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FOREST OPERATIONS RESEARCH IN THE NORDIC BALTIC REGION

Proceedings of the 2010 OSCAR conference held in Honne, Norway, October 20-22, 2010

Edited by Helmer Belbo

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NORSK INSTITUTT FOR SKOG OG LANDSKAP

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Cover Photo: Forwarder mounted Owren 400 cable-yarder. Grong, Norway. Photo: Bruce Talbot

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FOREWORD

In attracting such a large and diverse group to the 2010 conference, the Operations Systems Centre of Advanced Research (OSCAR) has once again shown itself to be a viable and appealing platform for the forest operations research community in the Nordic-Baltic region.

Congratulations are due to the coordinating committee made up of representatives from each participating country. The OSCAR group have facilitated a structure and provided the means through which a large number of researchers have felt a strong affiliation to the various working groups and the CAR itself over the past 5 years. A successful virtual centre such as this reflects the sum of activity of the many individuals involved – from the newly started doctoral students to the well seasoned professors.

These proceedings are an impressive collection of abstracts, diverse in the issues they address, the methodologies applied in addressing them, and their geographic sources of origin. Yet they are closely knit under the umbrella of forest operations. Together with the proceedings from the 2008 meeting in Denmark and the 2006 meeting in Estonia, they provide a track record which documents a level of activity that must well exceed the original expectations of a CAR.

This is the final OSCAR conference within the first framework period. We are very proud to have had the opportunity to host this event in Norway, and I am sure that delegates will have good memories of the few days spent in Honne. It is always difficult to quantify the immediate gains of a networking event, and it requires additional sacrifices in our demanding schedules. For the large number of young researchers represented, gatherings like this play a strong role not only in benchmarking your current skills and ideas with your colleagues, but in forming a solid basis for future cooperation and networking. We look to you to not only keep this tradition alive, but to build on it and adapt it to fit the working lifestyle of the future.

On behalf of the Norwegian Forest and Landscape Institute I wish all the delegates a successful and inspiring conference, and trust that it will contribute to an even greater synergy in the future.

Arne Bardalen

Director – Norwegian Forest and Landscape Institute

PREFACE

The OSCAR network was formed in 2005 and includes five Nordic forest research institutes Metla (Finland), Mesäteho (Finland), Skogforsk (Sweden), Skov & Landskab (Denmark) and Skog og Landskap (Norway) and SILAVA (Latvia). The network is open for all relevant research bodies in the Nordic and Baltic countries. OSCAR is one of five virtual centres of advanced research financed by the Nordic Forest Research Cooperation Committee (SNS). The main target of OSCAR is increasing the excellence and critical mass of R&D within the field of forest operations research by integrating research resources and expertise, besides promoting and developing efficient, competitive and environmentally friendly forest operation systems on a joint Nordic basis.

This year, in October 2010, the third OSCAR conference was held at Honne in Norway. Fifty-eight contributions were made by participants from ten countries and sixteen different research institutes. The following topics were covered:

- Machine and machine-systems performance analysis
- Process modelling and control
- Transport and materials handling
- Geographical information – modelling and interpretation
- Ergonomics, the work environment and safety
- Small scale and urban forestry operations
- Supply chain management and associated methods & technologies
- Environmental impacts, Energy and Emissions
- Entrepreneurs, business process engineering and quality assurance

These proceedings constitute abstracts of all the research presented at the conference.

We would like to thank the Nordic Forest Research Cooperation Committee (SNS) for the financial support of the OSCAR network and this conference in particular. We would also like to extend our appreciation to the Norwegian Forestry Development Fund who granted additional support for encouraging increased participation from the Baltic region.

Ås, 2010-15-11

Helmer Belbo

Norwegian Forest and Landscape Institute

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Nordic Forest Research
Co-operation Committee (SNS)

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1. FOREST OPERATIONS RESEARCH IN THE NORDIC/BALTIC COUNTRIES.

Rolf Björheden
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Background

The industrial revolution ended the era of economic self sufficiency. Earlier, most goods had been produced within the family. In industrial production, workers performed highly specialized, but normally delimited tasks and were compensated with money. The industrial revolution also linked, in a large scale, the forest resources of the Nordic/Baltic region to international and global markets. Industrial scale forestry was introduced and spread from southwest over the Nordic/Baltic area.

Another effect of the industrial revolution was that the rural proletariat moved from forest work which was ill paid and took place in an uncontrolled and dangerous environment under poor social conditions to work in industries and factories which provided equal or better wages and a much better working environment. Forestry had difficulties recruiting enough skilled workers. The only solution was to increase the productivity of forest work, thus creating a higher wage paying ability. A new applied research field, Work Science, which had developed in the wake of the industrial revolution, seemed to provide the means for such a development. Forest Operations and Techniques (FOT) originates from early random applications of Work study and technical evaluations. Initially, much effort was spent at identifying and spreading suitable tools and methods but also at improving the working conditions, nutrition and lodging of the forest work force.

The emergence of Forest Operations and Techniques

In Sweden, from the 1940's FOT was institutionalized through Work Study divisions at the major employers. In 1949 when the forest industries financed a professorship in Forest Work Science, the subject was also established in higher forestry education. The scope widened over the years, adding more and more disciplines to the FOT toolbox. Initially technology and physiology were the main ingredients. From natural sciences, biology and physics soon played an important role, from formal sciences mathematics, statistics and operational analysis have been incorporated. Applied medicine and ergonomics, economics – FOT developed into a multidisciplinary thematic field of applied R&D.

Although FOT is of great importance to its stakeholders, it is a low status research field. Measured by the standards of 'high science', it may not even qualify as a real science. But it uses scientific methods and theories since they provide powerful tools for improvement of forest operations. This is synonymous to increased efficiency, i.e. higher output of resources per input resources. In simple measures such as workdays/harvested cubic meter, FOT has been extremely successful as shown in figure 1.

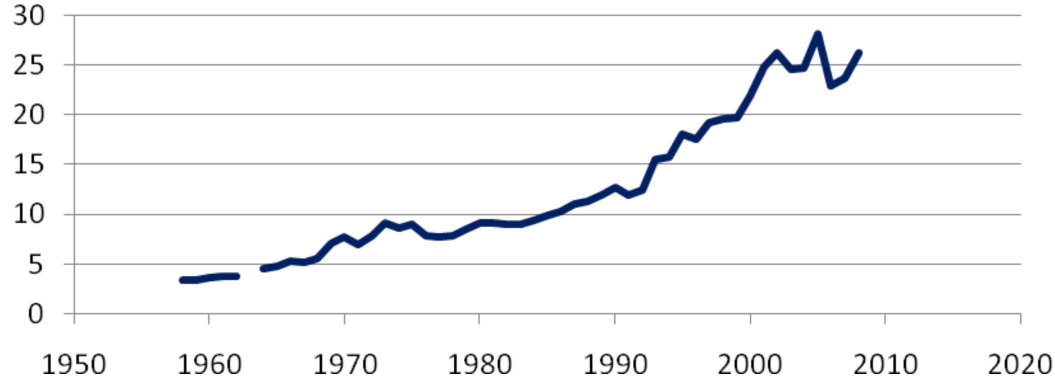

Figure 1. Productivity of Swedish forestry 1959-2008, as output cubic meter per input man-day

Problems of recent FOT
Nordic/Baltic FOT developed a *modus operandi* based on the interactions and joint interest of three distinct parties; the FOT research community, the users of FOT and the suppliers of FOT related tools, machinery and services. This relation is known as '*the good triangle*' (Fig. 2, left). Central to the functioning of *the good triangle* is the notion that utilitarian relevance is the central criterion. All projects and actions are judged by their potential for improvement of the input/output relation.

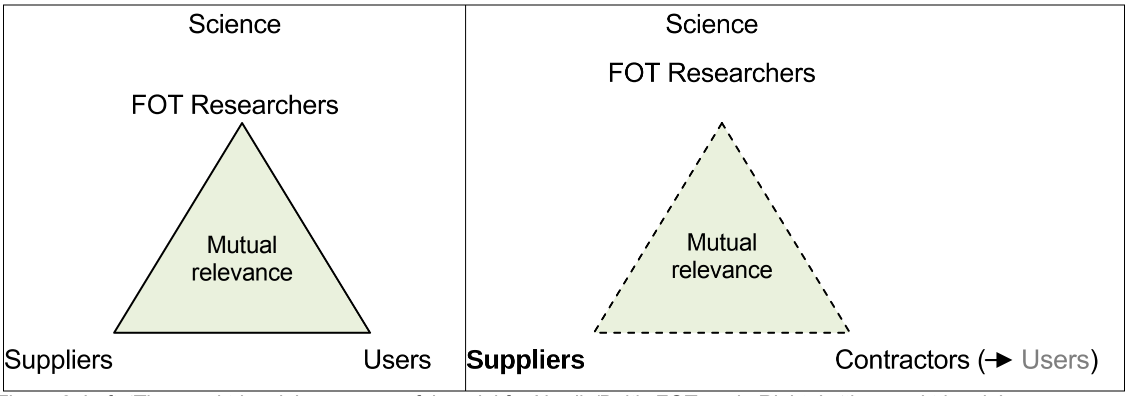

Figure 2. Left; 'The good triangle' – a successful model for Nordic/Baltic FOT work. Right; Is 'the good triangle' disintegrating? FOT research communities have decreased in size and numbers and in many cases need to orient themselves towards academia in order to receive funding. Users are often only indirectly involved in operations, which have been outsourced to contractors. Suppliers have been merged and often constitute minor divisions of larger companies. Will the demonstrated functionality of 'the good triangle' prevail in spite of such developments?

In my view, there are a number of disturbing tendencies for FOT in recent decades. A few of them are sketched in Figure 2, right. There are also some traditional weaknesses of FOT, e.g. the lack of unifying theories and thus a tendency towards regionalized research activities. A simple comparative work study performed in one country is normally not 'accepted' in another. This often leads us to unnecessary repetition of studies, instead of using the scarce FOT resources to investigate new topics.

Comparing the 'research activity profile' with the real problems and possibilities of forest operations also yields potentially distressing results. I did a simple quantitative survey of publications from some Swedish Forest Energy Programs. Stumps from final felling is the most notable source of additional biomass for energy, but of over 300 published studies, only 12 deal specifically with stump harvesting techniques. Logging residues is the fuel source that has been most widely used in practice. Almost 50 publications deal with logging residues but a staggering 130 studies are dealing with small tree harvesting& multi-tree handling which is a fuel source of relatively minor importance, both in practice and potentially. The findings of the latter studies point fairly unanimously at desirable developments, but suppliers have responded weakly through practical design efforts. This *may* indicate that the choice of research area is no longer decided by mutual relevance as presupposed by 'the good triangle' model.

Conclusions
FOT has a very limited value as a 'scientific discipline'. It is instead motivated by the great importance and potential in improving the working conditions, efficiency and quality of sustainable forest utilization. If the scope of such practical improvement is lost to the FOT research community, the discipline will quickly experience problems. It will then lose its justification for forestry and cannot establish itself as a science in quest of general knowledge.

For a sound development of FOT it is essential that we strengthen and empower the principles of 'the good triangle', that we keep a close contact with forest operations and strive to understand the real problems facing the practitioners of forestry. FOT can survive poor rating in academia, but if the connection to practical forestry is lost or severely obscured, the discipline will soon perish.

The OSCAR network provides good opportunities to counteract the negative trends outlined above. Weakened national research communities can increase their critical mass through the network and insufficient national resources may become adequate if they are used in co-ordination.

2. SIMULATING THE EFFECT OF STRIP ROAD SPACING ON THE TOTAL LOAD INDUCED BY FOREST MACHINES

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Traditionally harvesting operations on peatlands have been accomplished during the period of ground frost. More intensive utilization of peatland forest requires increasing logging activity during unfrozen conditions, when the soil load bearing capacity forms a severe obstacle for the prevailing harvesting machinery. In a research project carried out by the Finnish Forest Research Institute (METLA) and in close collaboration with the forest industry and the machine manufactures new harvesting solutions for effective and economically viable utilization of peatland forests is developed. In the project we have focused on two main themes, on prediction of bearing capacity and on new thinning treatments of peatland forests. In order to link these two research object together and examine the features of peatland harvesting as a whole, a new type of spatial harvesting simulator, LOGTRACK, has been developed together with the researchers from the Tampere University of Technology. In this presentation a first attempt to use the LOGTRACK-simulator with real forest data is outlined. The aim of our trials is to find balance between the magnitude of logging activities and the damage induced to the forest terrain.

The LOGTRACK platform comprises four GIS-based data layers, namely a logtrail-file, a treelist-file, a boundary-file and a ditch-file. Out of these only the first two layers the logtrail-file and the treelis-file are compulsory to make the simulation run. The logtrail-file, the ditch-file and the boundary-file can be generated from standard GIS coverages. The logtrail-file comprises all logging trails within the stand we want to simulate. The charachteristics of the logtrails are expressed with specific code that indicates the nominal width of the logging trail The original network of logging trails can be defined from a thinning stand that has already been harvested by a GPS recorder or the network can be digitized in advance by aid of original map or satellite map. The wood to be extracted via the logging trail network is described with a list of standing trees (the tree-list file). In this list each tree is given the location (x,y-coordinates), species, diameter, the proportion of the wood assortments within the tree and a code that indicates whether tree is proposed to be thinned or remained standing. In the boundary file the area from where the trees are harvested can be restricted. In peatland areas where ditches form a major problem for hindering the extraction of timber, a user may also localize and digitize ditches within the stand and construct a ditch-file with the same technique as with case of logging trails.

Cutting of trees and placing the logs cut into the piles is the first step in the simulation procedure of the LOGTRACK. The simulator does not take into consideration the lengths and diameters of logs. It only locates the whole volume of each assortment given in the treelist-file to the nearest pile. The pile where the volume is placed can not be located farer than the reach of the boom of the forwarder. After the simulator has placed the transported volumes into the piles, the system generates all possible routes to collect a load and transport it to road side storage(s). The number of roadside storages can be fixed. A sophisticated algorithm has been constructed that selects an optimized set of routes so that all piles become collected, while resulting the lowest possible terrain damage.

The simulator does possess advanced tools for analyzing and visualizing the location of trees, piles and the routes along the forwarder has been moving. The simulator reports the length of the route of forwarding (separately for moving empty, moving while loading and moving fully loaded), the time consumption for each load separately and in total for each assortment. The simulator also can depict the route for each load and as a summary the total disturbance caused by the complete forwarding operation.

The first attempts in utilizing the LOGTRACK-simulator shows that the tool works well and it helps the user in comprehending the complicated situation is peatland harvesting. With relevant data structures the tool can be very useful in developing new harvesting solutions for peatland forests.

Keywords: *tree harvesting, peatland, simulation*

3. A LOW-INVESTMENT FULLY MECHANIZED OPERATION FOR THE PURE SELECTION THINNING OF SOFTWOOD PLANTATIONS

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The operation designed and tested by the authors offers a low investment option for the fully mechanized, pure selection thinning from below of conifer plantations in flat terrain. Such operation is also characterised by high mobility, which represent a strategic requirement imposed by the fragmentation of non-industrial private forestry (NIPF).

The operation was geared to produce whole-tree chips, which allowed increasing the amount of merchantable product obtained from the thinning, while decreasing production cost. It also resulted in the almost complete removal of slash, which was a cost-effective way to reduce fire risk, particularly high in conifer plantations and in the Mediterranean region.

The trial was carried out in a pine plantation in Central Italy. The stand had been established with *Pinus halepensis Mill.* twenty-five years earlier and had never been thinned before. Terrain was relatively even, with a moderate slope gradient. The silvicultural prescription consisted in a selection thinning, with the purpose of removing 28 % of the trees, chosen among weak, dead and malformed individuals. Removal was 463 trees ha^{-1}. The average diameter at breast height of removal trees was 15 cm, and the average mass per tree was 59 kg dry matter . The operation produced 27.5 oven-dry tonnes (odt) of whole-tree biomass per hectare.

The operation consisted of a compact feller-buncher, a grapple skidder and a trailer-mounted drum chipper. General purpose prime movers were adopted for both the feller-buncher (a 4-tonne tracked skidsteer loader) and the skidder (a 4WD farm tractor), so as to minimize investment and favour deployment where investment cost, insufficient utilization level and limited service network prevent the efficient use of dedicated forest machinery.

The operation proposed in this study required an overall investment for mechanical equipment in the order of 250.000 €, accounted for as follows: skid-steer based feller-buncher 60.000 €; farm tractor based grapple-skidder 40.000 €; chipper with own tractor for relocation 150.000 € .

Figure 1. The compact feller-buncher

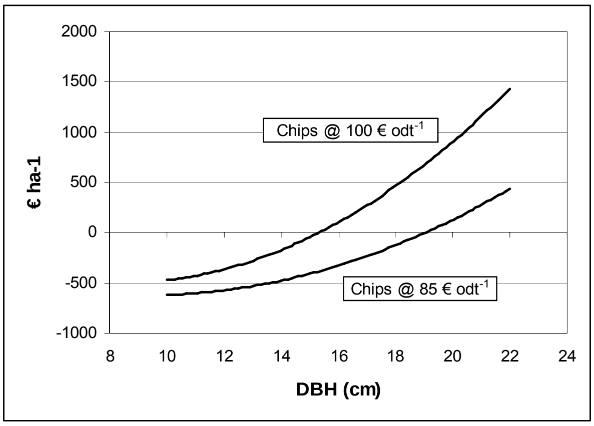

Figure 2. Harvesting profit as a function of chip price and DBH

The trial demonstrated that the skid-steer feller-buncher can manoeuvre in the 3 m wide inter rows, cutting removal trees and forming bunches of 4-6 trees, thus making extraction much easier. Occasional problems were caused by the very strong base sweep (pistol-butt) of some trees, which made it difficult to grab and cut the stem at the same time. In fact, the saw and the grab-arms are aligned on the same axis, and any significant deviation of the tree stem from the rectilinear form complicates the operation. In this case the best solution was to cut the stem above the base sweep and then finish the work with a second cut to cut the stump to the ground level.

A special warning must be given about the fire-hazard represented by the operation of high-speed disc saws during summer. The contact of the fast rotating disc with stones can generate sparks, which may start a fire under the appropriate soil, fuel and weather conditions. Since we are proposing this system for Mediterranean stands, it is important that readers realize the risks involved when the system is used during the dry summers so common in this region. For safeguard, disc saw operations should be avoided during the days when the fire risk is highest, and fire-extinguishers should always be available on the machine and at the landing. This is also needed when operating a chipper during the hot summer days, since chippers tend to develope a lot of flammable dust and engine heat, and are particularly prone to catch fire.

Extraction requires a tractor able to drag a load of about 500-600 kg. Ideally, this machine should be heavy and powerful enough to tow a small trailer for relocating the feller-buncher. This way one would obtain a self-contained operation, capable of quick relocation between sites and therefore specifically suited to harvesting the small-size tracts characterizing much of the NIPF holdings so abundant across Europe.

Felling and extraction were quite balanced, with an average productivity around 40 trees per scheduled machine hour (SMH), or 2.5 oven-dry tonnes SMH^{-1}. On the other hand, the industrial chipper was almost twice as productive as the other units. Since the typically small tract size discouraged doubling up the felling and extraction teams, chipping had to be separated from the other operations and occur at a later stage, or the chipper had to work in a stand-by mode.

Both options were simulated through a simple spreadsheet model, showing that operation in a stand-by mode is not much more expensive than the apparently more rational two-stage operation.

In any case, thinning cost was relatively low, and the operation could break at the projected 100 € odt^{-1} price target for forest chips. Such a result was remarkable, considering the extremely challenging specifications of low investment cost, full mechanization of the operation and capacity to perform pure selection thinning.

At this stage, it is important to stress that this harvesting method is only suitable to flat or gently sloping terrain, and it is recommended for conifer plantations.

The full mechanization achieved with this operation can be found attractive by local firms that operate in rural areas, since it can offer a relatively comfortable work place and a qualified employment to young loggers, while requiring reasonably low capital commitment.

Keywords: *feller-buncher, Non-Industrial Private Forestry, biomass, whole-tree harvesting, thinning*

4. EFFICIENCY AND ERGONOMIC ADVANTAGES OF SYNTHETIC ROPE FOR GUYING CABLE YARDERS.

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In mountainous conditions timber harvesting is often only possible using cable yarders. The installation of such cable yarders takes considerable time and is associated with a high physical workload as well as a higher accident risk. Time saving and ergonomic improvements can be expected during installation when using synthetic ropes instead of steel wire rope. Synthetic rope is up to 80% lighter for same strength capacity. Injuries due to sprags on the wire rope can also be avoided. The disadvantage is the three-fold price for synthetic rope, so expected amortization time is of interest.

A number of experiments were carried out using STRATOS® synthetic rope manufactured by the Austrian company Teufelberger. The core construction of these ropes is Dyneema®, and an additional tightly woven sleeve over the core provides protection from friction. The synthetic rope was compared to steel wire rope for cable yarder installation time and physical work-load using both research experiments and studies in practice. No significant time difference was established when guying the yarder for downhill extraction. For uphill extraction the installation times were reduced by 5 to 7 minutes (4 guylines) and pulling the rope out to the anchors can be done by just one worker. Even though the synthetic rope was pulled by only one person a heart-rate reduction of 30% was recorded. Depending on company system and set-up (number of uphill extraction settings, work schedule and number of workers per set-up) amortization time of 1 to 3 years were calculated. Uncertainly still exists about the working lifespan of the ropes. During operations to date only the protective sleeve has been damaged.

Keywords: *Cable yarding, synthetic rope, guylines, ergonomics, logging*

5. MASTER THESIS SCHOOL IN FOREST MACHINE TECHNOLOGY

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The issue of productivity in forestry is getting more into focus. Skogforsk has initiated and reinforced the cooperation with technological R&D environments, such as The Royal Technical College (KTH) in Stockholm and The University of Linköping. So far, on our initiative some 250 university students at KTH have taken courses where forest machines have constituted the project examples. In addition, 12 master theses and 9 project works involving forest machines have been conducted.

From this promising cooperation an idea about a strategic, knowledge-building ”Master Thesis School” has formed. During 2010 there was a call for a set of c. 5 master theses with the emphasis on forest machines. Each thesis contributes as one part of a larger picture, namely “carefulness” – towards the operator, the soil/water and the climate. Focal areas are chassis, drive train and operator’s environment. The intention is to build a generic, common knowledge base of value for machine manufacturers and for forestry. All projects are supervised by KTH, Dept. of Machine design.

The Master Thesis School is financed jointly by the forestry sector, through Skogforsk, and by a group of leading machine manufacturers. These founders have established a scholarship fund, from which the students had to apply for scholarships. There is a prize for the best thesis in the school. The jury consists of representatives from the financing bodies and from KTH.

A Master Thesis School aiming at forest technology builds bridges between forestry organizations, machine manufacturers and the technical universities. It creates a wider platform for forest technology. Furthermore, the school provides a great opportunity for marketing at the campus site, besides Scania, ABB, Ericsson, Siemens and other companies which are present there. More mechanical engineers with advanced knowledge about forest machinery will also create an increased base for recruitment. This project could be useful in the planning and establishment of larger R&D efforts involving public financing.

Keywords: *Chassis, drive train, innovation, operator’s environment, R&D cooperation, soil impact.*

6. COST-EFFICIENCY OF A SYSTEM WITH ONE HARVESTER THAT LOADS TWO FORWARDERS IN COMPARISON TO A TRADITIONAL HARVESTER-FORWARDER SYSTEM

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In the cut-to-length system, some alternative machine systems have lately challenged the conventional harvester-forwarder system. In the so called "Beast-system", manned forwarders take turns to remote control one un-manned harvester. In this system logs are loaded directly on the forwarder, and hence, less crane work is needed, logs are kept clean and do not risk to be forgotten. Moreover, each log is handled by only one operator and the unmanned harvester can be made cheaper than the cabin equipped manned harvester. The backside is that the system becomes completely integrated ("hot"), as the harvester cannot conduct work without a forwarder, and a forwarder cannot load without the harvester. Any numbers of manned forwarders could take turns in using the un-manned harvester, but two forwards were assumed in this study as other numbers of forwarders only rarely were more cost-efficient. Below this method of integrated co-operation between one harvester and two forwarders is called integrated forwarder loading (IFL).

Because harvester productivity is mainly affected by tree size and forwarder productivity is mainly affected by forwarding distance, there are intrinsic difficulties to balance the work time required by the machine types. In the conventional harvester-forwarder system, this can be handled in such a way that it does not necessarily cause delay time on machines, through changes in work time or alternative work tasks. For the IFL-system, delay time is only avoided when it for one forwarder takes as long time to transport, unload and return to the harvester as it takes to fill the other forwarder. If the forwarding distance is to short in relation to the harvester productivity (loading time), the forwarder will return before the other forwarder is loaded and will, thus, have to wait for its turn to use the harvester (to be loaded). If the distance is too long, the harvester will be left unused. As a consequence, the margin for balance between machines is thin and delays occur for most combinations of tree sizes and forwarding distances. Moreover, delays will occur due to machine down-time and unplanned interruptions even with perfect balance. Such delays happen to both conventional and IFL-machines, but in the IFL-system the delays to one machine affect also other machines. Thus, the level of machine availability will be considerably lower in the IFL-system.

In this study of theoretical potentials, the work method of an IFL-system with two forwarders was compared with a conventional harvester-forwarder system in final felling. The analysis shows that the integrated work method used by the IFL-system is considerably less cost-efficient than what has been previously estimated. When assuming the unrealistic mechanical availability of 100% (i.e. all main work time is productive work time), the IFL-system was the most cost-efficient system when the mean tree size was larger than 0.6 m^3 at a mean forwarding distance of 100 m when harvesting 300 m^3/ha. At 700 m forwarding distance, the trees had to be larger than 0.3 m^3. However, when assuming more realistic levels of mechanical availability, the IFL-system became less cost-competitive. At 100 m forwarding distance the trees had to be at least 0.9 m^3, and at 700 m at least 0.4 m^3.

The analysis of suitable combination of mean stand characteristics was applied to data on harvested stands in different Swedish regions. The results show that the volume of final felling on which the IFL-system is the most cost-efficient system is very limited, especially if also the system's extra cost for road transport of machinery is included (three machines to transport instead of two). The results showed that less than 15% of the volume of final felling is cost-efficiently harvested with the IFL-system under the conditions assumed in the analyses.

Even though the IFL work methodology offers some potential benefits over the conventional harvester-forwarder system, the analyses clearly show the backside of having harvester and forwarders co-operating directly. In a highly variable work environment it is difficult to avoid delay time when creating direct dependency between machines that are differently affected by various work conditions. Thus, the cost-efficiency becomes restricted to very specific and limited conditions.

Keywords: *Integration, harvester, forwarder, Beast.*

7. ADAPTIVE TREE BUCKING SYSTEM USING GROUP-GUIDING OF HARVESTERS – SIMULATION APPROACH

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Cut-to-length method in tree harvesting is the most commonly used in Nordic countries. In customer oriented forest resource use tree trunk is truncated into favourable logs already in the stand. Sawmill knows the demand of timber and forms the demand distribution of logs according to this. Harvester computer calculates bucking proposals by taking account the given cutting instructions. Computer aided bucking has potential to operate more effectively between forest and wood using factory. Tree bucking control has evolved from bucking to value to bucking to demand. When bucking to value tends to maximize the value of a one stem, bucking to demand also tries to fulfil the demand distribution as good as possible. Bucking to demand can be done in two ways; in adaptive price list -method or close to optimal -method. Latter method is used in this study. Improvement of bucking output distribution can be divided to two different approaches: 1) guiding tree bucking during the stand, 2) generating cutting instructions before entering the stand. These two levels are linked together with cutting instruction.

The objective of this study was to compare how the summed output distribution of independent harvesters differs from the summed output distribution of harvesters which bucking instructions are controlled between the stands. In this experimental simulation study harvesters can utilize other harvesters' bucking output. After every stand harvesters' output distributions were summed and used to generate a new cutting instruction to all harvesters for the next stand. In this adapting phase where the harvester's were formed as a group, a new price list was formed. 32 stands were simulated with four harvesters. Stands were real and made of harvester produced stem files. Guiding in adapting phase was made by four functions and functions were used change the values in the price list. Results were compared to the reference simulation which did not contain guiding, which makes total of five simulation chains. Goodness-of-fit was measured by apportionment degree. Log and pulpwood percentage was also calculated.

By guiding the price list, harvester group can fulfil the demand better than independently working harvesters. With the best function, group-guiding reached improvement from the reference chain up to 9 % better result measured by apportionment degree. However, the pulpwood proportion increased as a result of using group-guided method. In this case the problem was encountered when starting to focus on target distribution of sawmill. According to the results, by adapting the price list, the harvester group could meet the need of the mills customer better than independently working harvesters. Guiding the price list cell value a small amount at a time and including wide scale of variation in cell value, can improve cutting result. Group-guiding of harvesters contain a lot of development potential which this experimental study presents and encourages to for further studies.

Keywords: *cut-to-length method, bucking, harvester group, group-guiding*

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8. CONTINUOUS WORK STRAIN MEASUREMENT IN CABLE YARDER RIGGING

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This paper presents the measuring equipment, techniques and results of a study monitoring the heart strain experienced by cable logging crew while drawing out a light weight 4.0 mm synthetic strawline (11g m^{-1}) as against the conventional 3.5 mm steel wire (39 g m^{-1}). Setting up the skyline is not a frequent work process in steep terrain logging, but is regarded as one of the most strenuous tasks, and likely one of the major factors regulating recruitment into the sector. Two subjects were selected from a steep terrain logging crew. Each subject was made to alternately drag out the synthetic strawline, steel wire strawline, or walk with no load up a demarcated trail, with an outward length of 300 m. The sequence of doing this was fully randomised, with three replications of each treatment. The trail profile was divided into 12 segments, each of which were used as individual units of observation (fig. 1 left).

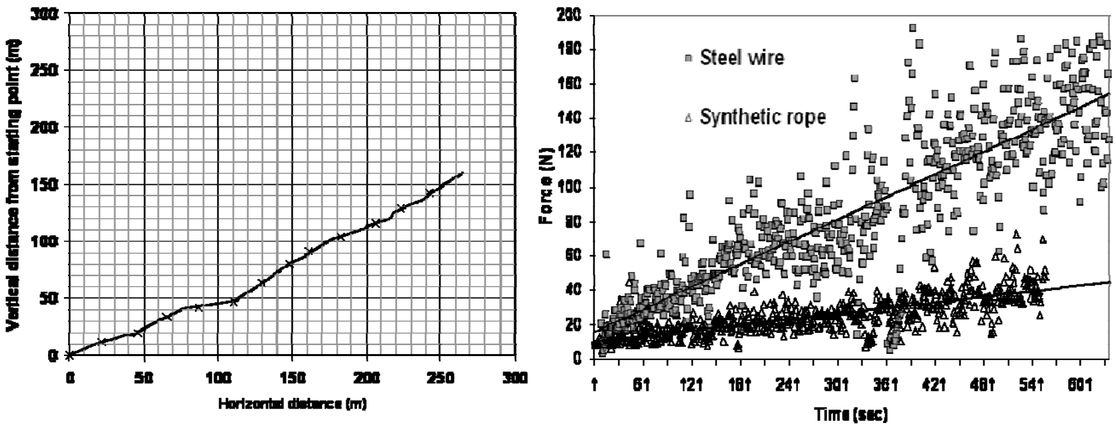

Figure 1 (left) the terrain profile with a 65% overall slope, and (right) an example of the tensile forces acting on the subject as he walks up the profile

The rope was attached to the subject with a 3.5 kN load cell (accuracy 0.1 %), fitted with a wireless transmitter which allowed for continuous logging of the tensile force in the rope. Heart rate was measured as a proxy for work strain using a Polar RS400 pulse monitor with continuous data logging and storage. Heart rate data was superimposed over the continuous tension measurements and the digital terrain model. Results showed a significant difference in force required in pulling out the two rope types. Differences in heart rates were also significant and indicated an extreme work load when pulling out the steel wire, where the recovery time was also significantly longer. The cumulative work load (Joules) increased exponentially toward the end of the 300m corridor for the steel rope, and suggested that this was approaching the maximum range for a single person to pull, while the synthetic rope could be handled more easily over longer distances.

***Keywords**: rigging, yarding, work strain, synthetic rope,*

9. THE COST-EFFICIENCY OF SEEDLING PACKAGING SPECIFICALLY DESIGNED FOR TREE PLANTING MACHINES

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Introduction

As an alternative to manual tree planting, mechanized tree planting has been revived in southern Sweden in the last five years. Currently, mechanized planting in southern Sweden is only performed using the crane-mounted Bracke Planter. The Bracke Planter plants seedlings with biologically similar (von Hofsten 1997) or better (Ersson and Petersson 2009) results compared to operational manual planting, but at a higher cost.

One of the key reasons why crane-mounted planting machines are still not economically competitive with manual planting in Sweden is the lack of automated seedling handling and feeding systems. The planting heads must instead be reloaded manually, and this task occupies from 15% (Rantala et al. 2009) to more than 30% (Halonen 2002) of the machine's effective working time. Moreover, as machine productivity increases, relatively more of the effective working time is spent manually reloading seedlings. There is, therefore, a need to automate the feeding and handling of seedlings if crane-mounted planting machines are to become cost competitive compared to manual planting.

The efficiency of automated handling and feeding systems is dependent on how integrated they are with the seedling transportation system. Considering that today's containerized seedlings are delivered to the clearcut either in cultivation trays or cardboard boxes designed for manual planting, there may also be a need to change how seedlings are packaged if the planting machines are to become more productive.

However, machine-specific packaging solutions warrant extra labour, packaging, and investment costs at the nursery as well as extra investment costs for the planting machine. Furthermore, seedling transport costs and work methods might also be affected. Thus, the anticipated gains in planting machine productivity due to decreased planting head reloading time must be contrasted with these extra costs.

The aims of this study were twofold: 1) to describe seedling packaging concepts specifically designed for planting machines; and 2) to compare the total cost of these machine-specific packaging concepts with today's most common seedling packaging systems (i.e. Hiko cultivation trays and cardboard boxes).

Materials and Methods

The four seedling packaging systems used in this comparative cost analysis were described as follows:

s1) Hiko trays: cultivation trays in which seedlings are also transported to the planting machine. From the nursery, trays are handled individually by hand and distributed to the contractor's depot by light courier trucks. Trays are returned to the nursery for reuse.
s2) Cardboard boxes: single-use boxes packed by a packaging line at the nursery. Boxes are stacked onto Euro pallets and distributed to the contractor's depot as standard shipping units by general groupage delivery trucks. From the depot, boxes are handled and transported individually by the contractor. Boxes are recycled after use.
s3) Band-mounted seedlings: seedlings mounted between strips of paper, rolled into a vertically-standing coil, and then packed into cardboard boxes at the nursery. Handling, transportation, and recycling of boxes is otherwise equal to s2.
s4) Container modules: containers the size of a Euro pallet containing 1500-2100 seedlings in linked pots. A packing line at the nursery packs both the pots and containers which are then distributed to the contractor's depot by general groupage delivery trucks. From the depot, the containers are handled individually by the contractor using a small

truck-mounted crane and a hydraulic lift on the planting machine. The containers are returned to the nursery for reuse.

The packaging systems were depicted as models based on a generic transportation chain. The chain started at the nursery with the seedlings being in their cultivation trays while aggregated on large frames after having been sorted and sprayed with insecticides. The chain ended when the empty seedling packaging had either been returned to the nursery or recycled.

Data were sourced mostly from a nursery company, a planting machine contractor, and other relevant companies in southern Sweden.

Results

Using the proposed model, s1, the reference system, was the most cost-effective even when the number of contracted planting machines was increased to 20, the primary transport distance increased to 400 km, or the interest rate reduced to 3%. Hence, the decrease in planting head reloading time when using the planting machine-specific packaging systems s3 and s4 could not compensate for the extra investment costs.

Further sensitivity analysis showed that the total cost of s3 was lower than s1 first when 10 planting machines were contracted, the baseline productivity of the Bracke planting machine was increased from 200 to 278 seedlings/E_{15}-hour, and the primary transport distance was increased from 100 to 200 km.

Conclusions

The cost-efficiency of nursery and packaging investments for planting machine-specific packaging systems are primarily dependent on the number of contracted planting machines, their hourly cost and their productivity.

Today's scenario of only two Bracke Planters operating in southern Sweden does not afford any economic room for investments in planting machine-specific seedling packaging systems.

Keywords: *mechanized planting, containerized seedlings, seedling transport, logistics, cost analysis*

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10. THE EFFECT OF WOOD PROCESSING COSTS TO WOOD PROCUREMENT CHAIN: ACTIVITY-BASED COSTING IN SAWMILL

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In modern mechanized cut to length harvesting method, the bucking decision is based on the information of log small end diameter, length, quality and the demand of that certain log class. Especially sawmills have various length-diameter-quality combinations in production. The assessment of the most suitable production pattern is based on cost-benefit analysis. The benefits (incomes from the end products) are determined by the markets; in normal market situation the company has only limited influence to the prices. Costs are controllable in industry – at least to some extent. The costing methods in companies must be as unbiased as possible; price settings and the profitability of the production pallet are essential elements in strategic planning.

The managerial accounting system provides information for management of planning and controlling the business. Activity-based costing (ABC) was developed in 1980´s to provide more accurate information of profitability of the production. In the ABC, the production is split into processes and costs are allocated to products by consumption of resources.

In this research we applied the ABC method in sawmilling industry and examined the formation and structure of costs in medium sized (annual production 200000 m^3) softwood sawmill. Most Nordic sawmills have seven main production processes: log receive, unload and sorting; debarking; sawing and edging the lumber; green sorting; drying; dry sorting and packing; and finally storing and shipping. With the process definition based cost calculation model, it was possible to study cost accumulation of sawing different logs with variable parameters such as sawing pattern. In order to get comparable results, we established a virtual green field sawmill. The costs were analyzed, summed up and allocated to lumber pieces, bark, woodchips and sawdust in order to calculate the total cost of sawing the log.

The results of cost analyzes revealed that the most expensive process of sawing is the drying. Depending on the tested sawing pattern, the share of drying cost was 30–55% of total sawmilling costs, which were approximately 7000000 €. Testing different sawing patterns for the same log also indicated that it is important to take sawing costs of different lumber classes more closely into consideration in production planning. The lumber class distributions are conclusively determined in harvesting, and the route of the raw material cannot be changed afterwards without some economical or quality losses. As the sawing costs are dependent on the sawing patterns, the upstream raw material flow is guided by the demand of the end product markets. This means that pre-harvest planning, tree bucking control and mill production planning must be connected more closely in order to get best possible result from entire logistic chain.

The next step in the study is to include the incomes to calculations. When the costs are subtracted from incomes, the profits of each sawing pattern become transparent and the material flows can be directed with more exact knowledge.

Keywords: *Activity-based costing, sawmilling process definition, sawing pattern.*

11. BALING LOGGING RESIDUES ON INTERMEDIATE THINNINGS

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Finland is one of the leading countries in the world when it comes to utilizing renewable energy sources and especially bioenergy from forests. As a result of the national climate strategy Finland has engaged to increase the share of renewable energy sources from current 28 % to 38 % by the year 2020. Different kinds of wood-based fuels such as small-sized wood, logging residues and stumps have the best prerequisites to grow their share. Collecting these materials from first thinnings and clear cut areas is already a common practice in Finland. Because of the absence of empirical study results and fear of possible growth losses, energy wood harvesting has not been applied to intermediate thinnings.

Because of the lack of information and the considerable potential of intermediate thinning stands as an energy wood source a study was carried out around this issue. For example in 2008 first thinnings were carried out on 255 600 ha and intermediate thinnings on 231 000 ha. Therefore the potential to bale logging residues from an intermediate thinning with a baler designed for final fellings was examined. Modification of harvesting method, baling logging residues and stump lifting in intermediate thinnings were studied. Objectives of this study were to compare the baling productivity and rate of damages between final felling and intermediate thinning.

During the summer 2008 the study was carried out in Norway spruce stand. Baling was conducted with a Timberjack 1490D residue baler on an area total of 8.7 hectares consisting of three sample plots. Baling was recorded and the 10 hour video footage was analyzed using *Ari Lauréns A_aikakone* time study application. For the study the effective work time was divided into sub-times as follows: 1.Loading, 2.Baling, 3.Loading, combined, 4.Cutting, 5.Loading while driving, 6.Loading while driving, combined and 7.Driving on stand.

A bale was 3 m long on average, 60-80 cm in diameter and weighted 559 kg. The total yield was 218 bales and yield per hectare was 26 bales. The time consumption per bale varied between the stands from 157 seconds to 196 seconds. The average time consumption was 182 seconds per bale which equals productivity of 19.7 bales in an hour.

Most of the effective work time consisted of work phases where several operations were done simultaneously. The majority of effective work time (45 %) consisted of combined loading. The next biggest share was loading while driving, 23 %, followed by loading (14 %).

After the baling, the damages caused by bundling were inspected from all the remaining trees in the 8.7 hectare study area. In this area only 4 damages were observed. This equals 0,5 damages/hectare and 0,1 % of the remaining stock.

When comparing the results from an intermediate thinning to those from final fellings (Metsäteho report 179) it was discovered that the yield was smaller. In intermediate thinning the yield per hectare was 26 bales whereas in the final felling it was 84 bales. Productivity per hour was in intermediate thinning 19.7 bales and in the final felling it was 24.3 bales. Also, time consumption per bale was higher in a thinning stand. In intermediate thinning time consumption per bale was 49 seconds bigger than in clear cut areas. Although the yield and productivity were not as good as in a final felling, baling in a thinning stand proved out to be a promising method.

***Keywords**: baling, logging residues, intermediate thinnings*

12. STUMP EXTRACTION WITH A STUMP DRILL FROM AN INTERMEDIATE THINNING OF A SPRUCE STAND

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Finland is one of the leading countries in the world in utilization of renewable energy sources. Over quarter of the total energy consumption comes from these sources. The most important renewable energy forms are wood fuels. In 2008 their share of the total energy consumption was 21 %. The national energy and climate strategy aims to increase the share of renewable energy from 28 % in 2008 to 38% by 2020.

The forest biomass has the best prerequisites of all renewable energy sources to further increase its share. Logging residues, small sized energy wood and stumps are already commonly recovered from first thinnings and clearcut areas. Stumps have been extracted from clearcut areas in Finland since the beginning of the millennium and today the total amount of stumps equals to 1.5 TWh/a. To increase that number we have now in this study extended the extraction to intermediate thinnings. These have so far been an unutilisized source of energy.

The stump extraction was carried out in an intermediate thinning of a Myrtillus -type spruce stand. The area of the stand was 0.7 hectares and there were altogether 189 stumps. Before lifting the stumps were numbered, located and the diameter of each stump was measured. The diameter varied between 13 and 46 cm and the average diameter was 29,8 cm. The stump lifting was filmed with a video camera and a time study was conducted on the video material with Ari Lauréns A_aikakone time study application.

The stumps were drilled with a stump drill attached to Timberjack 1270-harvester. Total of 188 stumps were drilled. One stump was located in such a way that the harvester could not reach it due to the terrain and remaining trees. Drilling of 188 stumps took 4,5 hours. After drilling the stumps were extracted from the ground with a logging residue grapple of a Valmet 860.1 – forwarder. This work phase took approximately 9 hours. Few stumps were left on the ground due to inadequate drilling or because the stump was located on a stone or between two stones. Also the number tag was lost from few stumps during the drilling, which ment that they could not be identified. Consequently I was possible to link the drilling time to 170 stumps.

Time spent for stump extraction was assorted by diameter classes into different work phases. The diameter classes were 13-19cm (7 stumps), 20-24cm (27 stumps), 25-29cm (55 stumps), 30-34cm (37 stumps), 35-39cm (27 stumps), 40-46cm (13 stumps). The drilling times increased from 44.8 seconds (13-19 cm) to 68.8 seconds (40-46cm) and extraction times from 96 seconds (13-19 cm) to 259.4 seconds (40-46cm).

The time spent on drilling increased moderately as the stump diameter increased. The difference in the drilling time between the smallest and biggest stump diameter class was only 24 seconds. Diameter has more influence on the time spent on pulling the stumps out of the ground. In this work phase, the difference in pulling time between the smallest and biggest diameter class was nearly 3 minutes.

Total extraction times (drilling and pulling combined) by the diameter class were 130 seconds in 13-19cm, 136.3 seconds in 20-24cm, 176 seconds in 25-29cm, 214.9 seconds in 30-34cm, 252.4 seconds in 35-39cm and 290.8 seconds in 40-46cm. Average extraction time for one stump was 197.7 seconds.

After stump extraction, an inventory was conducted where stem and root damages on the remaining trees were recorded. Random measurements on the size of extraction pits were also carried out. Root damage was defined as a breakage of an over 3 cm thick root. On sampled 0.7 ha area only 20 trees were damaged. Altogether there were 28 roots broken which means 1.4 broken roots per damaged tree. In addition to root damages, one tree had stem damage and two trees had damages caused by harvester/forwarder wheels. The average area of the 62 stump pits was 3.3 m2 and depth 16.1 cm.

When compared to extraction times of excavator mounted rake on clearcut areas, the harvester based stump drill has productivity of only one third of the productivity of the rake. This combined with durability problems means that the concept needs more developing.

Keywords: *Stump extraction, stump drill, intermediate thinning, spruce*

13. HARVESTING POTENTIAL OF FOREST FUELS IN SWEDEN

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Introduction
The European Union aims to increasing the amount of energy coming from renewable resources to 20% of total energy production (2008: ~ 8.5%) [1]. The total growing stock in Sweden is about 3.2 billions of m3 stem wood [2]. Within the near future the demand on woody materials is believed to get higher than the annual growth. In Sweden, the use of bioenergy has increased by an average of 3.3 TWh yearly the past 20 years and reached 125 TWh in 2009 which is 27 % of the total energy consumption [3]. Historic expansion has been possible thanks to an increased use of forest industry by-products. Wood wastes from forest industries are already fully utilized. The purpose with this paper is to present the annual forest fuel potential in the whole of Sweden and the extractable amounts at different marginal costs in south and north of Sweden for the time period 2010-2019. The relevance of the work is to guide players on the Swedish energy market for future ventures.

Material and Methods
The results were based on data collected in the Swedish Forest Inventory (SFI) from 2002 to 2006 for the project SKA-VB 08 [4]. SFI consists of a network of more than 3000 sample plots evenly spread over the complete forest area of Sweden. The individual plots were used as the unit for decision for different future silviculture and felling measures and a growth prognosis for the trees of each plot was produced. For the estimation of the potential harvestable amount of slash (branches and tops) and stumps (jointly referred to as logging residues) from regeneration fellings and thinnings three levels of environmental, technical and economical restrictions under the reference scenario (Swedish silvicultural practices are not going to change the next decade) were taken into consideration. For level 1 no extraction was done in productive forest areas that are situated in areas of nature protection. For level 2 a number of ecological restrictions were applied: wet areas and peat soils with low bearing capacity as well as all areas that are located 25 meters from a lake, sea, waterline or any other ownership category than forest were not considered. For the rest of the areas the amount of extractable logging residues was reduced by 20% and no hardwood stumps were collected. For level 3 a number of technical restrictions were taken into consideration, in addition to the ecological restrictions named on level 2. A further 20% (in total 40%) of the logging residues were left in the ground. This amount corresponds to the current degree of collection and utilisation of branches and tops in the Nordic countries. Areas that have a ground structure or a slope of class 4 or 5 according to the Swedish terrain classification scheme were not considered. Even regeneration felling areas of a size of less than 1 ha were not included (economical restriction). The costs for harvesting the logging residues, transforming it to chips and bringing it to the end user (nearest city with at least 10000 inhabitants) were also calculated. For slash the system that was used comprises of forwarding the slash to the roadside, chipping it at roadside and transportation to the industry by a container truck. Concerning stump harvesting, stumps were forwarded to the roadside, transported by truck to the industry and chipped there. Productivity and machine costs were obtained from practical experience and scientific studies [5]. All calculations were made with the FLIS tool [6].

Results
Harvest of logging residues are done after a conventional roundwood harvest. The annual roundwood harvest in Sweden for the time period 2010-2019 was estimated to 62.1 million m^3 from final fellings and 28.3 million m^3 from thinnings. Based on this level of roundwood harvest, and depending on the level of ecological and technical restrictions, the annual potential forest fuel harvest is estimated to 7.4 – 19.1 million metric oven dry tons (ODT) from final felling and 3.5 – 8.6 million ODT from thinning. Furthermore, 0.5 million ODT, originating from pre commercial thinning, can be added to the above mentioned potentials. A majority of the potential (57%) is located on private owned forest land. From a regional perspective, a majority of the potential (55 –

57%) is located in the south half of the country (Götaland and Svealand). The amount of slash that could be harvested up to a certain cost varies for the different regions of the country. Marginal costs were lowest in South Sweden. The costs rose rapidly with increasing distance to the industry. In South Sweden 90% of the harvestable potential could be harvested for a cost up to 800 SEK/ODT (Figure 1, left panel). For the north of Sweden two different pictures were given. To harvest 90% of the harvestable potential it would cost up to 950 SEK/ODT in the coastal area of Upper Norrland and ca. 1100 SEK/ODT in Upper Norrland Lappland (Figure 1, left panel). As expected marginal cost curves for stump harvesting starts at a higher cost level. In South Sweden to harvest 50% of the harvestable potential would cost up to ca. 900 SEK/ODT while at the coastal area of Upper Norrland and at Upper Norrland Lappland the cost would be 1100 and 1300 SEK/ODT respectively (Figure 1, right panel).

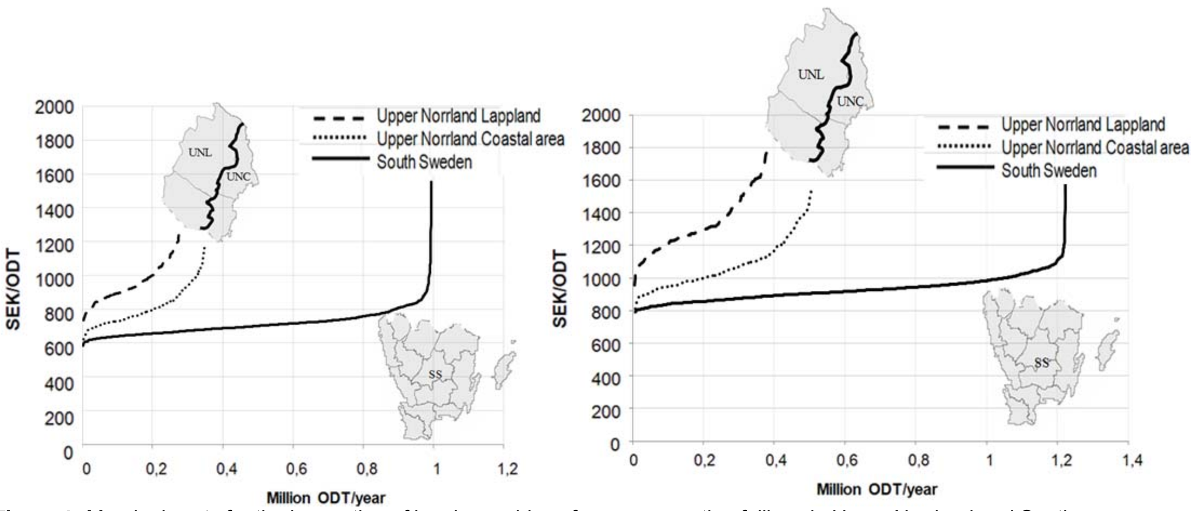

Figure 1: Marginal costs for the harvesting of logging residues from regeneration fellings in Upper Norrland and South Sweden, cumulative values (SEK/ODT as a function of million ODT/year). 1 Euro ~ 10 SEK. Level 3 on ecological and technical restrictions. ***Left panel***: slash. ***Right panel***: stumps.

Discussion

A rough estimate is that below 20% of the total annual forest fuel potential is currently utilized, and almost all of it consists of logging residues from final felling. For Swedish conditions, the total *present and sustainable* forest fuel potential is 2.8 to 4.4 times larger than the estimated bioenergy potential emerging from agricultural land 10-15 years into the future, presuming that 20% of the agricultural land is set aside for energy production (cf. [7]). The conclusions are that forest fuels will continue to have a leading role in the Swedish bioenergy systems, and that this position will be strengthened with expected developments on technique and logistics. Further, it is possible to harvest even more forest fuels if fertilizing or if small diameter roundwood is used as forest fuel instead of pulpwood.

Keywords: *Bioenergy, marginal costs, pre-commercial thinning, slash, stumps*

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14. THE IMPACT OF TIMBER HAULAGE ON LOADING OF FOREST ROADS

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Introduction

The significance of proper timber haulage, and primarily organizing appropriate road network, has been emphasized since XIX century, where C.A. Schenck (1911) briefly defined the issue: „Indeed, it might be stated, that forestry is essentially a problem of transportation". Costs incurred by the forestry enterprise to build and maintain a network of forest roads are a significant part, and are often the biggest cost of operating the forestry. From data of the General Directorate of State Forests in Poland (PGL LP) in 2007 for the construction, renovation and maintenance of road infrastructure earmarked 330 million PLN - 6.3% of total costs (84.93 million Euro). Among the costs associated with maintenance of road infrastructure and providing adequate technical quality, a significant part are the costs arising from the conditions of the project in differentiated physiographic conditions, and particularly to ensure the proper construction of forest road pavements.

Defining the road's load is associated with quantitative and qualitative analysis of traveling vehicles. On its basis it is possible to obtain data necessary to determine the axle load equivalency factors. Vehicles with a greater number of equivalent standard axles is characterized by an increased impact on the surface of the road. Number of researchers were engaged in determination of traffic and its structure resulting from the destination and types of vehicles driving on forest roads. Optimization of timber haulage in load capacity context and resulting gross vehicle weight GVW (car with trailer) were involved, Hamsley, Devlin and McDonnell. Overloading has an impact on forest road surface and accelerates its degradation, leading to the absence of proper timber transport.

Most of 32 million m3 timber harvested In Poland is being moved from place where is harvested and collected in forest directly to recipient or in place of handling (rail, depot handling) by road transport. This means that forest roads are exposed to high tonnage vehicles, often exceeding the GVW limit, what in effect gives load on the axis of the vehicle above the accepted design parameters and is the cause of accelerated degradation of the forest road.

Weight of timber load is a very variable feature. Vehicles are often overloaded and identifying GVW on the base of technical parameters of truck and weight of load calculated from number of m3 is highly inaccurate. The objective of this work was to examine the actual loads on the forest road from vehicles used for timber exports, resulting from the gross vehicle weight (GVW) as the sum of its own empty truck weight and trailer and load and the simultaneous distribution of pressure on vehicle axles.

Material and methods

As a place of study we selected the two major recipients of wood from the area of the northern Poland: first – accepting daily approximately 800-1000 m3 of pine logs (WC0) and the second - receiving 2000-4000 m3 of medium-sized material (S2) of various species. All the timber is delivered by high-tonnage trucks.

On the handling area, using gravity measurements, we made weight controls of every truck going in – GVW, and every truck going out – empty set weight. The difference between full and empty vehicle gave weight of load. The volume of timber transported in m3 was determined by a receipt issued by the seller. Measurement of load on each axle of high-tonnage vehicle has made using a mobile platform scale, where the weight of single wheel axle was determined. The hypothesis that differences in obtained results GVW and volume of timber transported between the various types of cars and the size of the load for a given set of axes are statistically significant has been tested by analysis of variance. Regression model of the GVW and the weight of load, depending on the load (in m3) of transported wood, has also been calculated.

Results and discussion

During the research timber was carried by the following vehicles: Mercedes, Man, Iveco, Scania, Volvo, Steyer, Daf, Sisu. During four days, 139 vehicles with trailers has been scaled. Those vehicles, suitable for transporting such timber as pine large size logs (WC0), supplied 4,253 m3 of timber. During one day in the recipient of timber medium size wood (S2) has been scaled on 90 vehicles that provided 3,172 m3 of pine, birch, spruce and alder timber.

Single loads varied between 20.1 to 43.4 m3 of timber, while the average for large size wood was 30.6 m3 and for medium size wood S2 depending on the species: 35.1m3 for pine, 33.8 m3 for birch and 38.9 m3 for spruce. For such volume of timber transported in a single load weight was obtained in the range from 20.1 Mg (WC0 pine) to 38.1 Mg (S2 pine). The average weight of a single load for all car brands and species of wood excess 30 Mg. Analysis of variance and post-hoc test confirmed the differences between the load of pine WC0 and S2 also confirmed the differences between load of birch S2 and WC0. In this study we obtained considerable average density of transported wood: pine WC0 - 1065 kg m-3, S2 pine - 885 kg m-3, S2 spruce - 839 kg m-3 and 911 kg m-3 birch, with a large span of 450 kg m-3 obtained for WC0.

The average GVW with wood for every vehicle was very similar and ranged from 49.9 Mg (for alder loads) to 52.6 Mg for pine WC0. This has been confirmed by analysis of variance and post-hoc test showing significant differences only between pine WC0 and pine S2. GVW results were observed in the range from 42.3 to 60.1 Mg. It can be concluded that the average weight 20.0 Mg of empty truck for WC0 transport and 19.8 Mg for S2 do not differ statistically, but such large values restrict the possible mass of timber load.

Average loads on a single-axle for a five-axle truck were as following: for axle no 1 – 72 kN and for others form 94 kN to 106 kN, over a range of results for the first axis from 40 to 81 kN and the other axis - from 69 to 136 kN. In a six-axle vehicle in average the most loaded is the second and the third axle of the truck (from 75 to 127 kN) and the first axle of trailer (fourth in total; from 79 to 121 kN). With so high pressure vehicles are equal to bigger number standardized axles, and thus - more aggressively act on road surfaces. The highest value of correlation coefficients (0.82) for dependences of gross vehicle weight (GVW) with timber Mg and single load capacity m3 was received for pine WC0 and birch S2 (table 1). Dependence of wood weight Mg from load capacity m3 at the significance level of 0.01 correlation coefficient of 0.85 was obtained for pine wood WC0.

Table 1. Regression analysis for GVW and cargo weight from single cargo capacity.

Dependence GVW from volume of load				
Load	Correlation Coefficient	R-sq, %	Standard Error of Est.	Equation Fitted Model
WC0 pine	0.82	67.57	1.96584	$23.007 + 0.966297 * m^3$
S2 birch	0.73	53.4	2.04115	$16.302 + 1.02857 * m^3$
Dependence weight of load from volume of wood				
WC0 pine	0.85	72.13	0.00179	$1/(0.00323193 +0.842698 / m^3)$
S2 spruce	-0.78	60.46	0.00195	$1 / (0.0642912 – 0.00086371 * m^3)$
S2 birch	0.67	45.42	1.78832	$4.88553 + 0.767202 * m^3$

Conclusion

Because of law limiting GVW to 40 Mg, with so high weight of empty vehicle (20 Mg) and timber density, safe volume of single transported load for pine WC0 is 18.8 m^3, spruce S2 - 23.8 m^3 and for birch S2 - 22 m^3.

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Keywords: *timber haulage,* gross vehicle weight, loading forest roads, loading axle

15. STUMP LIFTING PRODUCTIVITY WITH A PALLARI KH 160

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The harvesting of stumps after regeneration fellings could provide a considerable quantity of biomass for the energy sector [1], hinder the spread of root rot [2] and through the performed scarification prepare the site for planting [3]. The total annual potential of stumpwood in final cut stands in Sweden is 11.7 million oven-dry tonnes (mODT) [4]. After subtracting the amount that is situated in areas where ecological restrictions apply and difficult areas due to rough terrain and steep slopes the remaining available potential of stumpwood amounts to 4.2 mODT [4]. In Sweden stump harvesting is still performed on experimental basis where different concepts and machinery are tested in the field. Time studies can provide a good understanding of the stump lifting operations and the effect of some factors such as species and size on the productivity and the costs involved.

In this paper, results from two time studies of two excavators fitted for stump lifting are presented and the influence of stump diameter, terrain conditions and species on equipment productivity is discussed.

Two separate stump harvesting operations were time studied one in the north and the other at the south of Sweden. Weather conditions during both study periods were favorable (dry and clear with good visibility). A total of 1053 stumps (862 spruce and 191 pine) were time studied. The two time studies had similar designs: Harvesting residues (branches and tops) were collected and forwarded to the roadside prior to the initiation of the studies. The limits of all study units were marked and in each study unit the diameter, height and species of the stumps were recorded and each stump was numbered. Soil conditions around each stump were assessed ocularly concerning soil moisture, noted either as mesic (groundwater depth between 1 and 2 m) or moist (groundwater depth < 1 meter). Ground roughness and inclination in the parcels were also assessed ocularly on a five degree scale [7]. In this classification scheme 1 stands for very easy and 5 for very difficult conditions. All stump harvesting operations were recorded by means of a digital video recorder and time studies were performed at a later date on the recorded material by means of a Husky Hunter equipped with Siwork 3 time study software. In each study a Pallari KH 160 stump lifting tool was used. The tool had a mass of ca. 2000 kg, a gap opening of ca. 135 cm and a cutting force of ca. 50 tonnes [8]. It was attached to tracked excavators of a mass of 23 tonnes. In the study in northern Sweden the tool was mounted on a Hyundai 210 LC while in the study in southern Sweden it was mounted on a Volvo EC 210.

Differences observed at the processing time between the two time studies were mainly due to stump size, species and terrain conditions. The differences did not hinder that both studies were analyzed as a single one. Lifting, splitting and piling the stumps accounted for 17 %, 32 % and 32 %, respectively of the time consumption per stump while only 19% was due to other activities (moving, filling and smoothing the holes and other work-related tasks). Two models are presented. The first model predicts time consumption for different stump diameters and species. According to the model it would take 84 seconds to process a spruce stump with a diameter of 35 cm and 153 seconds for a spruce stump of 55 cm. The second model predicts the number of spruce and pine stumps that would be lifted per hour in areas with easy (ground condition, roughness and slope ≤ 2) or difficult terrain conditions (ground condition, roughness and slope > 2).

Tracked excavator-based forest machinery does not generally have the same mobility and working capacity of purpose built forestry machinery, although it is used in a number of different forest operations, e.g. road construction, soil preparation, tree planting and, currently, stump lifting. Its use is motivated by low operating and maintenance costs and great lifting power [9]. Purpose built wheeled forest machinery is environmentally and technically more adapted for working in a forest environment. It has better stability and higher working capability in steep and uneven terrain and provides better ergonomics for the operator. It is expected that in the future stump-lifting tools will be developed in accordance with the lifting capacity of the forest machines [9,10].

Keywords: *Stump harvesting, stump lifting, excavator, time study*

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16. COMPARISON OF WORKING TECHNIQUES IN A VIRTUAL HARVESTER SIMULATOR ENVIRONMENT

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The influence of the harvester operator on the productivity of harvester work can be divided into rating and working technique. Rating would mean perceivable speed that is visible in work functions and is highly dependent on the operator’s cognitive abilities and sensomotoric skills in the present-day harvester work. Instead, working technique is understood to be the visible and measurable movement of harvester and harvester head from one location to another. Working technique always includes some amount of operator-specific features of the harvester work and also personal tacit knowledge to a certain degree. To improve the cognitive abilities and sensomotoric skills of the operator have been seen demanding and, therefore, the focus has been directed more easily to working technique. In different working techniques differing amounts of boom work are focused on a single tree. Typically working techniques differ in work phases regarding tree catching distances, felling directions, tree moving distances, processing locations in relation to the harvester and the angles of bunching of logs in processing. Therefore, some working techniques diminish more unnecessary work movements than others, and are, therefore, more productive. The objective of this study was to compare how three working techniques for thinning and three for clear cutting differ from each other in the environment of single-grip harvester work, and which work phases cause the most difference.

Typically, forest conditions are so heterogeneous that a reliable comparison of the cutting results is not possible even inside one area. A rational solution for this problem are virtual harvester simulators. In the simulator environment varying terrain conditions can be standardized and simplified: the same stand can be cut in various ways and reloaded as many times as is necessary at the same eliminating factors that cause outlier datasets. For this reason, the cutting experiments of this study were performed using a virtual harvester simulator where the harvester operators worked in a thinning stand dominated by Scots pine (Pinus sylvestris) and in clear cutting stand dominated by Norway spruce (Picea abies (L.) Karst.). The studied working techniques in thinning were: right-angle piling, oblique piling and under the boom piling, and in clear cutting: one-sided piling, two-sided piling and forward felling. The work of five different operators were studied: operators 1-4 in thinning and operators 1-3 and 5 in clear cutting: operators 1-3 were the same in both cutting techniques. All the operators were experienced using real harvesters and were able to operate fluently in the harvester simulator despite its minor differences to real harvesters. The handling and internalizing of a specific working technique was controlled for each operator before the experiment. The boom speeds were the same for all the operators and the duration of the experiment was set to 45 minutes.

The results proved that in thinning the difference in productivity of the least productive, right-angle piling, and the most productive, under the boom piling, was about 7% with a stem size of 0.233 m^3, which was mainly caused by the faster felling work phase. The productivities of under the boom piling and oblique piling were about the same. In clear cutting, the productivities of forward felling and two-sided piling were similar (difference of about 1%). Their productivity compared to one-sided piling was about 12% higher with a stem size of 0.798 m^3. This difference was caused by about totally 5 seconds faster catching and felling work phase.

Keywords: *virtual forest harvester simulator, single-grip harvester, time study, working technique, operator.*

17. METHODS FOR THE STUDY OF HUMAN-MACHINE INTERACTION IN FOREST MACHINES

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Since mechanization of forest operations the performance of the machines has increased and at the same time the physical work environment has improved for the machine operators. To fully benefit from the performance of the machines of today and in the future there is a need to better understand and improve the interaction between man and machine.

Skogforsk has previously made studies on for example automation of sorting in a single grip harvester and on boom-tip control. Different interfaces have been studied, such as head-up displays for information presentation and speech recognition for harvester head control.

So far evaluation has been done by means of performance measures and by the operators´ subjective self-evaluation of the mental workload.

Skogforsk has begun the development of a methodological toolbox that will contain psycho-physiological methods as well as eye tracking and self-evaluation methods. With this set of methods the aim is to be better suited to evaluate future innovations in man-machine interaction as well as increase the understanding of the cognitive processes and information needs of forest machine operators.

Skogforsk will conduct a simulator study where we use eye tracking to determine where the operators of single grip harvesters are looking during work. The operators will then be asked, while looking at their eye tracking recording, to retrospectively “think aloud” and describe what they were doing. The purpose of the study is to gain insight into the work of harvester operators, especially how they gather and use visual information. The aim is also to find patterns of where operators direct their gaze and if possible relate this to performance and mental workload. The results of these studies will be presented at the upcoming OSCAR conference.

Keywords: *Mental workload, Human-machine interaction*

18. FOREST OPERATIONS - FROM DOING TO THINKING

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Forest operations used to be hard, physical work where the men tore themselves to an early retirement. If we believe the rare literature describing today's mechanised work it is hard, mental work where the men (and a few women) 'think' themselves into early retirement. Existing literature, although a little old, describe mechanised forestry work as complex and cognitive demanding with high mental workload which might manifest it selves in physical impairments and production losses [1, 2]. But why claim this sick-making *complexity* in mechanised forestry work? This paper will challenge the idea of the mental demanding and complex harvester work described in existing literature and propose some additional research on the subject.

Mental workload

If interested in health and safety of work one cannot only focus on the performance, output, of work but must consider the workload imposed by the human machine interaction. If interested in productivity only, mental demands was regarded by Gellerstedt to be the main limiting factor [3]. Thus, looking at mental workload is a win-win situation regardless if the goal is productivity or safety and health. Mental workload is though somewhat a 'catch phrase' which isn't easy to grasp, nor is it easy to study or evaluate. Consider mental workload as such, [4]:

workload is a hypothetical construct; it represents the cost incurred by human operators to achieve a specific level of performance and is not, therefore, uniquely defined by the objective task demands; and it reflects multiple attributes that may have different relevance for different individuals; it is an implicit combination of factors. (p. 144)

Workload is thus a property of the human as well as of the task demands and the context in which the task is performed. This interplay must be emphasised in the description and analysis. Let's consider what we know about the work of the harvester operator.

Secondary task analysis have been used to evaluate the workload of the operators and Gellerstedt came to the conclusion that they are not mentally overloaded as they are able to answer questions and recall radio news without interrupting their ordinary tasks [2, 3]. However, this simple method is not enough in it selves to answer the question of workload. The same author also states that there could be situations where the machine control inputs are too high and thus cause troubles in other cognitive activities. This reflects a period of information input overload (IIO) [5], or mental overload, where the operator shouldn't be able to complete the secondary task if the theory is accurate. Studies also show that the operator lacks information in many situations, bucking for example [2, 3, 6]. Examples are deficient information about tree quality, the environment in which they are operating, machine status and feedback from their past work (especially important in thinning). The information flow is furthermore limited by the fast processing speed of the trees, bad work postures, control handling, vibrations and noise etc. The state of information deficit is referred to as Information Input Underload (IIU) and could be as damaging to performance and health as IIO [7].

Complexity

Harvester operation has moreover been described as complex, which is another important aspect that has an impact on mental workload. But complexity is a complex concept and what the complexity in harvester work consists of isn't always clearly described or defined. What can be found [2] is that time pressure and intensive handling of controls seem to be characteristic of the complexity. 4000 control inputs per hour [2] is used to illustrate the complexity, but the problem in using numbers and frequency to explain and, in some way, define complexity lays in the fact that the mere reduction in numbers does not automatically provide a safer, easier or better work environment. Is 4, 75 or 2000 a reasonable number? The number of decisions one can make is also dependent upon the quality of the decision. Complexity could instead be seen as the pattern of interaction between different parts of a system [8], here the focus shifts from the complexity as such towards the sources of complexity. Only with the knowledge of the interaction between different parts of the system one can direct the effort where it makes the most use.

How do we go on?

Most of the human factors literature in forestry (including ergonomics) is written in the nineties and have thus become quite old by now. Since the claim that cognitive demands was the major limiting factor of operator efficiency [3], demands in operator attention and cognitive functioning has increased as a function of increased work hours, increased capacity of the machine, new environmental- and logging directives, introduction of computers and information systems etc. This makes it even more important to design the machine, tasks and operator training in ways suited for human usage.

Forest harvester operation has previously been described in a way that could be characterised by various stages of IIO and IIU, but the descriptions are too vague and the research too narrow to offer concrete guidance on how to move on. It is important to further study and identify critical parts of work where operators are likely to be working in those states because although forest machine operators aren't in constant IIO- (or IIU-) mode over the work hours it might cause problem dependent on duration, frequency as well as the situation in which it appears.

If using the terminology of Perrow [8] the problems (or complexity) of harvester work emerge from complex interactions between the human machine system and the changing environment in which the work is conducted. The work situation and thus the mental workload is furthermore affected by sometimes conflicting productivity- and environmental goals and the skills and knowledge needed to fulfil them. For the human part of the harvesting system part of the problem seems to be a matter of the quality in the information (needed and provided) in combination with the modes of interaction, but yet there has not been much research on the information need. We thus need more research on the mental aspects of the work; the information needed, how it is received, the impact on the operator and how to progress from that knowledge to improve the work situation.

Keywords: *Human Factors, HMI, forest harvesting, mental workload and complexity.*

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19. DEVELOPING PROFESSIONAL ENTREPRENEUR-SHIP IN WOOD PROCUREMENT PROCESS

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Introduction

At the beginning of the 20th century, there was a forest worker, a horse and an axe. At the beginning of the 21st century a typical wood procurement process is carried out by a professional entrepreneur, a computer system and a harvester. In forestry the development based on mechanization and rationalization of machinery and work processes has happened in a couple of successive technological cycles and radically decreased the cost per unit of timber (Kariniemi, A. 2010). The most recent cycle of technological innovations is based on information technology, the utilization of which has increased substantially in the forest industry during the last decade. This development has changed the division of labour in the wood procurement process. It has also made the development of so-called diversified independent contracting possible.

Data and methods

The data was collected in a development project called "Developing the concept of wood procurement process - supporting the model of diversified independent contracting and enhancing the well-being of forest machine operators" in a wood supply district in central Finland in 06/2008–03/2009. The project was organized as a Change Workshop intervention, which is an application of the Change Laboratory® method (Engeström & Virkkunen 2007) and derives its methodological ideas from the Activity Theory. Change Workshop is a participatory developmental method where the participants are guided to investigate the complex and often contradictory elements of their work and its development. The theory behind the method suggests that collective work activities are motivated and defined by the object and the outcome of the activity, that is, the central purpose of the activity (what we are doing, to whom and why). Thus, one of the main analyses conducted during the project concerned the changes in the object of each actor's work and the division of work in the wood procurement process from 1998 to 2008. As the methodology requires the analysis was produced together with the participants using interviews and other types of observational and ethnographic data of the wood procurement process and modelling the data with the analytical tools the methodology provides.

Results

The analysis showed a significant expansion in responsibilities and a notable increase in the level of autonomy in planning and execution of the tasks in each actor's work during the analyzed period of time. It was also noticed that many tasks and responsibilities have shifted "downwards" in the hierarchy, and new tasks have emerged. The outcome of the analysis is summarized in the table 1. For example, the forest machine operator's traditional object of work - logging and hauling the logs - has transformed into a technology mediated work, in which, besides operating the forest machine that incorporates highly advanced wood processing technologies, generating and processing of data for the collective information system has become a central part of the work. The work of the harvesting foreman, on the other hand, has changed from face-to-face supervision of work and order giving out in the forest to computer-based production planning and management, which is mainly carried out in the office. The change has been notable especially concerning the role of entrepreneurs. The role of entrepreneurs in the wood procurement process has step by step changed from contractors who worked under close hierarchical supervision of the foremen of the forest company into professional entrepreneurs. The earlier type of entrepreneur used to take care only of the execution of logging and hauling, and maintenance and transfers of the forest machines. Nowadays they also do the fine scheduling of process, including both the planning and the execution of logging, hauling and long-distance transportation (depending of the scope of their business). A key prerequisite for this is the shared information system of the procurement network, as all the important data concerning stands marked for cutting, short term plans and schedules are available also for the entrepreneurs. As entrepreneurs, they are also responsible of quality and quantity requirements of their assignments, working in close co-operation with the harvesting foremen.

Table 1. Changing tasks in the wood procurement process. Many tasks and responsibilities have been shifted "downwards" in the hierarchy.

	Earlier - 1998	Present - 2008
Regional manager	Operative management, "from forest to factory", instruction, supervision	Human resources, internal customers, interest groups
Harvesting foreman	Supervision of harvesting, inspections	Production planning and control, reporting, shot-term planning
Purchasing foreman	Timber purchasing	Timber purchasing and harvesting control
Entrepreneur	Harvesting, machine transfers, maintenance	Harvesting planning (schedules), quality and quantity control, invoicing, machinery
Forest machine operator	Logging and haulage	Logging and haulage, site planning, quality control, responsibility of accurate information in the data systems

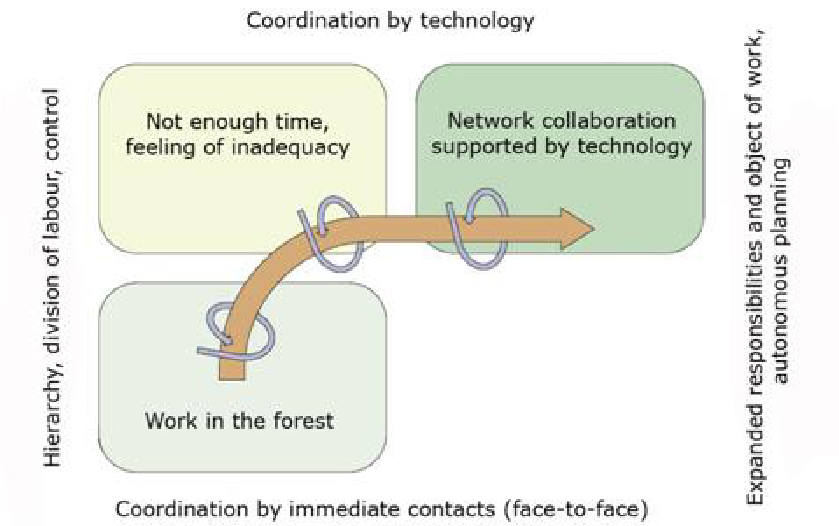

Figure 1. The change of operating concept of the wood procurement process. (Ala-Laurinaho. A., Schaupp, M., Kariniemi, A. & Strandström. M. 2009)

Conclusions

We claim that the entire concept of the wood procurement process is in a transition phase as depicted in the figure 1. It is precisely the information technology that allowed the major organizational change - the new division of work in the procurement process. Many tasks and responsibilities were shifted "downwards" in the hierarchy, which had started to dissolve the old hierarchical organization of work that was based on direct and personal supervision of the foremen. During the change work shop intervention, the material activity had already changed into network-like technology supported collaboration. But, orientations of the actors in the process were still lagging behind in 'work in the forest' orientation. This is shown in the transitional conception where the actual lack of time was a result of the mismatch between the materially existing form of network collaboration supported by the technology, and the old orientation. There was a general agreement that such a change from the work in the forest to a technology supported network-like collaboration is going on.

Keywords: *technological change, change of work, wood procurement, forest work, activity theory*

20. GREAT POTENTIAL IN CORRIDOR THINNING OF YOUNG STANDS FOR HARVEST OF BIOFUEL

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Great potential in mechanized corridor thinning

Harvest of forest energy from young stands is a steadily increasing modus operandi in Swedish forestry. Over the last couple of years the manufacturing and the sales of felling heads with an accumulating capacity have multiplied (Wide 2009). The task of developing and adjusting techniques and methods is improving which will result in increased efficiency and cost effectiveness (Wide 2009). The majority of forest energy extraction in young stands is still conducted with traditional methods, i.e. using strip roads, between which the trees are thinned selectively. The trees are gathered in bundles which are left along the strip road. Thinning in corridors would be one way to increase harvesting efficiency. This method has been thoroughly studied and tested in pre-commercial thinning stands where more effective and cheaper pre-commercial thinning was observed without losses in quality or in growth (Bergkvist 2007). Theoretical calculations and practical research of forest energy harvest from deciduous forests have been performed, on a smaller scale, but with promising results (Rytter 2006). According to Rytter (2006) a small harvester with a felling head with an accumulating capacity should have a speed of 8 meters/min. In a stand with a density of 10 000 stems/ha this equals a productivity of approximately 1400 stems/hour. The effect on quality and growth of different tree-planting patterns have been analysed during the spring of 2010 when experiments with symmetrically planted stands, established in the early 1980’s were evaluated. In these trials stands of Norway spruce, Scots pine and lodgepole pine planted in rectangular single and double rows were compared with trees of the same species planted in a square pattern. Single and double rows with spacing 1,33*3 m did not show any significant differences in either quality or growth (Bergkvist 2009). These results are supported by earlier research (Salminen 1993, Davidsson 2002). This indicates that forest energy could be harvested in corridors with as little as 2 m between the corridors assuming that the original stem density offers a considerably denser formation between the corridors. The most cost effective alternative would be to leave the area between the corridors without thinning but in reality the distance between the strips will probably increase, more or less involuntarily. That will cause a need for motor-manual thinning with chain/brush saw in that area. The stems that are left after the motor-manual thinning will, however, counteract the risk of decrease in growth that otherwise could occur when harvesting whole trees in young stands.

In this presentation, results from a study of mechanized thinning of whole trees using geometrical patterns will be reported. The study is to be carried out during spring 2010. The aim is to study the productivity of a small harvester with a felling head with an accumulating capacity when used for a traditional selective thinning as compared to when it is used in corridors with a short distance between the corridors. The study will contain practical tests as well as theoretical analyses. The ambition is to measure the differences between the two methods in regard to:

-Productivity in different stem density and average stem volume.

-Costs and revenues per volume and per area.

-Biomass removal per hectare.

Keywords: *Corridor thinning, biofuel, biomass removal*

21. ASSESSMENT OF ENVIRONMENTAL IMPACTS OF REMOVAL OF HARVESTING RESIDUES IN ESTONIAN CONDITIONS

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Purpose of the work

The aim of the work was the assessment of environmental impacts of removal of harvesting residues in Estonian conditions.

Scientific innovation and relevance

The general goals of promotion of bioenergy are pointed out in the Long-term Public Fuel and Energy Sector Development Plan until 2015 and the Long-term Development Programme of Promotion of Biomass and Bienergy year 2007 – 2013: by 2010 renewable electricity should account for 5.1% of gross consumption, and by 2020 electricity produced in combined heat and power production stations should account for 20% of gross consumption. During the next decades the available quantities of traditional wood fuel in Estonia will start to decrease and the main attention should be given to the utilization of harvesting residues otherwise in the long-run the supply with wood fuels will not be sufficient to keep the consumption on the present level. The need to utilize the harvesting residues will become particularly urgent, if the combined heat and power production from wood biomass will expand. One of the consequences of removal of harvesting residues is the increased loss of mineral elements from the forest soil. The goal of the study was to determine the influence in Estonian conditions.

Approach

As a result of the field experiments in 2009 initial data was collected. The first step of the study was determination the specific biomass functions of mature forests for different tree species. As the potential yield of harvesting residues depends on the characteristics of the forest (age, composition by the tree species, soil type etc.) sample plots were created in mature forests of Järvselja Experimental Forest District aiming to cover the variety of different conditions. The location and the tree species of all trees in sample plots were measured. Then in the middle of sample plots the sample trees were felled, measured and the residues were collected and scaled. The dead and live branches of trees were scaled separately. For the laboratory analysis, samples were taken to measure moisture, ash content and the composition by mineral elements. Based on the initial data the oven dry weight of the crowns of the sample trees were determined. Addition to the dry weight of the crown, also diameter and length of the stem, radius of the crown and location of dead and live branches of all sample trees were measured. Later the results were analyzed and the biomass functions were created.

The milled wood samples were analyzed in laboratory to determine the content of nitrogen (N), carbon (C), sulphur (S), potassium (K), phosphorus (P), magnesium (Mg) and calcium (Ca). To analyse total content of P, K, Ca and Mg the wet incinerating method with sulphuric acid was emplyed. The flame photometric method was employed to analyse the plant material for potassium and atomic absorption spectroscopy method to analyse calcium and magnesium content. Total phosphorus content was determined spectrophotometrically. Total nitrogen and carbon content of oven-dried samples were determined by dry combustion method on a varioMAX CN elemental analyzer (ELEMENTAR, Germany). Finally the impact of removal of harvesting residues was determined.

Results

As a result of processing initial data the formulas were created to calculate the oven-dry weight of live and dead branches. The weight of spruce and pine live branches was measured with needles and the weight of branches of deciduous trees without leaves. It was determined that the share of the branches compared with the volume of the stem in mature forests is 41,73 – 47,84 % for spruce, 12,61 – 17,42 % for birch, 7,17 – 10,19 % for black alder, 6,78 – 7,33 % for pine and 6,69 – 9,19 % for other deciduous tree species. We can draw the conclusion that the share of the branches compared with the volume of the stem in mature forests varies 6.7 – 47.8 % and therefore the removal of minerals with the harvesting residues varies also remarkably.

The average ash content of dead branches of sample trees from Järvselja was 1.1% and 1.91% for live branches, average for the whole crown was 1.61%.

The results of the study indicate that the average loss of minerals due to the removal of harvesting residues was following - N 198 kg/ha, C 17100 kg/ha, S 26 kg/ha, K 84 kg/ha, P 7 kg/ha, Mg 107 kg/ha and Ca 538 kg/ha. As the to the characteristics of forests varies a lot, also the quantities of harvesting residues vary. Therefore the calculation of the loss of minerals should issue from the volume of the harvested volume of the stems. Based on the data from the study, the input data for the calculation should be - N 0.465 kg/m^3, C 40.2 kg/ m^3, S 0.062 kg/ m^3, K 0.198 kg/ m^3, P 0.017 kg/ m^3, Mg 0.251 kg/ m^3 and Ca 1.267 kg/ m^3.

Acknowledgements
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Keywords: *forest biomass, harvesting residues, loss of minerals.*

22. PORTABLE TOOLS AND NEW METHODS TO PREDICT TRAFFICABILITY OF FOREST ROADS

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Forest roads are often not passable in the springtime due to frost thawing. After frost has thawed a considerable amount of water accumulates inside the road structure. Melted water in the surface layer is troublesome since it decreases bearing capacity of roads. Year-round use of the forest road network is an important economic issue faced by the Finnish forest industry. Approximately 100 million euros in costs are incurred annually because of thawing. Extra costs consist of storing and quality losses of timber and irregular use of harvesting and transportation machinery.

Knowledge of road bearing capacity is the key factor in estimating usability of forest roads. There are number of ways to measure the bearing capacity of a forest road. In this study, two light-weight portable measuring devices that measure bearing capacity of roads are tested. The studied instruments were Loadman and Dynamic Cone Penetrometer (DCP). A quick and reliable method for evaluating bearing capacity would be valuable in maintenance and repair operations. Decisions are easier to make based on measured values rather than visual estimation.

The study included 20 experimental plots. The experimental plots were situated along ten different roads comprised of road sections constructed on peat and mineral soils. One plot was located on both peat and mineral soil road sections. Every plot consisted of nine measurement sites, which were crossways and lengthways along the road. Measurements were carried out during spring, summer and autumn conditions. The measurements with the studied instruments were compared to values measured with the KUAB Falling Weight Deflectometer (FWD). The FWD is a professional pullable measuring instrument that is commonly used in assessing the bearing capacity of roads. In each experimental plot, moisture content, temperature and groundwater table level were measured. In addition, the thickness of each soil layer was defined and the variations of particle sizes were measured in laboratory conditions.

The results of this study revealed large differences between the three measuring devices. Variation in bearing capacity occurred naturally between the plots, but also inside the plots between sites. Values differed between the instruments. Interestingly, road bearing capacity was higher in peat soil than in mineral soil in six of eight plots with Loadman and DCP. On the other hand, the bearing capacity of mineral soil roads was higher than for roads which were constructed on peat in five of eight plots with FWD. This is perhaps a consequence of subjective selection of study sites. The mineral soil plots were selected from places which were in visually poor condition. Only in one site did Loadman and DCP values clearly diverge in comparison to FWD. An observable connection between DCP and FWD and between Loadman and FWD was apparent in about of half of the cases. Measurement values between DCP and Loadman were parallel to each other. When bearing capacity values were lower than the average rate on DCP and Loadman, there was no clear response on FWD values.

On the basis of the study results, it can be said that DCP and Loadman were useful and practical measuring instruments. The number of experimental plots amounted to only 16 sections due to problems with Loadman which malfunctioned a few times during the study. The results must only be proportioned to the scale of FWD measurements. In the future, reduced road construction costs may be achieved by allocating a little more time and effort towards measuring work. Another viewpoint is that during thawing it is possible to evaluate trafficability and avoid road damage. After measuring, it is easier to choose the appropriate reparative action to improve the condition of a given road. Monitoring and maintenance planning of forest roads will become an increasingly more important issue to forestry in the future because climate change will make winters shorter and unforeseeable which extends the thawing season in the spring and fall.

Keywords: *forest road, bearing capacity, loadman, DCP*

23. HARVESTING STUMPS FOR ENERGY IN FINLAND

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In 2009, the total consumption of forest chips for energy generation was equivalent to 12.2 TWh (6.1 mill. m^3) in Finland. Of the forest chips used in heating and power plants (10.8 TWh), more than one third was produced from logging residues in final cuttings in 2009. 15% came from stump and root wood. The use of stump wood for energy has been increasing very rapidly in Finland: at the beginning of 21^{st} century, the consumption of stump wood was equivalent to only 10,000 MWh in Finland, and nowadays more than 1.5 TWh. The state of the art of stump wood harvesting for energy in Finland is described in this conference abstract.

Stump harvesting operations are primarily directed at Norway spruce (*Picea abies*) dominated final cutting sites in Finland. Furthermore, there are some stump lifting tests in Scots pine (*Pinus sylvestris*) dominated stands. The typical stump wood removal is 150–180 MWh/ha.

Site preparation for stand regeneration is very often integrated with stump extraction in Finland. As a result, this represents considerable cost savings in forest regeneration. Stump extraction also minimizes the risk of infection by the root rot fungus (*Heterobasidion annosum*) in the soil and in the new tree generation.

In Finland, the period for stump lifting is limited to May–November when the ground has thawed. There can be a delay of a few months between industrial roundwood harvesting and stump lifting. The delay makes it easier to extract stumps from the ground. Stumps are extracted by tracked excavators equipped with a stump lifting head. When lifting stumps, they are split into 2–4 pieces (to clean and dry them) and piled in heaps at the recovering site.

When lifting the stumps, care is taken to ensure that the soil surface and humus layer are opened as little as possible in order to minimize soil disturbance and the leaching of nutrients. It is recommended that some stumps are left in the ground, as well as the majority of the thin roots.

Heavy-duty (working weight around 20 tonnes) tracked excavators are mainly used for the lifting of stumps. Approximately 200 excavators are currently used for stump lifting in Finland. Majority of all the stump lifting heads used were fitted with a splitting knife. When no splitting knife was used in stump lifting, the excavator weight typically exceeded 20 tonnes. The manufacturers of the most widely used stump lifting heads are A Hirvonen Oy (www.ahirvonenoy.net), Steelpa Oy (www.steelpa.fi), Finnkauha Oy (www.finnkauha.fi), Korsun Teräs Tmi (www.korsunteras.com), and Tervolan Konepaja Oy (www.tervolankonepaja.fi).

Stump heaps at harvesting sites are left to dry for one to two weeks in summertime and 2–4 weeks in autumn. After that they are hauled to the roadside landing area by a forwarder. The forwarders, either medium-duty (carrying capacity: 10–12 tonnes) or heavy-duty (14–15 tonnes) ones, are used in stump wood forwarding. These forwarders are usually equipped with a torn grapple, i.e. logging residue grapple, and a modified (i.e. somehow enlarged) load space. The stump load size is around 7–9 tonnes. It is recommended that the stump and root wood piles at roadside landings are as high as possible (4–5 m) to reduce the penetration of water and snow. Stumps are typically kept in roadside storage for at least a year. Rain and further drying improve the quality of the stumps.

Long-distance transportation of stump and root wood is done by so-called energy wood trucks. These trucks are also used for the road transportation of loose logging residues and whole trees. The frame volume of energy wood trucks is commonly 130–150 m^3. The frame volume of the biggest energy wood trucks is currently 160 m^3 in Finland. According to the machinery survey of Kärhä in 2007, there were 60 energy wood trucks in use in Finland. Typically, the stump load size in road transportation is more than 20 tonnes.

Heavy mobile or fixed stationary crushers are used for the comminution of stumps. Nearly 70% of all stump wood chips used for energy generation in 2009 were produced at power plants. In 2009, 28% of all the stump wood comminution was performed at terminals. Small stump wood batches were also comminuted at the roadside landings by mobile crushers.

When stump wood has a long storage period, it is an excellent source of fuel in winter when other wood fuels tend to be moist. The moisture content of stump wood chips is usually below 40% also during the winter months. Nowadays, impurities such as soil and stones are still the greatest problem in stump wood chip production. However, the quality of stump wood chips can be improved by developing extraction technology and techniques, carefully selecting extraction sites, and correct timing of the extraction operations.

Keywords: *Energy wood, Finland, Forest biomass, Stumps.*

24. SCRUTINIZING THE WOOD SUPPLY CHAIN – REPORTING FROM WORK IN PROGRESS

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Abstract
The Swedish forestry has during hundreds of years been developing the industrial wood supply to an undoubtedly functioning wood value chain. Major efforts have been invested in R&D on each link in the chain, from growing stands to mill yard. However –considering common logistic to measure the effectiveness of the chain as a whole has traditionally not been in main focus of R&D in Sweden.

A recently started research project at Skogforsk aims to scrutinize the wood value chain unbiased, to discuss it as an industrial value chain among others, and evaluate overall effectiveness and possible potentials of the wood supply system. During fall, bases of a framework for mapping forestry supply chain process types are emerging. The ambition is to define a limited number of typical and competitive supply chains in forestry, applicable regardless of country, region or company. The work includes analyses of production strategies, inventory strategies, information flows, system boundaries and organization effectiveness. A next step is to decide upon a set of KPIs, identified by using the well established SCOR model. The model is based upon identifying processes and dividing the processes in sub-processes until reaching an operational level, exploring metric values. This method makes it possible to carry out a fair comparison of different wood supply chain strategies, e.g. special assortments and customized production compared to bulk deliveries. The method also helps to pin point areas to improve within a given strategy.

The project is a subpart of the EU project named FlexWood which “ aim is to support the design of new innovative supply chains, business models, for the forestry to contribute with a higher level of agility and tailoring to the market”. To reach this, answers to the above described questions are an essential contribution.

Keywords: *wood supply chain, value chain, KPI, SCOR model*

25. MODELLING THE INFLUENCE OF MACHINERY OPERATORS AND TIMBER HARVESTING ENVIRONMENT ON PRODUCTIVITY AND FUEL CONSUMPTION

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This paper is concerned with modeling the actions of a human operator of timber harvesting machinery and integrating this operator model into training of a complex forest work in the complete machine and its environment. Because operators to a large degree affect how the machine is run by stem by stem, adaptive operator models are necessity, as the other simulation goals of the man-machine system are optimization of productivity and energy efficiency.

Simulation can be used in the machinery allowing the system's behavior to be learnt and tested. Simulation also provides benefits in studying the basics of operator behavior, which can be reached with repeatedly used constant system configurations. Therefore, harvester simulators provide a low cost and fast analysis tool for modeling of harvester work in the same stand. In this study, test series of the stand were performed to determine how five young professionals operate wheel harvester. Simulation was a very valuable tool in solving the research problem. The harvester operators' work was compared to determine how it may differ in the same stand.

Statistical analysis and principle component were used to explore the properties of the harvester work. Four factors of harvester work using different approaches were realized and integrated into a multi-domain model for determining total efficiency of productivity and fuel consumption (Table 1). Use of selected four factors of harvester work can be justified using additional analysis about productivity and fuel consumption. These variables formed reasonable and different patterns for effects on factors. The results indicate that the operators' productivity (m^3/h) was mainly the same as compared to each other (Table 2). However, the fuel consumption and machine productivity was different. This means that different performances of harvesters did not base on different selection and processing of stems done by operators. The results are satisfactory and the methodology is easily usable for other, new situations of harvester work.

Table 2. Independent Samples Test for equality of means of MachineProductivity and FuelConsumption. Levene's Test for Equality of Variances, t-test for Equality of Means.

Variable	Operators	F	Sig.	t	df	Sig	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
MachineProductivity	2-5	2.04	.16	2.60	140	.01	24.42	9.39	5.86	42.97
	3-5	.66	.42	2.25	130	.02	21.67	9.61	2.65	40.68
FuelConsumption	1-3	8.77	.00	3.19	102	.00	.22	.07	.08	.36
	1-4	14.70	.00	3.61	120	.00	.22	.06	.10	.34
	2-3	2.20	.14	4.55	166	.00	.29	.06	.17	.42
	2-4	4.32	.04	2.61	134	.01	.15	.06	.04	.26
	4-3	.17	.68	8.82	124	.00	.44	.05	.34	.54
	4-5	2.94	.09	2.72	148	.01	.13	.05	.03	.21
	5-3	1.09	.30	5.96	130	.00	.31	.05	.21	.42

Table 1. Results of a principal-components analysis (Three most important factors) of the timber harvesting of the stand. Underlined weightings describe fuel consumption and productivity.

Variable	I	II	III	Communalities
BreastHeightDiameter	**.950**	.000	.000	.915
Length	**.944**	.000	.000	.893
FellingDiameter	**.915**	.000	.000	.853
Felling	**.815**	.000	.000	.673
CrossCuttingNumber	**.798**	.000	.000	.680
CrossCutting	**.781**	.000	.000	.643
MachineProductivity	**.709**	-.161	.031	.536
HumanProductivity	**.689**	-.283	-.166	.589
CraneFeeding	**.681**	.304	.000	.583
MiddleLogProcessing	**.654**	**.590**	.000	.778
AutomaticFeeding	**.618**	.000	.000	.394
CutDecision	**.552**	.394	.000	.502
MiddleLogDecision	**.522**	.476	.000	.523
PureCrane	.000	**.838**	.000	.805
Crane	.466	**.780**	.000	.858
FuelConsumption	.315	**-.725**	-.043	.634
Processing	.419	**.655**	.000	.622
Bunching	.000	**.653**	.000	.468
MiddleLogBunching	.000	**.602**	.000	.422
MiddleLogBunchingSlewDistance	.000	**.557**	.000	.318
ManualFeedLengthChange	.000	**.549**	.000	.379
TotalDrive	.000	.000	**.929**	.897
ForwardDrivingDistance	.000	.000	**.827**	.747
ForwardCatchDrivingDistance	.000	.000	**.801**	.721
DrivingToStem	.000	.000	**.770**	.678
CraneMoveDriving	.000	.000	**.652**	.488
BackwardDrivingDistance	.000	.000	**.640**	.456
Moving	.000	.000	**.590**	.464
StemMoveDriving	.000	.000	**.588**	.456
Eigenvalue	8.069	4.964	4.498	Total of VIII factors (>1)
Proportion of the variation explained	23.73	14.60	13.23	79.39

Keywords: *harvester operator, human productivity, machine productivity.*

26. TIME CONSUMPTION DURING FORWARDING BASED ON THE NUMBER OF ASSORTMENT IN A LOAD

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Abstract

This study is going to be included in the doctoral thesis which one objective is to provide scientific information for the developing process of decision support systems in forestry. These systems are meant to provide for forest operators computer-based aid within decision making process. Lack of academic knowledge regarding forwarding is one factor which stalls product development of decision support systems.

When forwarding logs the number of assortments in a load must be decided. Collecting distance is inversely proportional to the number of assortments forwarded in a load. In a homogenous stand it means e.g. that when the number of assortments forwarded in a load is doubled will be the collecting distance halved. Besides of knowing collecting distance it is relevant to know; how the number of assortments forwarded in a load influences on overall time consumption of forwarding operations. Algebra is not alone able to solve time consumption problematic and therefore a fundamental field study was required.

The field study was carried out on the standardised circular test path. The time consumption of various combinations of log density classes [Volume/distance on the strip road] and the number of assortments in a load was measured. Working moments included into herein study are: loading, driving while loading, unloading and driving while unloading.

By comparing overall time consumptions of different combinations can be given a suggestion for the optimal number of assortments in a load regarding different log density classes [Volume/distance on the strip road]. As a hypothesis of herein study is stated that optimal number of assortments in a load is inversely proportional to the log density [Volume/distance on the strip road].

Time data is collected and pre-processed. Thus, some preliminary results and notes can be given already at OSCAR conference in Honne, Norway, on 20th – 22nd of October 2010. Nevertheless, the time data must be further processed considerably and the final results will not be ready before the end of this year (2010).

Keywords: *Sorting, number of assortment, forwarding, decision support systems*

27. AN EXTRACTION TRAIL GENERATOR USING LIDAR DATA AND TABU SEARCH

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The transport of timber from stump to mill relies on a range of machines and equipment for primary (forwarders) and secondary transport (road trucks). This makes optimization of timber transport a complex task, which also should consider road planning and construction. Given the complexity of optimizing timber transportation, exact methods are limited by problem size. In this case, metaheuristics is a method proven to give good solutions in reasonable time. Forest operations can be divided in several tasks. For a cut to length system, the tasks are felling and delimbing/bucking/sorting by a harvester and transportation and sorting by a forwarder. For other systems, the order of the tasks can be different.

This work describes a computer implementation of tabu search (TS) for generating good trails for wheel based forest machines using the cut to length system. The implementation uses a digital terrain model (dtm) from remotely sensed Lidar (light detection and ranging) data as well as raster interpretations of conventional road and soil data.

We use a dtm from high resolution Lidar, with an average of 10 measurements per m². Some of the measurements will be reflections from the forest canopy, used to survey the forest stand. However, depending on the density of the forest, some measurements are reflections from the ground, and from these measurements we can generate an accurate dtm at reasonable cost.

Tabu search is one of the most frequently used metaheuristics, and is proven to give good results. TS is a local search, we have a current solution and evaluate a neighbourhood. This neighbourhood is a set of solutions resulting from (small) changes in a (small) part of the current solution. Local search will accept a new solution if it has a better objective value, whereas TS also accepts a solution with worse objective value. To stop TS from going back, the old solution, or parts of it, is labelled tabu for some iterations. Hopefully, this will stop TS from getting trapped in a local minimum/maximum. The neighbourhood implemented is adding of a part of a trail. In addition, we will use a neighbourhood of deleting whole or parts of a trails, a neighbourhood of moving whole or parts of a trail and a routine for merging of trails.

In addition to the dtm and road and soil data, we will use environmental data from registrations of key species. The environmental impact will be implemented either as a penalty to the objective function or as multi objective tabu search.

We use a high resolution grid of 1m x 1m, and the digital terrain model from Lidar combined with soil data is used to evaluate both where the machines can operate and identify trails representing the lowest cost of terrain transport. The problem is to find the best subset of vertices representing the trails, while every vertice has a minimum distance to the subset. This minimum distance is given by the reach of the machines. This is a Steiner Tree Problem, and is NP-hard.

The method will be tested at a full scale level in a forest in Norway. Firstly, we will compare the estimated cost of harvesting with actually incurred cost at a stand. If the model gives good estimates, it will be useful to the forest owner, who can acquire a better estimate of the cost of harvesting. (Macro economics - better decisions from accurate pricing?)

Secondly, an interesting question is whether we can use Lidar to identify where a forest machine can operate. We will compare the suggested trails to terrain trails actually created by machine operators, and if the accuracy of the dtm is good enough, the method can be used for generating more efficient trails and reduce harvesting cost. Also, the method will be the basis in further research. An estimation of the trade-off between primary and secondary transport costs could provide the basis for the planning of new forest roads, and the method could also be used in matching harvesting systems to sites.

Keywords; *Tabu search, extraction trail generator*

28. PLANNING HARVEST ACTIVITIES AND FOREST ROAD INVESTMENTS

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Tactical harvest planning normally covers a period of 5-10 years and includes decisions of which stands to harvest each year and during which season of the year. Decisions have to, besides information on supply and demand, consider accessibility constraints on forest land and on roads, both public and private ones. These constraints are affected by storage possibilities and the use of CTI equipped timber trucks.

Climate change scenarios made by Rossby Center in Linköping indicates that precipitation will increase in northern Europe during the coming century. The increase is highest during fall, winter and spring and may be as high as 20-40 % compared to a 30-year reference period (1961-1990). More precipitation will affect both harvesting and transportation activities in forestry leading to less accessibility mostly during fall and spring. This leads to a demand of higher standard of the forest road network and better planning of harvesting activities.

In this presentation we describe a model to optimize harvest planning and forest road upgrade investments on a tactical level. The objective of the model is to minimize costs for road investments, harvesting, transportation and storage while fulfilling the demand of round wood from different pulp mills, saw mills and heating plants. The optimization model makes decisions on when to harvest (year and season), allocation, when and where to build storage and how to use different truck types.

Planning for an investment in forest road upgrading is a difficult task since the number of alternative solutions is very large when the planning period is long (10 years) and the planning stretches over a wide area.

In general there is a lack of harvesting sites to use in order to fulfil the round wood demand in some seasons of the year, especially during spring thaw. Normally this is solved by building storage before these critical periods. This makes it possible to deliver according to plan without the need for road investments. Timber storage is however expensive and not always a good solution.

Other ways to solve the problem is to upgrade parts of the road network and/or to use CTI equipped timber trucks. With CTI the trucks can access more roads during critical seasons. The equipment is however rather expensive and cannot be used more than a part of the year which makes it important not to have too many CTI trucks.

The optimization model is a part of a decision support system which makes it possible to analyze large areas in a short time. The system includes a database, a map interface and functionality for distance calculation and interpretation of results from the optimization. The system is adapted to use data from PlanWise, which is a tool for long term harvest planning, created by the Heureka project at SLU in Sweden. The data coming from PlanWise includes, for each stand and year, possible harvest volumes and net present value. This information is used as supply information in our model. The user adds figures on demand per assortment and season together with information of the length of each season. Road information is collected from the Swedish national road database and includes digitized information, particularly accessibility class, on all roads. We also include the positions of gravel pits since the forest road upgrade cost is dependent on the distance from the road to the pit.

The system has been tested together with Sveaskog in northern Sweden. The test area covered about 15 000 stands (about 190 000 hectares of forest land) and 2 500 km forest roads owned by Sveaskog, mainly gravel roads. 2.5 % of these roads are accessible all year around. Results from the analyses will be presented at the conference.

Keywords: *forest roads, harvest planning, optimization.*

29. ASSESSMENT OF VÄSTERBOTTEN CASE STUDY WITH THE AID OF THE TOSIA DECISION SUPPORT TOOL.

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Background

The model ToSIA is a product of the EFORWOOD-project for assessments of sustainability impacts concerning economic, environmental and social impacts of changes in forestry-wood production chains. The perspective is from the forest to the end-of-life of final products.

The forestry – wood chain describes a number of processes going from stand establishment – forest management – harvesting of wood and biomass for forest energy and its transport to mill-industrial processing - distribution to markets - consumption, and finally to the end-of life of wood products. In the EFORWOOD- project each cluster of processes was defined as modules. There are 26 indicators that reflect the performance, however, some of these pertain only indicator information to a certain module. Example of indicators are; *Gross value added, Production cost, Employment, energy use, Occupational safety and health, Greenhouse gas emissions and carbon stock* etc

The case

The Västerbotten case study is a raw material driven case that reflects the performance of the Forest wood chain from forest management to end user. This presentation demonstrates on;

i) indicator results from forest and logistics operations in relation to operations closer to the end market.
ii) indicators results depending on scenarios for technology used, especially in industrial processes.
iii) indicator results for anticipated future development until 2015 and 2025.

Results

i) Forest management and forest operations and management represents a minor part of the Gross value added (7%), costs (8%), environmental burden or employment (30%). In fact a larger part of the value added and employment (>50%) is taking place outside Västerbotten.
ii) Foreseen technological development until 2025 will decrease the raw material need for a certain unit of market ready products, If a viable alternative for rail transport, propelled by electricity (Swedish mix) is at hand, this will reduce environmental burden to a minimum compared to road vehicles. No such an effect is obvious concerning costs and employment.
iii) Future outlooks with anticipated economic growth until 2025 demonstrate a likely raise in raw material costs and gross value added, but general cost level will have almost no change at all due to efficient use of energy. Employment does not change much but renewable energy replaces fossil. The increased GVA is thus attained by insignificant contribution to Global Warming Potential.

Discussion

An important contribution to the discussion will be the surprisingly small importance of Forest management and operations has compared to the entire forest wood chain, but -; this is an example of the multiplying effects forestry has for other segments of economy. This is thus a valuable input in any discussion dealing with the interface between reduced area due to conservation or intensified use of forest land.

Keywords: *Forest Wood Chain Performance, Global Warming Potential, Gross Value Added*.

30. WOOD HARVESTING AND LOGISTICS IN RUSSIA – NORDIC BUSINESS POSSIBILITIES

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Objective of the study

Russia is undoubtedly important for the Nordic forestry related business being operational environment for ever-increasing number of enterprises and growing market for machinery manufacturers. To be able to hold market position and find new business possibilities enterprises and method developers must be well aware about the current status and future development of the Russian forest sector, and be familiar with the local conditions which are not similar to Nordic countries.

There is a lack of knowledge related to wood harvesting in earlier unmanaged and deciduous species dominated forests, both of which are very common in Russia, but of which very little is known in Nordic countries. In particular, knowledge related to productivity and prerequisites for machinery and technology for wood harvesting and transportation in such conditions is inevitably needed. Knowledge of the development of wood harvesting and wood transportation in Russia is important for foreign companies, since many of them are operating in Russia in these fields. Furthermore, Finnish research and technology developers urgently need this knowledge in order to be competitive and able to provide solutions for problems faced.

General aim of the project is to improve and secure business opportunities and competitiveness of Nordic forestry related companies and research in emerging Russian market through international research. Specific goal is to build and apply new research methods and approaches for improving know how on wood harvesting technology, wood energy and logistics in Northwest Russia. The secondary objective of the project is to intensify existing network between Russian and Nordic organizations in wood harvesting and transport operations research.

Material and methods

In order to produce and obtain new knowledge described earlier, international networking is established which includes 5 research organizations and 8 companies in Russia, Finland and Sweden. Work is divided into three work-packages: (1) Industrial Wood Harvesting, (2) Energy Wood Harvesting, (3) Transportation and Logistics. Materials for the analysis include information about forestry in Northwest Russia and Nordic countries:

- Characteristics of Russian growing stock, namely in unmanaged, oversized and deciduous forests
- Used technology, their utilization and status
- Markets of forest technology (Russian, international)
- Wood harvesting and processing capacity, their location
- Logistics, infrastructure and services
- Environmental impacts of wood harvesting
- Energy wood harvesting, power plants able to use wood, and pellet production
- Field data and results from recently completed projects “Comparison of Harvesting Methods - Impacts on Wood Quality and Overall Performance of Wood Harvesting Companies”, “Global forest energy resources, certification of supply and markets for energy technology”, and “Development of the forest road infrastructure and logistic system for industrial and energy wood transportation”.

Following specific methods are applied:

- GIS based technology
- Simulation techniques is developed and applied for analyzing logistics by programming in C++
- Optimization methods based on dynamic and non-linear programming
- Automatic data collection system is used to study individual work stages

- Cost calculation method
- Method of scenario development
- Methods of experiments planning

Case studies are selected in cooperation with the participating companies in the Leningrad region (UPM-Kymmene and Metsälliito), the Republic of Karelia (Stora Enso, Kesla, Ponsse), and the Tver region (John Deere).

Results

Results of the project include:

- Improvement of knowledge on:
    - Current and future development of industrial/energy wood harvesting and logistics
    - Productivity of machinery and methods in Russian conditions of Russian logging companies using Nordic technology
    - Wood procurement models for energy wood harvesting
    - Optimization of wood harvesting, terminal operations and transportation chain
- Know how about adaptation of Nordic wood harvesting systems to specific conditions in Russia, in particular in unmanaged forests with high share of deciduous species, soft soils, and undeveloped infrastructure and service (Gerasimov&Katarov 2010, Gerasimov&Sokolov 2009).
- Model for cost effective wood procurement systems in Northwest Russia utilizing Nordic technology (Gerasimov&Sokolov 2010).
- Software for optimization of wood transportation plan (Gerasimov at al. 2008).
- A new approach to explore business opportunities and evaluate competitiveness of Nordic forest based technologies and products in industrial and energy wood harvesting and logistics in Russian market (Gerasimov et al. 2009).
- A new operations model and approach to international cooperation in forest technology research with Russia.

Conclusion

Present wood harvesting and logistics practices in Northwest Russia have been studied from the point of view of business opportunities taking into account prevailing conditions. There are great differences between the Nordic countries and Russia in wood harvesting and logistic methods and systems. Application of the Nordic methods and systems would allow increased productivity and minimized costs of wood harvesting and transport and thus improved economics of the logging operations. The Nordic systems tend to have high reliability, good ergonomic performance of harvesters and forwarders, possibility to introduce thinning and energy wood operations, better quality of industrial round wood, possibility to measure wood removals in logging area, increasing requirements for using public roads and tightening rules of their utilization when applied in Russia. At the same time, wood harvesting by the Nordic systems tend to cause more impacts to forest soil than Russian traditional systems. Successful application of Nordic systems needs further adaptation to Russian conditions including capacity building, maintenance, and engineering changes.

Acknowledgements

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Keywords: *CTL method, forwarder, harvester, wood procurement, energy wood, optimization, GIS*.

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31. TESTING OF REVOLUTIONARY ROUND WOOD HAULAGE RIG IN SWEDEN

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Testing of a revolutionary round wood haulage rig has been going on for more than one year. The rig is 30 m in length, and has a gross vehicle weight (GVW) of 90 tonnes. On two round trips, the volume of round wood that this rig can haul is equivalent to that carried by three conventional haulage rigs. This reduces costs and CO_2 emissions, and also contributes towards enhanced road safety.

The rigid truck was manufactured by Volvo Trucks, and the trailer units by Parator. The latest technology and grades of Swedish steel have been used in the construction of the rig to keep the unladen weight as low as possible. Skogforsk is analysing costs, production, fuel consumption, and environmental impact. The Swedish Road Administration is monitoring road safety, road wear, and the load on bridges, and will also be assessing the reaction from the general public to longer and heavier haulage rigs on the roads.

Road haulage in Sweden accounts for 25% of the total costs in the forestry sector from stump to mill. Despite improvements in logistics and haulage vehicles, transport costs over the past ten years have risen by 2% per year, largely because of higher fuel prices.
In the 1980s and 1990s, the GVW for haulage vehicles in Sweden was increased from 50 tonnes to today's 60 tonnes. This resulted in a 20% fall in fuel consumption, thanks to fewer vehicles needed to complete the same haulage volumes. This benefited both the environment and the economy.

ETT, which is a Swedish abbreviation for *One stack more*, is a project initiated by Skogforsk to study the consequences of a higher GVW, and extended length, on round wood haulage rigs. The project is a collaborative venture with Skogforsk, the haulage companies, and a national association for the owners of private roads. The aim is to reduce fuel consumption and CO2 emissions by 20–25%. The project work includes studies on new haulage rigs, and testing of the ETT round wood haulage rig that is now operating on a 170-km run from a terminal in the north of the country down to one of SCA's large sawmills in Piteå.

Research Method
A number of manufacturers have been involved in the development of the ETT round wood haulage rig. Skogforsk is analysing costs, production, fuel consumption, vibration and environmental impact (CO2, NOx, etc.).
The Swedish Road Administration is monitoring road safety, road wear, and the load on bridges, and will also be assessing the general public's reaction to longer and heavier haulage rigs on the

roads. Several industrial forest enterprises are acting as hosts in the practical studies. Road haulage companies will be providing training for road safety and driver attitude.

Technology window

- The rigid truck is a Volvo FH 16, 6 x 4. It has a six-cylinder engine capable of developing
  660 hp. It has 3100 Nm of torque.
- The transmission is an I-shift — a 12-speed automatic mechanical transmission. Gear shifts are made according to current driving conditions by the electronic engine and transmission. This technology offers high efficiency and low fuel consumption.
- The vehicle is equipped with an EBS (Electronic Brake System), which is connected to both the rigid truck unit and the trailers. New technology ensures that all wheels brake simultaneously. This guarantees effective braking, and that the braking distance of the ETT rig will not be longer than that of a 60-tonne rig.
- The rigid truck has an air suspension system on the drive axles, and parabolic leaf springs on the front axle.
- The dolly, link and trailer were made by Parator. The trailer was engineered in SSAB Domex 700 graded steel, which is both lighter and stronger than the steel normally used by Parator.
-

Preliminary Results and Conclusions

The aim of the ETT project is to enhance the efficiency of round wood haulage by using fewer haulage vehicles, reducing fuel consumption, and minimizing CO2 emissions.
We have now been able to show what the technical solution might look like: a conventional round wood haulage rig, which incorporates standard modular units that are generally used for haulage on rural main highways. Testing to ascertain how the ETT haulage rig operates in ordinary traffic, together with the possible effects on roads and bridges, started in January 2009. The economic and environmental benefits are also being studied. The unique ETT project has attracted keen interest in the transport sector, and is being closely monitored. So far 40 ton diesel and 100 ton CO_2 have been saved. The transport cost is reduced with 20-25%

Keywords: *transport, fuel, costs, longer and heavier vehicles.*

32. IMPACT OF EXTRACTION CONDITIONS ON COSTS OF FORWARDERS IN FINAL FELLING

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Abstract
To determine the impact of extraction conditions on the productivity and costs of forwarders and to improve the payment procedure for forest operation services, JSC Latvia's State Forests, (AS Latvijas valsts mezi, LVM) in cooperation with Latvia's State Forest Research Institute Silava (LVMI Silava) carried out a research and development project in 2008. The results of the project have been incorporated into the business operations of LVM over the subsequent years.

In the context of the research project, the extraction conditions are divided into four categories:

1. Good;
2. Normal;
3. Bad;
4. Extreme.

Definitions characterizing each category of the extraction conditions were developed. Research work was undertaken in 'good', 'normal' and 'bad' conditions. Research work in 'extreme' conditions was skipped due to wide variations in productivity and costs in it. Prior to starting the research work, soil bearing capacity measurements were taken using Eijkelkamp's Penetrologger. The results of the measurements showed that the soil bearing capacity at the felling sites selected for the time study of extraction operations was in conformity with the defined extraction conditions.

Three different forwarders designed for timber extraction in final felling were used in the research work:

- John Deere 1110D with a standard load-carrying compartment, 11-ton load capacity;
- John Deere 1110D with a long load-carrying compartment, 11-ton load capacity;
- John Deere 1410D, 14-ton load capacity.

The results of timing of extraction operations demonstrate that extraction conditions have an impact on the productivity of all forwarders (Table 1).

Table 1. Productivity of forwarders, m^3 G_{15} at an extraction distance of 600 m in different conditions

Forwarders/Conditions	**Good**	**Normal**	**Bad**
John Deere 1110D standard	15.5	13.7	11.4
John Deere 1110D long	17.6	14.4	13.1
John Deere 1410D	18.2	15.2	14.6

Deterioration of extraction conditions leads to a decrease in the productivity of all forwarders and an increase in fuel consumption. These factors have a negative effect on the costs of extraction operations (Table 2).

Table 2. Average total costs of extraction operations at an extraction distance of 600 m in different conditions

Forwarders/Conditions	Good	Normal	Bad
John Deere 1110D standard	3.87 €	4.26 €	4.87 €
John Deere 1110D long	3.46 €	4.03 €	4.37 €
John Deere 1410D	3.46 €	4.01 €	4.24 €

Costs of extraction operations increase along with the decrease in the soil bearing capacity. Moreover, the costs of extraction of the forwarder John Deere 1110D with a standard load-carrying compartment are significantly higher than of other forwarders in all conditions.

Starting from 2010, LVM implemented a differentiated payment procedure for timber extraction operations, which is based on the results of the project and which determines different rates for 'good', 'normal', 'bad' and 'extreme' extraction conditions. Prior to changing the payment system for timber extraction operations, the company developed guidelines and an electronic model in MS Excel format for determination of the conditions, as well as conducted training of the employees. The guidelines and the electronic model are available to both parties LVM employees and providers of forest operation services. It ensures a uniform understanding of the timber extraction conditions when payment for the work must be agreed upon.

Keywords: *forwarders, extraction conditions, costs.*

33. EVALUATION OF DIFFERENT APPROACHES OF MECHANIZED BIOMASS HARVESTING IN GREY ALDER (*ALNUS INCANA* (L.) MOENCH) STANDS

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The grey alder is one of economically important tree species in Latvia. Total area of the grey alder dominant stands is 310 000 ha (10 % of forest lands in the country). Grey alder stands characterizes with with good growing conditions (fertile but usually wet soil) and high biomass increment values. At the same time grey alder stands usually have poor management history because of small financial benefits from low valued timber products, which did not motivate forest owners to invest into management of the grey alder stands. Growing demand of biomass in the energy sector changes the situation during recent years therefore concern about the grey alder as a potential woody energy crop is raising.

The article summarizes results of several studies implemented by the LSFRI Silava from 2004 to 2009 comparing growth, yields and different harvesting technologies in the grey alder stands. The scope of this summary is to evaluate which management and harvesting approach is the most beneficial for the forest owner. Compared technologies are:

- Coppicing using combined harvesting and comminution equipment applicable in uneven stands (AHWI AM 600 or Bender VI);
- Whole tree harvesting in young stands with following comminution at a road-side using guillotine type harvester heads (Ponsse EH-25 head);
- Harvesting of firewood assortment using ordinary harvester heads and cut to length approach.

The first step of the study is estimation of average forest stand characteristics (height and diameter at breast height of trees, number of trees per ha and growing stock). Calculations are based on measurement results from 171 grey alder dominant stands representing different age classes. The stands of age from 10 to 40 years were considered in further productivity and cost calculation. Roundwood assortment is considered starting from 17 years age when average diameter at breast height is at least 12 cm. Undergrowth is not taken in account in calculations of growing stock and productivity.

The second step is evaluation of the harvesting technologies to estimate logical criteria which determine when the particular technology can be used. For instance, limiting condition for AHWI AM 600 harvester is diameter of trees (8 cm at a cutting height). Taking into account that grey alder is a softwood tree specie, but the above-mentioned criteria refers to hardwood tree species, the same diameter (8 cm) at a breast height is assumed as limiting for the AHWI AM 600 in the grey alder stands. However field trials demonstrated that in case of presence of *Salix sp.* the machine tends to clogging. During personal communication representative of producer of the machine it was mentioned that the issue with clogging is solved in newer prototypes. According to the average characteristics of the grey alder stands the proposed technical limitation of diameter means, that AHWI AM 600 can be used until grey alder reaches 16 years age.

The third step is calculation of prime costs of harvesting using results of earlier productivity studies in young stands. During this stage harvesting technologies overlapping at certain age are compared according to the prime cost of biofuel production and the most feasible solution is evaluated further.

Using whole tree harvesting technology 10 years old grey alder stands can provide 106 LV[1] m^3 ha^{-1} of wood chips but 40 years old stands – up to 838 LV m^3 ha^{-1}. Production of firewood in 17 years old grey alder stands will result in 97 m^3 ha^{-1} of firewood but in 40 years old stands – 255 m^3 ha^{-1}. Share of harvesting residues is small in the grey alder stands (up to

1 LV – loose volume.

33 LV m^3 ha^{-1} in 40 years old stands), therefore it might be feasible to collect slash only in large clear-cuts.

Comparison of potential incomes from selling of biofuel demonstrates, that it is more feasible to sell comminuted biomass, however, if production costs are taken in account, production of firewood is more feasible. A profit before taxes from selling firewood is from 1 008 EUR ha^{-1} in 27 years old stands to 4 025 EUR ha^{-1} in 40 years old stands according to the average firewood prices in 2008. Note that only the prime costs are taken in account in the profit calculation. Information about average service costs published by the Central Statistical Bureau shows, that in practice the profit of the forest owner from selling of firewood in 40 years old old stand would be 1 249 EUR ha^{-1}. An important factor negatively affecting productivity and output of the firewood in the grey alder stands is considerable share of small dimension trees, which quite oftenly crashes in harvester heads, therefore harvesting can be done only manually and at much lower productivity. Additional cost (140-200 EUR ha^{-1}) may arise from cleaning of undergrowth before mechanized harvesting.

Utilization of combined harvesting and comminution equipment becomes feasible in the grey alder stands starting from 10 years age. A risk to reduce productivity due to high dimensions of trees increases at 15-16 years age, therefore in spite of theoretically good feasibility figures it is reasonable to switch to the whole tree harvesting at this age or to wait until trees will reach dimensions applicable for the firewood production (27 years). It is important to mention that increment of biomass in unmanaged grey alder stands decreases after they reach 15 years age. A profit before taxes from selling of biomass produced with the combined harvesting and comminution equipment is comparable with the one from selling of firewood, however this technology is not evaluated enough and the machinery applied in the time studies exists only as prototypes.

The whole tree harvesting technology is well known and commonly used in Latvia to remove woody vegetation from abandoned farmlands. However productivity estimated in time studies is low in a compare to the results obtained in Sweden. Therefore more studies with more advanced operators are necessary to estimate potential of productivity of biofuel targeted harvesting because in contrast to removal of vegetation there is no need to take care of small dimension trees and bushes. Results of the study shows that the whole tree harvesting will lead to negative cash flow with no respect to age of stand. However full tree harvesting has the lowest level of risk of fluctuations of productivity due to improper harvesting conditions because the technology is suited for the broadest range of conditions. This means that in real world conditions difference between full tree harvesting and roundwood production or combined harvesting and comminution could be considerably smaller.

***Keywords**: grey alder, harvesting, biomass*

34. ESTIMATING POTENTIALS OF SOLID WOOD-BASED FUELS IN FINLAND IN 2020

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Introduction

In the context of the Government's Climate and Energy Strategy, it is estimated that the primary use of wood-based fuels in Finland will be 100 TWh by the year 2020. The overall target set for forest chips is 25 TWh, i.e. around 13.5 million m^3. The objective of the research carried out by Metsäteho Oy and Pöyry Energy Oy was to produce as realistic as possible a total analysis of the possibilities of increasing the usage of solid wood-based fuels, and especially forest chips, in Finland by 2020.

Material and methods

Two different scenarios for the forest industry production of the year 2020 were created in the research. The scenarios were Basic scenario and Maximum scenario. The roundwood consumption and demand of forest industry were constructed based on the scenarios. Domestic industrial roundwood cuttings were 57 million m^3 in the Basic scenario and 68 million m^3 in the Maximum scenario in 2020. The cuttings by Forestry Centre and further by municipality in 2020 were allocated applying the latest National Forest Inventory data by the Finnish Forest Research Institute and the Stand Data Base by Metsäteho Oy. The calculated small-diameter wood supply potentials were based on the 10^{th} National Forest Inventory data of the Finnish Forest Research Institute.

Three different levels of potentials were determined in the study. In the research, the theoretical potential was the amount of:

- Logging residues and stumps, which are produced in regeneration cutting areas in the Basic and Maximum scenarios, and

- Small-diameter wood (whole trees) produced when tending and cutting operations in young stands are carried out on time.

The techno-ecological supply potential was the forest chip material raw base, which is harvestable when the following limitations are taken into consideration:

- Recovering percentage is less than 100,
- Substantial amounts of pulpwood are not burnt,
- Recommendations in the Guide for Energy Wood Harvesting are followed when choosing harvesting sites, and
- All energy wood does not come onto the market (forest owners' willingness to supply energy wood).

And techno-economical usage potential included the total supply costs and the willingness to pay of energy plants. The harvesting conditions for recovering sites were created applying Metsäteho Stand Data. The total supply system costs for forest chip quantities were calculated by Metsäteho Energy Wood Procurement Calculation Models. It was assumed that in 2020 the total supply system costs are 20% higher than currently. Pöyry Energy Oy's Boiler and Energy Plant, Pellet, and Forest Industry Data Bases gave a possible to research the usage of wood-based fuels in the study. Pöyry Energy Data Bases included almost all current plants and factories, as well as those under planning and contracting.

Results

According to the calculations, the technical usage potential of solid wood fuels in energy plants was 53 TWh in 2020 in Finland. The proportion covered by logging residues and small-sized thinning wood was estimated to be 28 TWh. Theoretical supply potential of forest chips was 105 TWh in the Basic scenario and 115 TWh in the Maximum scenario of the research.

Correspondingly, the techno-ecological supply potential was 43 TWh in the Basic scenario and 48 TWh in the Maximum scenario in the year 2020.

When modelling the usage of solid wood fuels in energy generation in the Basic scenario in 2020, the consumption of solid wood fuels was 44 TWh of which the usage of forest industry by-products lowered from the current level to 17 TWh and the consumption of forest chips increased up to 27 TWh. Particularly stumps raised significantly their proportion of total forest chip volumes. The most expensive forest chip quantities delivered to energy plant were more than 20 €/MWh in the study. In this case, pulpwood starts to be cheaper than that kind of very expensive forest chip volumes. In the Maximum scenario, the usage of solid wood fuels increased to 48 TWh in 2020. Especially in the Maximum scenario the delivered quantities of logging residue chips and stump wood chips increased and the quantities of small-diameter thinning wood chips delivered decreased.

The emission trade had a strong influence on the competitiveness of wood-based fuels and the use of such fuels in energy plants. When the price for emission rights lowered to the level under 20 €/t CO_2, the deliveries of wood fuels for energy plants decreased significantly. Respectively, when the price of emission rights increased over 30 €/t CO_2, the usage of wood fuels by energy plants did not significantly increase any more. The effect of emission trade focused particularly for the most expensive wood fuel fractions, i.e. small-diameter thinning wood and stump and root wood.

Also, the support by the Finnish State for producing chips from small-diameter wood from young stands had very strong impact on the usage volumes of small-sized wood chips in 2020. The effect of supports on the harvesting volumes of small-diameter wood chips pointed out when the price for emission rights was at the low level. When the price was low (10 €/t CO_2) and there was no support for energy wood harvested from young stands, there were no possibilities to harvest small-sized wood chips for energy generation.

Correspondingly, when the support for small-sized wood chips was 8 €/MWh under low price for emission rights, it made possible to rise the usage of small-diameter wood chips to 2.7 TWh. Respectively, when the price for emission rights was high (30 €/t CO_2) and the support for small-diameter wood chips recovered from young stands was 4 €/MWh, it made possible to increase the usage of small-sized wood chips up to 7.4 TWh in 2020.

Conclusions

The study showed that the growth objective set in the Government's Climate and Energy Strategy can be attained through the supply and consumption of wood-based fuels because, for instance, in the Basic Scenario the techno-economical supply potential was 27 TWh of forest chips in 2020. Realizing this potential would, however, require major investments throughout the entire forest chip production system. Industrial roundwood cuttings and the production of forest industries will also have to be at the level before the year 2009.

The emission trade had a significant impact on the competitiveness of wood-based fuels and the use of such fuels in energy plants. Increasing the proportion of wood-based fuels is very difficult at the current pricing level of emission rights (around 15 €/t CO_2). A strong increase in the use of wood-based fuels would require an emission rights price level of over 25 €/t CO_2.

We also have to pay attention to the fact that the forest chip production resources are extremely large. If the production and consumption of forest chips are 25 TWh in Finland in 2020, 1,900 units of machinery, i.e. machines and trucks, would be needed. This would mean total investments in production machinery of 530 million (VAT 0%). The labour demand would be 3,400 machine operators and drivers, and 4,200 labour years including indirect labour.

Considering the major resources required by the forest chip production system and the current low competitiveness of forest chips, it is estimated that the use of forest chips in Finland with the low price for emission rights and current incentives by the State will reach the level of 20 TWh at the earliest by the year 2020. Implementation of the Government's Climate and Energy Strategy presupposes certain measures directed at improving the operating environment in the field of forest chip production.

Keywords: *Emission trade, Energy wood, Forest chips, Potentials.*

35. PRODUCTIVITY OF SINGLE GRIP HARVESTERS IN THE NORTHERN EUROPEAN PART OF RUSSIA

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Objective of the study

Many developments were also made towards cut-to-length (CTL) method and its mechanization in Russia during the previous decade, particularly in northern European regions. The CTL harvesting system minimizes labour needs, work safety risks, environmental damage, and landing areas compared to the traditional tree-length and full-tree (FT) systems. However, a fully mechanized FT harvesting system based on a feller-buncher is still more productive than the CTL one because specific tasks are assigned to each machine. Taken into account that the fully mechanized CTL wood harvesting system is still being introduced in Russia while the fully mechanized FT system was developed in the USSR era and widely utilized, further development of productivity of the CTL system in Russia will improve the economic performance of harvesting operations in Russia. The objective of this study was therefore to develop a harvester productivity model of CTL harvesting of unthinned mixed forest stands in the northern regions of the European part of Russia. With such a model, the prospective users of harvesters may evaluate the inherent operation costs under different conditions and assess the competitiveness of the alternative options. It was also intended to facilitate the adaptation of CTL harvesting for naturally growing forests, especially in those companies where worn-down domestic machines are still available and where cheap labour prevents investment in purpose-built forestry machines.

Material and methods

The study experiments were carried out in typical working conditions of northern European part of Russia in 2008–2009. Midsized class wheeled harvesters (John Deere 1270D) were used in cuttings. A new version of the John Deere's machine performance and condition monitoring system (TimberLink 2.0) was used for collecting data on productivity and condition follow-up (tree sizes and species). In the harvesting operations 38 harvesters were studied, of which 9 were in Karelia, 8 in Vologda and Arkhangelsk, 16 in Komi, 2 in Leningrad, 2 in Tver, and one in Kirov. The wood harvesting volume of all harvesters was 1.4 million m^3 and a total of 4.3 million trees were observed. Harvested stands were not managed or thinned before final felling. A typical stand was mixed in terms of age and tree species. The tree species composition included spruce (48% on average), pine (19%), birch (22%), and aspen (11%). The average stem volumes of each studied harvester varied between 0.15 m^3 and 0.33 m^3 with an average value 0.31 m^3.

Results

From the data collection period the average productivities of harvesters varied from 4.3 to 14.9 m^3 per productive machine hour (PMH) and 16.0 to 49.5 m^3 per processing machine hour ($P_{proc}MH_0$). A machine evaluation analysis and a regression analysis were used to develop models for predicting individual machine productivity over time. Regression models were developed to estimate the productivity of the harvesters in the regions taking into account two significant factors influencing the productivity: the stem volume and tree species of the felled trees. The results indicate a significant relationship between harvester productivity and stem volume and tree species. Productivities per cubic metre of processed timber per PMH were calculated according to the evaluated stem volume and tree species distributions in most forest-covered regions.

Conclusion

The productivity of harvesters did not differ much from what is obtained from Russian logging companies in Russia. However, the productivity of single grip harvesters in Nordic countries is higher than in Russia when comparing stem volume. There are a number of possible explanations for the differences between Russia and Nordic countries. Operators' skills and experience levels have a remarkable influence on productivity in harvesting operations. Moreover, the lower productivity in Russia is a result of divergent distributions of stem volume and stem quality due to different forest management traditions in these countries. Stands in Nordic counties are more or less regularly managed and thinned, while in Russia stands are seldom managed and thinned before final felling. These factors have distinct influence on harvesting productivity. From the operational viewpoint, Russian harvesting companies need improvements for machine evaluation. They still have great potential in machinery utilization, and the possibility of increasing the share of processing time in order to reduce harvesting cost should be explored. On the basis of the results of this study, it would appear that harvester productivity per PMH can even be doubled in some cases.

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Keywords: *Wood harvesting, CTL method, stem volume, tree species*

36. ANALYSIS OF LARGE-SIZE AND MEDIUM-SIZE WOOD SUPPLY

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Background

The management of forest resources is a very complicated task. Modern forestry must be managed in a way that ensures sustainable development of all forest functions, at the same time must meet higher demands of forest products customers. One of the challenges which forestry is facing today is to optimize the transport of timber. This problem was noticed in the forestry long time ago. Research carried out on a solution needs to take into account many factors, often specific to each country. Polish forestry on the background of the European Union countries has one of the highest proportion of state forests in relation to the entire forest area of the country. Over 80% of Polish forests with a total area of 7,431 thousand ha are state owned. The amount of timber harvested is increasing each year. In 2008 has been harvested over 33 million m^3 of which 10.7 million m^3 was a large-size coniferous wood, 2.5 million large-size broadleaved wood and medium-size wood respectively 12.7 and 5.1 million m^3. At the same time all operations related to timber harvest and transport are carried out by private companies. Most of them are small one-person businesses with low level of development and little capital. This causes serious problems both in organization and development of timber haulage system in Poland. The diagnosis of the current situation in wood transport sector is the key to identifying the needs, risks and process optimization.

Material and methods

In this paper analyzed raw material supply to the two leading companies, located in northern Poland. The first receiver take only large-size pine wood, which is transported there by high-tonnage vehicles. Daily they are able to absorb up to 1000 m3 of wood. Second company is processing middle-sized wood of different species. As previously loads are delivered by high-tonnage vehicles. The size of the daily supply oscillates around 4000 m^3. Analyzed supply documentation of receiver and recipes from Forest District Unit. On the base of that material was possible to identify sources of timber supplies, single load volume, average number of truck delivering raw material in one day and time necessary for weight control, load capacity control by sorters and unloading process. It also has been described the number of cycles for each vehicle in one day as well as supply structure during a day. The distance of transport has been described as the shortest distance measured between geometrical center of Forest District Unit and location of receiver. It assumes that the movement of the vehicle on forest and public roads, can occurs on road category where single-axle load over eight Mg is permitted. For this propose routeplanner was used. Average transport distance was determined as the quotient of transport work and the total volume of transported raw material.

Results

In company No 1 observation lasted five days, during this time 4143 m3 of large-size pine wood was delivered in 144 courses. Wood supply to this receiver took place from 22 different Forest District Units. Average transport distance was 72 km. The average volume of a single load was 30.15 m3. The average time of vehicle maneuvering on the square was 47 minutes. Receiver accept timber every day from 7:00 am until 6:00 pm. The biggest number 52 trucks has delivered wood in the time interval from 1:00 pm until 2:59 pm. Definitely the lowest frequency of 10 deliveries occur in the afternoon from 3:00 pm to 5:59 pm. During the four day analyze to the company No 2 14768 m^3 of medium-size, different species was delivered. In majority it was pine – 6.5 thousand m^3 and birch - 4.2 thousand m^3 and others like spruce, aspen, alder and larch. This timber was harvested and delivered from 124 different Forest Unit District. Average delivery distance was 202 km. The largest part 44% of the raw material comes from the distance of 101 to 200 km. As many as 11% accounted for raw material supplies which the distance was more than 400 km. The volume of single load was in average from 33.8 to 38.9 m3 and depends on species of wood. Unlike company No 1 timber is accepted around the clock. The biggest part of supply took place in time interval between 12:00 pm and 2:59 pm, when was adopted 118 vehicles in the

next three hours period observed sliced decrease in number of trucks to 103. And from 6:00 pm it falls very clearly to 51 vehicles. The lowest number of trucks 22 is accepted between 12:00 am and 2:59 am. Average time for each vehicle for checking and unloading was 48 minutes.

Receiver No 1, which process large-size wood, in average accepted 13 trucks a day, receiver No 2 in average accepted 135 single loads. Taking into account conducted research in area of GVW of timber transport vehicles as well as recognized in the literature problem of overloading, has taken an attempt to answer the question - how to alter the number of vehicle, and hence the daily supply structure with an adjusted volume of cargo to the size limited by the law. In case of company No 2 number of vehicles would increase 24%. Time needed for weight control and volume of load control for this number of trucks would be around 25 hours. The research shows, that in one time six vehicles can be process, so real time by which would extend the operation of additional vehicles would by 4.5 hours. This will certainly increase waiting time for every truck.

Keywords: *timber haulage, wood supply chain, large-size timber, medium-size timber*

37. FELLING HEADS VS HARVESTER HEADS IN BIOMASS HARVESTING FROM EARLY THINNING

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Introduction

To increase the productivity of small tree harvesting, multi-tree harvesting heads have become a popular option for so-called energy thinning. Multi-tree harvesting heads are now available on the market in a large number of brands and models. Some of the models are developed and modified from simple felling heads, now capable of felling and accumulating several trees in each crane cycle. Other models are modified single grip harvester heads, capable of felling, delimbing and bucking several trees in each crane cycle.

Aim of study

The aim of this study was to compare the efficiency of accumulating felling and harvester heads in biomass production from very dense mixed stands of pine and birch, where proper tending had been neglected and regular tending or thinning would not be feasible. Two different types of accumulating felling heads (Naarva-Grip 1500-40E, Bracke C16.a) and one type of accumulating harvester head (Log Max 4000B) were studied.

Figure 1; The heads used in the study. From the left; Bracke C16a, Log Max 4000B, and Naarva-Grip 1500-40E.

Results and discussion

The productivity was in the range 2.5-3 metric ton dry matter per effective hour in the stands with the smallest average tree size (4-9 kg dry matter per tree), and in the range 3.5-5 ton d.m. per effective hour in the coarser stands (17-19 kg d.m. per tree). There were significant differences in the productivity between the machine configurations, but the study layout prohibited a reliable statistical comparison. The disc-saw based felling head (Bracke) seemed to be the most efficient head in stands with the smallest tree sizes, while the modified harvester head (LogMax) was most efficient in the coarser stand. The latter statement is congruent with findings in other comparable studies.

Keywords: *Energy wood thinning, time studies, productivity, accumulating harvesting heads*

38. INTEGRATED SMALL-SIZED WOOD HARVESTING FROM YOUNG STANDS

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The integrated harvesting of industrial roundwood and energy wood utilizing the "two-pile cutting method" has increased steadily in young forest stands in Finland during the past two years. In field studies carried out by Metsäteho Oy and TTS Research, the integrated harvesting of energy wood and pulpwood was researched to: i) determine the time consumption and productivity of cutting work when using integrated cutting of first-thinning forest stands, ii) clarify the development of the total removal of integrated harvesting operations, and iii) investigate the quality of pulpwood logs when using integrated cutting with multi-tree handling technology.

The studies indicated that with integrated wood harvesting, the total removal of the harvesting operation increases significantly, when compared to that of a conventional separate roundwood and energy wood harvesting operation from early thinnings in small-sized diameter forest stands. With the total removal of the harvesting site increased considerably, there was a significant increase in the productivity of cutting work with integrated wood harvesting compared to the harvesting of pulpwood separately. Cutting methods tested in the study included: separate cutting of energywood, integrated whole tree cutting of roundwood and energywood, and integrated delimbed stem wood cutting of roundwood and energywood. Costs and cost components of each cutting methods supply chain including either roadside chipping or chipping at plant were identified. Relative cutting costs of delimbed stem wood were found to be higher than those of integrated and separate whole tree harvesting.

It was also found that with the increases in productivity, the delimbing quality and bucking accuracy of the pulpwood logs processed with multi-tree handling technology were comparable to those produced with a single-tree handling system. As the field studies indicated, integrated wood cutting and harvesting operations are likely to provide promising results by increasing productivity and cost-effectiveness of an operation in first thinnings with small sized diameter forest stands. Due to the increases, we are likely to see a continued use and development of integrated harvesting supply chains and techniques.

Keywords: *Integrated harvesting, energywood, pulpwood, productivity.*

39. COMBINING ADAPTED DUMP TRUCKS AND REDUCED ROAD STANDARDS IN LOWERING THE COST THRESHOLD FOR ACCESSING TIMBER IN WESTERN NORWAY.

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In Norway, less than 40% of the sustainable annual cut is harvested, significantly less than the neighbouring countries of Sweden and Finland, who utilise more than 80% of their net annual growth. The low level of activity can partly be ascribed to the very limited degree of access to the forest resource in many parts of the country. Especially in the western parts, which are characterised by steep and rugged terrain, road densities can be as low as 10% of the recommended 30 m ha^{-1} needed for rational cable-yarding operations (fig.1). Around 40% of the harvestable volume is located in such areas (roughly 100 million m^{3}). At the same time, the number of roads built or upgraded in Norway decreased by 60% in the period 1998-2008, suggesting that the situation is not likely to improve in the medium term, despite the road construction (or upgrading) cost remaining relatively constant over the same period (Statistics Norway, 2009).

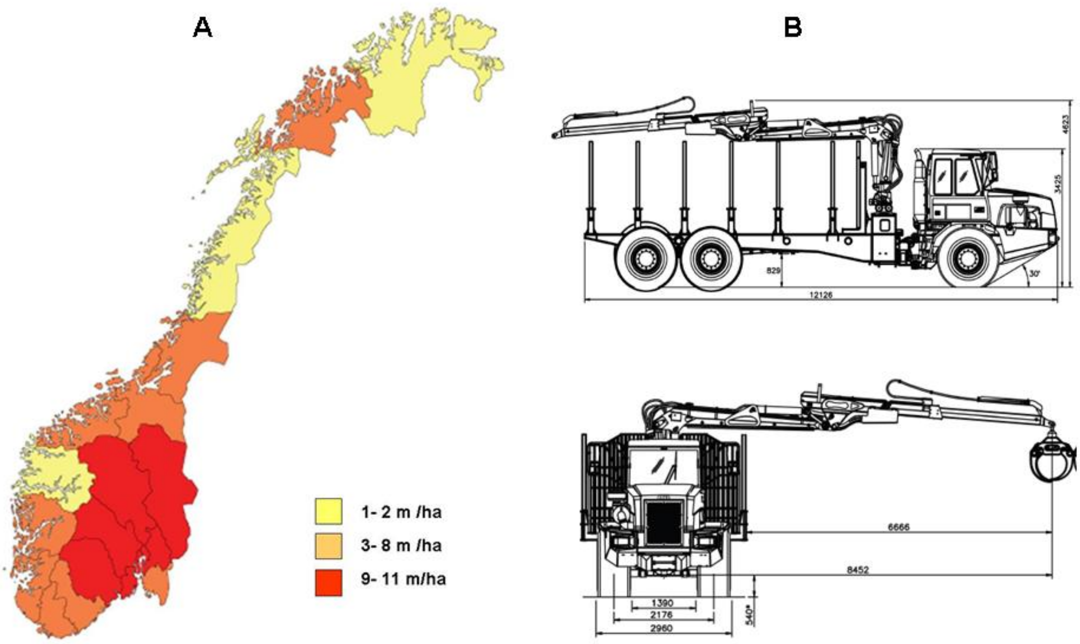

Figure 1 A Forest road densities in various parts of Norway (m ha^{-1}), excluding public roads (adapted from Statistics Norway), and B, Dumper fitted with timber loadbed and crane.

The potential to revitalise the level of forest activity in this region is limited by the large investments in machines and infrastructure and lack of experienced entrepreneurs with proven business success. Articulated dump trucks fitted with timber bunks are capable of hauling timber in-field, on poor roads, and at higher speeds on good roads (fig. 1B). They are commonly available in Norway and converting the base machine to timber hauling is a relatively low cost investment that can provide additional turnover for entrepreneurs in rural settings. When working in areas with poor roads, or accessing new areas under constrained economic conditions, it can be advantageous to invest in portable equipment rather than infrastructure. Lileng and Haartveit (2004) put forward a 'total cost' approach to calculating the delivered cost of timber. This approach assesses the trade-off between vehicle performance and road construction costs in minimising the total delivered cost from stump to customer. In this paper, we apply the total cost approach in testing the viability of doing an intermediate haul with an adapted dump truck instead of building roads to truck standards. Using time study data, road construction costs, and a simulation of likely standards and distances, the economic analysis attempts to show the potential for lowering the investment threshold necessary in accessing new forest areas.

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Statistics Norway (2009)

Keywords: *simulation, haulage, road classes, trucks, delivered cost*

40. THE DRYING OF WOOD CHIPS WITH SURPLUS HEAT IN NORWAY

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This study has investigated the drying of wood chips through use of surplus heat from two hydroelectric plants in the western part of Norway. The wood was chipped and loaded into the dryer; both a tractor-trailer and a container were used. The dryers had perforated floors where warm air from the plants was funneled into the dryer, using an electric fan of 4 kW.

Four separate trials were conducted in September and October 2009. The drying capacity of the trailer and the container was roughly 11.5 and 29 loose m3 respectively. The effective height at which drying took place wa 1.2 m and 1.9 m. The temperature of the air channeled into the dryers was 14–18 °C in the trailer and 25–26 °C in the container.

The fan was operative for 139 hours (2 times) for the trailer and 121.5 and 67.5 hours for the container. The fan used 556 kWh (2 times), 486 kWh and 270 kWh of electricity respectively. The chips located at the bottom dried first, and chips located above dried later. The moisture content in the chip was 66.1 to 52.1% (wet base) before drying and 9.6 to 6.9% (wet base) after drying. Upon completion of the drying procedure, there was no substantial difference in moisture content from top to bottom of the pile of wood chips. The wood chips were weighed before, during and after drying. In the trailer, the wood chips weighed 5300 and 5165 kg before drying and after drying 2185 and 2165 kg. The chips in the container weighed 7845 and 7045 kg before drying and 4010 and 4935 kg after drying. An estimate of applied energy from the power plant was 1432 and 2037 kWh in Kleive and 2115, and 2604 kWh in Viksdalen. The net calorific value as received ranged from 1340 to 2170 kWh per tonne before drying and 4710 to 4860 kWh per tonne after drying. The air current through the dryers was tangible in both locations. The counter pressure from the chips was not sufficient to prevent ample ventilation.

For the container, drying cost roughly one cent USD per kWh; the cost of the trailer was twice as much. This indicates that the drying volume must be as high as feasible. The cheapest option for production of fuel chips is natural drying and chipping at the roadside. In one of the two locations, this costs roughly 2 cents USD per kWh. If the feedstock is detoured through a terminal for conversion to wood chips and on to artificial drying, the cost is about 3 cents USD per kWh.

Artificial drying of wood chips using surplus heat is an alternative when there is a demand for supply of chips with low moisture that produce more heat released during combustion, lower emissions, and better fuel boiler efficiency.

Keywords: *Bioenergy, wood fuel, wood chips, surplus heat.*

41. FINANCIAL SITUATION FOR FINNISH AND SWEDISH CONTRACTORS

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The financial situation for contractors in Finland and Sweden has been analysed and compared. In Finland the situation for small enterprises (turn-over < € 75 000) varies a lot (fig 1).

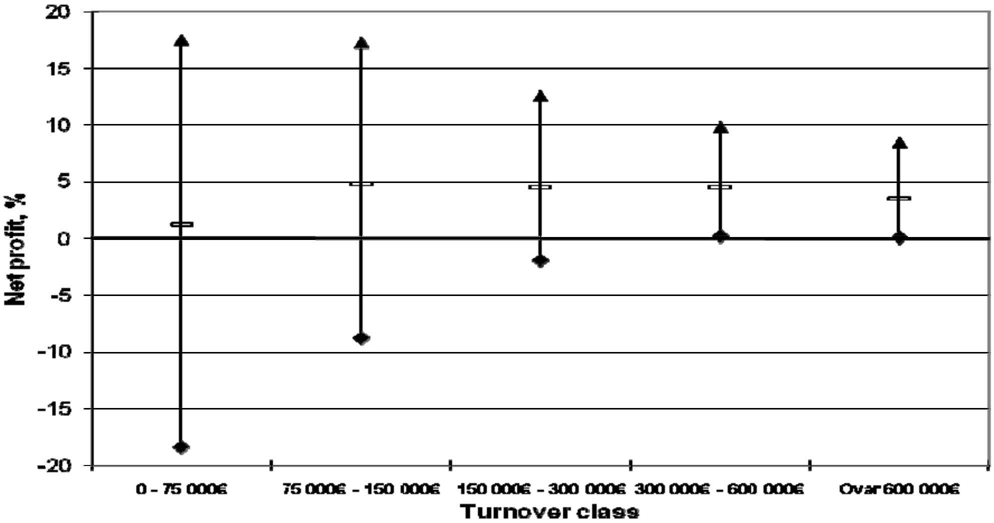

Figure 1. Profitability for Finnish forest machine enterprises with different turnover. Median and upper and lower quartiles.

Many of them are not showing any profits at all, while other seems to be quite profitable. For larger enterprises the situation is less variable and they also show a small profit. Possibly the better part of the small companies can adapt their work to the changing conditions and have alternatives to find their means. On the other hand, the hard competition and overwhelming negotiation power of customers keeps a part of smaller enterprises unprofitable. Not even the record cuttings in 2007 in Finland helped the situation.

Swedish forest contractors have similar development as their Finnish colleagues (fig 2). Except for 2005, which was an exceptional year due to the large storm-felling in Southern Sweden, the profitability shows a decreasing trend during the latter part of the 00 decade.

In general it can be concluded that too many of the forest contracting companies show a volatile economic situation. The figures for 2009 are not yet available, but the presumption is that the economic decline has not been as severe in Sweden as in Finland, which should show. However, closing of businesses is difficult to find. List of bankruptcies do mostly not show closing of a forest machine enterprise. Machines are usually the only possession. The financing company take machines and the owner stays with possible surplus debt.

In Finland the economic depression has forced forest industry to close many mills for good. They also downsized their wood procurement organisations with the goal to decrease the number of forest machine contractors working for them. Entrepreneurs have to grow their enterprise or many entrepreneurs have to form a network to work for big customers.

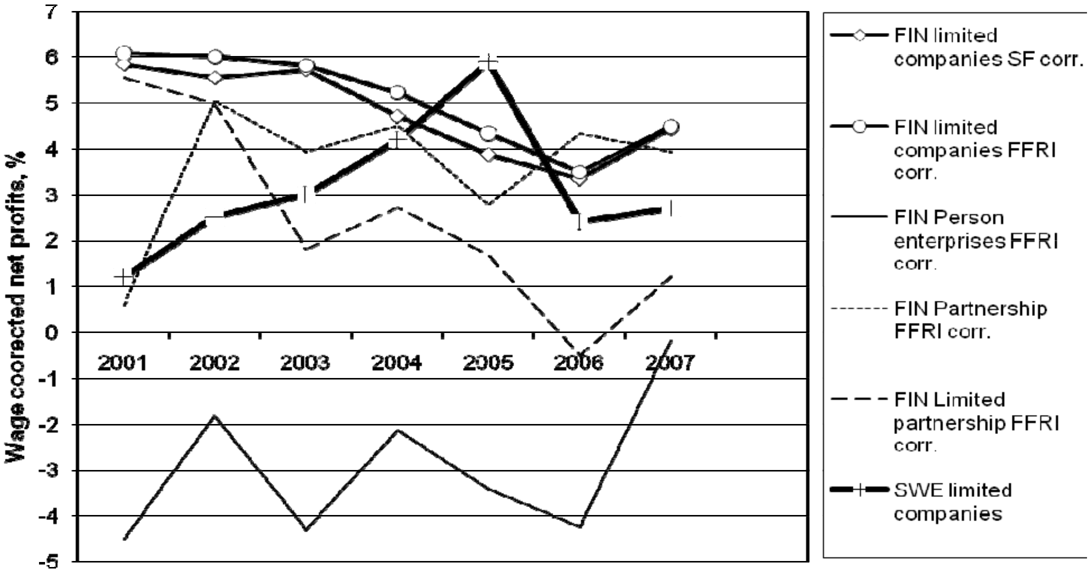

Figure 2. Development of profitability for Finnish and Swedish companies 2001 - 2007. The figures for the Finnish non-limited companies are corrected for owners' wages.

Figures analysed showing the economic situation includes profit values, debts, survival times, reserves and share of investments (fig 3). Salaries are the biggest single cost factor, but after that come depression and capital costs. Constant workload would help to bear these, but there are seasonal and economic variation of workload, against which entrepreneur is barehanded to fight.

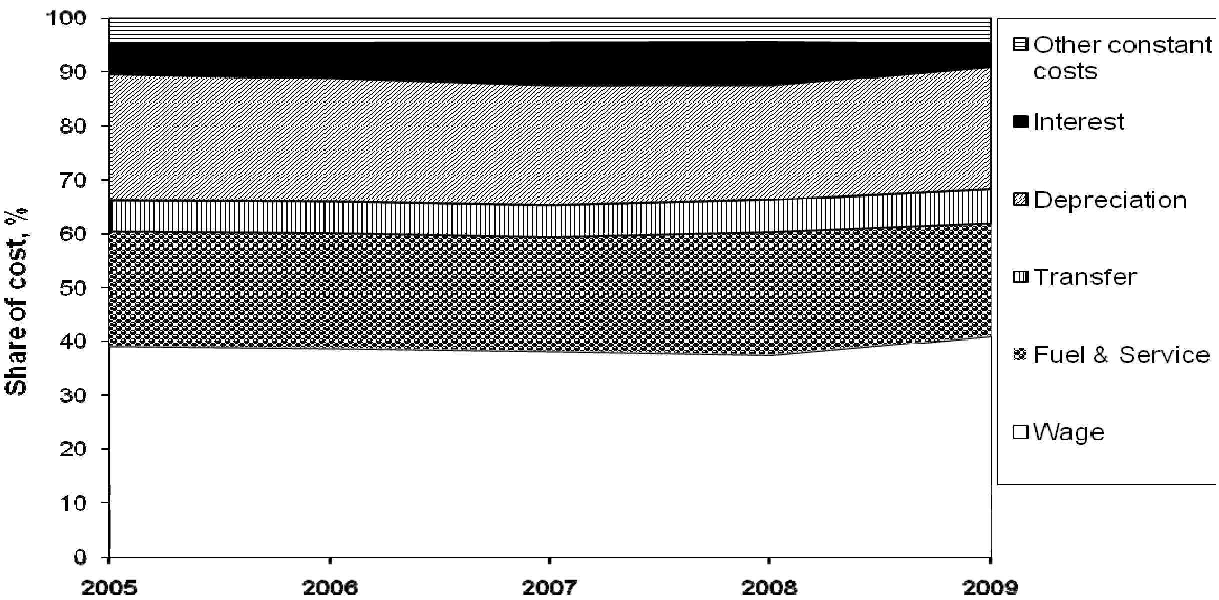

Figure 3. Cost structure of Finnish machine forest enterprises. Average of studied companies.

In order to maintain and develop forest contracting enterprises there is a need to find larger margins and higher profitability. Enlarging of enterprise is a way, which is promoted by big customers. There is need to improve entrepreneurs economic and personnel management knowledge.

Keywords: *Forest machine enterprise, profitability, turnover, cost structure*

42. EXTRACTING AND CHIPPING HARDWOOD CROWNS FOR ENERGY

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Introduction

We studied the feasibility of extracting and chipping hardwood crowns for energy after motor-manual thinning in stands of common beech. Large crowns were extracted and chipped from stands where only sawlogs had been produced (treatment 2), while small crowns were extracted and chipped from stands where sawlogs and firewood had been harvested (treatment 1). Four product-mix alternatives were considered (figure 1).

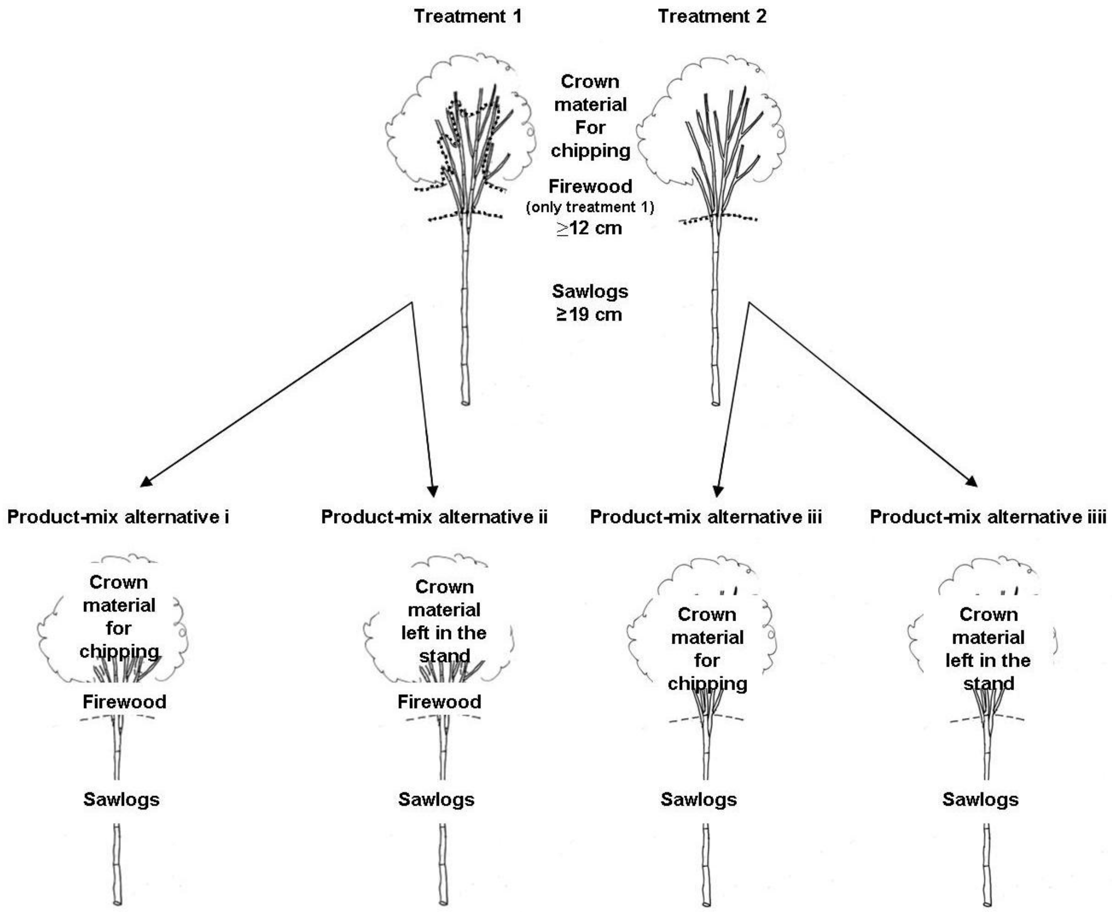

Figure 1. The two treatments and the four product-mix alternatives.

Results

The fuel chip yield was 15 m^3_{solid} per ha when extracting and chipping large crowns while it was 8 m^3_{solid} per ha when extracting and chipping small crowns. The productivity for extracting and chipping large crowns was 8.5 m^3_{solid} per work place hour and 5.9 m^3_{solid} per work place hour when extracting and chipping small crowns. There was no significant difference in the productivity for forwarding sawlogs or sawlogs and firewood. Extracting and chipping large crowns gave a net income of 167 € per ha (11 € per m^3_{solid}), while extracting and chipping small crowns gave a lower net income of 23 € per ha (3 € per m^3_{solid}). In table 1 it can be seen, that the total economic output for product mix alternative I, ii and iii are quite similar.

Table 1. Total economic output from the four product-mix alternatives.

Treatment		1 (small crowns)		2 (large crowns)	
Product-mix alternative		**(i)**	**(ii)**	**(iii)**	**(iv)**
Production of chips		**YES**	**NO**	**YES**	**NO**
Income					
Sawlogs	€ per ha	1205	1205	1205	1205
Firewood	€ per ha	322	322	0	0
Fuel chips	€ per ha	236	0	450	0
Total Income	€ per ha	1762	1527	1655	1205
Costs					
Harvesting	€ per ha	211	211	122	122
Forwarding sawlogs	€ per ha	196	196	196	196
Forwarding firewood	€ per ha	64	64		
Extracting and chipping of tops	€ per ha	213		283	
Total Cost	€ per ha	684	471	600	317
Net income	**€ per ha**	**1079**	**1056**	**1055**	**887**

Discussion

Because the difference in economic outcomes is small between the three product-mix alternatives (i), (ii), and (iii), the rational choice would be to produce only two assortments in each stand, either product-mix alternative (ii) (sawlogs and firewood billets), or product-mix alternative (iii) (sawlogs and fuel chips).

In stands where firewood billets are produced, the minimum top diameter can possibly be reduced, and the utilised volume could thereby be increased. Firewood billets should be the product of choice in stands of poorer quality, as a larger proportion of the harvested volume would not meet sawlog specifications but would meet the size requirements for firewood. An increased firewood fraction in the product-mix would make a larger economic contribution than an increased chip fraction.

Fuel chips should preferably be done in stands with large crown residues. The stands should also be of some size minimising the relocation costs.

The study showed that extracting and chipping large hardwood crowns is feasible and can make a substantial contribution to woody biomass feedstocks.

Keywords: *Bioenergy, chipping, firewood, forwarding, fuel-chips, hardwood.*

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43. ENERGY CONSUMPTION BY ENERGY WOOD SUPPLY

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Renewable energy resources, including biofuels, have received considerable attention in recent years. The amount of energy used to harvest and transport biomass in relation to the amount of energy harvested is an important factor in the assessment of energy gain this energy carrier represents.

The aim of the study was to determine the energy consumption of forest fuel supply chains. Three different chains were analysed: stemwood, small diameter trees and logging slash. The entire chain from harvesting to final delivery to energy plant was included. By-products from forest industry and stumps were not included in this task. The indirect energy use, like construction of machines, roads etc., were not taken into account.

By comparing different logistic chains and systems, it was possible to analyze which operations that was more energy effective than others. The analysis was based on previous research of productivity and fuel consumption of harvesting, chipping and transportation of industrial wood and forest fuel. Out of that data, the total energy consumption for the whole chains were calculated. The results showed that the direct energy consumption by harvesting and transportation of forest fuel is very little compared to the energy output of the fuel. For a typical supply chain from forest to energy plant, the input versus output of energy was approximately 3.2 % for stemwood, 2.8 % for small diameter trees and 2.5 % for logging slash.

It is important to notice that there are a number of uncertainties when calculating the fuel consumption of the various supply chains. For instance varies transport lengths, which affect consumption significantly. In addition, it is important what the energy content of the product harvested and transported represents. It will include a huge difference between harvesting stemwood of oak, which has high energy content, compared with harvesting small diameter trees of spruce with low middle dimension. In addition, there are variations between seasons, for example consumes forestry machines more fuel in the winter when there is a lot of snow.

Figure 1; Consumption of diesel oil divided on different assortments. Litres of diesel / m^3 solid of wood supplied.

Keywords: *Energy consumption, forest machines, energy wood supply.*

44. COMPARATIVE SHELTER-WOOD HARVESTING IN POLAND

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Problem and objectives:
In 2003 in Poland there were 15 harvesters (acquired about 1% of wood). In 2008, the number of harvesters increased up to 180 harvesters (acquired about 8% of wood). The main factors for increase in the number of machines are: dwindling number of forest workers due to "hard labor" and change of attitude in the society to using machines in the forest. Harvesters are currently the largest application for clear cutting forest. However, due to the increase of protected areas such as Nature 2000 sites, shelter-woods are increasingly used, mainly taking into consideration the natural regeneration of young stand.

The aim of this study was to compare two methods of cutting wood (without skidding) by using the harvester in shelter-wood system: short-wood-system (2.7 - 6.0 meter) and long-wood-system (> 6.1 meter). It should be emphasized that the method of long-wood-system is typical for the Polish logging. The aim was to identify which method is more efficient in the context of demand of long-wood assortment in Poland. The damage to the residual stand, especially young stand was also taken into account.

Material and methods:
In this study, eight areas of research were selected. On the areas of research, the plots were divided. On the plots all the trees to be removed were numbered. Operating routes were predetermined by an average of 20 m away from each other. The tests were performed on both plots using "photo-timing" with accuracy of 1 second, on the basis of which efficiency, time-consuming, labor costs, and damage to trees were examined. The entire machine work was registered by the camera to later resolve any ambiguities in the record made directly on the surface. The numbering of trees was to facilitate the passage to find the necessary film. In these studies, efficiency of harvester in cubic meter/time (m^3/h), unit costs, and direct cost per unit were calculated.

In this study the damage of the remaining stand after the work was assessed. Damages in the young stand and old stand were assessed separately. The damage of young generation assessment was performed using transects. A diagonal strip of 2 m width was designated on each of the research plots. Then, all intact and damaged trees in young stand were counted on the defined area.

Results:
In the case of the short-wood-system, yield is set at 14.90 m^3/h, while for the long-wood-system - at 12.05 m^3/h. The difference between the yields of methods was 2.85 m^3/h. In order to determine the reasons for the discrepancies, the course of work on individual plots was analyzed. In the long-wood-system method, maneuvering of the harvester head occupied over one fifth of the total working time. The machine needed a slightly smaller percentage of time to travel (approx. 18%) and for the pruning and logs (about 17%). Total support time of the entire machine (consisting of travel, repairs and interruptions) accounted for more than 30%, and effective time was about 70%. Regarding the harvester working time structure using the method characterized by a smaller assortment (short-wood-system), the inefficient time was 5% shorter (approx. 25%). Time spent on travel accounted for approximately 7% less than using the method of long-wood-system. The effective working time accounted for almost 40% of the delimbing time and crosscut rollers and logs. As far as damage in the stand is concerned, applying the method of short-wood-system resulted in less damage.

Conclusions

The increase of semi-protected areas will cause an increase in the share of forest harvester machinery in shelter-wood. In this case, the study examines the application of the short-wood-system and the long-wood-system. The main conclusions are:

1. very high average time of machine head maneuvering decreased the efficiency significantly in both cases, but the efficiency of the short-wood method yield is about 24% higher than of the long-wood-system method,

2. higher percentage of damaged trees (young stand) occurred in the long-wood-system, which could be the cause of difficulties arising from the long-wood assortments,

3. long-wood-system method is a more costly solution, in addition to the fact that obtaining logs significantly affects the acceleration of wearing of the working machine systems and their unreliability.

Keywords: *shelter-wood harvesting, short-wood-system, long-wood-system*, *damage to trees*, *Poland.*

45. EFFECT OF BOGIE TRACK AND SLASH REINFORCEMENT ON SINKAGE AND SOIL COMPACTION IN SOFT TERRAINS IN RUSSIA

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Material and methods

A study of the effect of bogie wheel track and slash reinforcement on the sinkage (as rut depth) and soil compaction (as bulk density) of silt loam soil was carried out in the spring and autumn seasons at two harvesting sites in Russia. The first study experiment on the effect of a bogie track was carried out at a cutting area in the Republic of Karelia, Russia. The tests were conducted in late spring. The forwarder used in the study was a Ponsse ELK. The second study experiment on the effect of slash was carried out at a cutting area in the Tver region, Russia. The tests were conducted in early autumn. The forwarder used in the study was a John Deere 1410. Soils in the test areas were silt loams, and moisture contents were 80%, 88%, and 93%. Slash mat densities for Tver conditions were about 15 kg/m^2. The six treatments (combination of ground contact devices, surfaces, moisture contents W) with one to ten passes were assigned to one each of the plots within each block. On each plot, measurement points were set as follows: left rail, right rail, and cutting strips (monitoring of natural properties). The rut depth was measured in both right and left rails and the average value of the trail depth was calculated. To determine the compaction of soil, the organic layer was removed from each measurement point and soil samples were taken using a soil hammer. Soil samples were taken at measurement points according to a standardized methodology from the surface layer of 0–5 cm in the middle zone of the skid trails. The soil samples were delivered to the soil laboratory in airtight packaging and weighed with electronic balances. The bulk density of the soil samples was also determined. Soil compaction was analysed using changes in bulk density following traffic. The soil samples for bulk density were collected with a soil hammer with a 4 cm diameter and 4 cm length rings. Oven-dry weight (12 hours at 105 °C) was used to express bulk density as weight/unit volume (g/cm^3) and moisture content. Four samples were taken for bulk density at each of 11 depths in the soil profile (0–5 cm) for a total of 44 from each plot. This sampling regime was applied to both pre-treatments (total of 20 samples per plot). In addition to changes in soil physical properties, soil disturbance was quantified using measures of rut depth at the midpoint of each plot. All samples were collected after traffic, with undisturbed samples collected from the rut centre line.

Results

In the case of a wheel with a tyre on wet soil (Karelia, W=93%), the initial soil bulk density value was 1.06 g/cm^3. The post-treatment bulk density increased slightly up to 1.15–1.17 g/cm^3 during the first 5 passes. It was slightly lower by the 6th and 7th passes at 1.11 g/cm^3, and grew again and stabilized by the 9th and 10th passes at 1.14 g/cm^3. The rut depth increased rapidly up 0.71 m, particularly during the first 5 passes. The forwarder clearance (0.67 m) was exceeded on the 9th pass.In the case of a bogie track on wet soil (Karelia, W=93%) the initial soil bulk density was 1.03 g/cm^3. The post-treatment bulk density increased slightly up to 1.17 g/cm^3 within the first 6 passes. Then it decreased slightly by the 7th to 10th passes and stabilized at 1.13 g/cm^3. The rut depth increased evenly up 0.48 m, particularly during the first 3 passes. The forwarder clearance was not exceeded. In the case of a wheel with a tyre on moist soil (Karelia, W=80%) the initial soil bulk density was 1.06 g/cm^3. The post-treatment bulk density increased up to 1.33 g/cm^3 within the first 4 passes. Then it decreased slightly by the 5th to 7th passes at 1.29 g/cm^3, decreased again, and stabilized by the 8th to 10th passes at 1.24 g/cm^3. The rut depth increased rapidly up 0.40 m, particularly during the first 7 passes. The forwarder clearance was not exceeded. In the case of a bogie track on moist soil (Karelia, W=80%) the initial soil bulk density was 1.05 g/cm^3. The post-treatment bulk density increased slightly up to 1.33 g/cm^3 within the first 6 passes. Then it decreased slightly by the 7th to 10th passes and stabilized at 1.30 g/cm^3. The rut depth increased evenly up to 0.22 m. The forwarder clearance was not exceeded. In the case of a conventional wheel (Tver, W=88%) the post-treatment bulk density increased slightly up to 1.10

g/cm^3 within the first 5 passes. Then it stabilized by the 6th to 10th passes at 1.11 g/cm^3. Ruts were not detected (less than 0.05 m). In the case of a bogie track (Tver, W=88%) the post-treatment bulk density increased slightly up to 1.08 g/cm^3 within the first pass. It then stabilized at 1.10–1.11 g/cm^3. Ruts were not detected (less than 0.05m). Bulk density and rut depth trend curves based on the obtained data were constructed using a Cubic regression model with R-square values of 0.99 for depths and 0.80–0.99 for density. Soil type was classified according to the Russian soil-classification standard based on the plasticity index and the relative proportions of the various soil separates as described by the classes of soil texture. The relative proportions of the various soil separates in the studied soils corresponded to the silt loam class.

Conclusion

Regarding soil compaction, the CTL system met the ecological requirements for this type of forest soil (1.4 g/cm^3) within the bounds of the experimental design. However, an increase in bulk density was found in all treatments at the silt loam soil surface (0 to 5 cm depth). The magnitude of the increase was a function of the number of passes, the slash/track presence, and the moisture content. In comparison with conventional wheel treatments, bogie track treatments showed that compaction of wet and moist silty loam held irregularly. The formation of a compacted zone under the traction element, helped by the reinforcement of forest soil roots, took place in the first phase. With the increasing number of passes the compacted zone deepened and partly collapsed, and there was a lateral bulging of the soil. Then there was a slight increase in density, due to the formation of secondary hardened zones. The results for slash reinforcement treatments indicated that a layer of slash mitigated the effect of a single forwarder pass and subsequent passes. The bulk density did not change considerably. The increased bulk density for the forest soils was nearly 10% of that of the slash covered soils. Also, the present of the combination “slash + track” made no apparent difference within the bounds of the experimental design. Regarding sinkage, the CTL system with a conventional wheel did not meet the ecological requirements for thinning (rut depth should be less than 0.15 m). Moreover, rut depth reached the forwarder clearance of the machine (0.67 m) on wet soil. The results of bogie track treatments showed that the rut depth did not met the ecological requirements for thinning (0.15 m) particularly on wet soil, but was within the design clearance of the machine. In the slash treatments the rut depth changed only slightly. All mechanized harvesting systems applied in Russia cause different kinds of negative environmental impacts. When applied on sandy or sandy loam soils, all mechanized systems demonstrated almost the same impacts on soil. However the proportion of sandy soils is small in Russian forests in comparison with loams and clays. On loams and clays, the traditional tree-length and full-tree systems, unlike the CTL system, resulted in significant soil compaction, but at the same time formed almost no track. Over 50% of the harvesting sites in Russia are on wet and soft soil terrain. Therefore, the application of the CTL system has to be improved in order to reduce rut formation in the most common soil terrains. Hence, the associated CTL machine ground contact devices and slash layer must be suitably adapted for specific harvesting sites, based on terrain classification criteria. The adaptation requires a further study of the effects of the ground contact device (tyre or track) and size of slash layer, the induced ground contact pressure, and the physical characteristics of the slash layer that are affected during soil deformation, which negatively influence the CTL system’s cross-country ability and environmental impact.

The fully mechanized CTL wood harvesting system based on a single-grip harvester and a wheel forwarder has become more common in Russia. Many reasons are given for this statement, including reductions in labour needs, work safety risks, environmental damage, and landing areas in comparison with the traditional tree-length and full-tree systems. In many specific conditions the CTL system is cost competitive with tree-length harvesting. However, some of the advantages have not been sufficiently defined for specific conditions, particularly related to cross-country ability and ecology on soft terrains. This research was intended to investigate how a bogie track and slash reinforcement influence the sinkage and compaction of prevalent silt loam soil, and how these effects interact with forwarder traffic and moisture content.

Keywords: *CTL method, forwarder, rut depth, bulk density, slash, bogie track.*

Acknowledgements

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46. NECK MUSCLE ACTIVITY PATTERNS AMONG NORWEGIAN MACHINE OPERATORS IN DIFFERENT BRANDS OF FOREST HARVESTERS

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Background

Several investigations have shown that the prevalence of musculoskeletal disorder is high among forest machine operators. The ergonomic designs of workplaces are important in prevention of work-related musculoskeletal disorders (1) and in the mechanized forestry, neck pain and sick leave among forest machine operators working with extremely pronated hands have been reported (2). We wanted to investigate if the ergonomic design of the harvester workplace could be related to differences in neck pain.

Our hypothesis was that different ergonomic construction of control lever in harvester brands could give exposure to different level of static muscle work, disposing for neck pain.

Material and methods

Timberjack and Valmet harvesters were chosen for the investigation. These brands show clear differences in several construction details of possible ergonomic importance. In the Timberjack harvester the control lever operation is often a combination of using small joysticks by the fingertips and a keyboard designed to be operated like a piano with the palm of the hand in a horizontal position. In the Valmet harvester most functions are gathered in large joysticks where the palm is used in a vertical position and the hand grasps around the stick and the fingers press the buttons like an accordion. The ergonomic difference between these two designs is that the hand/fingers in the Timberjack shift between a horizontal and vertical position while in the Valmet the work load will be only in the vertical position of the hand. On both vehicles the cabin can be rotated 360 degrees, but on the Timberjack the crane is installed directly on the chassis, while on the Valmet it is either in the middle or on the right side of the cabin. As a consequence of the design, the body postures for the operator in the Timberjack will involve increased twisting of the head to follow the movements of the crane, while in the Valmet no such extra movement is necessary.

From a broader study of 39 forest machine operators driving several brands of vehicles, operators driving Timberjack (n = 7) and Valmet (n = 6) were selected. Muscle activity was continuously measured during a whole working day. Surface electromyography (sEMG) was used for this purpose and the amplitude and frequency parameters in the right and left upper trapezius muscles were recorded. A period with sustained low-level muscle activity **(**SULMA period) is defined as a period with continuous (without interruptions) static muscle activity above 0.5% EMG_{max} for 1.6 s or longer (3). The number of SULMA periods was calculated and analyzed for both right and left neck muscles in ten predetermined intervals: 1.6 – 5 sec, 5 – 10 sec, 10 - 20 sec, 20 sec -1 min, 1- 2 min, 2 - 4 min, 4 - 8 min, 8 -10 min, 10 - 20 min, > 20 min. The number of SULMA periods was also expressed in cumulative periods above the minimum value of the already predetermined ten intervals. Discomfort/pain in the neck was rated within five categories according to the Standardized Nordic Questionnaire: 0 days, 1-7 days, 8-30 days, more than 30 days and daily (4). The scale was also dichotomized into categories with pain ≤ 30 days (0) and pain >30 days.

Results

The operators in the Timberjack showed a significantly higher number of SULMA periods with short duration in the *right upper trapezius muscle* compared to the Valmet operators (Fig. 1a). The Valmet operators had significantly more SULMA periods > 10 min duration per hour compared to the Timberjack operators (Fig 1b) in the *left upper trapezius muscle* (5). A slightly higher amount of Valmet operators reported neck pain > 30 days compared to the Timberjack harvesters (non-significant).

Conclusions

This study showed that operators driving Valmet vehicles had a significantly higher number of periods with sustained low-level muscle activity (SULMA) above 10 min duration per hour in the left upper trapezius muscle and the same tendency in the right. A higher level of static muscle activity and less muscle rest were also found among the Valmet operators in the same two muscles. This finding may be explained by the more fixed postures in the Valmet vehicle. The increased number of cumulated long SULMA periods among the Valmet operators was explained by the hand/wrist in work postures being either pronated or suppinated in a vertical position during control lever operation. The higher exposure of low level muscle activity found in the Valmet brand indicate a possible higher probability of developing muscle pain in operating such kind of control lever.

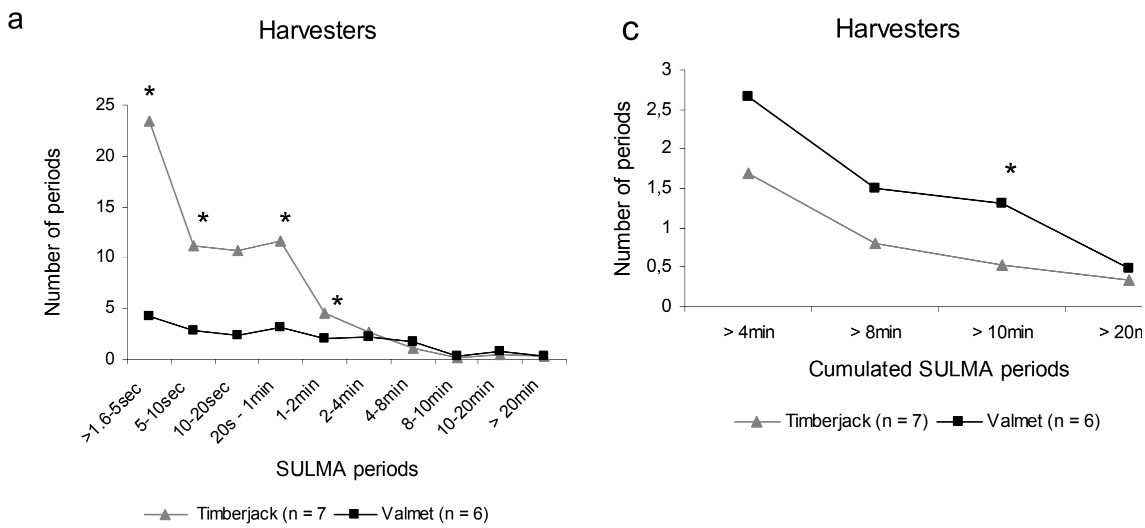

Figure 1 Mean number of periods with sustained low-level muscle activity (SULMA) *in the right upper trapezius muscle* among machine operators operating control levers while driving Timberjack and Valmet harvesters (a) and mean number of *cumulated* SULMA periods in the *left upper trapezius muscle* (c).

Keywords: *sustained low level muscle activity, control lever, machine construction*

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47. BOOM AUTOMATION

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To stay competitive internationally, the Swedish forestry sector must increase its productivity by 2 to 3% annually. There are a variety of ways in which productivity can be increased. One option is to develop remote-controlled or unmanned machines, thus reducing the need for operator intervention. Another option — and one that could be achieved sooner than full automation — would be to make some functions semi-automatic. Semi-automatic operation of the knuckle boom and felling head in particular would create “mini-breaks” for the operators, thereby reducing mental and physiological stress. It would also reduce training time and increase the productivity of a large proportion of operators.

The objective of this work has been to develop and evaluate algorithms for simplified boom control on a forwarder. Algorithms for so called boom tip control, as well as automatic boom functions have been introduced. The algorithms solve the inverse kinematics of kinematically redundant knuckle booms while maximizing lifting capacity. The boom tip control was evaluated – first by means of a kinematic simulation and then in a dynamic forest machine simulator. The results show that boom tip control is an easier system to learn in comparison to conventional control, which can lead to savings in production due to shorter learning times and operators being able to reach full production sooner. Boom tip control also creates less mental strain than conventional control, which in the long run will reduce mental stress on operators of forest machines. The maximum lifting capacity algorithm was then developed further to enable TCP path-tracking, which was also implemented and evaluated in the simulator.

An evaluation of the fidelity of the dynamic forest machine simulator was performed to ensure validity of the results achieved with the simplified boom control. The results from the study show that there is good fidelity between the forest machine simulator and a real forest machine, and that the results from simulations are reliable. It is also concluded that the simulator was a useful research tool for the studies performed in the context of this thesis work.

The work had two overall objectives. The first was to provide the industry and forestry sector with usable and verified ideas and results in the area of automation. This has been accomplished with the implementation of a simplified boom control and semi-automation on a forwarder in a recently started joint venture between a hydraulic manufacturer, a forest machine manufacturer and a forest enterprise. The second objective was to strengthen the research and development links between the forestry sector and technical university research. This has been accomplished through the thesis work itself and by a number of courses, projects and Masters Theses over the last three years. About 250 students in total have been studying forest machine technology in one way or the other.

Keywords: Hydraulic manipulator, redundancy, kinematic control, local optimization, knuckle boom, forest machine, forwarder, boom tip control, joystick control, simulations, path following.

48. COST-EFFECTIVENESS OF THE MECHANIZED SEEDING FOR REFORESTATION OF SCOTS PINE IN LATVIAN CONDITIONS

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Direct-seeding is a widely used reforestation method for Scots pine (*Pinus sylvestris* L.) in countries of Northern Europe - Fennoscandia and Estonia. Scots pine is a most widespread conifer tree species in Latvia growing mostly on relatively poor sandy soils where, direct seeding can be a viable alternative for reforestation. Artificial regeneration applies to about a half of the forest area restocked annually in Latvia, however, share of direct seeding in that is negligible. Despite the fact that direct seeding of pine (both – manual and mechanized) successfully was applied in Latvia till the nineties of last century, nowadays, manual planting following soil scarification by disc trenching machines is nearly the only reforestation method used in Latvia.

In 2009 the study was performed to examine the progressive technology of mechanical seeding in Latvia. The objective of the study was to compare the cost-effectiveness and silvicultural effect of mechanical seeding to other reforestation methods – manual seeding and planting. The experiment established in the spring of 2009 included three reforestation variants of pine – manual planting, manual seeding and mechanical seeding ((Bracke seeder S35.a attached on M26.a two-row mounder).

Based on our study the prime costs of reforestation (including costs of reproductive material) of one hectare using mechanical seeder was 475 EUR while that of manual seeding and planting was 437 EUR and 643 EUR respectively. Our study revealed that mechanical seeding is a cost-competitive to manual seeding and more beneficial in comparison to planting.

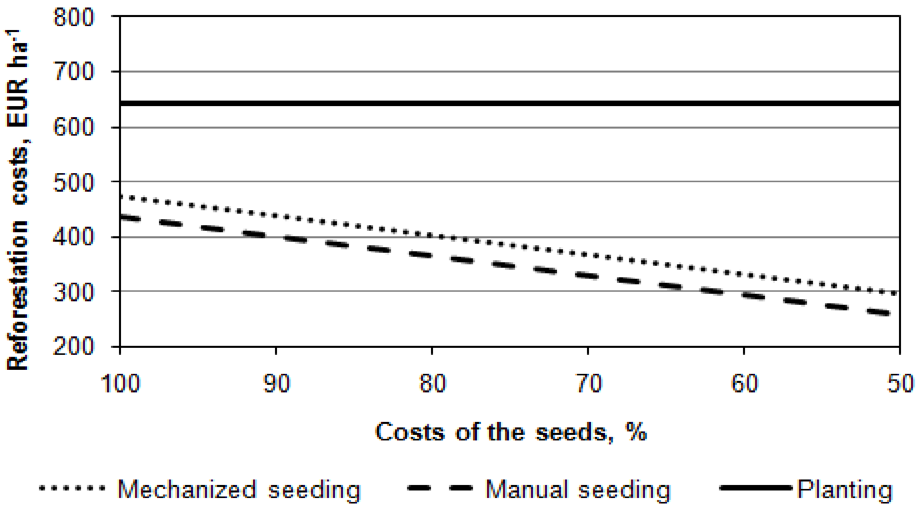

Figure 1 The costs of regeneration of 1 ha pine stand in relation to costs of the seeds (% of the base price – 714 EUR per kilogram).

The costs of the seeds have a crucial impact on regeneration costs accounting for ¾ of the total costs of mechanical seeding. The regeneration costs can be reduced substantially if the price of the pine seeds is diminished (Fig. 1). The seeds with low germination's rates are not desired by managers of forest nurseries for rearing of planting stock wile can be successfully applied in direct seeding offering the option for reduction of costs of mechanical seeding. In order to make mechanized seeding costs more gainful the import of seeds from neighbour countries can be considered as well.

For evaluation of the cost-efficiency of mechanized seeding of pine the further investigations are needed to assess the costs for tending of established stands according the reforestation methods applied.

Keywords: *Mechanized seeding, cost-effectiveness, reforestation.*

49. THE LOCATION, AMOUNT AND ENERGETIC POTENTIAL OF COPPICE UNDER THE POWER LINE TRACES IN ESTONIA

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Purpose of the work
The aim of the work was to assess the volume of biomass growing under the power line traces, its energy potential and location of different counties in Estonia.

Scientific innovation and relevance
During the next decades the available quantities of traditional wood fuel in Estonia will start to decrease and therefore biomass from power line traces should be considered as additional source for wood chips otherwise in the long-run the supply with wood fuels will not be sufficient to keep the consumption on the present level. The general goals of promotion of bioenergy are pointed out in *the Long-term Public Fuel and Energy Sector Development Plan until 2015* and *the Long-term Development Programme of Promotion of Biomass and Bioenergy year 2007 – 2013*: by 2010 renewable electricity should account for 5.1% of gross consumption, and by 2020 electricity produced in combined heat and power production stations should account for 20% of gross consumption. The need to utilize coppice from the power line traces will become particularly urgent, if the combined heat and power production from wood biomass will expand. The goal of the study was to establish sample plots to assess the volume of biomass growing under the power line traces, its energy potential and location which could be used as an input for wood chips demand-supply modeling.

Approach
As a result of the field experiments in 2009 initial data was collected. At first 42 areas were selected according to different soil types and 126 sample plots were created. The location and amount of trees crowing inside the sample plots were measured. According to the methodology sample trees were collected from outside the sample plots. To model the growth of trees the height, age and the diameter of the stem and additional diameters from the height 10cm, 50cm and 125cm were measured. For the laboratory analysis, stem branches and leaves/needles of sample trees were separated to measure mass, moisture, ash content and the calorific value. Later the results were analyzed and initial growth models were made. In addition using different map layers the potential growth and location of biomass in consideration of length and width of power line traces were assessed separately for all counties of Estonia.

Results
The results of the study indicated that according to age of trees and soil type the amount of biomass varies between 39.2 kg/ha to 18149.9 kg/ha and gave an average of 1743.9 kg/ha. Average gross calorific value of the stems was 19.956 kJ/g and 20.732 kJ/g for branches. Average ash content for stems was 1.854% and 2.710% for branches. Based on the results of the study the analysis of the biomass potential of the power line traces of all counties of Estonia was carried out. It was determined that the biggest biomass potential have Ida-Virumaa, Harjumaa and Pärnumaa counties. During the coming years the inventory of the sample plots will be repeated to estimate the growth and the productivity of the coppice.

Acknowledgements
The work was supported by the Environmental Investment Centre of Estonia (grant Nº 48).

Keywords: *biomass potential, power line traces, gross calorific value, ash content, growth* models

50. MODELLING PRODUCTIVITY OF NOVEL MACHINE SYSTEMS – APPLICATION ON FOREST FUEL EXTRACTION AND LONG-TERM FOREST SCENARIO ANALYSES

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Background

In long-term scenario analyses in forestry, forest growth and management activities are simulated based on assumptions of the forest's development and forest owner's behavior and often evaluated using economic, social or ecological terms. Economic aspects such as extraction costs are considered either directly through optimization (e.g. Backéus *et al.*, 2005) or indirectly through simulation according to management guidelines or previous management history, or both (e.g. Holm & Lundström, 2000). Management simulations result in an estimate of the logging potential for the forest area at hand. Forest fuel logging potential has typically been derived from appending forest fuel extraction to roundwood extraction treatments considering economic and ecological constraints (cf. Skogsstyrelsen, 2008). From the very same simulations the future forest state, expressed as e.g. development in number of stems per hectare over time, and also the need for a particular machine system (cf. Skutin *et al.*, 2006) could be derived. Unlike final felling, revenues from forest fuel extraction during first thinnings are expected to be of about the same magnitude as the revenue from roundwood extraction or the cost of pre-commercial thinning. This will probably influence the timing and type of all forest management activities throughout the rotation period of a stand (cf. Heikkilä *et al.*, 2009).

Over recent years, as a result of energy policy at global, European and national levels (Anon., 2010), the prices and demand for bio-fuel from the forest have increased (Anon., 2009). This has lead to increased extraction rates and decreasing marginal net revenues for different forest fuel assortments (cf. Athanassiadis *et al.*, 2009). New and improved methods and techniques for extracting logging residues, stumps and whole-trees from young stands are therefore currently being investigated (e.g. Bergström *et al.*, 2007). The accuracy of forest fuel extraction potential estimates, both from thinnings and other treatments, will likely be improved if productivity in forest fuel extraction is modeled accurately and fully incorporated within the ordinary logging potential estimate. Furthermore, the forest stakeholder's goal fulfillment (e.g. increased economic outcome) will also increase. This abstract summarizes a report by Sängstuvall (2010) covering productivity estimates with a focus on forest fuel. In order to estimate the harvestable volume based on economic, ecological and practical criteria we must have some measures of the properties and influence of these criteria. Whole-tree or tree-section logging, particularly in young forests, has been little used in Nordic forestry and hence most time studies that are available are comparative. Felling productivity expressed as the number of trees processed per time unit usually decreases with increasing tree size and with increased quality of the output of the felling operation. Forest haulage productivity decreases with, among others, increasing transportation distance, decreasing load size, and decreasing grapple size.

Approaches to modeling forest operations not yet known using a theoretical framework

For harvesting, using a simulation model similar to the one used by Eliasson (1999) seems to be a promising approach. The author has performed a simulation study of a harvester working according to different harvest patterns and with different felling equipments and a journal article on that subject is expected during the next year.

For forest haulage, a different approach has been tested. A theoretical, partially deductive, framework for the time associated with forwarding (Gullberg, 1997) has been adapted to the specific environments described in a number of studies (e.g. Laitila *et al.*, 2007) and time consumption for work similar to that investigated in the time studies has been estimated using the adapted deductive functions. Comparing the calculated time consumptions with the actual results from the time studies shows that the adapted deductive time consumption model has a high level of accuracy. Both the influences of important independent variables as well as the distribution between different work elements were modeled in a good way. This indicates that the time consumption for forwarding under defined working conditions (e.g. pile size, proportion of solid volume) not yet studied or experienced can be modeled in advance with acceptable accuracy. A few questions still remain with respect to the way to adapt the theoretical model to specific situations, since different approaches seemed more or less successful in different cases.

Keywords: *Forest management planning, harvest potential, productivity, simulation, deductive functions, forwarder*

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51. MECHANIZED WOOD HARVESTING: LITHUANIAN CASE STUDY

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Mechanization of wood harvesting (cutting) started in Lithuania in 2005. Unemployment rate was very low (4-6%) and forest sector faced with the absence of forest workers. This factor encourages forestry enterprises to start use harvesters. During the last years the demand for mechanized wood harvesting is increasing in Lithuania. Harvesting machines produced only 3.8 % of wood in state forests in 2005 and this amount increased up to 23.1 % in 2008. About 50 forest harvesters are used in Lithuania presently.

The aim of the study was to investigate the productivity and costs of the most popular harvesters used in Lithuania. The research was performed on 29 cutting sites. It was found that three types of harvesting machines are most popular in Lithuania: harvesters designed for clear and selective cuttings (Timberjack 1270D, Valmet 911.3), excavator based harvesters (New Holand Kobelco E135SRLC) and harwarders (Ponsse Wisent Dual, Ponsse Buffalo Dual, Valmet Combi). The harvesting machines were filmed in normal working situations and data were analyzed by time study method.

Due to different work conditions, productivity of harvesters in study areas varied from 7.6 m^3/hour (average stem volume 0.168 m^3) to 46.5 m^3/hour (average stem volume 1.067 m^3). The models for calculation of harvesting machines' productivity in relation with stem size were formed (different for every machine type).

It was found that in comparative conditions, harvesters designed for clear and selective cuttings reached the highest productivity but the wood production costs were lowest when excavator based harvesters were used. The harwarders had the lowest productivity and the highest wood production costs.

Some aspects of possible reduction of mechanized wood harvesting costs were analysed also. The use of suitable harvesters, increase of experience and education of harvesters' operators and improvement of harvesters' service are the main factors for reduction of mechanized wood production costs in Lithuania.

Keywords: *harvesters, productivity, costs*.

52. PRODUCTIVITY OF HARVESTERS AND QUALITY OF REMAINING STANDS IN COMMERCIAL THINNING IN LATVIA

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One of the key factors affecting the formation of high-quality forests is thinning. The potential of thinning today is not fully realized because it is a complicated and hard work. Latvian's yearly budget accumulating of commercial thinning timber volume is not met, the quality of forests stands is declining, the forest industry does not receive significant volume of timber and forest owners are not able to maximize profits. Today, only about 50 % of the total timber stock in thinning timber volume in Latvia is produced by harvester-type machines. The remaining amount is harvested by using a conventional approach of logging with chainsaws and forwarding with specialized forwarders. Until 2005 it was not possible to use harvesters in commercial thinning in Latvia due to the restrictions of Regulations of Cabinet of Ministers No 217. According to these regulations the area of strip roads should not exceed 12 % of the total area of stand. Consequently, the distances between the technological corridors should not be less than 30 m. Harvester boom cannot cover all of the area between the two corridors during thinning. On the 15th of March, 2005, as the result of a scientific research significant changes were introduced into Regulations of Cabinet of Ministers No 217 allowing the use of up to 20 % of stand for technology corridors. Consequently, the strip roads can be installed every 20 m, which significantly increases the efficiency of harvesters in commercial thinning and secure that all trees marked for removal can be reached by a crane implementing silvicultural targets of forest owner and commercial targets of a logging company.

Despite the above, broad utilization of harvesters in commercial thinning is hindered also by economic factors and forestry restrictions. Logging companies are not satisfied with the productivity performance of logging machines. Productivity of harvesters in commercial thinning is expressed as the volume of timber (cubic meters) harvested per unit of time (per hour). To increase the productivity of logging machines in commercial thinning it is necessary to explore the main factors affecting the productivity of harvesters. The first real use of commercial harvester thinning in Latvia conditions revealed several problems. The most important of them - how to increase the productivity of harvester, while ensuring the quality of remaining stands.

Consultation the literature and the similar studies in Scandinavia as well as the daily work of monitoring the operation of machinated logging of trees in commercial thinning have revealed the main factors affecting labour productivity:

1. Stands thickness (number of trees per hectare);
2. Average volume of harvested trees;
3. Dominant tree species;
4. Stand structure (number of species);
5. Stem form of harvested trees;
6. Stand type (soil resistance);
7. Harvesting time (during daylight hours or night work);
8. Operator's skill and knowledge in forestry.

Taking in to consideration all these factors together "harvester productivity accumulating thinning" becomes a multi-variable complex. To clarify the most important factors, the tests have been done conducted. In the summer at 2008 and 2009 harvester productivity studies were performed in 12 different stands. Felling was selected at geographically different points of Latvia. In all of the selected felling areas the time studies of a crane cycle were implemented using full operation in time for a wood processing approach. Time studies were organized during daytime and at night. The separate study was carried out at specially prepared area of stands where prior to harvesting trees were marked by luminescent color and operator had to cut down only the marked trees in the prepared areas and decide, which trees to cut according to good practice guides and regulations in unmarked area. This work was carried out during night time using the same operators in each felling area fixing the time of processing of trees and species of trees.

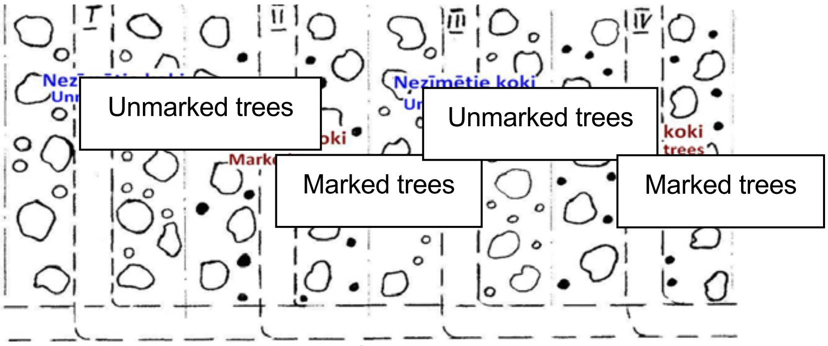

Figure 1. Marked trees felling scheme.

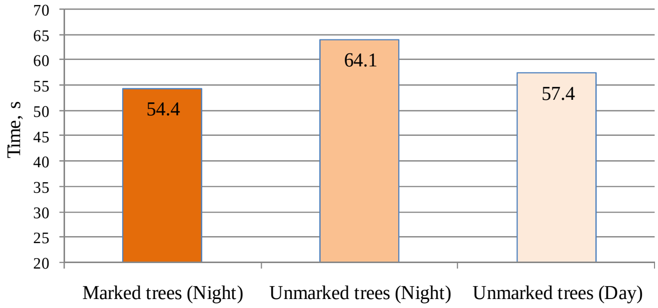

Figure 2. The time spent for processing of single tree working at daytime and during night separately for marked and unmarked trees.

Sample plots were created in all felling areas. Sample plots were evaluated for residual stand quality.

Table 1Quality characteristics of remaining stands

Characteristics	*%*
Dry trees	1.5
Defects in crowns	2.7
Defects of trunks	3.0
Mechanical damages	4.2
Healthy trees	88.6
Total	*100*

Table 1 shows the average health status of trees in the 12 evaluated stands after thinning. It should be considered before the final conclusions that an environmentally friendly forestry guideline assumes the decision of the future ecological trees already during last commercial thinning.

As the Result of this work have been obtained the following main conclusions:

1. Closer to the technological corridors stands are thinned more intensively than more distant areas, the most common reasons for such difference are insufficient accessibility of trees in areas located away from the strip roads and hastiness of operator.
2. At night hours the productivity of a harvester decreases by 12%, while marking trees for cutting with fluorescent color increases the productivity of harvester during at night hours by 15%.
3. The productivity of harvester in thinning depends on the average volume of harvested trees. As soon as the volume of trees increases the productivity of a harvester increases too.
4. The time of machinated harvesting of non-standard trees is 1.5 - 3 times more time than harvesting of ordinary trees.

***Keywords**: thinning operation, harvester productivity.*

53. PRODUCTIVITY AND COSTS OF WHOLE-TREE BUNDLING SYSTEM IN EARLY THINNINGS

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The field studies assessed the competitiveness of industrial roundwood and energy wood procurement based on the Fixteri II whole-tree bundler. The objectives of the studies were: *i*) to analyse the properties of whole-tree bundles and their correlation with stand parameters; *ii*) to define the productivity of whole-tree bundling and the forwarding and long-distance transportation of whole-tree bundles; and *iii*) to determine the procurement costs of the whole-tree bundling supply chain and to compare these costs with those of other industrial roundwood and energy wood supply chains.

The average diameter of the whole-tree bundles measured in the study was 65 cm and the average length 268 cm. The whole-tree bundles harvested from the bundling time-study sample plots averaged a green mass of 476 kg. The average solid volume of the bundles was 495 dm^3, of which branches accounted for 17% on average. The whole-tree bundle size increased in line with increase in average stem size of removals.

The study showed the productivity of the Fixteri II whole-tree bundler to be significantly higher than the first prototype bundler (Fixteri I). An increase in average removal volume from 20 dm^3 to 75 dm^3 nearly doubled the productivity per effective (E_0, excluding delays) hour of whole-tree bundling using the Fixteri II bundler: at a removal of 20 dm^3 the productivity of whole-tree bundling was 3.4 m^3/E_0, and at a whole-tree removal of 75 dm^3, 6.1 m^3/E_0. The considerable improvement in the productivity of whole-tree bundling was due to the fact that the new Fixteri felling head enabled direct feeding of accumulated whole-tree bunches into the bundler, without intermediate bunching or loading. Additionally, the bundler operator applied multi-tree handling during cutting to great extent. Working stages were also effectively overlapped.

Whole-tree bundling increased the size of grapple load in loading and unloading when forwarding, and forwarder load size increased markedly when compared to conventional pulpwood and loose whole trees. In the time study, the average load size was 22 whole-tree bundles. The productivity of whole-tree bundle forwarding was 23.8 m^3/E_0-hour (bundle size 0.5 m^3, whole-tree removal 60 m^3/ha, and the forwarding distance 300 m).

In long-distance transportation, the loading and unloading of whole-tree bundles was slower due to the small bunch size (short bundles) compared to long (5 m) pulpwood, even though the overall load size was approximately the same. With whole-tree bundles, two bundle stacks were placed onto the truck and three onto the trailer in order to achieve approximately the same load size as with long pulpwood. The binding and unbinding of the five bundle stacks took more time than binding and unbinding of three pulpwood stacks. In addition, significantly more time was required for cleaning of loading and unloading sites with whole-tree bundles than with delimbed pulpwood.

In the study, the costs of the whole-tree bundling supply chain were calculated and compared with the costs of optional supply chains in the procurement of small-diameter early thinnings. The lowest pulpwood procurement costs were attained in integrated roundwood and energy wood procurement using the two-pile method. The total costs of whole-tree chip procurement were also competitive in integrated procurement. The procurement costs of fuel chips produced from energy wood bundles were higher than the procurement costs of separately or integrally harvested whole-tree chips.

Comparative calculations indicated that the competitiveness of the whole-tree bundling supply chain increases in line with decreasing first-thinning pulpwood size. The results of the study illustrated that the optimal scope of application for whole-tree bundling is in first-thinning stands with a removal stem size of 7–10 cm dbh. The relative competitive strength of whole-tree bundling is in the integrated procurement of, in particular, pulpwood and energy wood. The

study's cost calculations showed the cost competitiveness of whole-tree bundling in exclusively energy wood procurement to be poor. The efficiency of the whole-tree bundling supply chain must be improved from its current level.

Keywords: *Bundling, early thinnings, Fixteri, whole trees.*

54. A PROCESS-PERSPECTIVE ON TIMBER TRANSPORT VEHICLE ROUTING

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A number of studies have mapped management processes in timber transport. Estimating the potential for improved efficiency in these operations through centralized optimized vehicle routing has also been a popular research subject. In many countries, however, timber transport vehicle routing continues to be the domain of the individual contractor. In the search for potential improvements it may therefore be useful to be familiar with how the contractor handles these issues.

The aim if this study was to map the manual process which contractors typically use for weekly and daily vehicle routing. 15 contractors from the Södra Skogägarna forest owners association were selected for the mapping. The respondents had a median of 4 trucks per contractor (range = 2 to 12). The respondents' trucks had a median transport volume of approx. 40 000 m3/yr and median utilization of approx 4500 hrs/yr.

The mapping resulted in a basic process model with 2 variants. The basic model aggregates activities to 4 sub-processes: information gathering, preparatory planning, solution and final adjustments. Two main variants were found which deviated from the model above. These consisted of simplifications of 1) preparatory planning 2) solution.

Key performance indicators for both profitability and service were collected for a one-year period. Profitability was measured by net operating margin (net profit after financial costs / turnover). Supplier servicer was measured by the reported proportion of landings where all volumes were transported within one month of transport order activation. The results show that contractor profitability decreased (from 15 % to 1 % net operating margin) with increasing levels of supplier service (from 89.5 to 97 % of orders completed within one month). Within this gradient, those with weekly mill quota steering had an average net operating margin of 4.1 %. Those not limited by quota steering had an average margin of 9.2 %. Based on these preliminary results we can conclude that higher service levels in timber transport do not necessarily lead to improved profitability for the contractor.

***Keywords**: hauling contractors, vehicle routing, service levels, profitability*

55. CALIBRATED ROUTE-FINDER FOR TIMBER TRUCKS

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The Swedish National Road database (NVDB) was developed in a collaboration between the Swedish National Road Administration, the Central Office of the National Land Survey, the Swedish Association of Local Authorities, and the forest industry. The database contains digital information of all Swedish roads: the state road network, the municipal road and street network, and private road networks. All roads, over 570,000 km, are described geometrically, topologically, and with detailed information about each road segment. This includes road manager (owner), road classification, road designation, height restrictions, load bearing obstacles, surface material, width, and traffic regulations. For transportation on forest roads there are also special details about accessibility, special forest roads, preferred routes in cities, turning radius, barriers etc. These details are handled as an add-on to NVDB thus creating the Forestry National Road database (SNVDB).

When forest companies and transporters agree on the transportation cost it is generally expressed as a function of the distance. It could be a linear or concave piecewise linear function. Today there exist many road data bases with detailed information of the underlying network defined through sets of arcs and nodes. Here, the distance between any pair of two points can be computed by solving a shortest path in the network. In most cases the objective can be chosen as the shortest distance or the shortest time. However, in the forest industry the computed distance should represent the route actually driven and this depends on many attributes (as mentioned above). Currently, there are several systems used in the Swedish forestry and there is an aim to develop one common system where all the distances used as a basis for invoicing is used. In this system it is important to set the weights on all attributes used in the system in order to get only one weighted cost for each arc in the network.

In this project we describe an approach to find a set of optimal weights of the attributes such that the set of weights will provide routes that are the ones actually driven. An important part is a set of detailed "Key routes" where the forest companies and transporters have agreed on the best route between a set of start and end nodes. A start node is a harvest area and the end node is an industry such as a paper, pulp or sawmill. Within the project more than 1200 such routes have been collected. Given this set of "Key routes", an optimization model is formulated where the main decision variables are the weights on each attribute. In our application there are more than 50 attributes. The constraints are used to select the best reduced cost route between any pair of nodes. Here we make use of binary variables. The reason for this is that we need to be able to identify if the selected weights provide the "Key route" or not. The model requires that many shortest path calculations are done in order to establish all necessary routes. The objective is to generate shortest paths which are identical to the "Key routes". In case this is not possible, we first want to find as many as possible and secondly as long same distance as possible. We describe the result and analysis on finding the best possible weights. The results also include an analysis how well it describes the actually more than two million invoiced routes during 2008.

We will also describe the results from a pilot project where six companies during September 2009 to January 2010 have tested a system “Calibrated Route-finder” (Swedish “Krönt Vägval”) based on our model. A new version of the proposed model has also been developed adding new attributes. The system is provided by SDC, which is an economic association/industry consortia owned by the forestry industry in Sweden.

56. SIMULATION OF SKYLINE SYSTEMS IN NORWEGIAN CONDITIONS

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Introduction

Large volumes of spruce-dominated forests established on steep terrain are maturing in western Norway (>70 mill.m^3). Their harvesting calls for investments in cable yarding, processing and transport systems and knowledge on the appropriate technology for the Norwegian conditions. Cable yarding and truck transport have strong interactions due to limited buffer storage between them. Discrete-event simulation has been applied successfully in the analysis of a wide variety of wood harvesting and transport systems, where the productivities of different parts in the supply chain are interlinked (Asikainen 1995, 1998, 2001, 2010; Talbot et al. 2003, Myers and Richards 2003, Väätäinen et al. 2005).

Material and methods

In this study a discrete-event simulation model was programmed to find optimal setups for the timber yarding-processing-truck transport system in the Norwegian conditions. The simulation model is based on dynamic operation using typical performance levels and breakdown patterns of a yarding system. The model estimated the performance and costs of the yarding-processing unit and truck transport system. The work of a yarding-processing unit was divided into two main phases: actual operation and randomly occurring machine delays. As the yarding system was operating, its output was set to 10 m^3/effective hour. The variables describing the time between machine failures or any other delay were drawn from a random number distribution that had a mean value of 5 hours. Delay time was also a negative exponential distribution having 1 hour as mean value.

The timber truck with a trailer was modelled for the road transport of timber. Its average driving speed was set to 50 km/h and load volume to 30 m^3. In the simulation experiments the average transportation distances are 20-180 km, with a SD of 10 km. Additionally, the number of trucks varies from 1 to 3. The yarder places the processed timber on the truck road next to the yarder. If there is no truck at the landing, the yarder has to wait. The trucks enter the model on the road leading to the landing. As the truck arrived at the landing, it first loads the wood in the buffer storage and then waits (if necessary) that yarder processes the rest of the wood to fill the truck load. When the truck is fully loaded, it leaves the landing and drives to the mill and unloads. If there is more than one truck in the system, queuing can take place at the roadside landing and at the receiving terminal. The trucks have randomly occurring machine failures according to negative exponential distributions, where average time between delays is 5 h and average delay 0.5 h.

Results

Cable yarder blocked time increases rapidly as the transport distance exceeds 60 km and only one truck is used for transportation of timber. When more trucks are used, blocked time is modest up to 140 km (fig. 1A). Queuing time of trucks decreases as the transport distance becomes longer (fig. 1B). Sufficient buffer storage between the skyline system and truck transport was found to be 40 m^3 (fig. 1C). It smooths the impacts of random arrivals of trucks or delays of the yarding system. Finally the costs of yarding and truck transport were summarized to find out the optimal number of trucks at different transport distances (fig.1D).

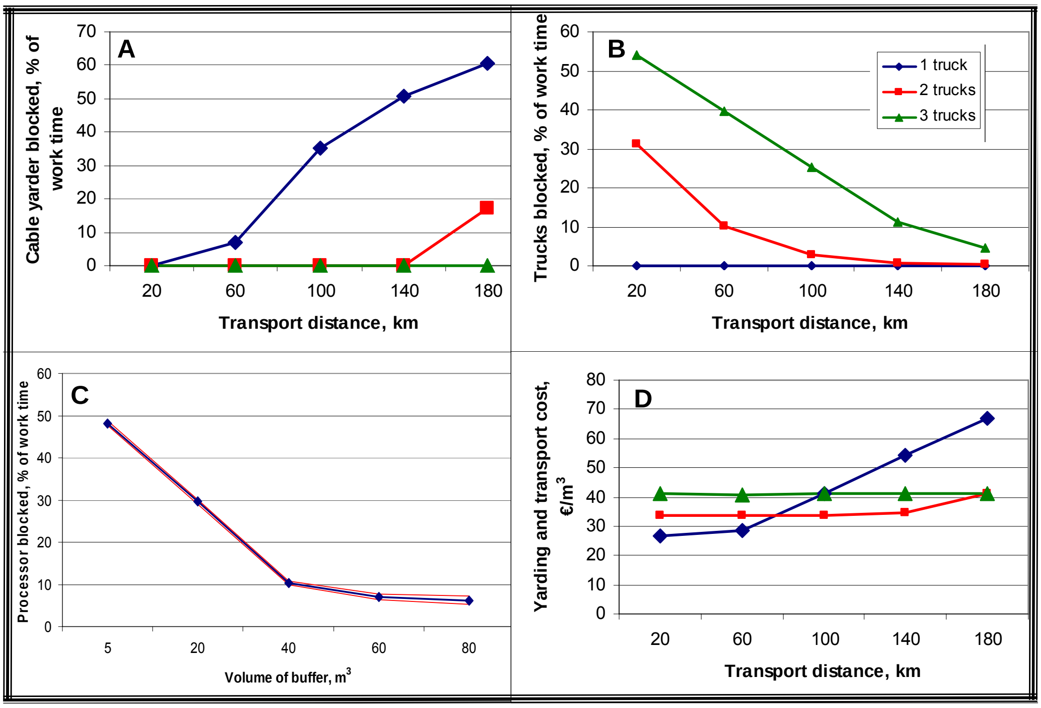

Figure 1 (A) Cable yarders' blocked time and (B), trucks' blocked time, (C) Impact of buffer storage's volume on the processor's blocked time, (D) Total costs of yarding and truck transport

Up to 80 km transport distance one truck is sufficient. At distances 80-180 a system based on two trucks is the most cost efficient and above 180 km distances three trucks are needed.

Next steps

In the next phase the model uses real logging site data from western Norway. The activity times for logging, yarding of trees and processing them into assortments will be calculated with available functions (Stampfer et al. 2003, 2006). Finally the alternate skyline system solutions are compared and the optimal technology for different stand categories is recommended.

Acknowledgements

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Keywords: *cable yarders, simulation, systems analysis, interference, transport*

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57. VOLUME AND COST CALCULATOR FOR BIOMASS HARVESTING FROM SMALL DIMENSION STANDS

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A growing demand and increased price on forest fuels over the last years has led to a growing interest to harvest forest fuel in early thinning of small dimension stands. Harvesting of small trees is still very costly and it is often hard to conduct those thinning in a profitable way.

A great challenge and problem for persons that plans these thinning and buys them from private forest owners is to estimate the possible volumes to harvest, and thereby estimate revenues and cost in the operation. Today estimates, if any are done, are very rough are often built on experience or guessing. The request for a volume and cost calculator for biomass harvesting from small dimension stands is therefore very large.

In small dimension stands we normally have to decide between three options; 1) cleaning and a following pulpwood thinning, 2) forest fuel harvesting or 3) leaving the stand as for now. When the average stand diameter is around 8-10 centimeters, it is possible to take out some of the volume as pulpwood. Depending on machine systems, raw material prices and stand conditions combined felling of pulpwood and forest fuels could then be profitable.

With a tool that can calculate assortment volumes and takes into account different prices on the assortments and also calculate the cost for harvesting and forwarding of the different assortments, using models for time consumption per hectare (Belbo, 2009) it becomes easier to compare the outcomes of the different options. A more advanced version will also calculate costs for chipping, storing and transporting the material to the industry.

Software like this would lead to increased profitability in early thinnings and higher precision in analyses of different systems and their economical outcome in early thinning. The possibility to make a simple calculation to compare the outcome of harvesting pulpwood, forest fuel or a combination harvest in each stand would provide a good decision support and increase the possibility the reach a profitable result in the operation. The tool will also be able to calculate economical consequenses of possible growth reduction and higher costs in coming forest operation due to the forest fuel harvest.

Requested stand data;

- Geographical information
- Dominated tree species (%)
- Stems per hectare (before and after thinning)
- Average diameter
- Average height

Keywords: *Biomass harvesting, small dimension stands, calculation, decision making*

58. HARVESTING WOOD FROM SPRUCE SWAMP STAND DURING SUMMER

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Introduction

Metsäteho Oy conducted a joint study with its cooperation partners into soft-ground harvesting of Norway spruce (*Picea abies* L. Karst.) swamp stands in Pälkäne, Finland, in September 2009. The study investigated the effects of forest machine equipment on cross-terrain mobility. The focus of the study was on the effects of the use of different tyre inflation pressures and track types.

The study covered four harvester models: a 4-wheel harvester (ProSilva 910), 6-wheel harvester (John Deere 1270D Eco III), 8-wheel harvester (Ponsse Fox) and a rigid-tracked harvester (ProSilva 810 T). The study also included three forwarders: an 8-wheel forwarder (John Deere 1110D Eco III), 10-wheel forwarder (Ponsse Wisent 10w) and a rigid-tracked forwarder (ProSilva 810 T). For the study, nine different harvesting systems were formed and a research sample plot was established for each harvesting system. Each sample plot was first felled and then the empty forwarder was driven through the plot. The forwarder was then loaded and driven in ten passes through the sample plot.

The sample plots were staked at three-metre intervals after felling. Each stake served as a measurement point at which the vehicle rut formation after the drive passes and the peat layer thickness were measured. In addition, the felled volume at each stake was calculated, and the quality of ground reinforcement with residues (good = ample logging residues on rut; average; poor = no logging residues on rut) was assessed for each vehicle rut. The number of damaged trees and stumps along the vehicle ruts were also recorded, as well as whether or not a strip road bend occurred at the staked measuring point. The groundwater depth was also measured at each sample plot.

Results

Rut formation was significantly reduced when the harvester (John Deere 1270D Eco III and ProSilva 910) tyre inflation pressure was lowered. With high tyre inflation pressure the average rut depth was over 3 cm, whereas with the lowest tyre pressures used in the study the average rut depth was just 0.5 cm. Tracked harvesters produced the same average rut depth as harvesters with the lowest tyre inflation pressures. The results show that reduced tyre inflation pressure significantly improves harvester cross-terrain performance.

The study showed that lowering forwarder tyre inflation pressure enabled the number of passes over the plot to be increased: With high tyre pressure only two loaded passes were possible, whereas with the lower tyre pressure used in the study four loaded passes were possible, and with the lowest tyre pressure five passes were achieved. Reduced tyre inflation pressure however showed no significant effect in the study on average forwarder rut formation.

With the wheeled forwarder the quality of the ground reinforcement with residues had a highly significant impact: With good ground reinforcement virtually no rutting occurred. Conversely, with average or poor ground reinforcement, rutting became rapidly more severe as the number of drive passes increased. On the basis of the study, it can be concluded that harvesting on soft-ground sites is viable if a wheeled forwarder and effective ground reinforcement with residues are used. Insufficient or uneven application of residues for ground reinforcement is correspondingly detrimental. In the absence of effective ground reinforcement, the optimal operating scenario for wheeled forwarders is summer thinning of spruce stands on load-bearing mineral soils.

When forwarders (John Deere 1110D Eco III and Ponsse Wisent 10w) with “traditional” flexible tracks were used, the execution of a full test series, i.e. ten loaded passes, was possible and rut formation was minimal. Even with poor ground reinforcement, the average rut depth remained below 2 cm until the fifth load. Significant rutting began to occur only after the tenth loaded pass. The significance of ground reinforcement with residues was considerably less with flexible tracked forwarders than with wheeled forwarders. The ground reinforcement quality had no influence on flexible tracked forwarder rut formation during the first few passes. Only from the sixth loaded pass onwards did ground reinforcement with logging residues have an effect on flexible tracked forwarder rutting. The study showed that forwarders equipped with wide flexible tracks and an auxiliary wheel can serve as effective harvesting machinery in soft soils.

The third forwarder category in the study was a rigid-tracked forwarder (ProSilva 810 T). The trials yielded positive results with the average rut depth at the sample plots remaining predominantly below 2 cm. A key finding was that with the rigid-tracked forwarder ground reinforcement with logging residues had no affects on rutting. The most probable explanation for this is that the fixed track moves across the most load-bearing spots and does not “seek out” the weaker soft spots and, in addition, also levels the ground to some extent. Based on the study, fixed tracked forwarder can be considered as a highly promising machine concept for roundwood harvesting on low carrying capacity soils and, particularly, for the whole-tree harvesting of energy wood (where only minimal logging residues is available for ground reinforcement).

Conclusions

In addition to the quality of ground reinforcement with residues, rut formation was affected by strip road bends, stump occurrence, and peat layer thickness. However, the effect of these site factors was clearly smaller than ground reinforcement. Deeper rutting tended to occur at strip road bends compared to straighter stretches. Similarly, rut depth was deeper if a stump occurred on one side of the vehicle rut, or where the peat layer was thicker.

The study highlighted a number of soft ground harvesting aspects in which forest machine operators should be provided clearer guidance:

1) Sufficient ground reinforcement with residues is indispensable with both wheeled and tracked forwarders; branches and tops must be distributed more effectively onto vehicle ruts.
2) During felling, strip roads must be made as straight as possible; S-bends, in particular, must be avoided.
3) In addition, strip roads must be made sufficiently wide. Narrow strip roads easily result in stem and root damage during forwarding.
4) Stumps occurring on vehicle ruts must be sawn as low as possible. The taller and bigger the stump, the more it will tip the load onto the opposite vehicle rut, which will in turn gradually deepen with each vehicle pass. In addition, trees bordering the strip road can be damaged by the forwarder operator attempting to navigate around stumps.

Based on the above points, it can be concluded that a felling operation creates the possibilities for the successful harvesting of spruce swamp forests and other soft soil sites, especially during summer.

Keywords: *rutting, summer cutting, soft soils, tracks, tyre inflation pressure*