field tests will be conducted during the spring of 2015.

Keywords
sensor, forestry machinery, monitoring system, time study, energy-harvesting systems

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Topic 14

Poster abstracts

Professional capability of forest enterprises in operating cable yarders in the Italian Central Alps

O. Mologni, S. Grigolato, R. Cavalli*

Abstract
Cable cranes represent one of the most important yarding systems on steep terrain. These machines show a lot of positive aspects, such as limited environmental impacts and the possibility to reach hard to use areas, but they also require long time periods and higher costs of installation. Furthermore, appropriate planning and dimensioning are needed to respect work safety conditions. In this context, the aim of the present paper is getting an overview regarding the level of professional capability of forest enterprises in using cable cranes in the Italian Central Alps.
The information and data was collected through a semi-structured questionnaire addressed to 55 forest enterprises with direct interviews. The required information concerns different parameters; technical features of the machines, intensity and use condition of cable cranes, management of timber yards, experience in use of cable cranes, and procedures in planning and installing of cable crane lines. Each parameter has been evaluated according to four different levels so forest enterprises reach for each parameter a partial score ranging from 1 to 4. The total score, derived from the sum of the partial ones, defines three different categories according to the professional capability of using cable cranes.
The results from this investigation show the presence of a consistent group of forest enterprises (27%) with high professional capabilities, while most enterprises (58%) are distinguished by a medium level of professionalism and with some deficit in machinery inventories or in technical knowledge. Instead, a small group of forest enterprises (15%) is characterized by a low level of professional capabilities in using cable cranes, mainly because of outdated machines and limited technical knowledge. In conclusion, the situation appears generally positive; a lot of forest enterprises present high professionalism in using cable cranes and most of them show high potential and room for improvement. To ensure the development of the forestry sector and the innovation of forest enterprises, public administration has to guarantee economic support for old machine substitution as well as offer professional courses for planning and installation of cable cranes.

Keywords
cable yarding, professional capability, Italian Alps

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Assessment of reduced-impact logging on felling time using neural networks

H. Bayati, A. Najafi*

Abstract
Tree felling is the most important among the tree harvesting components. Improved harvesting methods can reduce tree felling time. One of these methods is the use of directional felling. Regression analysis is a common way in designing models for felling net time. Today beside previous, common methods, new methods are applied. Artificial Neural Networks is one of these techniques. This study was carried out to evaluate the effect of directional felling on the reduction of felling time of a cutting operation in the NEKA CHOOB forests. For this purpose, using marked trees, directional felling of 42 trees was determined with the help of supervisor and the falling path of selected trees was specified by paint on the trunk of trees. Also, net time of felling per tree was estimated by Multi Layer Perceptron and Radial Basis Function and also by the common method of linear regression analysis. Comparison time of direction determination, in directed and undirected trees showed that this time was more than 3 times in undirected trees. Results of estimation showed that the Radial Basis Function network provided more accurate results in net time of tree felling estimation than the MLP neural network. Also from comparison of obtained evaluation criteria's of neural networks and regression analysis, the neural network method outperformed the linear regression method.

Keywords
directional felling, neural networks, forest harvesting, felling time, MLP, RBF

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Application of an artificial neural network in tree felling time estimation

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Abstract
Tree felling is the most important among the tree harvesting components. Production estimation of forestry equipment is an important part of cost management in forestry departments and is associated with operating expenses reduction. In other words, the high cost of investment in forest utilization, is a good reason for forest engineering research and modelling. Many techniques such as regression, fuzzy logic, neural networks, etc. are utilized to estimate tree felling time. They make a logical connection between the tree felling time and independent effective parameters, and could be used in future operations to predict tree felling time. In this study two neural network models; Multi-Layer Perceptron (MLP) and Radial Basis Function (RBF), were used to predict the tree felling times in a felling operation in Neka choob Co. In order to collect felling time data, the continuous time study method was used. For this purpose, 84 trees marked trees were selected and a net time of felling per tree was estimated by Multi-Layer Perceptron and Radial Basis Function. Results showed that the Radial Basis Function network provided more accurate results of net time of tree felling estimation than the MLP neural network. Comparing evaluation criteria for ANN showed that MLP and RBF neural networks had RMSE values of 0.94 and 0.81 respectively.

Keywords
forest engineering, time study, radial basis function, multi layer perceptron, forest harvesting

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GIS-based forest road network model for forest protection purposes

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Abstract
The arrival of the fire trucks and ground teams into the forest fire areas in the shortest time period possible is very crucial in order to effectively fight forest fires in time. In this study a GIS (Geographical Information System) based system has been developed to decide the route which minimizes the arrival time to the forest fire area. The study area was the city of Erbil, located in the north of Iraq. In the study area, there are nine fire stations for firefighting teams. In this study, firstly the road network, locations of the headquarters, and possible fire locations were digitized by using ArcGIS 10.0 software. Then network databases were generated based on the digitized data by using the Arc Catalog module. Finally, the optimum route providing the fastest transportation from fire stations to possible fire areas was determined by using Network Analyst working under the Arc Map module. Also, the areas that can be reached by firefighting teams in the critical response time were determined. It was found that six of the fires were not accessible by the teams within the critical response time. Thus, only four of the potential fire areas were reached within the critical response time. These results indicated that new fire stations should be established in the study area to provide sufficient firefighting response to all forested lands. Besides, new fire access roads and increasing the design speed on current roads should be considered to increase firefighting response capabilities.

Keywords
forest road network, network analysis, shortest path, GIS, fire protection

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A model for the optimization of the forest wood chips supply chain in Southern Italy

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Abstract
In the last years public and scientific debate about the reduction of CO_2 and pollution emissions has intensified and the importance of renewable energies and fuel has increased. Scientific research on the economic possibility to use wood and biomass to obtain electric and thermal energy has shown contrasting results. The biomass for energy purposes, coming from agroforestry systems and timber industry, can provide various environmental and socio-economic benefits. Among all renewable energy sources, agroforestry biomass represents both an important alternative source to fossil fuels and an opportunity for the socio-economic development of various marginal areas in Italy. In the supply of biomass for energy use, the planning of operations is the basis for the sustainable development of an agroforest system. In South Italy the use of wood for heating was promoted with; European structural funds, rural development plans, energy projects, and regional and provincial funds.
The general objective of this research is to study the local biomass supply-chain with cooperation between different sectors and examine the innovations used to produce renewable energy from biomass with small and low-cost pyro-gasification plants (< 100 kW). These systems are also characterized by a remarkable operational and maintenance easiness, and great versatility in the type of biomass used, which can range from wood chips to the refuse-derived fuel to zootechnical waste. Therefore, this paper focuses on development of guidelines for increasing a sustainable biomass supply chain at a local scale, in order to facilitate energy planning that considers the local system carrying capacity and the potential of substitution of fossil fuels.

Keywords
biomass, pyrogasification, mechanization, costs

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Risk assessement of repetitive movements in forestry supply chain

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Abstract
Forest workers are an important part of the forest-wood industry chain, and the forest supply chain is a major industry activity in Italy. Calabria is one of the most important regions for production of roundwood and firewood and was chosen as the study area. Motor-manual timber cutting–harvesting operations are still the main harvesting system in Italy and are one of the hardest and heaviest types of physical work. The forest work is characterized by long working hours per day, limited numbers of breaks and no regular rotation of tasks. This research was performed taking into account the whole cycle of work and the various activities carried out by forestry companies. A group of workers was examined using a precise criteria selection; kind of tasks, equipment used, seniority, and experience. To complete the picture of biomechanical demands requested of workers, postural commitment of each phase of the activity was evaluated. Between 2010 and 2014, surveys were conducted with the aim of verifying the muscular-skeletal risk using the OCRA (Occupational Repetitive Actions) checklist method. On the basis of the results obtained, this method could well become a possible tool in implementing prevention measures for all workers involved in forestry industry operations and not only those in the first step of the supply chain. Studying the real exposure of the workers, means analysing actual exposure throughout the work day and for this reason the objective of future research is to obtain a greater number of epidemiological data and create simple tools and practical steps to estimate the calculation of risk.

Keywords
safety, ergonomics, OCRA, forestry

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SIMWOOD focus study – Sustainable mobilization of wood by dissipating the technical constraints in managing small forests in Germany

N. Karl*, H.-U. Dietz, U. Seeling

Abstract
The SIMWOOD project aims to mobilize forest owners, promote collaborative forest management and ensure sustainable forest functions. Amongst others it carries out case studies in several model regions in Germany. The task of KWF is to provide expertise in harvesting procedures and techniques in small forests. Characteristic of many small forests is a lack of opening-up and difficult accessibility. Steep slopes and weak soil conditions are further regional constraints for sustainable forest management. Efficient harvesting processes for small-scale forestry have to be conducted under these various conditions. The KWF has described and evaluated basic harvesting procedures for small-scale forests by using functiograms to describe the technical steps of conversion from standing tree to traded assortment and to locate the process from stand to forest road. Adapted harvesting operations in small forests must also consider technical equipment as well as work input and qualification of the forest owner. The results of selected case studies conducted by the KWF will be presented.

Keywords
small-scale forestry, adapted harvesting procedures, managing small forests

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Analysis of physico-mechanical properties of energy willow shoots

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Abstract
Hardness directly affects the energy consumption during the the processes of harvesting and processing of energy willow and is decisive for the construction of working assemblies. This paper presents an analysis of one, two, three and four-year-old shoots of the 1049 willow variety. The measurements of the shoots were carried out at several points: the butt-end part and 1 and 2 meters away from the butt end. Tests were also conducted at different moisture values, namely 50%, and 20%. Hardness measurements were performed using the Shore method. The research showed that the hardness of willow stems varies slightly depending on their position relative to the root collar and that an average value at a moisture content of 50% is 36.7 ± 0.9 MPa while at a moisture content of 20%, it is 39.9 ± 0.9 MPa. The study was performed using one-parametric statistical Kruskal-Wallis variance analysis assuming the significance level $\alpha = 0.05$.

Keywords
energy willow, hardness

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Recognition of the variability of energy willow root biomass in the aspect of selection of a plantation liquidation technology

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Abstract
Energy willow plantations are used in cycles of 20–25 years. After such a period of use, or earlier, plantations should be liquidated. In the case of arable land, liquidation of a plantation also means restoration of the original production properties of the soil. In particular, this means: permanent elimination of the possibility of plant regrowth from the above-ground rootstock and root systems and disintegration and mixing of the above-ground rootstock and root systems. The present authors undertook the task of developing a technology of liquidation of energy willow plantations that would have the advantage of lower energy consumption and execution costs than the technologies used so far. The development of a new machine for the disintegration of the above-ground rootstock and root systems requires recognition of the variability of their morphological parameters and their biomass. For that purpose, a head for planting trees was used to sample rootstocks, extract them and a number of biometric parameters were determined with the division into thickness fractions.

Keywords
energy willow, root system, plantation liquidation, land reclamation

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Analysis of the work performance of timber harvesting with use of Highlander harvester

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Abstract
This paper presents the work performance analysis of timber harvesting with the use of a Highlander harvester produced by KONRAD Forsttechnik GmbH. The analysis was performed based on the timing of the working day. We also assessed the organization of the machine work in the research area and functional capability. The study was conducted in Forest Department Międzylesie, Forestry Nowa Wieś (the south of Poland) with the type of forest habitat was fresh mixed mountain forest, strongly fresh variant, in which the machine acquired spruce. Timing was performed based on the registration of the machine work on the video camera (one shift work) and the measurements of collected assortment. Based on the results of measurements and analysis, it was found that the organization of the machine work was not the best. While operating a one shift work system with a duration of 6 h per shift, it was found that the effective working time only occupied 67.9% of the shift time (about 4 hours). This resulted in a reduction of the operating performance during the working day, which was only 12.7 m^3 h^{-1}, with an effective high-efficiency performance at 18.7 m^3 h^{-1}. The machine has a number of advantages, which allow work to be performed in difficult conditions, as well as having a focus on operator comfort.

Keywords
timber harvesting, work performance, harvester

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Cable skidder productivity in mountain logging operations of Castanea sativa coppice stands in steep sites in Northwest Spain

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Abstract
Chestnut is one of the most important species in the Cantabrian coast of Spain. A peculiarity and challenge for forestry in Asturias is the steep terrain that characterizes the region, which along with the fact that 80% of forests are in individual private ownership, are often small in area, (75% are not above 10 ha) and difficulties of access, make harvesting more difficult and costly. As a result the typical harvesting system employed in the region uses a cable skidder, which is better able to cope with these characteristics. The effective planning of such forest harvesting systems is essential and the aim of this work is to determine the efficiency of operations using this machine. A continuous time study using the software UMT was conducted to evaluate the productivity of the John Deere 540D skidder, in three chestnut coppice stands in northwest Spain. Models were fitted to predict skidder productivity according to key parameters (from continuous timing and independent variables recorded in the study) by linear or non-linear regression with SPSS. These models considered time and productivity per effective machine hour and per scheduled hour as a function of extraction distance and volume extracted per cycle. The productivity per effective hour (PMH) was approximately 6 m^3/h with an average skidding distance of about 1000 m.

Keywords
chestnut, productivity, skidding distance, GPS, steep slope

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Socioeconomic and environmental assessment on the sizing of a biomass power plant for the rural development in Mexico

U. Flores*, D. Jaeger

Abstract
The level of development observed in rural communities inside Mexico is depending on socioeconomic and environmental aspects, according to availability and management of natural resources throughout the supply chain. Together with local forest management, energy supply chains from lignocellulose biomass make forest resources a driving force for the development of marginalized communities. The creation of bioenergy supply chains opens a range of opportunities for forest utilization and sustainable development. The goal of this research is to develop methodology for assessing bioenergy supply chains within the Mexican rural sector to activate development through sustainable forest utilization. The conjunction of aspects based on proper technology and sustainable forest management is significant for efficient energy supply chains that enable development of the rural sector. The sizing of a biomass power plant and an evaluation of its impacts, comprising of an analysis on its chain throughout biomass production, biomass management and biomass supply, are addressed within the project. The feasibility and practicality of the methodology are reviewed in case studies. An assessment of the status quo of quality and quantity of available lignocellulose biomass for bioenergy supply is covered. Moreover the forest management practices for bioenergy supply, including harvesting, extraction, transportation and supply are evaluated. The theoretical available energy from lignocellulose biomass against local energy demand is analysed as well. Availability and appropriateness of lignocellulose biomass, forest management for bioenergy supply and energy balance are presented as research modules. These modules include indicators on availability of species (current and mean annual increment), forest management practices (productivity, costs) and energy balance (energy demand, energy supply), with the objective of assessing the technical, economic and ecological feasibility. Using existing literature from national research institutes, a regional scale (north and south central) is presented, estimating a biomass flow chart for forest biomass and sawmill waste for energy purposes. A comparison of the status quo against proposed scenarios will result in a methodology for holistically evaluating the feasibility of decentralized bioenergy plants for lignocellulose forest biomass as a renewable energy resource within the Mexican context.

Keywords
bioenergy, sustainable forest management, Mexico

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Equipment analysis and measurement of machines work parameters using GSM-GPS controllers in forest nurseries in Southern Poland

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Abstract
Forest nurseries in Poland cover about 2.5 thousand hectares and produce over 800 million tree seedlings and nearly 13 million bushes per year. Most nurseries are classic ones, where the production of forest seedlings deal with bare root seedlings system. Apart from these, there are modern container nurseries. The monitoring of nursery units work is conducted in five selected forest nurseries using geomatics. GPS satellite navigation systems collects data on working time, position, unit velocity, fuel consumption, engine rotation speed and temperature of the tractor engine. All parameters transferred to the system are recorded into its memory. Collected information is presented immediately on the system website, but can also be analysed later. The data obtained allows very accurate determination of the annual use of tractors and machinery in forest nurseries. It will also allow for the analysis of working time, the way of driving, operating speeds used, fuel consumption, and engine load of the tractor. In view of the rapid development of innovative geomatics, the applied method of data collection with GPS allowed the development of methodology that can be widely used by forest companies for monitoring and online adjusting of the organization of units work in forestry.

Keywords
monitoring, GPS, forest nursery

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Productivity model and cost estimation for the planning of cable yarding in the French Alps

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Abstract
In France, cable yarding is a new activity with less than twenty operating companies in the field. In the French Alps, around 50 000 m^3 are harvested annually by five French companies, sometimes including foreign teams using different kinds of machines. With this low level of activity and experience, contractors and forest owners may have difficulties determining the exact logging costs. During the period of one year, 80 cable lines on 34 logging sites were monitored to collect data on forest stands and field conditions for each logging operation (e.g. time schedule, number of intermediate pylons, time devoted to the specific phases). The objective was to develop a productivity model that allows an accurate prediction of the three phases of a cable yarding operation; installation time, hauling and removal time. The following analyses were performed: testing of significant effects of factors, interactions between factors and co-variables (variance analysis and PLS regression), analysing the parameter estimation of significant factors and co-variables, and checking and validation of model assumptions (residual analysis). To ensure the robustness of the models, the data was divided into two parts, a calibration set to build the models and a validation set to test them. Selected models are those with the best results and validation set. Installation and removal time are related to the type of equipment used (uphill or downhill way, auto-motor carriage or haul-back line) and the number of pylons to be installed. The hauling productivity is related to the length of the line, the direction (uphill or downhill) and the roughness of the site which includes several parameters like; slope, weather conditions, obstacles, and many more. The results were presented and discussed with practitioners. A new software is being implemented in summer 2015. With this tool, companies will be able to estimate the duration of each phase and the cost of the logging operation by taking into account the characteristics of a site. Their feedback will be available and presented in October.

Keywords
cable yarding, productivity model, French Alps

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Skidding time prediction models of a Zetor skidder in a mountain forest using feed-forward artificial neural network

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Abstract

Artificial intelligence has been applied in modeling of various parameters in many fields of scientific research. Due to non-linearity of relationships between variables in forest operations, generating model with soft computing methods could promisingly lead to models with high performance. One of the important prerequisites of production and cost estimation of skidding operations and even solving machinery allocation problem of forest companies, is to generate a reliable time model to reasonably predict the time of one cycle skidding. The aim of the present research was to evaluate the efficiency of Artificial Neural Network (ANN) in prediction of skidding time of the Zetor skidder. The times of 85 skidding cycles were investigated and used as the training, validation and test data in a modeling process using feed-forward neural network. The components of every skidding cycle has been studied with the continuous time study method. Effective factors on time of skidding were; skidding distance, skidding slope, number of logs, and volume of load. Various types of topologies and transfer functions were applied to create the models. Results showed that a combination of tangent-sigmoid and log-sigmoid transfer functions generate a model with the highest generalization power. The determination coefficient and the root mean square error for the best-trained network were 0.95 and 0.177, respectively. The study indicated that Feed-forward backpropagation ANN provided a good accuracy for estimating the time of one skidding cycle time of a Zetor skidder.

Keywords
neuron, bias, tansig, logsig, Matlab

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Last application of artificial intelligence in forest engineering operations

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Abstract
There has been an increasing interest in using modern optimization techniques in forest engineering operations due to advancements in computer hardware, optimization algorithms, and remote sensing technologies. In recent decades the application of artificial intelligence (AI) in forest and natural resource management started with the development of expert systems. AI technique, being capable of analysing long-series and large-scale data has become increasingly popular in forest engineering operations among forest manager and forest engineers. The high cost of investment in forest harvesting is a good reason for forest engineering research and modelling, thus the major objectives of the study presented in this paper are to investigate several AI technique applications in forest engineering operations, these include; artificial neural networks (ANNs) approaches, adaptive neural-based fuzzy inference system (ANFIS) techniques, genetic programming (GP) models, and support vector machine (SVM) methods. The paper also discusses most of the current challenges as well as future directions in relation to the use of AI techniques in forest engineering prediction and modelling.

Keywords
artificial intelligence, forest harvesting, forest management, optimization

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Forest road network analysis considering fire fighting management (FFM) in natural resources lands, Chehel-Chay Watershed, Golestan Province, Iran

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Abstract
In natural resource lands as general, and particularly in the northern forests of Iran, fires have destructive effects on forests. Fire risk mapping is one of the solution methods for; identification of highly dangerous areas, diagnoses of fire occurrence, decreasing fire effects, and prevention of fire occurrence. The existing, appropriate and effective road networks accessing and passing through the forest area is one of the management factors that is important to understand for fighting fire.
The purpose of this study is zoning the Chehel-Chay watershed for fire risk probability and the analysis of road network in order to MFF in natural resources lands. Initially in this study, using effective factors of fire occurrence such as; climate, topography, vegetation, human elements, distance to water recourse and occurred forest fire points (OFFP), the study area was mapped by support vector machine (SVM) for fire risk probability. Then, the fire risk map was divided into four fire risk categories; low dangerous (LDC), medium dangerous (MDC), dangerous (DC), and highly dangerous (HDC).
The road network type (pave, gravel, and dirt road) was analysed according to each fire risk category. The result showed that 63% of fires that occurred were located in distances of less than 100 m to roads. Also, 29.5 km of paved roads, 7.9 km of gravel roads and 113.2 km of dirt roads are located in the low dangerous category, 9.82 km of pave roads, 0.33 km of gravel roads and 69.82 km of dirt roads are located in the MDC, 13.62 km of pave roads, 0.26 km of gravel roads and 22.5 km of dirt roads are located in the DC, and 30 km of paved roads, 2.22 km of gravel roads and 70.09 km of dirt roads are located in the HDC.
In the high danger zones, roads pass through forestlands, but in low danger zones, the roads are passing through farmlands. On the other hand, 0.36% of pave road are located in the HDC. According to high ratio of traffic, high density of population (local, tourists) in edge of roads and closing of (OFFP) to roads can be concluded that pave roads are one of reason for fires in study. This is because all of vehicles can travel on this roads, but only mini trucks and pickups can travel on gravel roads and tractors can travel in dirt roads. On the other hand, 42% of watershed and 67% of HDC zone are not covered by roads.
Therefore, appropriate road network planning for this area according to MFF or using of suitable fighting fire vehicles for forest mountainous region is necessary. Considering to this result, in highly dangerous zone it can prevent of fire occurrence or when the fire is occurring the different fire fighting vehicles can be used according to type of road instead using alone human power can prevent the separated of fire.

Keywords
road, fire risk map, fire fighting vehicles, support vector machine (SVM)

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FORMEC Austria 2015

ISBN 978-3-900932-29-9