



## **The Nordic-Baltic conference on forest operations**

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# The Nordic-Baltic Conference on Forest Operations

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By Kjell Suadicani and Bruce Talbot (Eds.)



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advisory services within  
the fields of forest and  
forest products, landscape  
architecture and landscape  
management, urban planning  
and urban design

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## Foreword

This document is a collection of just over 50 abstracts from the Nordic-Baltic Conference on Forest Operations, hosted by Forest & Landscape, Faculty of Life Sciences, at the University of Copenhagen. This biennial conference formerly known as the NSR-conference was previously hosted in Tartu, Estonia in 2006. There is little doubt that new life is being breathed into the many disciplines collectively recognised as defining the field of 'forest operations'. Since the previous meeting, Finland, Sweden and Norway have made significant financial commitments in promoting national research and education in forest operations – driven perhaps by the need to gain economically feasible access to vast biomass resources. The collection of abstracts received is evidence of this heightened level of activity. Both the number of newer researchers represented and the diversity of their work is encouraging.

The purpose of these conferences is to bring together researchers primarily from the Nordic and Baltic countries to present and discuss results within forest operations research. They are, however, also open to colleagues from the entire world. The conference is sponsored by OSCAR, an Operations Systems Centre for Advanced Research established and financed by the Nordic Forest Research Co-operation Committee (SNS) under the Nordic Council of Ministers.

OSCAR is a virtual centre within forest operations built by Nordic and Baltic research institutions. The OSCAR objectives are;

- To increase the excellence and critical mass of R&D within the field of operation systems by integrating research resources and expertise.
- To promote, initiate and develop efficient, competitive and environmentally friendly forest operation systems on a joint Nordic basis, with special emphasis on technology and support systems.

The overall purpose of the SNS is to promote research into the diverse functions of the forests in sustainable forestry, as well as to advise the Nordic Council of Ministers on questions concerning forests and forestry research.

Through visionary activities in research co-operation and communication of knowledge, the SNS wishes to contribute to the responsible management and utilisation of forests and timber resources in the Nordic-Baltic region along social, economic and ecological dimensions. The areas of responsibility of the SNS encompasses forestry, forests and other wooded areas (wooded landscapes, parks, urban trees and marginal land), the utilisation of wood and other forest products, as well as the non-commercial value of the forests.

Forest & Landscape are privileged to host this important event and trust that all the participants will benefit from the synergies that must be forthcoming from a meeting of people passionate about their field and aware of the contribution they are making in addressing some of the complex issues facing society at the beginning of the 21<sup>st</sup> century.



*Niels Elers Koch*

Director General of Forest & Landscape, University of Copenhagen  
Member of the Board of the Nordic Forest Research Co-operation Committee (SNS)

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# Whole tree bundling: A new concept for integrated pulpwood and energy wood procurement from early thinnings

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According to Finland's National Forest Programme, the annual need for first thinnings is 250,000 hectares in Finland. During the 2000's, however, only 167,000–206,000 hectares have been thinned annually. Consequently, the total area of delayed first thinnings amounts to 600,000 hectares. Based on the latest forest inventories, the target for first thinnings should be increased to 300,000 hectares per year during the next ten years.

In 2007, 3.0 million m<sup>3</sup> (solid) (6.1 TWh) of forest chips were used in Finland. Only one quarter (1.4 TWh) of the commercial forest chips were produced from small-diameter ( $d_{1.3} < 10$  cm) trees harvested from early thinnings. The annual use of forest chips for energy generation is to be increased to 5 million m<sup>3</sup> (10 TWh) by 2010, and by 2015 up to 8–12 million m<sup>3</sup> (16–24 TWh). These goals presuppose that the harvesting volume of small-sized thinning wood is tripled, or even quadrupled, from the current harvesting volume.

High harvesting costs, particularly cutting costs, are the main problems in early thinnings, when harvesting both industrial roundwood (i.e. pulpwood) and energy wood. In order to increase the annual volumes of energy wood and pulpwood harvested from early thinnings, their harvesting costs will have to be significantly reduced. This can be done through in-depth integration of pulpwood and energy wood procurement using a recently developed supply system based on whole-tree bundling.

In 2007, the first prototype of the Fixteri bundle harvester capable of incorporating compaction into the cutting phase was launched by Biotukki Oy ([www.biotukki.fi](http://www.biotukki.fi)). Cost savings, especially in off-road and on-road transportation, can be achieved by increasing the load sizes of non-delimbed assortments by compacting them into bundles of about 0.5 m<sup>3</sup> in solid volume.

The first prototype of the bundler was mounted on the rear end of a Valmet 801 Combi harrower. The work cycle of the Fixteri whole-tree bundler is as follows:

- The trees are felled and accumulated into bunches with an accumulating harvester head. Thereafter, the bunch of whole trees is lifted onto the feeding table of the bundler.
- The feeding rolls pull the stems into the feeding chamber of the bundling unit.
- The stems fed into the feeding chamber are cut to a length of 2.6–2.7 metres with a chain saw installed at the chamber gate.
- The stems sections are lifted from the feeding chamber into intermediate storage above.
- A sensor detects the amount of wood in the intermediate storage, in which the trees are compacted. When the storage is full, the bundle is lifted into the compressing chamber above for the final compaction and wrapping with sisal string.



- After wrapping, the bundle is dropped down along the strip road.

Except for placing bunches onto the feeding table, the bundling process is autonomous, enabling simultaneous cutting and accumulation of subsequent bunches. In addition to bundles with pulpwood-dimensioned trees, separate energy wood bundles composing of undersized trees and undesirable tree species can be produced. The bundles are hauled by a standard forwarder to the roadside storage, from where pulpwood bundles are transported by a standard timber truck to the pulp mill and potential energy wood bundles to the end-use facility to be comminuted for energy generation.

Separation of the pulpwood and energy wood fractions takes place in the debarking drum. The pulpwood bundles are fed into the debarking process as blends with conventional delimbed pulpwood harvested from first thinnings. The method enables an increase in the volumes of energy wood harvested from early thinnings without endangering the pulpwood supply for the forest industry.

In a feasibility study carried out by Metsäteho Oy and the Finnish Forest Research Institute, the required productivity level of bundle harvesting (i.e. cutting and bundling) in Scots pine (*Pinus sylvestris* L.) dominated stands was assessed by comparing the total supply chain costs of the system based on whole-tree bundling with those of the other pulpwood and energy wood supply chains by means of system analysis.

The calculations indicated that whole-tree bundling enables undercutting the current costs of the separate procurement of pulpwood and energy wood from first-thinning stands. The greatest cost-saving potential lies in small-diameter ( $d_{1.3} = 7\text{--}10\text{ cm}$ ) first-thinning stands, which are currently relatively unprofitable sites for conventional pulpwood procurement based on single-tree harvesting.

The productivity of the bundle harvester, however, will have to be raised well above 50% of that of conventional feller-buncher. This means, for example, that the performance of bundle harvesting must exceed  $4.6\text{ m}^3$  (9.2 bundles) per effective hour ( $E_0$ , excluding delays) with bundle size of  $0.5\text{ m}^3$ , when the breast height diameter (DBH) of the trees to be removed is 7 cm. In the case of trees with DBHs of 11 and 13 cm, the productivities must exceed  $7.6$  and  $8.7\text{ m}^3/E_0\text{-hour}$  (15.1 and 17.4 bundles/ $E_0\text{-h}$ ), respectively.

Cost savings with the procurement system based on whole-tree bundling can be achieved especially in the case of relatively long forest haulage and road transportation distances. When whole-tree bundling is applied to the harvesting of only energy wood ( $d_{1.3} < 7\text{ cm}$ ), significant cost savings are not achieved.

Metsäteho Oy and the Finnish Forest Research Institute will carry out further time studies and economic analyses on the whole-tree bundling system in 2008–2009. The R&D project is funded by the National Technology Agency (Tekes) and the Finnish forest industries.

*Keywords: Bundling, Integration, Small-diameter wood, Energy wood, Pulpwood, Early thinnings.*

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# Optimal point of comminution in the biomass supply chain

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The choice of technology and location for comminution of forest fuels is decisive for the configuration of the supply chain. Cost structure and cost levels as well as the quality parameters are also strongly correlated to the build-up of supply chain. A Skogforsk project; *Optimised comminution* is dedicated to analysing these factors, to simplify operational decision-making on choice of supply chain configuration and, ultimately, to lower the costs of forest fuel production. The project is part of the *Efficient forest fuel Supply Systems* (ESS) programme (<http://www.skogforsk.se/skogsbransle>) managed by Skogforsk and funded by the forestry and energy sectors of Sweden together with the Swedish Energy Authority.

Combining available technologies and methods creates different systems for comminution and transports. Every such system has its competitive niche, where it is superior to other methods. Important factors that decide the competitive niche are the type of raw material (logging residues, stumps, small trees etc.), the location of the material (in terrain or at roadside) the size of the tract (volume per landing) and the distance from landing to end consumer or terminal point.

In the project *Optimised comminution*, a number of basic analyses have been performed through simple simulations through FLIS, an Excel based systems analysis tool developed by Skogforsk. The objective is to show the extent of competitive niches for some alternative supply systems and illustrate how the variation in tract conditions will influence the competitiveness of the respective systems. In a first step, only logging residue chains have been analysed. Later, as a more comprehensive data base is built up, the ambition is to include stumpwood and smallwood supply chains. Finally, there is an ambition to benchmark proposed new supply systems against the well documented and proven systems included in the first analyses.

The first set of analyses shows that the simulation provides useful help for decisions of investment in new supply system, based on the often unique characteristics of tract variables. It is also possible to create simple rules of thumb that will aid in tactical and operational management and planning of forest fuel supply. These results are exemplified and evaluated.

Finally, the suitability of a simulation approach for benchmarking proposed technologies against the established systems is discussed.

# Facing the challenge of sensitive site harvesting

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Due to intensive draining operations in the 1960s and 1970s, Finnish peatlands have a large harvesting potential. The present annual removal of 5 to 7 million m<sup>3</sup> could be doubled in next decades. However, utilizing this potential calls for well-timed thinnings and ditch maintenance operations. In the coming ten years the need for peatland first thinnings is 100000 ha/a.

Up to present peatland harvesting has mainly been carried out in the winter, resulting typically 60 to 160 days of operating time. The past mild winters in addition to increasing need for domestic roundwood have raised the need for operations on unfrozen peatlands.

The approaches to achieve the goal vary. Light and/or rubber-tracked machines designed especially for peatland have been tried, yet they were less than satisfactory from the durability and economy point of view. Equipping a standard forest machine cost effectively for soft terrain would give one the alternative to switch back to normal specification and hence operate in all conditions with just one base machine.

The mobility and rut formation of a standard 8-wheeled forwarder was studied with four different chain/track equipments. The tested tracks varied in both design and width. Additionally, the forwarder was equipped with an add-on axle in the rear, resulting in a 10-wheeled forwarder. This was tested with the widest set of tracks. A six-wheeled forwarder from the 80's was used to link the results to the earlier studies. The tests were conducted on an abandoned peat field and on a pine bog

According to the results, wheel/chain equipment has a great effect on mobility and rut formation owing to reduced ground pressure and track design. On the pine bog, the 10-wheeled forwarder clearly had the best mobility and the least rut formation, whereas the six-wheeled forwarder displayed the worst results on both test sites.

Equipping a standard machine appropriately accompanied with the adaptation of best working routines, improved planning and entrepreneur training are key factors in facing the challenge of sensitive site harvesting.

*Keywords: Peatland, forwarder, tracks, mobility, rutting, equipment.*

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# The cost of harvesting operations – web based applications

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Norwegian Forest and Landscape Institute has developed web based applications for calculation of operational costs for harvesters and forwarders. These tools are available on the website of the institute.

The result presents in diagrams with productivity ( $\text{m}^3/\text{t}_0\text{-hour}$ ) and costs (NOK/ $\text{m}^3$ ). For the harvester the results are calculated based on average tree size, costs per hour, and the percentage share of none productive time during the working day. For the forwarder the results are calculated based on average transport distance, costs per hour, driving speed, terrain transport distance, load size and number of assortments.

The applications are mainly designed for practical use by different actors in the forest industry, such as buyers of round wood, forest owners and forest contractors. There has been an increasing demand for these types of simple tools for conducting sensitivity analysis for harvesters and forwarders. The user can easily calculate the effect on productivity and unit costs by changing the values in the input variables based on their own premises.

The development of the web based applications are based on results from numerous time studies, operational statistics and costs accounts carried out from several projects carried out by the Norwegian Forest and Landscape Institute. This paper presents how to use the calculators, how they were developed and how the results can be used.

# Comparison of harvesting methods in northwest Russia – Impact on wood quality and overall performance of wood harvesting companies

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## Objective of the study

The objective is to provide information on the advantages and disadvantages of three different wood harvesting methods in common use in Northwest Russia. The Nordic cut-to-length (CTL) and Russian tree-length (TL) and full-tree (FT) methods were compared to analyze them in terms of impacts on wood quality and overall performance of wood harvesting companies. The goal is to provide information to Russian harvesting companies to support their decision making on the selection of harvesting methods and to give harvesting machine manufacturers scientifically justified arguments for marketing their technology in Russian conditions. Comparison of the harvesting methods was done by collecting empirical field data on the impacts of the Russian and Nordic harvesting methods on wood quality, work safety and ergonomics, economical productivity and forest environment.

## Material and methods

Altogether 15 logging enterprises were investigated in the Republic of Karelia in 2006-2007. The annual actual cut of the companies was 2,2 million m<sup>3</sup> which was one third of the total wood harvesting in Karelia. Altogether 865 800 m<sup>3</sup> was logged by the CTL method (39% of the actual cut), 935 400 m<sup>3</sup> (43%) by the TL method and 385 300 m<sup>3</sup> by the FT method (18%). Five key systems of wood harvesting were studied: fully mechanized CTL “harvester + forwarder” (12 machinery sets) and FT “feller-buncher + skidder + delimber” (2 sets), partly manual CTL “chainsaw + forwarder” (5 sets), FT “chainsaw + skidder + delimber” (1 set) and TL “chainsaw + skidder” (7 sets) produced by John Deere, Komatsu, Volvo, Husqvarna etc.

The comparative study of the harvesting systems’ influence on

- efficiency and economics was done by collecting empirical field data and statistics from 15 companies. The following factors were estimated: productivity of the harvesting systems, m<sup>3</sup>/shift, productivity of the single machine or machinery, m<sup>3</sup>/h, direct harvesting costs, €/m<sup>3</sup>
- forest environment was done by collecting empirical field data in 15 cutting sites in summer time and in 7 cutting sites in winter time. Altogether 44 forest sites and 1620 soil samples were measured, and following impacts estimated: restrictions on cutting area (road-side storage area, width of strip-roads, width of cutting strip, share of strip-roads in cutting area), influence on growing trees (damage to remaining trees), influence on undergrowth (undamaged undergrowth), influence on soil (decreasing porosity, degree of mineralization, depth of trail)

- conditions of work was done by collecting empirical field data on 28 forest machines (7 harvesters, 9 forwarder, 10 skidders, feller-buncher, delimber) and 9 chainsaws. The following impacts were estimated at the machinery: 38 parameters of working place (body pose, sitting, cabin and sitting position), 29 parameters of visibility (observation angles, visibility in working direction, visibility in driving direction, windshield cleaning rate), 38 parameters of steering system (steering components location and stroke, effort on steering components, steering components operated by hand, steering components operated by foot), algorithm of work (fixed index of stereotype, fixed index of logical complexity), 21 parameters of noise and vibration, 32 parameters of safety (cabin access etc)
- round wood quality was done by collecting empirical field data in 10 cutting sites in summer time and in 7 cutting sites in winter time. The total number of the measured spruce, pine and birch logs was 23 400. The following impacts were estimated at these samples: mechanical damages (tear-out, galling, bark stripping, saw kerf, notch, gash, nick, jag), processing damages (branch, butt damage, split in the butt end of stem, crack; sloven; chamfer cut), soiling, size discrepancy (length, diameter at butt, top diameter).

# Forest operations under scrutiny

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## Background

The European Union has supported the integrated EU-project Eforwood. This project is developing a Tool for Sustainability Impact Assessment (**ToSIA**) of the Forestry-Wood-Chain (FWC). Several well renowned European institutions, representing the whole chain from forestry over industry to end consumers are a part of this effort. **ToSIA** will be a decision support tool for a comprehensive evaluation to be used by various stakeholders.

In EFORWOOD partial models for parts of the FWC are also developed in order to assess the dynamics of specific issues. This paper will demonstrate how such a model is used for a vital part of this chain: **harvesting** of wood **and logistics** to mill gate.

## Purpose

With the aid of a partial model examine traits of two case studies in the Eforwood project, namely Västerbotten (Scandinavian production case) and the Baden-Württemberg regional case, and to quantify their sustainability against an economic, environmental and social background.

## Method

The ToSIA model operates with a set of ca 30 indicators. Some indicators covers the whole chain from stand establishment to end consumer, but selected sets of.

# Towards more cost-efficient wood harvesting from young stands

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In order to increase the harvesting volumes of energy wood and industrial roundwood (i.e. pulpwood) in young stands, the cost-efficiency of wood harvesting will have to be increased significantly. Several research papers have discussed the problems of harvesting small-diameter wood in early thinnings. Furthermore, a lot of viable guidelines are currently available for more cost-effective harvesting of pulpwood and energy wood from young stands. Many of the most profitable guidelines have, however, not been utilized properly in Finland, and similar situations may be expected in other countries as well. The adoption of suitable guidelines needs to be promoted.

A study carried out by Metsäteho Oy and the University of Joensuu listed the different potential approaches for reducing the harvesting costs in young stands. The study ranked also the proposed potential approaches for increasing the cost-efficiency of small-diameter energy wood and industrial roundwood harvesting from early thinnings.

The potential approaches were prioritized by conducting personal interviews. Research data, based on a total of 40 interviews, was collected during January and February, 2008. The interviewees were divided into four groups: i) Managers in wood procurement organizations, ii) Forest machine contractors (many harvesting wood from early thinnings), iii) Forest machine manufacturers and vendors, and iv) Wood harvesting researchers.

The interviewees were asked to evaluate the significance of a number of factors related to problems in energy wood and industrial roundwood harvesting in early thinnings. The significance of different potential approaches for more cost-efficient harvesting in energy wood thinnings and first thinnings was investigated, and the interviewees were evaluated on how comprehensively each approach is currently used in harvesting operations in Finland. The potential of each approach to increase the cost-efficiency of wood harvesting in young stands was calculated by subtracting the current utilization score of the approach from the significance score of the approach.

The interviewees highlighted that currently the primary problem is poor harvesting conditions in the industrial roundwood harvesting of early thinnings. From the harvesting conditions, the respondents emphasized that the small stem size of the removal, low roundwood removal per hectare and stand, dense undergrowth, and poor carrying capacity of the terrain are the most critical condition factors in young stands.

On the other hand, the interviewees expressed that the primary problem when harvesting energy wood from young stands is the lack of professional forest machine operators. The managers in wood procurement organizations pointed out this significant problem: that the shortage of professional forest machine operators is currently a very serious problem in



both industrial roundwood and energy wood harvesting in early thinnings. The respondents disclosed that poor harvesting conditions are also very problematic in the energy wood cuttings of young stands. The forest machine contractors underlined that the dense undergrowth is the biggest problem in the pulpwood and energy wood cuttings.

In industrial roundwood harvesting, the respondents considered that the most significant approach to achieve more cost-efficient wood harvesting is comprehensive pre-clearance of dense undergrowth. In particular, the forest machine contractors highlighted the significance of pre-clearance. In the opinion of the interviewees, the second most important approach was effective tending of seeding stands, and the third was improving the training of new forest machine operators. Other meaningful approaches were more working hours for harvesting machines, careful selection of operator candidates, developing cutting techniques and working methods, development of machine technology, careful selection of stands for harvesting, broadening the practical training, and multiple-tree processing. The wood harvesting researchers considered that multiple-tree handling is the most important approach for more cost-efficient roundwood cuttings in early thinnings.

The interviewees estimated that the most important approach for increased cost-efficient energy wood harvesting from young stands in Finland is to boost the training of new forest machine operators. The second was careful selection of harvested stands. The managers in wood procurement organizations stressed that the most important approach for increasing cost-efficiency in energy wood harvesting is grapple scale measuring. Correspondingly, the forest machine contractors considered that the most significant approach is careful selection of forest machine operator candidates. The forest machine manufacturers stressed the importance of developing cutting techniques and working methods, and researchers, more working hours for harvesting machinery.

The greatest potential for improving the cost-efficiency of industrial roundwood harvesting was careful selection of forest machine operator candidates. Pre-clearance of undergrowth and the effective tending of seedling stands had the second and third largest potentials for boosting the cost-efficiency of roundwood harvesting. Respectively, the greatest potential to improve the cost-efficiency of energy wood harvesting from young stands in Finland was the implementation of energy wood harvesting as a part of the wood production chain. There was also considerable future potential in the careful selection of operator candidates for forest machines and in the grapple scale measuring.

The strong message given by the interviewees was that the education of forest machine operators must be made more effective in the future. The results indicated that the training structure for forest machine operators will have to be examined very carefully in the near future.

In the opinion of the respondents, there is a great potential to increase the cost-efficiency of wood harvesting in the future through improving harvesting conditions. The interviewees also underlined that harvesting methods can be rationalized. The most profitable guidelines must be more effectively utilized immediately. Cost savings of at least 5–10% can be achieved and, in some cases even 30–40%, compared to current wood harvesting costs in early thinnings.

*Keywords: Young stands, Cost-efficiency, Energy wood, Industrial roundwood, Harvesting, Costs.*

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# Technical options for the harvesting and supply of forest biomass

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Due to a booming bioenergy sector, forest biomass harvesting is becoming very popular all across Italy, which now hosts about 15 CHP plants, and a couple hundreds of district heating stations. As the profitability of green power generation becomes higher, so does the interest in finding cost-effective solutions to wood fuel supply. To date, many operators have equipped for the purpose and tap a variety of feedstocks: forest residue, thinnings, riverbed cleaning operations, stumps and short rotation coppice (SRC). Such a diversified range of feedstocks implies that no single recovery system is dominant: different operators resort to different solutions, which results in a large variety of cost figures. CNR has worked on biomass harvesting and supply since the mid-70s, and the revival of this business in recent times has allowed for new and deeper research activities. In particular, CNR has worked on five different subject: developing a set of a models for predicting the cost of biomass recovery from a variety of different forests and silvicultural treatments; comparing technical options for the processing and transport of biomass (chipping, bundling, bulk transport); developing a model capable of returning reliable estimates of chipping productivity and cost, on the basis of user-entered input data; analysing SRC harvesting options, and the related economics; investigating stump recovery under the typical conditions of Italian plantations.

To date, industrial power plants are the main consumers of wood chips and set the pace for the whole market. Power stations offer between 40 and 45 Euro/fresh tonne, delivered at the plant. At this price, harvesting forest chips is economically viable only where chipping configures as residue disposal or where harvesting conditions are especially favourable. Smaller district heating stations can offer up to 60 Euro/fresh tonne, which makes the exclusive production of forest chips sustainable in most tractor-accessible forests, and where tree size is not exceedingly small. When terrain features require the use of cable yarders or tree diameter is below 20 cm, then the exclusive production of forest chips is not viable even if the price paid at delivery is as high as 60 Euro/fresh tonne: capturing this material requires a further increase of chip price, or an integrated harvesting strategy. At the moment, the latter seems to have a higher potential, and has already worked in several instances, both on the Alps and on the Apennine. More information about this aspects can be obtained by downloading (for free) the handbook recently published by CNR at the following link:

<http://www.ivalsa.cnr.it/Files/manualecippatoforestale.pdf>

Within the scope of a the above-mentioned project, CNR analyzed three recovery alternatives for logging residue and identified the conditions that make one preferable to the others. Experimental data were used to assemble spreadsheet models that return the delivered cost of biomass as a function of working conditions and costing assumptions. Chipping, bundling and transporting loose uncomminuted residue are all viable options, and they are indeed applied on a commercial scale in several Countries, including Italy. Transporting loose uncomminuted residue is the simplest method, which avoids investing in costly equipment. However, this system is constrained by the difficulty of fully exploiting vehicle payload: it is not

suitable to the handling of fine slash, and is preferable only over short hauling distances. Bundling is so far the most expensive option, but it offers logistical advantages, especially when used under mountain conditions. Chipping at the landing is technically the most effective method, but it requires close co-ordination of the transportation fleet. If truck delays exceed 40 minutes per load, then bundling becomes a better choice.

As chipping at the landing showed as the most effective option, CNR has devoted much attention to it. In 2001, CNR released a freeware capable of returning reliable estimates of chipping productivity and cost, on the basis of user-entered input data. The model contains a set of predictive equations derived from the results of 102 field trials, conducted with 30 different machines, under a range of working conditions. In order to facilitate comparison with other estimates and to achieve methodological transparency, the equations are assembled into a simple *Microsoft Excel* workbook, and the costs are calculated with standard costing methods currently used in Forest and Agricultural Engineering. Since then CNR has continued to work on the subject, with the goal of updating and refining the model. Such work has included 41 validation tests and a separate study on the delay time typical of different chipping operation layouts: the task was concluded in 2008 and confirms that the model developed by CNR can provide reliable estimates of chipper productivity under a range of operational conditions. Current improvements include a correction factor for the chipping of log material, and a set of statistically significant utilization rate figures for the most common occurrences. We believe that such a model can assist European foresters in keeping ahead with the growing biomass sector, thus helping them to seize an important business opportunity. The free handbook and the Excel model can be obtained respectively at the following links:

<http://www.biomassaforeale.org/ivalsa/file/IndagineSullaCippaturainItalia.pdf>

<http://www.biomassaforeale.org/ivalsa/file/chipcost.zip>

The booming biomass industry has also spurred the development of dedicated plantations: supported by favourable grant schemes, in the last five years north-Italian farmers have planted over 5000 ha of Short Rotation Coppice, mainly in the Swedish-style one- and two-year rotation systems. The plantations are established with selected poplar clones and their success relies on the integrated development of all different production stages, from planting to harvesting. To date, Italian SRC is a commercial business, steadily gaining momentum. On good fields, yields can reach or exceed 30 green tonnes/ha year and the farmers can sell their product to 15-20 €/green tonne, facing cropping costs that are only a fraction of those incurred with traditional food crops. Rationally organised, harvesting and transport can be performed within the 25 €/green tonne cost limit, meeting the 45 €/green tonne delivered price target, offered by the local power station. Commercial harvesting is based on modified foragers, equipped with dedicated SRC headers. Four different header types are used in Italy, two on a commercial scale. The current trend towards increased rotations is straining the limits of modified foragers, and innovative solutions are being adopted for enabling these machines to cope with the larger trees. A comprehensive set of information sheets on Italian SRC (in English) is available for free download from the following link: <http://www.ivalsa.cnr.it/ISCHP07/Alpenenergywood.pdf>

Performed with mechanized systems since the late '80s, root recovery is enjoying a revival in these days. It is exclusively performed in flatland poplar plantations, whose trees develop a deep taproot. Italian contractors have developed recovery systems that are both efficient

and cheap. Extraction and cleaning units are based on general-purpose prime movers, easily available on the market. Under favourable conditions these units can achieve a very high productivity: 150 stumps per hour for the extraction unit and 170 for the cleaning unit. Delivered cost varies widely, ranging from 30 to 70 € per green tonne. Typically, one hectare of plantation can yield about 10-15 odt of root biomass.

People interested in watching some harvesting and chipping operations conducted in Italy can connect to the CNR Video Gallery at:  
<http://www.ivalsa.cnr.it/fmf.html>

The activities of our research group are described (also in English) in a dedicated website, where further publications/models are available for free download:  
<http://www.biomassaforestale.org/>

# Mechanized planting in Latvia – preliminary results

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## Purpose of the study

According to the State Forest Service, artificial forest regeneration in 2006 was used in 11 th.a (37% of afforested area). The State forest company "Latvijas valsts meži" regenerated artificially 7,3 th.ha (73%) and private forest owners – 3,7 th.ha (19%).

A share of container seedlings in the artificial forest regeneration increased significantly during the last years, especially in the state forests, where in 2007 4 th.ha of forests and agricultural lands were planted with container seedlings, including 2,2 th.ha with pine, 1,1 th.ha – spruce and 0,7 th.ha – birch.

Forest planting up to now is hard work with fast growing share of salaries and as fast reducing availability of qualified workers. The lack of labour may become the most significant problem hampering qualitative and well timed forest regeneration. Therefore more efficient technical and organizational solutions of the forest regeneration should be elaborated and introduced into practise.

Target of the study is to estimate potential of increase of the efficiency of artificial forest regeneration, using container seedlings and combined soil preparation and planting technology. The key activities of the study are (1) evaluation of experience of mechanized seedling and planting of container seedlings; (2) estimation of productivity and working quality of *Bracke P11.a* discrete planting head in different soil conditions; (3) elaboration of prime costs' model of the forest regeneration using the *Bracke P11.a* planting head and (4) elaboration of recommendations for the mechanized forest regeneration using container seedlings.

## Methods

The base machine, *Daewoo 155CLV* excavator, with length of the boom 7,8 m and *Bracke P11.a* planting head had used in the study. The age of the planting unit was 6 years. Operator was well trained with experience in planting, stump harvesting and forwarding.

Planting had been done in sandy (pine), silt (spruce) and clay soil (birch). In the most cases operator planted seedlings on top of mounds, but other planting methods – on a "bridge" and hollow were evaluated as well. Planting density – 2,5-3 th.ha, depending from specie. Planting time 13.10.-16.10.2007.

Within of the scope of time studies 7 separate operations (driving, boom manipulations, mounding, planting, refilling, other and non-work operations) were accounted using Allegro CX field PCs and SDI software.

## Results

The broadest planting mounds (76 x 100 cm) *Bracke P11.a* makes in dry sandy soils. In clay soils mounds are dense and compact (68 x 93 cm). Average height of mounds – 12 cm. Mineralized area is at least 30 cm in radius around planting in planting conditions.

Time studies shows, that the smallest number of excessive planting cycles are done during planting of pine (1,1% of total time), and the biggest – during planting of spruce (1,9%). A share of excessive manoeuvres depends from quality planting material and soil characteristics. In case of spruce substrate of container seedlings was too loose, causing often clogging of the feeding mechanism. In clay soils the most of problems caused clay, which blocked planting tube.

No significant variations of the productivity found in different soil conditions, but considerable variations of productivity causes planting density and time consumption for refilling of the cartridge. Average productivity of the efficient hour is 190-199 seedlings, but of the working hour – 178-187 seedlings. Reduction of refilling time (improved seedling quality) would let to increase productivity by 18-30% depending from the specie.

Planting density and machine load are the most significant factors affecting costs of the mechanized forest regeneration. Prime-costs of planting birch on agricultural lands (density 2000 plants ha<sup>-1</sup>) are 0,50 EUR/seedling or 991 EUR/ha, including costs of the planting material – 331 EUR. Prime-costs of planting spruce with the same density are 0,48 EUR/seedling or 974 EUR/ha, including planting material – 294 EUR. Prime-costs of planting pine with density 3000 plants ha<sup>-1</sup> are 0,47 EUR/seedling or 1413 EUR/ha, including planting material – 441 EUR. Switching to two shifts operation would reduce costs by 15%.

Reduction of number of trees to minimum requested by regulations in plantation forests would reduce costs of planting significantly: in case of spruce by 58%, birch – 37%, and pine 62% in compare to requirements for natural forests.

More research should be done to evaluate silvicultural effect of the mechanized forest regeneration using planting units able to adjust planting space for each seedling. Planting on mounds is efficient in autumn in the most of conditions, but information about spring and summer plantings is very limited. Another issue of the same importance, especially in fertile sites, is after-care of the stands, which becomes more complicated in case of “discrete” planting in contrast to ordered planting.

## Conclusions

- Planting spaces formed by Bracke P11.a unit as well as planting density in the studied areas corresponds to the national forest regeneration requirements.
- It is necessary to use broader shovel with boards at both sides in clay soils to make lower and wider mounds. Bigger planting material is recommended as well in case of birch.
- Substrate of the container seedlings should be compact, with well developed root system and without weeds and mosses, causing clogging of the feeding mechanism. Better quality of seedlings would let to reduce refilling time and to increase productivity up to 195-197 seedlings per working hour.
- Planting costs in Latvia using Bracke P11.a unit at the same planting density (1700 plants ha<sup>-1</sup>) would be less than in Finland, because of higher average productivity estimated in parallel studies and lesser machine costs.
- Costs of mechanized planting are still higher in compare to manual planting in Latvia, but better survival and, consequently, lesser planting density can make mechanization of the forest regeneration feasible.

# Modeling stump biomass of stands using harvester measurements

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In Finland stump wood became a potential raw material for energy and pulpwood production during the energy crisis of the 1970s, but technical and financial factors limited its use. As energy prices have risen, stumps have again become a potential source for bioenergy. In 2006, the consumption of stump wood for energy generation was equivalent to more than 900 GWh. Nowadays, stump lifting is common practice and new cost-efficient methods have been developed. Accurate estimates of belowground biomass of trees are important when estimating the potential of stumps as a bioenergy source for an energy mill at the operational working level.

The objective of this study was to evaluate the usability of the stump biomass model by Marklund (1988) at the operational working level, and to develop a locally calibrated biomass model to predict spruce stump biomass using forest harvester data. The major focus was to apply stem related information recorded by harvesters and the allometric potential of diameters of relative heights as independent variables. True weight of stumps (i.e. dry weight) by stands was used as the reference data.

The data was collected in Central Finland from 38 logging sites where the share of spruce was more than 50% of the total removal and the stumps were lifted. The total removal of timber by stand varied from 217.1 m<sup>3</sup> to 2173.2 m<sup>3</sup> (mean 652.0 m<sup>3</sup>). Before delivery to the mill storage the stump material was weighed by delivery lots, and the weight was converted into dry weight using a conversion factor defined as an average moisture factor derived from daily sample measurements. The harvester data consisted of 55 490 stems – spruces (78.8%), pines (7.1%) and birches (14.1%) from which a total of 35 230 spruce stems was selected for final analysis. For these stems the stump biomass estimates were computed using the model by Marklund (1988). To construct a calibrated biomass model regression analysis was applied to find a better fitting model in the data.

In tests of goodness of fit for the linear relationships, the adjusted R<sup>2</sup> values of the stump biomass model by Marklund (1988) was 52%. Marklund's model tend to overestimate the biomass of stumps in stands for low biomass densities, (t/ha), whereas the model lead to underestimates for high densities. In the calibrated best fitting model the independent variables were the cumulative sum of biomass estimate of Marklund, and the cumulative sum of the square of diameter at the relative height of 30%. In tests of goodness of fit for the linear relationships, adjusted R<sup>2</sup> value was 60% for this model.

*Marklund, L. G. 1988. Biomassfunktioner för tall, gran och björk i Sverige. (Biomass functions for pine, spruce and birch in Sweden). Rep. No 45. Department of Forest Survey. Swedish University of Agricultural Sciences. (In Swedish)*

# Harvesting of energy willow plantations on soft soils in Estonia – a case study

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During the last decade there has been a major movement towards the usage of renewable energy and finding replacement for fossil fuels. One of the possibilities is to establish energy willow plantations for production of woody biomass. In Estonia growing willow for production of energy wood have been studied since the beginning of 1990ies but there are few experiences of harvesting of willow. The aim of the present study was to investigate the productivity and the costs of harvesting of willow plantations in Estonian conditions. The study was carried out in spring of the year 2008 in South-Eastern Estonia. The area of the plantation was about 12 ha containing eight different clones of willow. Before harvesting the volume of woody biomass of each clone was measured. The harvesting was carried out with the combine Claas Jaguar 870 with the special wood harvesting attachment able to cut the stems up to 8 cm diameter. In addition two farm tractors with trailers were used to gather the woodchips and to transport it to the storage site. As a result of the study several models of the biomass from willow plantations were calculated, productivity of the equipment was analyzed and the overview of earnings and outlays were made.

*Key words: willow, biomass, wood chips, energy wood harvesting*



# Cost-efficient sound new methods in boreal peatland forest silviculture

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## Introduction

In Finland there are over 4 million hectares of drained peatland forests. The majority of these forests are situated on private lands, but also on lands owned by the state and forest companies. Primary forest drainage was mostly undertaken during the 1960s and 1970s, and these drained peatland forests will require further silvicultural treatments in the near future to ensure previous investment profitability.

Currently, peatland drainage is no longer practiced; rather the emphasis has shifted to the maintenance of old ditch networks. Annually ditch network maintenance is carried out over an area of approximately 65 000 hectares, but the area in need of maintenance actually totals around 100 000 hectares. The annual growth of round wood on drained peatlands is over 20 million cubic meters, but only five to six million cubic meters are harvested annually. In the future, the need for thinning and maintaining ditch networks in peatland forests will increase, as will the pressure to take currently unused resources under more effective utilization. For environmental and economic reasons, harvesting and maintenance ditching operations should be done simultaneously. In this study, new models for comprehensive silvicultural operations in peatland forests are described.

Private people own 59 % of forestland (annual growth  $> 1 \text{ m}^3/\text{hectare}$ ) in Finland. The average size of a forest estate is relatively small, approximately 35 hectares. The division of ownership leads to troubles when silvicultural works and maintenance ditching should be undertaken in any specific peatland area. For environmental and economic reasons, it is preferable to plan all silvicultural works simultaneously in the entire peatland area. The handling of the entire peatland area at the same time minimizes the costs related to planning and execution of operations, increases profits from sales of round wood, and especially increases the effectiveness of water preservation structures, which are implemented to prevent soil and nutrient runoff into water systems after maintenance ditching.

At present, peatland forest maintenance ditching projects are typically planned and organized by forest centre authorities, local associations of forest owners or by private forest entrepreneurs. The state subsidizes maintenance ditching and covers approximately 60 - 75 % of the overall costs involved. Local forest centres supervise the use of subsidies and the quality of maintenance ditching projects. The main purpose of this study is to create and test new models to execute comprehensive silvicultural works in peatland forests.

## Materials and methods

The working methods of this study were to describe which kinds of organizations are executing comprehensive peatland forest silvicultural work projects, precisely describe the used working models, and measure the effectiveness of different kinds of models. After first describing currently used models, models were compared and strengths and weaknesses of

each model determined. On the basis of collected data, three new, presumably more cost-effective models were created to execute peatland forest silvicultural work projects.

The material used includes over 20 interviews with peatland forestry professionals, including for example authorities, entrepreneurs and field workers from different organizations. On the basis of interviews and field observations, exact process descriptions were composed. Working processes were divided into smaller stages, which were described separately. In the follow-up study, the use of working time and other resources during different parts of the maintenance ditching process was inspected.

## Results

A major finding of the follow-up study was that the differences between working methods were significant. The variation in time used to plan maintenance ditching and silvicultural works in different organizations and working methods ranged from 0.4 to 1.13 hectares per hour. The variation revealed that some methods are at most more than twice as effective in planning as others.

On the grounds of collected data, three new models were created to execute peatland forest maintenance ditching and thinning projects on a more cost-effective and shorter schedule. When creating new models, special attention was paid to the models' cost-effectiveness, the lead-time associated with undertaken projects, as well as the quality and fluency of round wood thinning and harvesting. The new models are **(1.) Contracting model**, where the local forest centre seeks out the peatland area and receives bids from organizations and entrepreneurs for carrying out the necessary peatland forest silvicultural works. **(2.) Letter of attorney model**, where the peatland area owned by several land owners is treated as one unit when performing silvicultural works and maintenance ditching. Project costs and benefits are directed to each land owner separately. **(3.) Forest machine enterprising based model**, where the machine enterpriser administers and executes the necessary silvicultural works and subcontracts, if needed, to fulfil his knowledge in certain aspects of the project.

Currently, 14 pilot projects are underway to test these new models in practice in co-operation with different forest organizations. In the long run we hope to decrease the costs of thinning and maintenance ditching in peatland forests in Finland and to increase the quantity of silvicultural works and thinnings undertaken.

*Key words: peatland forest, silvicultural works, maintenance ditching*

# Whole tree harvesting in early thinnings and landscape management

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The important tending activity in young stands is by many forest owners neglected, resulting in dense stands with high risk of damage caused by competition and heavy snowfall. One reason might be that such operations are expensive and give no direct economical return, as the market for sub-pulpwood sized trees is not well developed. The same situation appears for brush cleaning along roadsides and power lines, and for other landscape management issues. The market situation is however assumed to improve rapidly as woodchip-fuelled heating plants are currently being projected and built all over Norway.

The economy of harvesting small trees is a classical challenge. Hourly operation costs are not sensitive to tree size while the production rate is highly dependent. To decrease the time-consumption, several trees may be collected during a single crane cycle by accumulating felling devices. Accumulating felling heads for small-sized trees have been available on the market for thirty years and are now gaining popularity. Typically they are low-weight, with low hydraulic needs and easy to handle, which makes them possible to mount on most types of base-machines without major adjustments on the hydraulic system.

This paper presents results from a series of work-studies of the Nisula 280E accumulating felling head. The felling head was mounted on a Valmet XM mid-steered farm tractor with a timber trailer. The equipment was tested in pre-commercial thinning of a dense young spruce stand and in brush-cleaning of roadsides and overgrown former pasture. The methods tested were direct loading during the harvesting operations and separate loading after felling.

The overall productivity, including harvesting and loading into timber trailer, in brush cleaning was in the range 3-6 solid m<sup>3</sup> per hour when the average tree size varied from 12 to 45 litres per tree. The corresponding figures in pre-commercial thinning was 1,8 to 2,7 solid m<sup>3</sup> per hour when the average tree size varied from 15 to 40 litres per tree. For both harvesting sites the direct loading method was preferable when sufficient amount of biomass was accumulated in the grapple before loading, while the separate loading method was preferable when smaller amount of biomass was accumulated. Other similar studies are reviewed and compared to the findings published here. Compared to published studies of other felling heads, the performance recorded for Nisula in these studies was lower. Several possibilities for improved design of the felling head and improved work methods are discussed.

# Improved efficiency of rigging in cable crane operation

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Twenty years ago the activity in steep terrain was high in Norway. About 700 000 m<sup>3</sup> were harvested annually in steep terrain. A large share of the harvesting was carried out with cable cranes. Presently the annual steep terrain harvesting is only 50 000 to 100 000 m<sup>3</sup>. The Norwegian government has developed a national strategy to increase the annual cut. If the strategy is to be followed, a large part of the increase has to come from steep terrain harvesting using cable cranes.

Studies conducted at the Norwegian Forest and Landscape Institute show that nearly 30 % of total time in cable operation is spent when rigging the equipment up and down, and moving it on the harvesting site. This paper presents preliminary results from testing fiber rope for anchoring on two cable crane operators. Time studies indicate that this contribute to increased efficiency. The fiber rope also reduces the work load.

The main goal is to increase the productivity in cable crane operation with 15 % by reducing the unproductive time by improving, and develop new and faster rigging methods. Development of new and low-weight equipment such as blocks is also a part of this ongoing project.

# Competitiveness of harwarder system in industrial roundwood harvesting

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The productivity and profitability of harwarders in industrial roundwood harvesting, as well as in energy wood harvesting, have been investigated in many studies. However, these trials have been almost exclusively time studies. Comprehensive, long-term follow-up study data on harwarders have been produced in only a few studies.

One of the strengths of a harwarder is considered to be the lower transfer costs compared to the two-machine (harvester–forwarder) harvesting system. The distance, time consumption, and costs of harwarder transfers have not, however, been reported in the previous harwarder studies. A follow-up study of harwarders in industrial roundwood harvesting, as well as a study on the transfers of the harwarders, were carried out by Metsäteho Oy. In the study of Metsäteho, the possibilities of harwarder systems in wood harvesting in the near future in Finland were also evaluated.

A total of five harwarders (three Ponsse Wisent Duals and two Valmet 801 Combis) were covered in the follow-up study. The amount of harvested industrial roundwood in the follow-up study totalled nearly 30,000 m<sup>3</sup>. The number of harvesting sites totalled 92, and data about the harvesting conditions were obtained from 70 of the sites. The harwarders were primarily used in thinnings in the follow-up study. Furthermore, harwarders were used principally for real harwarder work, i.e. both cutting and forwarding were done by a harwarder at the harvesting site. Harwarders were also used to balance two-machine harvesting systems, with the cutting carried out by a harwarder and the forwarding performed later on by a forwarder.

The research data on transfers with harwarders was collected by interviewing 13 harwarder entrepreneurs, in addition to conducting time studies on two harwarder transfers. The interviews were conducted during April 2003, and the time studies were carried out in October 2003 and January 2004. Research data on harwarder transfers were also collated from the follow-up study on harwarders.

In real harwarder work within the follow-up study, the productivity per operating ( $E_{15}$ ) hour in first thinnings was, on the average, 5.1 m<sup>3</sup>/ $E_{15}$ -hour and in other thinnings 6.4 m<sup>3</sup>/ $E_{15}$ -hour. In the case of thinnings, the productivity per operating hour of real harwarder work was best explained by the average stem size in the marked stand. In the final cutting of the real harwarder work within the follow-up study, the average productivity was 7.7 m<sup>3</sup>/ $E_{15}$ -hour.

The harwarder systems were more competitive than the two-machine system when the average stem size of the marked stand was relatively low, i.e. less than 120–180 dm<sup>3</sup>. In this case, the industrial roundwood removal is below 60–70 m<sup>3</sup>/ha. Furthermore, harwarders were the

most competitive in low-removal stands, particularly at harvesting sites that were below 50 m<sup>3</sup>. As the stands average stem size and roundwood removal per hectare/stand increased, the competitiveness of the two-machine harvesting system improved in comparison to that of the harwarder systems.

In the follow-up study, the proportion of the total work-time of harwarders used in transfers between harvesting sites was 2.5%, and the effective transfer time was, on the average, 1.3 hours/transfer. The harwarder entrepreneurs interviewed calculated that the transfer distance with a harwarder from one stand to another is, on the average, 28 km. The transfer costs of a harwarder were less than half (43%) those of a two-machine harvesting system.

Currently, the total number of harwarders in use in Finnish forests is slightly over one hundred, of which more than half are mainly engaged in industrial roundwood harvesting and the remainder in energy wood harvesting. The number of harwarders will undoubtedly significantly increase in the near future in Finland; within a few years, the number of harwarders engaged in industrial roundwood and energy wood harvesting may even be as much as 200–300. This development forecast is based on the following factors:

- 1) *Cost effectiveness in wood harvesting is being sought at the level of the stand marked for harvesting, as well as from the point of view of the forest machine business.* A harwarder has a clear competitive advantage in small-removal thinnings and final cuttings, forest fellings in the archipelago, the harvesting of wind-felled trees, and in seed tree and shelter-wood fellings. It makes sense to harvest relatively small-removal and small-diameter stands marked for harvesting with a harwarder while, conversely, it is more worthwhile to harvest sites with larger removals and trees using a two-machine harvesting system, thereby raising the profitability of two-machine harvesting systems.
- 2) *The structural change in cuttings is setting new demands on the harvesting machinery.* Wood harvesting volumes of thinnings and on peatlands will grow during the next ten years. The harvesting conditions described above (small stem size and low removals) are ideally suited for harwarder.
- 3) *As a result of changes in the forest machine business field, the size of forest machine contracting businesses is growing and large regional responsibilities in contracting are increasing.* These changes are creating a potential for the use of specialized harvesting machinery. In this respect, the acquisition of a harwarder alongside two-machine harvesting systems may be a sensible alternative.

When evaluating the competitiveness of harwarders, the relatively short development track of harwarders must be kept in mind. Harwarders have been actively developed for only about ten years. By developing harwarders and their working methods and organization, it will be possible to further improve the competitiveness of harwarders.

*Keywords: Harwarders, Wood harvesting systems, Cost-efficiency, Industrial roundwood, Finland.*

# Tractor based combined bunk; boom and cable skidding in hardwood extraction

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## Introduction

Close-to-nature forestry often includes some kind of certification of forests, which should guarantee a sustainable and environmentally lenient silviculture.

Soil compaction is believed to cause serious and long lasting damages to forest sites. Therefore forest certification provides for the establishment of permanent strip roads.

Permanent strip roads are a challenge for Danish forestry, because the most common method used for the extraction of hardwood lumber, the grapple skidder, includes driving on most of the forest site.

In Germany permanent strip roads have been used for a longer period than in Denmark, and therefore methods and machinery for the extraction of hardwood lumber has been developed and tested there.

One solution is the so-called boom tractor. A boom tractor consists of a grapple mounted on the end of a strong boom pivoted to the rear of a tractor. A winch mounted near the base of the boom makes it possible to winch in timber which is beyond the reach of the grapple. A complete version also includes a clambunk or similar equipment mounted at the back of the tractor. This combined unit was evaluated using time and motion studies in a beech stand in Grib Forest, Denmark. Extraction using a boom mounted grapple was compared to extraction with the same equipment using a winch. The forwarding component was not studied specifically, but it was observed and discussed during the study.

## Results

As expected, driving in and out of the stand did not show any difference in time consumption between the two methods. Skidding speed was 3,9 km/h loaded and 6,3 km/h unloaded, and start and stop added about 1 minute to the time consumption. It means that driving in and out took around 2 minutes per log for extraction distances about 30 meters and around 5 minutes per log for extraction distances of 150 meters.

Loading and unloading using the grapple and boom took less than one minute per m<sup>3</sup>, and because loading and unloading of large logs took more time than for small logs, the time consumption per m<sup>3</sup> was fairly constant between 0,8 and 1 minute.

Loading and unloading using the winch did not seem to be dependant on log size, which confirms the experience, that log size is crucial in winching operations. Winching distance is of course quite important. A function between winching out and the winching distance

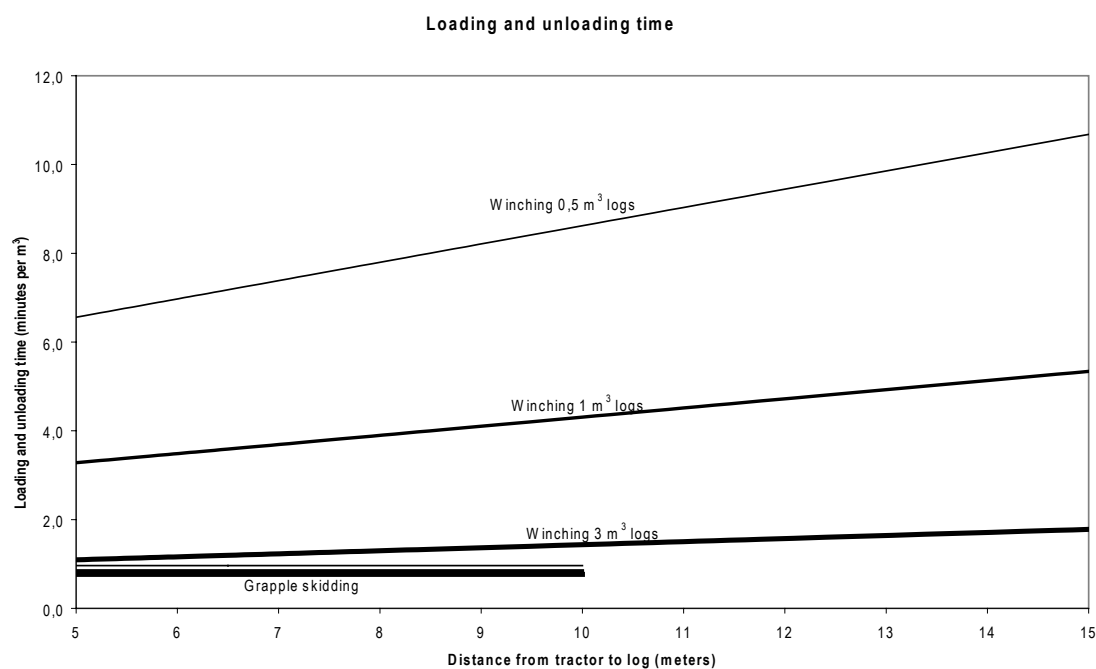
could not be calculated on basis of the time study, and therefore it was calculated using a walking speed of 1 km/h. The time study data showed that winching-in speed was approximately 0,4 km/h. Start and stop and attaching the winch to the log took about 0,7 minutes per log.

### Discussion

The results indicated that forwarding is preferable irrespective of the driving distance. Most forwarders can handle logs up to 1-1,5 m<sup>3</sup> in beech, and those logs should be forwarded if possible.

In all cases extraction with grapple and boom was faster than extraction using the winch. The biggest difference was found in the extraction of small logs. It showed that winching should be minimized and only be done if the boom can't reach the log.

The equipment is able to extract two logs at a time if one log is fastened to the winch and one log is hold by the grapple. This is a relevant option, especially for small logs and long extraction distances.





# Productivity of slash bundling at landing by a truck mounted bundler prototype

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When recovering logging residues (slash) for bioenergy, the material's low density implies a low usage of load capacity in hauling and road transports. To compress the slash increases the density and improves the profitability of the work. Performance of in-field compression by the use of forwarder mounted bundlers is nowadays common, as an alternative to e.g. in-field or landing chipping and handling of loose slash. The concept of hauling loose slash and bundle it at landing site has, however, not yet been evaluated. Potential benefits for the bundling process are higher concentration of slash and not having off-road requirements on the vehicle. This study evaluates the bundling productivity of a truck mounted bundler prototype at landing site. Larger and heavier bundles than at in-field bundling were created of both green and brown slash (mean bundle size = 2.5 m<sup>3</sup> (392 kg dry matter (DM))). The mean productivity was 17 bundles per effective hour, which was equivalent to 6 700 kg DM/E<sub>0</sub>h or 33 MWh/E<sub>0</sub>h. The green and brown bundles were estimated to use 70 % and 55 %, respectively, of a truck's load capacity (40 tonnes). The results indicate that the bundling-at-landing-concept can be an interesting alternative to present slash-recovering concepts.

# The operational efficiency and the damages on sawlogs of feed rollers of the harvester head

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**The damage on sawlogs and productivity of 6 different steel feed rollers of single grip harvester were compared. The traditional rollers with spikes were most effective in processing and fuel consumption but at the same time their damages on sawlogs were deepest.**

## 1. Introduction

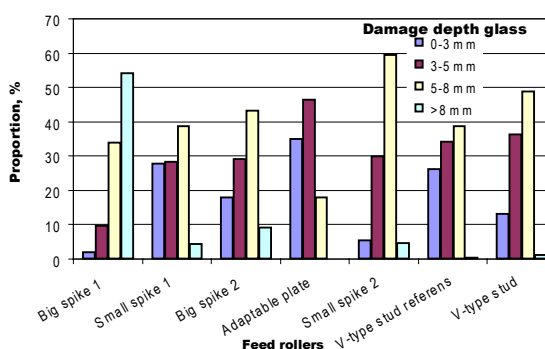
Feed rollers damages have existed since the mobilisation of the first steel rollers in 1970's. Recent studies about feed rollers have been made in Skogforsk (Sweden) by Hallonberg et al. (2004) and Brunberg et al. (2006). In these studies rubber-tyred rollers caused much less damages than steel rollers equipped only with studs, but the traction of them was much poorer. *The objective of this study was to compare the damage on sawlogs and productivity of 6 different steel feed rollers of single grip harvester.*

## 2. Material and methods

In the study six different types of steel feed rollers were tested: Two small spike rollers, two big spike rollers, one roller with studs in v-angle (v-type stud) and one roller with adaptable steel plates on the ring of roller (adaptable plate). Processing time and fuel consumption of the study stems were collected by using the automated data collector of the harvester and damages on the logs were measured by using a electronic meter.

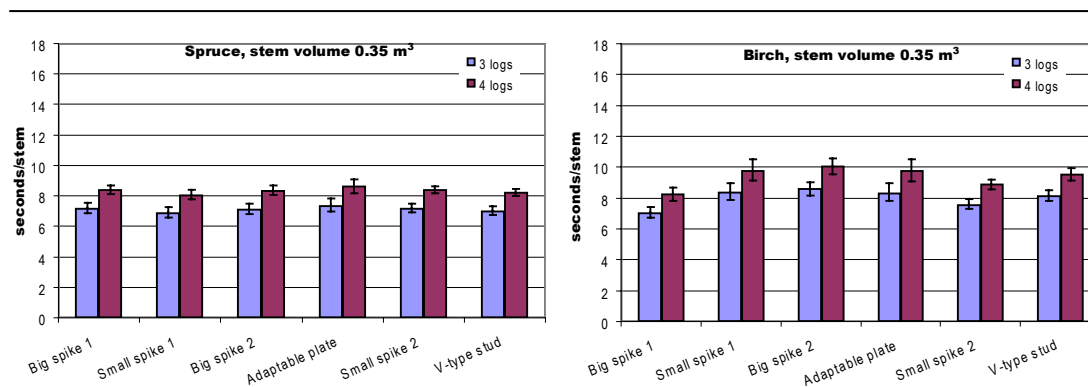
## 3. Results and discussion

The roller *adaptable plate* averaged lowest damages of 3.7 mm. Damages of roller *big spike 1* were deepest with an average of 7.8 mm. Most of the roller's *adaptable plate* damages were in the depth of 3-5 mm and for roller *big spike 1* damages of over 8 mm were dominant (fig 1).



**Figure 1.** Damage depth classes of feed rollers for unbarked stems.

Effective feeding time did not include cutting and pause times. For pine, spruce and birch small stems of volume  $0.05 \text{ m}^3$  roller type *adaptable plate* had shortest effective feeding time, 11%-41% less compared to slowest rollers. *Big spike 1* was fastest by birch medium stems of volume  $0.35 \text{ m}^3$  with 19% difference compared to slowest *big spike 2*. For medium spruce stems the shortest time had roller *small spike 1* (fig. 2). When processing big spruce stems of stem volume  $0.65 \text{ m}^3$  the slowest roller *adaptable plate* was 11% beneath the fastest *small spike 1*. Time of roller *big spike 1* was shortest by big pine and birch stems.



**Figure 2.** Effective feeding time for medium spruce and birch stems, sec per stem.

Fuel consumption per processed stem was in the range of  $0.1\text{--}0.6 \text{ l/m}^3$  -depending on the stem volume. Fuel consumption of roller type *adaptable plate* was lowest for small stems of volume  $0.05 \text{ m}^3$ . For medium size birch stems roller *big spike 1* was the most economical roller. For big spruce stems ( $0.650 \text{ m}^3$ ) the most economic roller was *small spike 1*. Respectively roller *v-type stud* for pine and *big spike 1* for birch, where the range of differences was 6-19%.

The effective feeding time differences between feed rollers had significant influences on the total effective cutting time: For medium stems the range of differences was 6-19%, which increases the effective time consumption of cutting 1-3%. There were significant differences between fuel consumptions of feed rollers. With a range of 15-25%, depending on the stem volume, the biggest difference between the rollers was found by birch.

#### 4. Conclusions

On the basis of the study results it can be assumed that the traditional rollers with spikes were most effective in processing and fuel consumption, but at the same time their damages on sawlogs were deepest. Roller type with adaptable steel plates was most effective for small stems.

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# Impacts of decline in Russian wood import to the forest industry in the Northern Finland

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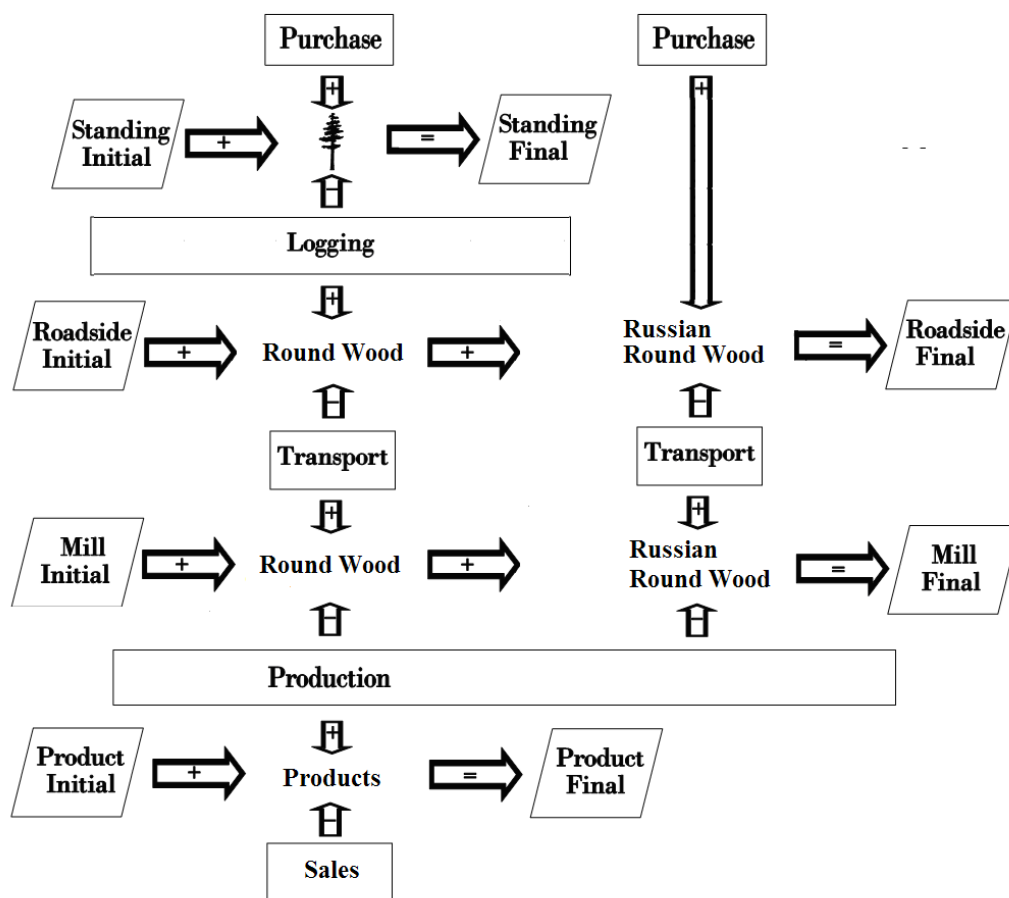
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The impacts of decline in Russian round wood import to the forest industry were examined applying timber-flow models for strategic wood procurement planning. The managers of the forest industry are looking into ways to lessen the blow of high Russian timber tariffs on Finland's wood procurement. There are further a lot of strategic changes in the domestic logistics environment of the wood product manufacturers, which are complicated with sequence-dependent wood procurement chains. For example, there are targets to increase the annual use of domestic round wood by 10 mill m<sup>3</sup> per year by 2010, and by 15 mill m<sup>3</sup> per year by 2015 (Anon. 2008). These targets presuppose that the delivering of forest round wood to the production is increased 20 %, or even 30 %, over the current delivering volume.

Data for round wood import was downloaded from public sources and internet. The parameters for costs and volumes of the wood procurement functions were calculated and computed based on real life research data.

The basic timber-flow model for experimental impact analysis of Russian tariff hikes is described in figure 1. Based on this model four different sub-models were formulated. The model #1 described the situation with round wood supply and demand in 2005. The model #2 described the situation where mills' round wood demands were changed for successful production schedule, and in the model #3 the round wood import was reduced by 50 %. The model #4 described the situation where the round wood import was totally closed down. In the models, the import was described as timber storages at the Finland/Russia border stations. The experiments were examined both in one-way transportation and back-hauling situations.

The analysis used Dynamic Linear Programming (DLP) to formulate the models. The optimization runs was made using the experiments on a 2393 Mhz x86 Family 6 Model 15 Stepping 10 GenuineIntel –laptop workstation with 4 GB RAM and Windows XP Professional operating system. The procurement scheduling algorithm was implemented using C programming language and the program was combined with a user interface created with MS Visual Basic of MS Visual Studio version 6.0 (Figure 2). The Lindo Api version 5.0 with standard settings was used as the LP-solver. Research to further improve the solution quality is not necessary, as the methodology guarantees a global optimal solution within a reasonable computational time. The methodology can be used as a powerful core of a decision support system for the managers and has great potential for the significant improvement of strategic procurement planning efficiency.



**Figure 1.** Dynamics of resource inventories including round wood import from Russian: Vertical arrows describe sequence-dependent effects of system; Horizontal arrows describe time-dependent effects of system.

The results showed that impacts of Russian tariff hikes required a lot of adjustment in timber flows of Finnish forest industry. The increase of timber price causes changes of wood supply to mills for successful production schedule. However, the reduction or total closure of wood import would cause severe shortage of timber, causing need to cut down pulp production. After removing one pulp mill from the model, the global optimum solution for wood procurement planning problem could be found. The use of backhauling could support wood procurement logistics in this complicate wood procurement environment. Backhauling also decreased transportation costs by 10 - 20 %.

Anon. 2008. Kansallinen metsäohjelma 2015. Lisää hyvinvointia monimuotoisista metsistä. (National Forest Programme 2015. More welfare from multiused forests). Ministry of Agriculture and Forestry, 31.1.2008.

# Possibilities for energy wood procurement in northwest Russia

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Share of biomass and waste is insignificant, about 1 % in the total primary energy supply in Russia, while that of fossil fuels is about 90 %. Russia differs from most of the countries in that it is self-sufficient in energy sources and actually exporting substantial amounts of gas and oil. In addition to large fossil energy sources country has also nearly 20 % of the global forest resources. Even though part of the forest resources are inaccessible, their utilisation could be much higher than it is today. Forest resources are better accessible in Northwest Russia than in Siberia, where large part of the resources are located. Possibilities for energy wood procurement in the Northwest Russian regions have been considered in this analysis.

Actual fellings were in Northwest Russia in 2006 about 50 million m<sup>3</sup>, which was about 43 % of the allowable cut. Approximately 80% of the wood came from final fellings. Based on the 2006 fellings, 21.8 million m<sup>3</sup> of energy wood would be available in cutting areas and central processing yards as non-industrial round wood, unused crown mass, defected wood during logging, and after clearfelling lifted spruce stumps. In addition, 6.3 million m<sup>3</sup> would be available as by-products from sawmilling. Fellings are largest in Arkhangelsk, Vologda and Leningrad regions, and thus accumulation of energy wood also largest (Figure 1).

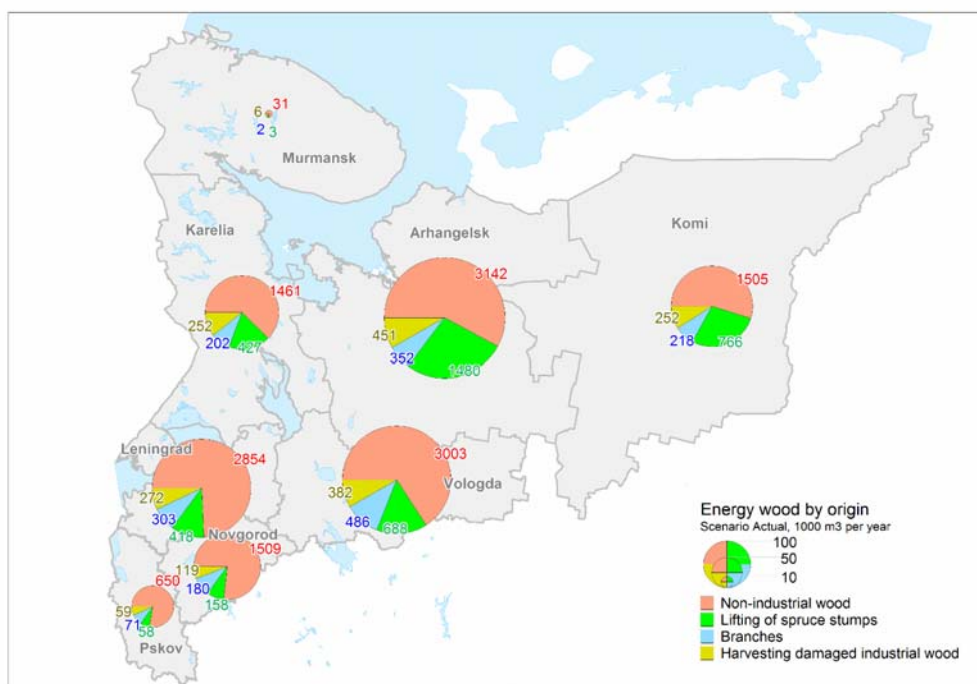


Figure 1. Availability of energy wood in Northwest Russia regions based on actual fellings in 2006.

Nearly 65 % of the energy wood from logging operations is non-industrial round wood, 19 % after clearfelling lifted spruce stumps, 8 % unused branches and tops, and 8 % defected wood during logging. Nearly 60 % of the energy wood from logging is pine and spruce. There are, however, big differences between the regions and within the regions. Deciduous tree species (birch and aspen) dominate in Novgorod and Pskov regions. It should be noted that currently part of the non-industrial round wood from central processing yards are utilised for heating houses in the countryside and that part of the residues from sawmills are used for pellet production.

Obviously it is possible to intensify utilisation of forest resources and thereby also to increase the use of wood in energy production. Annually available amount of energy wood could be 155 % higher or 55 million m<sup>3</sup> if the allowable cut could be utilised completely, and as much as 270 % higher or 81 million m<sup>3</sup> if also thinnings could be utilised completely. Also amount of by-products from sawmilling would be higher in these cases. There are big differences in the potentials between the regions and also within the regions, as the utilisation of forest resources varies from nearly zero to full, due to poor infrastructure, vast intact forest landscapes etc. Although more intensive forest management based on cut to length technology would provide also more material for energy production, it would also mean that major part of the energy wood would be concentrated in cutting areas. This would limit availability of energy wood in residential areas where central processing yards and sawmills are located, and thus would require development of supply and utilisation systems for energy wood.

# Techniques and methods for harvesting of small trees

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Bio fuels from small trees are estimated to have a sustainable fuel potential of 5 TWh/year in Sweden. The option to harvest energy in young stands may provide some incentive for early stand management. Thus, intensified treatment of young stands is desirable from a silvicultural point of view and also offers a sustainable source of energy. But small tree harvesting is costly. Technology, methods and systems must be improved significantly to provide economical viability.

Recently, several heads for bio energy harvesting have been introduced on the market. Since felling is a critical part of the operation it is important to find and use the best techniques and methods for harvesting of small trees. By formulating recommendations and provide guidance for choice of technology and allocation of systems, costs could be reduced by around 10 percent. Improvements of methods may lead to another 10 percent cost reduction, vital for the future of this assortment.

Cleaning of young forests is mainly done through motor-manual methods, without harvesting forest fuels. It can also be done mechanized, with accumulating felling heads, that harvests the trees one by one selectively or in corridors. With continuous harvesting the capacity could increase 2-3 times compared to today's techniques.

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.

Currently, the most common machine system within stands are harvesters with chainsaw felling heads and additional accumulating equipment. Long cranes are more common than short. Normally the material is forwarded to the roadside where it will be chipped and then transported to the customer. Along roadsides and pasture land it seems more common to use cutting knives or guillotine-style grapple head, that often have been mounted on a forwarder.

< 20 cm	< 25 cm	< 30 cm	< 50 cm	> 50 cm
	Bracke C16	Silvatec		
		Risutec		
		Silvaro K 250		
		Keto Forst	Valmet 330.2	SP 451 LF
			Logmax 4000B	JD 745
				Waratah HTH450
Nisula 280E	Pinox 220	Naarva 1500-40E		
Cut2	ABAB 250	JD 730		
	Silvaro K 250	Moipu 300&400 ES		
	Ponsse EH25			
	Naarva 1500-25EH			
	Mecanil EG 250A			
	Moipu 200 ES			



# Roundwood trucking – factors influencing profitability in mid-Sweden

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Generally, the economic results for Swedish roundwood trucking companies have not been good. Profitability is important for maintaining the stability in the transport business, which is a condition for long-term development in the forestry sector. The purpose of this study was to identify factors that influence profitability for roundwood trucking companies and quantify this influence.

The study was made within a single forestry trucking organisation in mid-Sweden. The study was carried out in four steps. In the first step economic results from all hauliers were collected and a random sample was taken from classes of net margin. In the second step 11 truck entrepreneurs were interviewed to map their views on their situation and identify probable success factors. In the third step further data on the identified factors were gathered through a questionnaire to 35 entrepreneurs. In the fourth step correlation- and regression analyses were carried out in order to structure and quantify the connections between identified factors and profitability (1- and 3-year horizon). The results of the study which were statistically significant ( $p < 0.05$ ) are summarized in the points below.

- 1) Shorter transport distances ( $< 60$ - $70$  km) had a negative effect on profitability. This is because short transport distances reduce the possibility for self-loading trucks to disconnect their loaders and leave them at the landing, which reduces the paid load size accordingly. This also increases the fuel cost. Generally, the transport distances to rail terminals were shorter than for direct deliveries to mills. A larger proportion of transport volumes to rail terminals decreases therefore the average transport distance and indirectly has a negative effect on profitability.
- 2) Vehicle tare weight had a strong effect on profitability. Increased tare weight ( $> 22$  t) directly reduces the load size and had a negative effect on profitability. Increased tare weight also increased the fuel cost.
- 3) The proportion of total transport volume from thinning also had a negative effect on the load size for the hauliers. The negative effect of thinning wood was larger for lighter self-loading trucks than for heavier self-loading trucks ( $\geq 23$  t).
- 4) Limitations in receiving hours (those without 24 hr staffing) had a negative effect on profitability. Hauliers who agreed that the economic compensation for waiting time generally compensates for the increased costs generally had a higher profitability than those who disagreed.
- 5) A connection between back-hauling and profitability was not found in this study. It is therefore reasonable to further examine the factors determining the influence of backhauling on haulier profitability.

**Key words:** *trucking contractors, net profit margin, investment decisions, planning decisions.*

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# Wood value optimization including logistic costs, production costs and product incomes: a case study in central Finland

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Tree bucking control can be divided into two main tasks: (1) what products (wood assortments) in what quantities we cut from each stand and (2) what kind of logs in terms of small-end diameter and log length are cut within one product. It is in most case undesirable to cut many products from the same stand because it implies too many loading and transportation operations. Therefore, it would be necessary to choose which products in what quantities may be cut from each stand. This means that tree bucking control and wood transportation problem should not be considered as separate tasks but they should be optimized as a whole. If they are considered as separate processes the gain that are achieved as better product characteristics are being lost due to increasing transportation costs.

We have managed to develop a tree bucking optimization system that is capable to integrate transportation cost and product values into current tree bucking optimization procedures. During this study we have updated new productivity models for tree harvesting and long distance transportation. In addition new method for activity/product based costing has been developed.

Optimization procedure is carried out with Genetic Algorithm (GA) based solution. The GA-based optimization system operates with solution trials consisting of demand matrix strings. Each matrix string has a demand log tally for each log product in each stand included in the optimization process. The objective is to assign each stand a product mix and, further, each product a demand matrix so as to maximize the overall net profit from all stands. Following iterative process is applied:

- Each stand, described in the STM-format, is converted into logs through a bucking-to-order procedure under the control of the fixed product-specific price matrices and the demand matrix candidates (the first matrix population is initiated randomly)
- Each demand matrix string is evaluated by calculating the costs and revenues induced by the resulting log output matrices
- The best demand matrix string along with the corresponding bucking outcome is stored at each iteration cycle

New population of demand matrix strings is created using tournament selection, uniform crossover, and mutation with random replacement

Within the case study area wood procurement company delivered pine raw material to five different production plants; two sawmills, one joinery factory, one log house factory and one pulp mill.

The case study tries to mimic real harvesting, transportation and tree conversion actions as much as possible. The data is based on harvesting sites that were marked for felling and were in summer 2004 harvested by local wood procurement company. The calculations concentrated on optimizing and comparing the production flows of pines (*Pinus sylvestris*). The study material comprised 15 mature pine forest. While harvesting data on tree profiles and volumetric information about wood assortments were stored in the STM-format by the harvester's computer system.

Processing costs we formed theoretically. First cost structure of each process were defined i. e. share of raw material (wood) costs, operative costs, capital cost and profit. Then the effect of size and type of log on operative costs was defined. Calculation of harvesting and long transportation costs were based on time studies and new cost calculation procedures developed in this study. Cost parameters and market prices correspond to cost level of year 2005. Revenues of main products and by-products were also formed theoretically. Revenues in wood supply chain are the incomes that come from selling the main product and associated by-products sold in open markets. Share of different type of products were based on different types of publications.

Demand of each assortment was set so that the cumulative sum of demand of all assortments were 5% higher than the actual cumulative volume of wood of all 15 study stands. This restriction forced optimization systems to allocate all wood from all stands to some destination. In case study, optimization system was tuned to optimize two different targets: search for the best possible solution (highest net profit) and search for the worst possible solution (lowest net profit).

Optimization system found big differences between the best solutions of these targets. Best feasible solution gave net profit of 9.89 €/m<sup>3</sup> and worst feasible solution 6.97 €/m<sup>3</sup>. The difference between the best and worst net profit was 2.92 €/m<sup>3</sup> (41.9%). Volume of wood of those 15 stands was roughly 5000 m<sup>3</sup>. Since actual annual amount of deliveries from that district to those factories is roughly 340 000 m<sup>3</sup>, the potential gain of improving net profit is 1 million euros.

Our case study showed that it is possible to theoretically compare and optimize net profit of wood allocation problems even at stem level. This type of optimization approach can not be applied in operative planning but this type of strategic planning can reveal long-term relevance of creating tailor-made wood supply chains. Quite propably, competition on energy resources and desire to develop new processes ( bio-refinery) calls for these kind of tools that can compare net profit of wood supply chains.

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# Early respacing in naturally regenerated beech using a boom-mounted sickle-bar mower

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## Introduction

Much work has been done on methods to reduce the number of stems per unit area in naturally regenerated forest stands (e.g. Skovsgaard et. al., 2006). In Denmark regeneration is typically induced in stands of European beech (*Fagus sylvatica* L.) through a regeneration cut, sometimes simultaneously with a light form of scarification. The combination of increased light incidence and exposure of mineral soil in promoting germination can lead to very high initial stocking densities of more than 100,000 seedlings ha<sup>-1</sup> on good sites. With such high densities the seedlings are continually exposed to significant mutual competition in their early development. While a certain degree of competition is beneficial in promoting stem quality, the wood quality of beech is not negatively affected by rapid radial growth, and a better spatial distribution from an early age is likely to lead to more vigorous growth. Importantly, changes in silviculture and forest management practices are recognised as a means of potentially increasing the yield of biomass-for-energy from existing forests. Here, a re-spacing at an early stage is anticipated to result in a development that could make an ensuing biomass-for-energy motivated thinning feasible.

The initial reduction in stocking density in hardwood stands is conventionally done using a tractor fitted with a mulcher which traverses the stand removing all vegetation in alternating bands of 1-2 m in width. The result of this is 'hedges' with a density equalling the pre-treatment stocking, alternating with bands totally devoid of a productive tree crop. While perhaps not biologically optimal, the system has been considered rational and the development of the stand satisfactory. The notion of utilising the available productive area in a more dispersed way to ensure improved growth on individual trees to improve a successive energy harvest would require the adoption of new techniques.

Now, certification standards adopted in Denmark forbid vehicle traffic outside of a permanent strip-road network (20 m interspaced). This makes the use of 3-point linkage mounted implements obsolete in any forest considering certification, including all the national forests. Future mechanised operations will therefore almost always require the use of boom-mounted implements.

## Materials and methods

A desktop analysis of the technical and economic parameters required of a boom-mounted sickle-bar mower was carried out using supplier data for a commercially available unit.

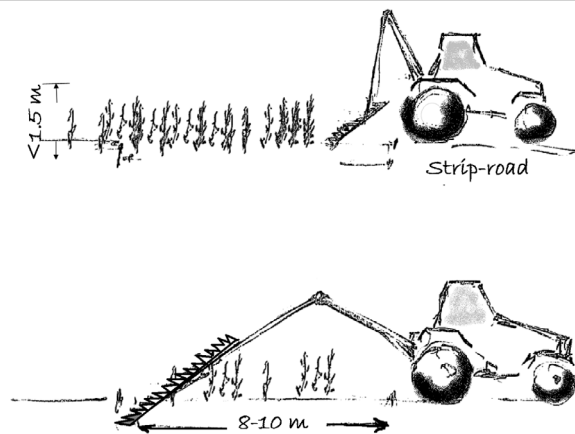


Figure 1. The envisaged operational environment

It was assumed that the boom could reach the full 10 m inter-row, and that the sickle-bar was adapted by removing alternate teeth, thereby functioning as a ‘thinning comb’, and that it was available in a number of sizes, with widths ranging from 2.0-4.5 m (Fig. 1). Important variables include tractor repositioning time, boom operating speed, swath width and the machine unit operating cost (which varied from € 80 to €130 per machine hour). Qualitative variables such as the suitability of the treatment in terms of damage and growth on the remaining trees (height of treatment, uprooting, bark damage) were not factored in, and will be addressed in the field trials in phase 2 of the project. The main variables were run against each other in a spreadsheet and plotted in a nomogram (Fig. 2) in providing a detailed overview of the technical requirements such a machine would need in order to make it competitive with the conventional mulcher, which was set to a cost of € 600 ha<sup>-1</sup>.

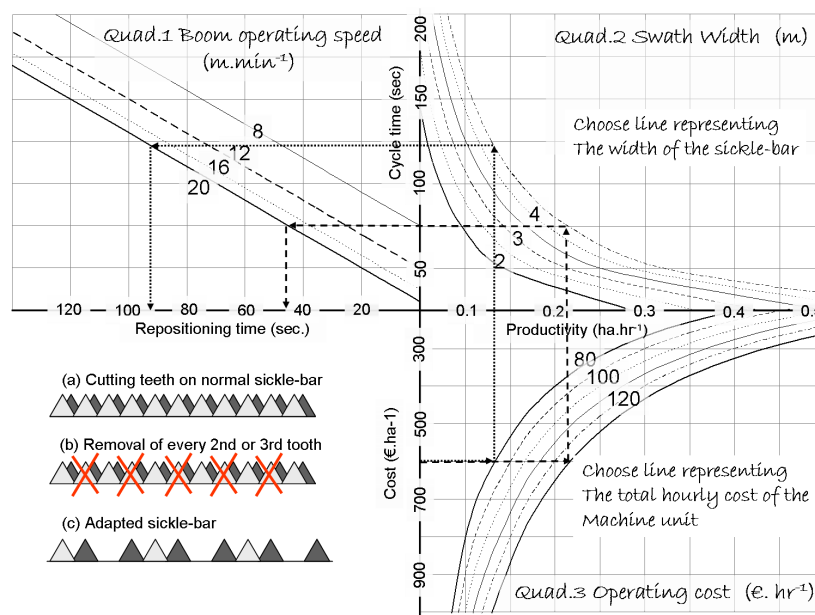


Figure 2. Quadrants 1-3 show the internal relationships of the primary variables. Assuming an alternative treatment cost of € 600 ha<sup>-1</sup> (y-axis, quad.3) the figure can be used to delineate the solution space for all major variables depending on whether a cheap (€ 80 hr<sup>-1</sup>, dotted line) or expensive (€ 130 hr<sup>-1</sup>, dashed line) base machine is used. The insert shows how the sickle-bar can be adapted to ‘thin’.

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## Results and discussion

Results of the desktop study (Fig. 2) show some of the technical constraints that have to be met given a targeted cost, or conversely, the economic consequences of technical limitations. The boom operating speed is obviously an important component of cycle-time, but is likely to be limited by the cutting capacity of the sickle-bar, which is determined by the amount of oil that can be delivered. It is anticipated that thinning would have to be limited to winter as the presence of leaves is likely to slow the boom speed and exacerbate damage through uprooting and bark scraping. Quadrant 2 shows the influence of the width of the sickle-bar, where 2.5 m is standard. Wider bars might be difficult to manage unless fitted with a stabiliser or skids. Finally, the implement can be fitted to an agricultural tractor with limited adjustments. This means that the operational cost could lie in the lower end of those given in quadrant 4. The benefits of an improved stand development and early biomass yield could outweigh any additional cost.

## Acknowledgements

Thanks to the Danish Forest and Nature Agency's Fund for Practical Forestry Experiments.

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# Kemera supports and the profitability of small-sized wood harvesting from early thinnings in Finland

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When harvesting small-sized thinning wood in young stands, the stem size harvested typically has a breast height diameter ( $d_{1.3}$ ) of less than 10 cm, and the stems are harvested as whole trees (stem with branches). In Finland, typical harvesting conditions in early thinnings may be described as where whole-tree chip removal is around 40–70 m<sup>3</sup>/ha and the average stem size of removals in stands ranges between 10–40 dm<sup>3</sup>. High harvesting costs, particularly cutting costs, are the primary problems in early thinnings. Small stem size, low removal per hectare and harvesting site, and dense undergrowth result in low productivity and high cutting costs.

When producing whole-tree chips from young stands, the total supply chain costs are approximately 17–22 €/MWh. In the beginning of 2008, the mean price of forest chips at the gate of energy plants was 14.4 €/MWh in Finland. In order to speed up the production of small-sized wood chips in young stands, the Finnish State provides production subsidies for small-sized wood chips in early thinnings, according to the Sustainable Silviculture Foundation Law (Kemera).

Metsäteho Oy undertook a study on the total production costs of small-sized thinning wood chips with and without the Kemera supports. This conference paper introduces the Kemera support system for energy wood harvesting in early thinnings in Finland, and presents and discusses the effect of the Kemera supports on the profitability of whole-tree chip procurement.

The Kemera support is paid only for young forests owned by non-industrial private forest owners in Finland. The Kemera support is paid for the non-industrial private forest owner's own work, as well as for contracted work. The area, to be eligible for the support must be greater than 1 hectare. A principal element in the Kemera support system is that supports provided are restricted to be given only once throughout a stands rotation cycle. There are currently four support instruments offered for young stands in the Kemera support system:

- 1) Support for thinning young stands,
- 2) Support for small-sized wood harvesting,
- 3) Support for chipping, and
- 4) Support work clarification.

When assuming that a non-industrial private forest owner has a valid forestry plan, the forest owner does not carry out work activities, work activities are conducted according to guidelines, size of stand is 3.0 ha, and whole-tree removal is 50 m<sup>3</sup>/ha (150 m<sup>3</sup>/stand), then the maximum total support is 2,498–2,750 €/stand depending on the support zone. The largest support instruments are the support for small-sized wood harvesting, the support for thin-

ning young stands, and the support for chipping. In confirming work clarifications, the level of support provided is smaller. The maximum total support per harvested cubic meter is around 17–18 € (8–9 €/MWh).

When calculating the total production costs for whole-tree chips, it was noted that production costs were relatively high, 35–43 €/m<sup>3</sup> (17.5–21.5 €/MWh) in average harvesting conditions (average size of removed whole trees: 20–30 dm<sup>3</sup>) of young stands compared to the average price of forest chips at the gate of plant (14.4 €/MWh). Hence, the cost calculations illustrated that small-sized wood chips (whole-tree chips) cannot currently be produced without the Kemera supports from young stands with typical harvesting conditions.

When operating without the Kemera supports, the average stem size of whole trees harvested must be greater than 80 dm<sup>3</sup>, at the current price level of small-diameter wood chips in order for harvesting of small-diameter energy wood from young stands to be economically profitable in Finland. When the average stem size of whole trees is approximately 80 dm<sup>3</sup>, the stand is typically a small-diameter first-thinning stand for industrial roundwood (i.e. pulpwood) harvesting in Finland.

When including the total maximum Kemera support for the production costs of whole-tree chips, the production of whole-tree chips was economically viable in young stands with the average stem size of removal (20–30 dm<sup>3</sup>). Actually, the results indicated that small-sized thinning wood can be harvested from relatively poor harvesting conditions (the average size of whole trees 15–20 dm<sup>3</sup>) with the Kemera supports. State authorities justify the levels of Kemera supports by stating the aim of the Kemera support system, which is to encourage recovery of small-diameter thinning wood for energy generation, which also includes harvesting poor quality sites.

There are several ongoing discussions that the Kemera support system would direct pulpwood for energy generation instead of pulping. Currently, there hasn't been research, which has studied the amount of pulpwood being allocated for energy generation within the Kemera system. Furthermore, it should be noted that guidelines determine very clearly that the average  $d_{1.3}$  of remaining trees must be less than 16 cm after a thinning operation, which eliminates wood harvesting operations for energy generation from relatively large-sized early thinnings with the Kemera supports.

When discussing the Kemera supports, it must be noted that they play a very important role in Finland, so that young stands are managed in a way that promotes healthy silvicultural conditions. Without the Kemera support system, it can be estimated that there would be greater occurrences of untended young stands in Finland. In Sweden, for instance, where there is no similar support system for young stands, such as Finland's Kemera system, there are currently significant silvicultural problems with their young, dense and small-diameter stands.

*Keywords: Kemera, Production supports, Small-diameter wood, Energy wood, Costs, Early thinnings.*



# Thinning intensity and the harvesting costs of first-thinning wood in Scots pine stands

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During the 1970's and the beginning of the 1980's, the artificial regeneration area for Scots pine (*Pinus sylvestris* L.) in Finland totalled over 100,000 hectares annually, of which over two-thirds consisted of planting. Part of the area planted with pine included excessively fertile sites, resulting in poor quality, thick-branched pine stands. It is estimated that there are more than 0.5 million hectares of poor-quality Scots pine stands in Finland.

In the new forest management recommendations drawn up by the Forestry Development Centre Tapio, one cultivation alternative for Scots pine is intensive cultivation in which the quality of a poor or mediocre pine stand is improved by carrying out an intensive, quality first thinning. This type of thinning leaves ca. 700 trees per hectare, whereas a normal first thinning leaves 900-1,000 trees per hectare. The research conducted by Metsäteho Oy investigated how harvesting conditions and costs change when the thinning intensity is increased and intensive, quality thinnings are carried out in first-thinning Scots pine stands.

When calculating the wood harvesting costs, it was assumed that the removal density in an intensive quality thinning is 250 industrial roundwood trees/ha greater than in a normal first thinning. Three different alternatives were generated for the cost comparisons between an intensive quality thinning and a normal first thinning. The alternatives were:

- 1) Stem size of the trees to be harvested did not increase,
- 2) Stem size of the trees to be harvested increased by 25 %, and
- 3) Stem size of the trees to be harvested increased by 50 %.

When harvesting 250 trees per hectare more than in a normal first thinning, in a first-thinning Scots pine stand with intensive quality thinning in typical harvesting conditions (i.e. stem size: 50-100 dm<sup>3</sup> and industrial roundwood removal: 20-60 m<sup>3</sup>/ha), the thinning intensity increased by 13-21 %-units. This increased removal density and in turn, the industrial roundwood removal of the marked first-thinning stand. When the average stem size of the trees harvested in intensive quality thinnings was not increased, the industrial roundwood removal was 13-25 m<sup>3</sup>/ha higher than in normal first thinning of a Scots pine stand in typical harvesting conditions.

When the average stem size of the harvested trees was raised in an intensive, quality thinning, the industrial roundwood removal increased significantly compared to that in normal first thinning. When the average harvested stem size was raised by 25 %, the removal increased by 21-44 m<sup>3</sup>/ha in typical harvesting conditions. When the average harvested stem size was increased by 50%, the removal increased by 29-64 m<sup>3</sup>/ha compared to normal first thinning.

An increase in the average stem size of the trees harvested in intensive, quality thinning had a significant impact on the productivity and costs of cutting work. When the average stem size of the trees harvested in intensive quality thinnings was not raised, the cutting costs were 2-7 % (0.4-1.0 €/m<sup>3</sup>) lower than in normal first thinning in typical harvesting conditions. The relative forest haulage cost savings were similar to those of cutting. The overall harvesting costs were 0.5-1.5 €/m<sup>3</sup> lower than in normal first thinning in typical harvesting conditions in a Scots pine stand.

When the average stem size was increased by one quarter, the cutting costs were over 20 % (2.2-4.7 €/m<sup>3</sup>) lower than in normal first thinning in typical harvesting conditions. The smaller the average stem size of the harvested first-thinning stand, the higher were the cost savings in cutting. The effect of average harvested stem size on the forest haulage costs was lower than the effect on the cutting costs. When the average stem size of the harvested trees was raised by 25 %, the harvesting costs fell by 15-19 % (2.6-5.3 €/m<sup>3</sup>) compared to normal first thinning in typical harvesting conditions.

When the average harvested stem size was raised by 50 %, the cutting costs were more than 30 % (3.4-7.0 €/m<sup>3</sup>) lower and the forest haulage costs 6-12 % (0.4-0.9 €/m<sup>3</sup>) lower than in normal first thinning. The overall harvesting costs were 23-28 % (3.9-7.7 €/m<sup>3</sup>) lower than in normal first thinning in typical harvesting conditions in a pine stand.

The study showed that the harvesting conditions in intensive quality thinnings are superior, resulting in lower harvesting costs than for normal first thinnings. One item of particular interest was the decrease in cutting costs. Intensive quality thinnings have less of an impact on the forest haulage costs. The reduction in harvesting costs, and especially in the cutting costs, is related to how much the average stem size of the trees to be harvested increases throughout the marked stand. The extent to which the average stem size harvested is increased in intensive quality thinnings, depends on the spatial distribution and structure of the first-thinning stand. It can be assumed, that the average stem size harvested in intensive quality thinnings will be higher than that in normal first thinnings.

When the average stem size of the trees to be harvested increased by 25 %, which is a relatively realistic increase in the stem size harvested in the stand, the harvesting costs were around 3 €/m<sup>3</sup> lower than in normal first thinning in average harvesting conditions in Scots pine stands in Finland. The cost savings were significant: in 2007, the average wood harvesting costs in mechanized first-thinning stands were 15.1 €/m<sup>3</sup>.

*Keywords: Thinning intensity, Industrial roundwood, Pulpwood, First thinnings, Scots pine, Wood harvesting, Costs.*

# Productivity and quality in first thinnings with strip roads and intermediate passages

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In cut-to-length thinning with harvester-forwarder systems, both machines normally travel on all strip roads. An alternative is to only use certain roads for extractions. The harvester then concentrates logs to those roads when thinning from the intermediate passages. This has advantages in increasing log density for the forwarder, decreasing width requirements on intermediate passages and it also decreases the ground area multiply affected by heavy machines. However, due to increased need of crane work far away from the harvester, there are risk for decreased harvester productivity and an increase in residual tree damage. To evaluate the different methods, a comparative study was conducted between conventional strip road thinning and thinning with one and two intermediate passages between strip roads. The machines studied were a small harvester (Forestline MPM C90) and a medium sized forwarder (Timberjack 1110).

There was no significant difference in harvester productivity between the three thinning methods. The forwarder's productivity was significantly higher when using intermediate passages compared to strip roads, but the different numbers of intermediate passages did not influence productivity. On a system scale, there were no productivity differences between thinning methods. The expected increase in residual tree damage with increased number of intermediate roads was observed, but the differences were not significant.

# Corridor thinning productivity in young dense forest stands

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## Introduction

The bioenergy resources in Swedish young dense stands is huge but can only be fully utilized if technical solutions and work techniques for harvesting is developed. Today, dense stands are selectively thinned with conventional harvesters with accumulating felling heads (AFH). Several studies show that such operation only is productive in stands with high standing volumes (Bergström et al. 2007). One possible way to improve the efficiency of the operation is to harvest trees in 1-1.5 m wide and ca. 10 m long corridors between strip-roads. When harvesting in corridors the time for re-positioning the AFH between trees is likely to be reduced. In this field study comparison of selective/conventional and the proposed “corridor” thinning was made (Fig. 1).

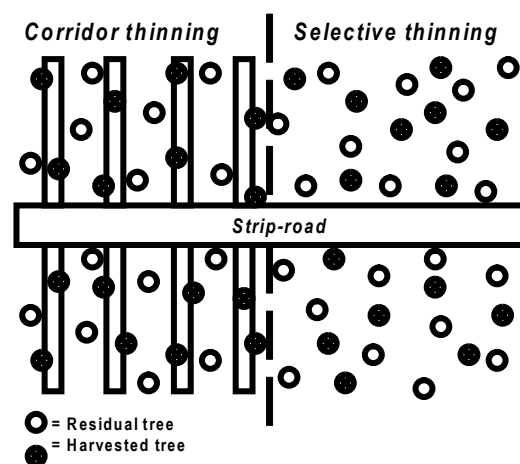


Figure 1. Thinning methods compared in the study

## Materials and methods

The study area was dominated by Scots pine (*Pinus sylvestris*) and had in average 8300 trees/ha, a basal area of 22.1 m<sup>2</sup>/ha, a diameter at breast height of 9.6 cm and a tree height of 8.5 m (weighted by basal area). A mid-size harvester equipped with an AFH was used in a randomized block design (8 blocks/16 study units). Harvesting of strip-roads was included in both thinning methods.

## Results

In average, the harvest reduced the basal area with 38% and the number of trees with 28 % (all trees higher than 1.3m included).

**Table 1.** Stand characteristics before harvest and harvesting results of the selective and corridor thinning operation (mean values for all study units presented), DM=dry matter.

	Selective	Corridor
Initial stand density (trees/ha)	5800	5600
Dbh (cm)	5.3	5.3
Productivity (trees/E <sub>0</sub> )	460	500
Productivity (tonDM/E <sub>0</sub> )	3.8	4.4

Productivity (tonnesDM/h) with the corridor thinning method was 16 % higher compared to the selective thinning method. The difference in productivity between corridor and selective treatment is highest when harvesting small trees (Fig. 2).

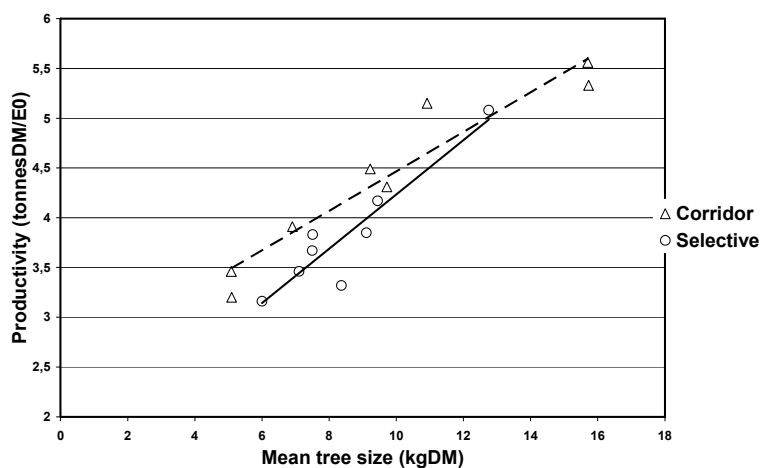


Figure 2. Productivity of selective and corridor thinning operations as a function of mean tree size.

## Conclusions

The corridor thinning improved productivity in spite of the fact that the driver was new to the method and that the accumulating felling head was not developed for corridor thinning. With development of suitable technology the potential for further improved productivity is therefore large in biomass harvest operations in young, dense forest stands.

## References

Bergström, D., Bergsten, U., Nordfjell, T. and Lundmark, T. 2007. Simulation of Geometric Thinning Systems and Their Time Requirements for Young Forests. *Silva Fennica* 41(1): 137-147.

**Keywords:** operational efficiency, fuel-chips, multi-stem, fuel-wood, pre-commercial-thinning, early thinning

# Efficient handling of wood fuel within the railway system

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## Background

The supply of wood fuel in the populated regions of the Sweden is limited. As demand grows, the interest for efficient transports from distant inland forest areas has increased. Rail transport may offer a solution, but technical and logistic systems must be developed and evaluated to reduce the transportation cost.

To study the feasibility of rail for forest fuel transportation a project has started in cooperation between Skogforsk and twelve companies within the forestry, transportation and energy sectors. The project will run for two years and was started in January 2008.

## Goals

The project aims to deepen our knowledge of how efficient handling of wood fuel on railway terminals should be arranged. A practical goal is to present a specification of how a sending and a receiving terminal should be arranged and equipped in order to provide the most efficient system for rail transportation of wood fuel. This will be given for 2 different terminal sizes.

## Accomplished studies within the project

Two case studies of wood fuel transportation from the inland to coast of north Sweden have been completed. Both tests have run parallel once a week for 11 weeks during the winter period 2008. Goals for these two studies were to evaluate and compare the different systems and to find significant efficiency factors in the handling process.

The first test concerned standard 35m<sup>3</sup> containers, which also can be transported by trucks. The containers were offloaded by a forklift 17 km from the CHP-plant and delivered by truck.

In the other test special voluminous rail-containers, 46 and 57 m<sup>3</sup> respectively, were used. At the receiving terminal, the chips were emptied by a big forklift truck turning the containers



Offloading of 46 and 57 m<sup>3</sup> containers with a 42-ton forklift truck.

upside down. The forklift could, if necessary, shake the containers to empty also chips that may be stuck frozen to the container surface.

### Results and conclusions

Winter testing has allowed the study of problems with freezing, - which makes it difficult to empty the containers. To decrease this risk the containers should be free from snow before loading. Powdering the containers with a bottom layer of dry chips also decreases the risk of freezing.

Standard containers are limited by the maximum weight for the truck (60 ton). If the material is slightly wet the whole volume of 35m<sup>3</sup> can not be used, which decreases the efficiency of the system. The specialized containers performed best in terms of transportation capacity and low tendencies of freezing. But the machine offloading and handling these containers must be big and thus expensive and often highly specialized. High utilization of the container loader becomes essential to the economic efficiency of the system.

Simulation of a case with two full trains running each week, year around, show that the handling costs from loading on terminal to offloading at the CHP-plant (rail transport excluded) comes down to approximately

8,76 SEK/MWh for the 35-m<sup>3</sup> containers

7,87 SEK/MWh for the 46-m<sup>3</sup> containers

6,85 SEK/MWh for the 58-m<sup>3</sup> containers

The costs of rail transport of wood chips vary with a number of factors. A study aiming establish good estimations of these costs is yet to be performed. Nevertheless, we know from experience within the project group that handling costs are low compared to the transportation cost. Any errors of the estimated handling costs in our example will not significantly alter the results.

Other outcomes from the study was mapping of obstacles at the loading and receiving terminals. When loading the big containers, a problem was that the driver of the loader had no sight into the container, since the cab of the loader was located lower than the container rim. It was also difficult to spread out the chips on the top since the lift arm of the wheel loader



*Emptying at the receiving heat-plant.*

could just reach over the top of the container. Constructing an elevated loading platform would simplify the loading. This might be a factor to take into account when planning new sending terminals.

The smaller containers were emptied at their destination by a truck tipping each container backwards. The tipping angle could have been higher, which would have simplified the procedure, if the height of the ceiling had allowed. Approximately 7,2 m would have been enough height to avoid problem for this truck.

### **Future plans for the project**

During the project more studies will be made. Focus will be on the technology and logistics of the terminals. Much effort will also be made to adapt our recommendations to the conditions of the receiving terminals.

In the two completed tests in northern Sweden only two wagons per week were transported. In October a new case study will be performed where a complete train-system will be tested. A train set will run alternately from 3 sending terminals to a CHP-plant in Örebro. In order to identify the recipients' logistical requirements, a survey will be conducted in the autumn of 2008 to provide a broad picture of the conditions that generally applies to Swedish heat and power producers within the biomass sector. New techniques such as containers, handling machines and weighing equipment will continuously be studied within the project.



# Hardwood log extraction by grapple, winch and sulky – a comparative study

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Three methods for log skidding were compared in a 120-year old shelterwood stand of beech (*Fagus sylvatica*) in an early stage of natural regeneration. The study area comprised 8 hectare of rolling moraine soils with somewhat varying texture and moisture conditions. A reasonably dense natural regeneration (0.5-1.5 m tall) was present, sheltered by approximately 400 parent trees; among these 87 trees were cut during the present study. The area was sub-divided into 3 x 3 experimental plots in order to facilitate a comparison between the three methods.

The skidding implements included in the study were:

- 1) 4 WD Tractor with a rear-mounted, hydraulically operated grapple. Total weight 6.2 tonnes.
- 2) 4 WD Tractor with a rear-mounted cable winch. Total weight 6.3 tonnes.
- 3) A purpose-built heavy sulky with steerable wheels. Sulky weight 3.5 tonnes + tractor 5.6 tonnes.

Use of grapple and sulky require the tractor to be driven right up to each log. Using the winch, the intention was to restrict the driving to (semi)permanent trails. However, due to driver's preference and a short but heavy cable, this intention was not fully met and a fair amount of off-trail driving occurred during the winching operation.

The study aimed at answering the following questions:

- a) Does the skidding operation result in any measurable soil compaction, and do the skidding methods differ in this respect?
- b) To what degree is the natural regeneration damaged by the operation, and do the skidding methods differ in this respect?
- c) Does the driving distance of the tractor depend on the choice of method?
- d) Are the methods significantly different regarding cost and productivity?

Soil density on the average was 7 % higher in the ruts than outside. The highest degree of compaction occurred by grapple skidding but the variation was too high to reveal a statistically significant difference between the methods.

The actual skidding trails occupied 3.5 % of the area but a detailed vegetation analysis revealed that between 12-15 % of the area was affected by the operation. The winch and grapple were similar in this respect, whereas the sulky operation inflicted slightly more damage to the regeneration.

Positioning the sulky required much driving. The grapple and winch were equal regarding trail length, while the trails left by the sulky operation were on average approximately twice as long. Even when the different shapes and positions of the trial plots is taken into consideration, this difference remains significant.

Time consumption per cubic meter was taken as a measure of productivity. Grapple skidding demonstrated the best performance (2.7 min/m<sup>3</sup>) followed by sulky (3.9 min/m<sup>3</sup>) and winch (5.3 min/m<sup>3</sup>). Moneywise the use of grapple skidding is by far the most economical method. Due to the higher purchase price of the sulky, the winch and sulky are almost equal in terms of skidding costs, both having in the range of 60% higher costs than the grapple.

In the ongoing efforts to apply more environmental-friendly technical solutions in forest operations, one of the goals is to avoid driving heavy vehicles on the forest floor. The study shows that grapple skidding may cause damage to soil and regeneration, but it is very cost efficient. There is a need for developing alternative log transport methods that do not require driving outside permanent tracks, while being economically competitive.

# DIAG-FOR: a benchmarking/continuous improvement tool for forest contractors

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## Summary

Typically, forest contractors have limited tools at their disposal to analyze their operations, benchmark their performance or develop a continuous improvement plan for their business. Based on its previous experience in dealing with forest contractors, the Feric division of FPIInnovations developed a diagnostic and process improvement tool called DIAG-FOR (DIAGnostic for FORest contractors).

Diag-For is an internet-based tool that contractors can access to benchmark their performance level for eight management indicators against the average results contained in the database. The eight performance indicators are human resources, machine productivity, mechanical availability of equipment, utilization rate, product quality, health and safety, environmental compliance and business management. Articulated around a series of progressively more difficult questions as the user advances in performance level, the answers generate a performance level attained for each indicator. The contractor can then obtain a report card describing his level of performance, as well as a series of recommended actions for improvement and progression along the performance scale (level 1 [basic] to 5 [world-class]). The tool has been designed to be used in any jurisdiction or country by any size or level of forest contractor.

# Stump-harvesting: Best practice and 25 years old innovative approaches

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Stumps are harvested for bio-energy purposes in Finland, and to some extent in Sweden. Conventional stump-harvesting is conducted with 22-24 tonnes excavators, limited to easy terrain near roads and with productivity on 2.2-3.0 tonnes DM/G<sub>0</sub>-hour. The productivity is only slightly higher than measured already during the 1970ies and high levels on whole-body vibrations are reported. For the future, it is of interest to harvest stumps using ordinary forwarders or harvesters. The limitation is the need of high lifting torque on the boom, which is 360-400 kNm on excavators and 140-190 kNm on large forest machines. But, already 25-30 years ago other technical principles was presented were the lifting torque was within the limits of forest machines. There are today manufactures that develops these principles to the “second generation stump harvesters”. Studies with the aim to measure the force needed to lift stumps as function of their size will be done during spring and summer 2008. The aim is also to compare the force needed with new and old technical principles as well as to measure the productivity as function of stump sizes. The study approach and the first results will be presented at the NSR/OSCAR conference in Copenhagen.

The volume on stumps are presented in figure 1 below, and the time consumption for lifting stumps with an excavator equipped with an ordinary stump extraction head is presented in figure 2.

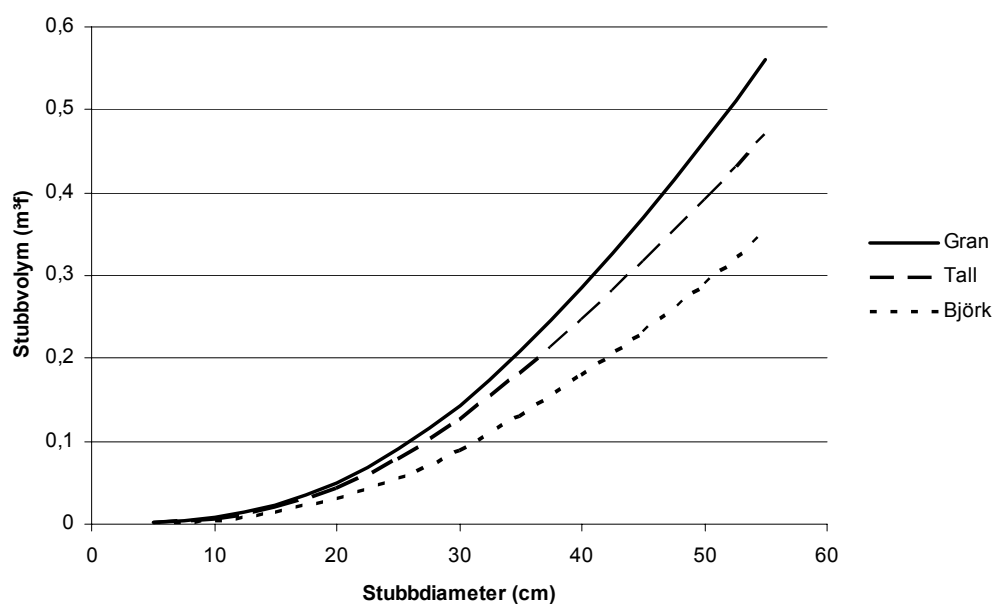


Figure 1. The volume of a stump as a function of the diameter on the stump for spruce, pine and birch (From Marklund 1988).

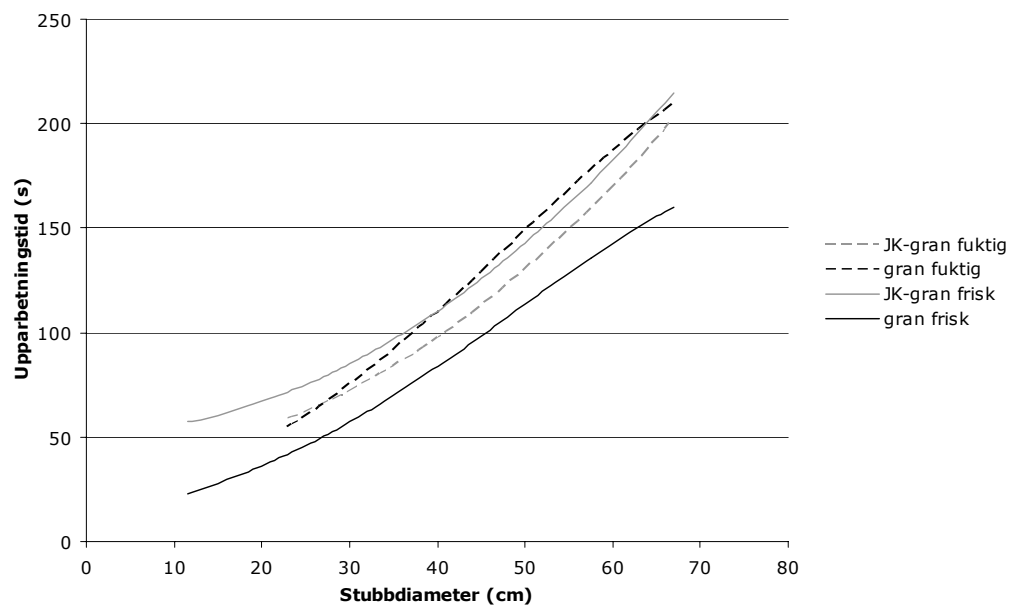


Figure 2. Time for processing of spruce stumps as a function of stump diameter. Comparison between two recent studies and on two types of soil.

# Forest roads in North-western Russia – planning and construction

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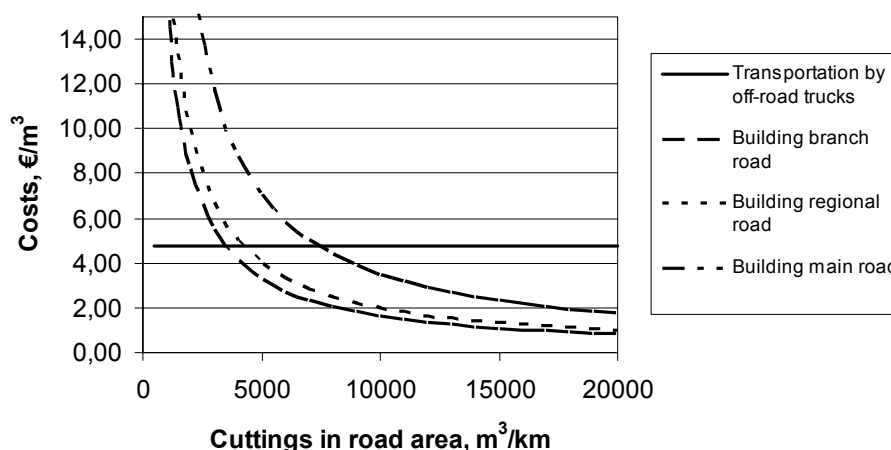
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A study was made in the Tikhvin district (Leningrad oblast) in north-western Russia on forest road building and upgrading of existing road network. Road construction is relative expensive in the area due to fine granular soils and lack of good road building material. Most forest roads are in so bad condition that timber transportation is possible only by off-road trucks (small trucks with 6 wheel drive) to the closest main road. The density of good forest roads is only 0,8 m/ha. Because of the poor forest road network, transportation costs are high and only 80 % of the annual cutting plan is profitable to cut. The traditional way of building a forest road is to use a bulldozer, which simply clears the road area from all vegetation. Now, road building technology which deploys an excavator and gravel on the top has been introduced. The result is a more costly road, but one that can be utilized during a longer period of the year without the use of six wheeled trucks. The objectives of the study were to find methods for calculating costs and benefits of forest roads and to optimize forest road network and standard in north-western Russian conditions.

The road network was digitized and the quality of the roads was estimated. The forest map and connecting records were also digitized. Existing and potential sources of gravel for road building in the area were mapped. Finnish forest road standards were adapted to the conditions of north-western Russia. Furthermore, a system utilizing GIS and functions for estimating costs and benefits of forest road building and restoration was created.

**Transportation by off-road trucks compared  
on restoration of road**



Depending on the conditions (soils and availability of gravel) the building of a new forest road costs between 10 000 and 40 000 €/km and the cost for restoring an old forest road is between 4 000 and 35 000 €/km. The main cost is gravel and the transportation of gravel (~65%). The cost of an excavator is about 25 % of the total. In spite of high costs, the study shows that road construction can be profitable in many cases. Estimates give that a new forest road is profitable if cutting plan is over 4 000 m<sup>3</sup>/km road and restoration of old roads is profitable if cutting plan is over 3 500 m<sup>3</sup>/km (see figure).

The results also suggest that in some areas where less extensive harvesting is possible, roads of the lowest standard are preferable to higher cost alternatives.

The general plan for developing the forest road network in the area of 184 000 hectares includes 335 km restoration of old roads and building 70 km new roads. Building this amount of forest roads would cost approximately 11 million €.

# Total digital control of the road side stock and optimized terrain transports

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During 2008 and 2009 Skogforsk conducted a project to examine the possibilities of implementing forwarding optimization together with the exact reporting of extracted round wood. The first attempts will be performed during late autumn 2008.

Forwarding corresponds to approximately 10 % of the raw material cost of round wood in Sweden. A more frequent reporting of stock at load points along with a reduction of terrain transports by the forwarder reduces cost and ensures the delivery of fresher timber. Earlier studies have indicated that optimization of forwarding routes reduces terrain transports by 8 %.

Transportation routes can be calculated using operation research (OR) algorithms based on the information in the production file (PRI-file) generated by the harvester. All parameters and GPS (Global Positioning System) positions are included in the StanFord production file. The data used for the optimization model is provided by the harvesters PRI-file. This includes positions, volumes and assortments of the log piles together with the harvester's track choice. The latter to guide the forwarder driver to the harvesters tracks. The system should also enable the harvester drivers, using GIS-interface, to indicate bad tracks, for example swamps, which are also included in the conditions for optimization.

The heuristic optimization method, based on Repeated Matching (RM), minimizes the goal function which describes the total time it takes to accomplish the routes. The previously utilized RM-method uses iterative routes to create more effective routes by means of solving a matching problem. Beginning with a start solution, the matching implies that:

- two routes can be combined to one
- two routes can be combined to generate two other routes
- two routes are unmodified

The goal function indicates which matching choice is used.

The RM-method is suitable for an operative environment due to the limited time window between the loading and sorting at the load points. The optimization model will be implemented as a separate module and can therefore easily be built into existing systems from basic optimization components. The optimized routes are presented through a GIS-interface.

A prerequisite for a low cost efficient delivery system is an operable GPS along with continuous data transfer to enhance communication and coordination between all transportation points. Because the precision is in question which adds a level of uncertainty to the project, the first practical attempt will be performed at a final felling creating a tree free area.

Through mobile broad band communication, the harvester can continuously update timber volumes at load points as well as PRI-file information. This communication, coupled to a continuously polling internet connection, can send information to a data base regarding road side stock quantities. This will provide better input data to the whole logistics system.



# The LogTracker Vision-system

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Dralle A/S is provider of mobile automated forest scaling (mensuration) and logistic systems that is targeted to significantly increase the competitive advantage of the wood production chain covering the entire range of primary timber production to the highly advanced wood processing industries while at the same time providing means to ensure the political and public demand for sustainable management of forests.

The fundamental company idea is to measure and assess quality parameters of logs by vision systems mounted on fellers, forwarders, trucks etc. and use these results as documentation, means of commercial trading as well as information to logistically optimize the production chain. Excellent size and quality parameters are provided by such a system - in real time and on location. Combining vision measurements with location information as GPS registered positions, and taking advantage of the wireless Internet gives incredible options to optimize the entire production line. Further, documentation of measured results by for example images improve the information value considerably. State of the arts in this company and a little look into the future will be demonstrated by this presentation.

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# Integration of railroads and waterways to forest fuel logistics in Finland

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## 1 Introduction

Forest biomass supply quantities for energy production purposes in Finland have grown rapidly from the beginning of the 21<sup>st</sup> century. In 2000, the annual use of forest fuels (including firewood) was still under 2 TWh, but it was more than tripled by the year 2006 when a record of 6.9 TWh was set [1]. The downward price development of emission allowances in 2007 had an impact also on the statistics. Wood fuels were partly replaced by other fuels, (e.g. peat) in combined heat and power (CHP) plants resulting in a 12% cutback of wood energy use. However, the use of wood fuels, including forest fuels, is expected to grow again as fewer allowances have been issued to the emission trade markets in 2008.

The Commission of the European Communities has set a target of 20% share of renewable energy sources by the end of 2020 [2]. It is obvious that bioenergy production is one of the main elements in fulfilling the conditions. Forests are the most important reserve of renewable biomass in Finland. It is estimated that the techno-economical potential of the annual forest chip production is 30 TWh [3]. Compared to the current situation, harvesting that amount of biomass would cause extensive needs for purchasing extra machinery and employees for the supply chains. According to Kärhä [4], 1,100 machine and truck units were employed in forest fuel supply chains in 2007. An increase in forest fuel supply amounts to 15 TWh would cause a need for 600 additional machines and trucks, and if the consumption was 25 TWh the requirement for machinery would be 2,300 units.

The figures presented above apply to supply logistics based totally on road transports with present equipment. Besides technological improvements in forest fuel production e.g. intensifying productivity of machines and enhancing the capacity of rolling stock, also alternative transport solutions are to be considered in future supply logistics. From the biomass suppliers' point of view, the challenge of expanding forest fuel procurement areas calls for transportation modes suitable for longer distances i.e. railroad and waterway transports. For these means of transport, it is typical that trains and vessels can normally carry 20-50 truck loads of forest chips at a time. However, trucks cannot be totally replaced because they are the only vehicles to reach the roadside storages of forest fuels.

The main purpose of this study is to determine technological and economic factors that have negative influences concerning the decisions of replacing long distance (longer than 100 km) forest fuel transports by road with rail and waterway transports. Such factors could be, for example, winter-time conditions on the lakes or the basis of rail cargo tariffs. A geographic focus is set to Southeastern Finland where the infrastructure for all possible transportation methods is rather good. The study is related to a larger research project where biomass resources and their optimal supply and use are explored.

## 2 Material and methods

### 2.1 Technology

New transport systems call for technological solutions that differ from conventional systems. In the supply of logging residues and small-diameter trees, logistics based on roadside chipping has turned out to be a universal solution suitable for almost all circumstances [3]. Stationary crushers are used when supply volumes are high and the fuel derives from the near surroundings of the end-user point. With more robust material, like stumps, the comminution process takes place at a terminal when there are no possibilities for crushing at the end-user, or when the terminal itself causes indirect benefits, e.g. improved security of supply. In rail and waterway transports terminals are an essential part of transportation chain because in both systems at least one point for loading and unloading is needed. It is presumable, that the comminution process takes place at this point, so that the long distance transport section becomes more effective in many ways. For instance, in forest chip transportation by barges it has been observed that the bulk load density is approximately 25 % higher than in chip transports by 60-ton trailer trucks [5]. Terminal operations require equipment, such as material handling machines for loading and unloading. Their suitability for handling of forest fuels has not been studied to a larger extent. Experience has shown that development in grabs and buckets should be done also for forest fuel handling purposes. The material for this part of the study is based on both interviews of terminal and transport operators, and information from studies related to different bulk material handling techniques. The methods are time-cost calculations and simulations of various alternatives for material handling and processing.

### 2.2 Supply chain costs

In the current thinking of supply chain cost analyses, terminals are counted as an additional cost unit vis-à-vis logistics based on direct transports from forests to the end-users. Terminals cannot be run without expenses but their proportion of the cost structure can be cut with integrating the systems with other goods. Waterway transports would become more efficient if return transports were possible using for example roundwood as another transportable material [5]. Most likely, similar benefits can be gained also in rail transports and terminal operations. This study scheme explores with an economic viewpoint the possible synergy gains of connecting deliveries of other goods to forest fuel supply chains. Roundwood is an important subject, but also other goods are considered. The methods are profitability calculations related to operations in railroad and waterway logistics. The material is collected from cost-statistics and with inquiries of respective business actors.

### 3 Results and discussion

This study yields information on the obstacles that hinder the adoption of long-distance transportation methods in Finnish circumstances. The results will be presented in either quantitative or qualitative format depending on the study methods. The reasons beyond the obstacles will be issued within the following preliminary categories:

- Technological factors
  - Climate
  - Terminal equipment and machinery
  - Design of terminals
  - Capacity of transport network
- Economic factors
  - Transportation tariff basis
  - Terminal costs and profitability
  - Synergy gains from integration of forest fuels with other products

Logistical arrangements of forest fuel supply are always case-dependent. This study will be of help to the decision makers to analyse possible changes in supply chain cost-structures and define reasons behind them. Technological and economic factors are linked to each other, especially when implementations of new technological solutions require large investments.

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# Productivity, fuel consumption and emissions of machinery involved in full tree harvesting operations

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## Introduction

Estimating and attempting to predict productivity and fuel consumption of forestry equipment is difficult. They are complex machines working, even during a single shift, in a wide range of site and stand conditions. However such a estimation and a consequent prediction is of importance for forest company personnel and machine owners for planning and control of logging operations and for machine evaluation and comparison. It is of importance to know how variables such as slope, terrain and stand conditions, affect productivity and fuel consumption and thus the cost (both environmental and monetary) of harvesting operations.

## Machines, materials and methods

This study was an attempt to identify and quantify the influence of some key variables that affect fuel consumption (and productivity) through close monitoring of 6 pieces of equipment (two feller bunchers, two grapple skidders, one delimber and one log truck). Data collection methods were consistent during the following up of all equipment (with the exception of the log truck). Prior to the commencing of the monitoring the operators were informed on the aim of the study and were asked to work at their normal working pace. In the beginning of the shift all machines were fully tanked. At the end of the shift the machines were tanked at the same level. The quantity of the fuel was recorded by means of an electronic fuel meter. During the shift, operating time, stop time, idling time, and travel time were separately recorded. Ground strength, ground roughness and visibility were estimated visually, slope and skidding distance were measured with the help of a GPS receiver. The bunches were separated to softwood and hardwood, amount of trees per bunch was counted and for most of the bunches all trees in the bunches were scaled. While the feller buncher was proceeding through the cutting block measurements of the basal area of the stand ahead of the machine were taken by means of a relascope. Occasionally number of trees per swath and time it takes to build a bunch was recorded.

## Results

In total 4.3 l of diesel oil are needed to bring to the sawmill 1 m<sup>3</sup> of wood. Greenhouse gas emissions from the combustion of the oil amount to 12.4 kg CO<sub>2</sub> equivalents/m<sup>3</sup>. An annual volume of 400,000 m<sup>3</sup> would mean that a total of 5,000 tonnes of CO<sub>2</sub> equivalents are emitted to the atmosphere annually.

## Feller bunchers

The first feller buncher (a Timberjack 850 feller buncher with a 950 undercarriage) worked in a black spruce stand with a density of about 750 trees/ha over a broad spectrum of con-

ditions including moderate (25 %) slopes, high frequency of stones, areas of low visibility due to fir/spruce/poplar/birch undergrowth and sites with lower stocking with high proportions of big dimension (27 cm average butt diameter) aspen and birch. The second feller buncher (also a Timberjack 850 feller buncher with a 950 undercarriage) worked in a jack pine stand with a density of about 1000 trees/ha under favourable terrain conditions with few slopes and some sites with high proportion of small dimension hardwoods.

Feller buncher productivity ranged from 36 to 43 m<sup>3</sup>/PMH or 213- 288 trees/ PMH. Fuel consumption per m<sup>3</sup> was very consistent ranging from 0.9-1 l. Fuel consumption per PMH ranged from 34.5 to 40 l.

#### Skidders

Two skidders and three operators were studied. The first skidder (a Caterpillar 535B skidder with a dual function grapple) worked at the same area as the first feller buncher and the second skidder (a Timberjack 660D skidder with a dual function grapple) worked at the same area as the second feller buncher. Productivity ranged from 30-62.5 m<sup>3</sup>/PMH or 147-455 trees/PMH with average values of 46.5 m<sup>3</sup>/PMH and 305 trees/PMH. The low productivity occasion was when the skidder had to skid uphill over distances longer than 250 m. For the same skidder areas with high frequency of stones and high stumps also contributed to low productivity (and high fuel consumption). Fuel consumption ranged from 0.4 to 1 l/ m<sup>3</sup> (0.55 l/ m<sup>3</sup> on average) and 19.5 to 31 l/PMH (24.5 l/PMH on average).

#### Delimber

One delimber (a Kobelco SK 250 LC equipped with a Denharco 4400 delimbing device) and two operators were studied. Productivity ranged from 20-21 m<sup>3</sup>/PMH or 147-157 trees/PMH. Fuel consumption per m<sup>3</sup> was very consistent and ranged from 1.2 to 1.3 l. Fuel consumption per PMH varied from 20 to 25 l. The fact that most of the trees handled by the delimber were of small diameter affected the output negatively.

#### Log truck and loaders

One log truck and one driver were studied. Fuel consumption was 1.25 l/m<sup>3</sup> at a transport distance of 50 km (one way). A gross estimation was also made on the fuel consumption of the loaders. Based on a fuel consumption of 30 l/hr fuel consumption per m<sup>3</sup> loaded and unloaded amounts to 0.3 l.

### Discussion

The feller bunchers and the skidders worked over a broad spectrum of conditions ranging from very even to uneven terrain, from areas of very good to areas of poor visibility, from 0% slope to short areas of 25% slope. Aspen and birch occurrence was a major slowdown for both types of machinery. For the feller buncher aspen and birch occurrence resulted to a reduced amount of trees cut per hour either because it reduced the accumulation potential or because it resulted to longer cycle times due to longer travel times between set-ups for felling. However the greater volume per tree offset the reduced output of trees felled. Also the presence of areas of low tree density affected bunch size, accumulation of trees in the felling head, and the amount of travel between set-ups. This also slowed down the skidder operation since more bunches had to be accumulated for one full load. For the skidder occurrence of small bunches (1-3 trees/bunch) made that the skidder had to accumulate two or more bunches and bring them to the roadside. Again when it concerns aspen the greater volume per tree offset the reduced output of trees skidded.

# TimberLink as a tool for measuring the fuel consumption of a harvester

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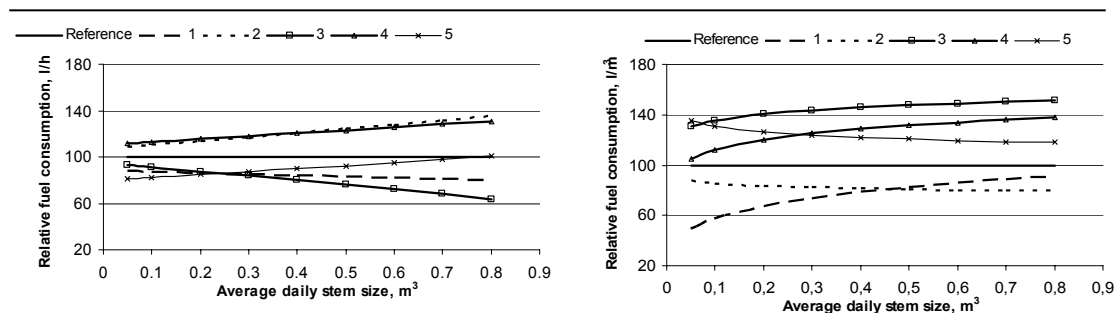
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Fuel price has risen rapidly in past few years, which makes important to monitor fuel consumption because it is important factor in machine entrepreneurs profitability. Decreasing fuel consumption affects profitability greatly in longer period. Only a one litre per hour decrease in fuel consumption makes a lot in a year period. High fuel consumption can be caused by several reasons like operator skills, stand properties or machine failure. By monitoring the harvester fuel consumption and productivity, problems can be discovered. There has been only minor research about the topic. Recently several institutions have studied this issue (Rieppo & Örn 2003, Brunberg 2006). The problem has been the difficulty to measure used fuel.

TimberLink software is a tool for monitoring productivity and fuel consumption of a harvester. Performance values of a harvester are calculated automatically from the CAN-bus traffic. TimberLink can be used for searching possible problem spots in machine condition, which can be noticed as increased fuel consumption or decreased processing productivity. The objective of this study was to discover the difference in fuel consumption of five harvesters with TimberLink.

The study was made by collecting daily average values of fuel consumption. The data was collected from five John Deere 1270D harvesters with TimberLink software. Collecting period was 50 days, but one of the periods was only 15 days (harvester number 3), because the harvester had worked only that period. The total harvested amount was 36 503 m<sup>3</sup>, average daily stem size of the whole data 0.24 m<sup>3</sup> and the average daily number of trees harvested 739. Harvesters were operating in one long shift or in two shifts. Data collecting period was aimed at winter time, when usually stands are cut and most of the harvesting operations are performed. The harvesters were compared with each others and the difference in fuel consumption was examined.

For discovering the difference in fuel consumption between harvesters, relative fuel consumption values were calculated for litres per hour and litres per cubic meter (figure 1).



**Figure 1.** In the left figure is relative fuel consumption per hour and in the right figure is relative fuel consumption per cubic meter as a function of an average daily stem size.

Harvesters' efficiency varied notably. The most fuel consuming harvester spent 33.9% more fuel per hour than the least consuming harvester with the average stem size. The same difference was 64.0 % measured in litres per cubic meter value.

Harvester number one was a good example of an effective harvester. Harvester has low fuel consumption measured in both ways. Number one was exception because the others did not reach the same fuel consumption level. So, the harvester processed tree trunk effectively and machine condition was good and so was the operator.

In the harvester number two the relative fuel consumption per cubic meter was one of the lowest. However, the relative fuel consumption per hour was one of the highest. One explanation for this is that the harvester was operated effectively when the fuel consumption per cubic meter is good but the hourly consumption increases due to numerous crosscutting work phases. Crosscutting (saw) consumes most fuel of the work phases.

Harvester number three had the highest relative fuel consumption per cubic meter and one of the lowest relative fuel consumption per hour. For some reason, harvester uses a lot of fuel per cubic meters and only operator skills do not explain the difference. In this case, stand circumstances affected the fuel consumption; it had worked a lot in first thinnings, which caused increased fuel consumption that way.

Harvester number four was consuming fuel over the average measured in both ways. One of the reasons could be the operator skills. Harvester was operated by differently skilled operators; there was a trainee with less working experience and on the other side was an operator with longer working experience. Also the harvester head feeding fuel consumption was one of the highest compared to other harvesters.

Harvester number five was consuming fuel under the average measured in litres per hour and over average litres per cubic meter. According to the fuel consumption data, feeding phase consumed more fuel than other harvesters same phase which suggest that there is some malfunction in the harvester head.

The main result of this study was that the fuel consumption can differ substantially between the harvesters. The main reasons for the fuel consumption differences can be found from the cutting circumstances, operator skills and machine condition. TimberLink enables monitoring of machine condition well. It gives also valuable information for estimating the influence of circumstances and operator skills for the fuel consumption. However, these factors are dependent on the visual estimates at the moment. Harvester operator has a big effect on machine entrepreneurs cost effectiveness. The results show that skilful operator can stay on a reasonable fuel consumption level but also harvester must be in reasonably condition to achieve good performance level like harvester number one.

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# To catch the gaze of a forest machine operator

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## Introduction

In times when forest operations have been fully mechanized, the work of the forest machine operator has become a growing subject of interest. To continuously increase productivity but also improve the working conditions of the machine operator, focus is drawn to improvements of the interaction between the operator and the machine. Work to reduce the physical stress to which operators are subjected has been done successfully over the years. However, little research has focused on the cognitive aspects of the work and the interaction between humans and the machines. As a part in a larger research project on how to measure mental work load in forest machines, Skogforsk has started to develop a method to collect data on the information the operator obtains during his or her work. This data will be a valuable piece in pinpointing the areas of mental load.

The overall objective is to measure the mental load on the operator. One part of this assessment comprises information about what the operator sees, in terms of e.g. information type, source and frequency of the obtained information. In this first study the aim was to get a rough idea of where the operator direct his or her gaze. The method was at first evaluated in a forest machine simulator. Subsequent studies are planned under field conditions.

## Materials and methods

To register the gaze of the operator the eye-tracking equipment Smart Eye Pro 4.5 was used. The system installed in the Troëdsson forest technology lab at Skogforsk used 4 cameras. These were placed on stands in front of the operator, two on each side of the computer display (Fig. 1). The machine applied in the simulator was a Valmet 911 where the crane and cabin rotate simultaneously using the same turntable. The crane is attached to the right of the cabin.



Figure 1. The four eye-tracking cameras mounted inside the simulator.

The gaze direction was sampled at a frequency of 60 Hz. The system was set to separate between looking at 1) the head screen, i.e. mostly the harvester head, 2) the left window, 3) the right window and 4) the display.

A forest machine operator that were already familiar with the simulator was asked to fell 30 trees in a final felling operation. No further instruction was given. The operator felled the trees at a high, even somewhat forced pace.

In the log file, data were filtered allowing changes between the defined areas of gaze only with a duration of 100 ms or longer.

### Results and discussion

It took the operator 845 seconds to fell and process the 30 trees (128 trees/hour). This generated c. 43,500 observations in the log file. The absolute majority of time was used to look at the harvester head and adjacent through the front window (Table 1). Each glance at the computer display was on average 0.2 s. A duration of 100 ms is reported to be enough to distinguish the information looked for (cf. Salvucci, 1999: *Mapping eye movements to cognitive processes*. Tech. Rep. No. CMU-CS-99-131, Carnegie Mellon University). The operator looked at the display 1.4 times per tree.

Table 1. Results from the eye-tracking study. The study comprised 30 trees and 845 seconds

	Forward (harvester head)	Left window	Right window	Display
No. gazes	74	11	21	43
Gaze duration (s)	10.9	0.85	0.59	0.36
St.dev. (s)	12.1	1.31	0.33	0.22
Range (min-max)	0.45 – 57.9	0.27 – 4.77	0.27 – 1.35	0.12 – 1.12
% of total time	95.6	1.1	1.5	1.8

The shortest glances recorded were less than 0.3 s for the right and left window and the display. With very few exemptions the duration of a glance at the display or through any of the side windows lasted shorter than 1 s. The shortest glance through the front window was 0.45 s.

Had a machine with a fixed cabin been studied, the right and left windows should probably have been more frequently used by the operator. Likewise, in a thinning operation the operator is expected to put more attention to the trees located beside the machine.

The definition of the "world" in the simulator or a forest machine will have a high impact on the results. However, a high resolution allowing many areas of gaze will increase the number of close-to-border observations. Filtering and calibration will then be more complicated than in this study. It is possible and important to tailor the areas of gaze to the actual study purpose and the machine environment studied. We found the setting of this study good enough for our purpose. The equipment used is highly flexible in terms of how to define the areas of gaze. The results are encouraging, and the data will serve as test data for several up-coming study designs and analyses, in the lab as well in the field.

From this pilot study, no general conclusions can be drawn with respect to operator behaviour, mental stress etc. However, the method applied will be a useful component in further testing of the mental workload on forest machine operators. It will be possible, for example, to compare visual behaviour of operators using different machine types or various user interfaces or control functions.

# Visuospatial cognitive abilities in harvester work

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Nowadays, all single-grip harvesters of the same size are almost as productive as each other in similar conditions. Reasons for this are that harvesters are partially composed of parts delivered from the same suppliers and that a certain kind of machine construction has been seen as the most practicable among harvester manufacturers and operators. Therefore, the reduction in the importance of the brand of the harvester places more significance on the skills of the harvester operators, as over 40% differences in productivity have been observed among operators in similar cutting conditions.

However, significant information flow from the surroundings (trees, ground obstacles, etc.), with repeated decision-making situations in a dynamic working environment with contradictory demands, mentally strain and stress the operators. This kind of cognitive work results in a large mental strain on the operator since memory, learning, thinking, perception, vigilance, creativity and problem solving abilities are strained. The mental strain has been stated to be the biggest limiting factor in the processing of information. In harvester work information from the harvester surroundings is collected mostly visually, thus perception and visual abilities are emphasized. The harvester head is steered in a 3-D environment, where trees have a certain spatial location in relation to others. By combining visual and spatial demands, the importance of visuospatial cognitive abilities grows in harvester work. Visuospatial means the visual perception of spatial relationships among objects. In addition, mental models, schemas, which are based on previous experiences and reactions, are strongly linked to cognitive abilities.

Nowadays, harvester training is very expensive and, therefore, the training time needs to be effective. In general, when the most important abilities and key features of harvester operating are known, exercises to practice these in operator training can be created. In addition, the abilities of candidates typical for the productive operators can be tested when harvester contractors select new operators. The objective of this study was to determine the visuospatial cognitive abilities of harvester operators and operator students.

Six professional harvester operators aged between 29 to 56 years and 40 operator students (26 second and 14 third year students) aged between 18 and 19 of vocational harvester operator school were psychologically tested. The psychological tests used in this study have all been widely used, validated and commonly used for group and personal testing. Tests AVO-9, WAIS-III and WMS-R includes sub-test of which suitable tests were selected for this study to measure visuospatial abilities, long and short-term memory, concentration, attention span, non-verbal deduction and psychomotorics in various ways. The psychological tests were carried out individually on the professional operators while the students were tested as a group.

The results indicated that harvester education has an influence on productivity. Productivity levels were higher for the 3<sup>rd</sup> than 2<sup>nd</sup> year students and the most productive students reached even the level of the professional operators. Reasons for the differences between the classes are larger amounts of training and, especially, an ability to plan and predict the upcoming work better. However, variation in productivity was larger in the 3<sup>rd</sup> class compared to the 2<sup>nd</sup> class. The results showed that motivated students were more productive. From the harvester school and contractor's points of views it is beneficial to note that training has significant influence on the productivity, but to motivate and arouse the students' interest in harvester work is a big challenge. Motivation is an indirect way to increase productivity.

The operators' performance in the memory tests varied. The most productive operator performed normally, whilst the not so productive operators varied on both sides of normality. From the viewpoint of productivity the whole memory capacity should be used effectively. The operators' high performance in the verbal test supports this conclusion. In addition, concentration test points were high among the operators. This indicates that comprehensive control of memory abilities and an ability to concentrate are characteristics of a productive operator. Concentration is one of the axioms of effective work.

The students' performance in the psychological tests varied between each test, but on the whole they attained an average level. In digit symbol and symbol search tests both students and operators performed below the norm, which can be explained by the aspiration to work carefully. In addition, the digit symbol test, which mostly measures perceptual speed, correlated negatively with the productivity and the same correlation was also low for the operators. The productive operators also performed well in the matrix reasoning test, which measured perception of details and attention. In general, the operators reached higher points in the organization of perception than in speed of perception factor. In addition, hand-arm coordination, in connection to speed and speed of perception, seemed to only slightly explain productivity. These results confirm that perception of details and entirenesses, non-verbal deduction, spatial perceiving and concentration are more important from the viewpoint of the operator's work and productivity than speed and accuracy although those cannot be completely excluded.

However, previous studies found that speed is an essential ability. An explanation for the result can be found from the operators' control of behavior and thinking: swift work pace is based on schemas, which are adopted during working life. These schemas consist of information about the forest, the felling plan, operators' experience etc. This explanation corresponds with the common concept of the importance of speed in harvester work. Speed is an integral part of the work, but it is not necessarily an independent ability. Above all is a habit, which is acquired by training.

The correlation of the verbal comprehension with productivity was unexpected. If the harvester work is considered in the context of the schemas, the high correlation of verbal comprehension will be understandable. High level schemas are based on symbolic signs, and therefore verbalization must play an important role in the harvester operator's control of thinking and behavior.

The behavior and thinking of an operator is based on automated processes, well organized schemas and task specific cues that speed up perception and behavior. The connection of schemas to memory functions confirms that productivity is not necessarily dependent on one memory

area since schemas operate in all sensor channels and memory areas. This study indicates that productive operators have a combination of well controlled cognitive abilities. Significant differences in productivity can also be explained through the schemas: some operators develop more effective ways of observing and orientating to changing work situations than others. Therefore, productive operators have also the capability to change operation models according to situation.

This study confirmed that comprehensive perception, wide use of memory functions, non-verbal deduction, spatial perception, coordination, concentration, motivation are characteristics of a productive operator. The training of these abilities should be included in harvester operator education. Verbal ability can also be an important ability depending on the coding of the stimulus. Spatial perception is a central ability. Fast perception and visuomotoric abilities are important in harvester work. On the whole, the cognitive abilities do not need to be exceptional to attain high productivity, more important seems to be the mastering of different kinds of abilities. Therefore, when selecting harvester operators using psychological tests, the test battery should widely evaluate the abilities mentioned. To become a productive operator, a student does not need any special abilities.

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# Efficiency and ergonomic improvements for cable yarding operations in steep terrain

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Cable yarding continues to be an efficient and effective harvesting system for the extraction of timber on steep terrain. Modern European silvicultural strategies result in smaller harvest areas, lower extraction volumes and a shift from clear-cut to thinning operations or single tree extraction. Yarder installation time has, especially as a proportion to the extraction time, increased significantly, resulting in higher extraction costs. Also the releasing of the chokers at the landing is very time consuming and cost causing.

The main aim of this research paper is the optimization of cable yarding installations and operations in mountainous regions. The application of synthetic ropes in installations (as guy lines for anchoring of tower yarders and intermediate supports, as well as extensions of the skyline) of tower yarders shall provide ergonomic and economic improvements. The rationalization potential by the introduction of radio controlled chokers will be investigated and the ergonomic impact shall be evaluated. An analyses of the technical reliability of the radio controlled choker systems will be carried out collateral.

The application of synthetic ropes will be analyzed in comparison with conventional steel wire ropes. A factorial layout was utilized to investigate the impact on time consumption and work load. Using the design factors “rope” and “yarding direction” a 2x2 design with one repetition each leads to 8 yarding corridors. For the effects of radio controlled chokers also a factorial layout with 3 repetitions was designed. In 6 cable corridors the timber will be extracted alternating the choker alternatives. Whole tree cable yarding systems will be applied in all experiments. Time studies and heart rate measurements represent the methodical instruments and shall lead to the estimation of time consumption and work load.

# Simulation of stump crushing and road transport of chips

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Use of stumps in energy production has grown rapidly in Finland being now about 0.5 mill. m<sup>3</sup>/a. Practically all stumps are comminuted either at plant or at terminals whereas major part of small diameter trees and logging residues are chipped at roadside landing (Kärhä 2008). By now crushing of stumps has been done with heavy, often stationary crushers. In smaller plants construction of a stationary crusher is not economically feasible. In addition, transportation of stumps calls for special trucks and economic transport distances are short due to small payload.

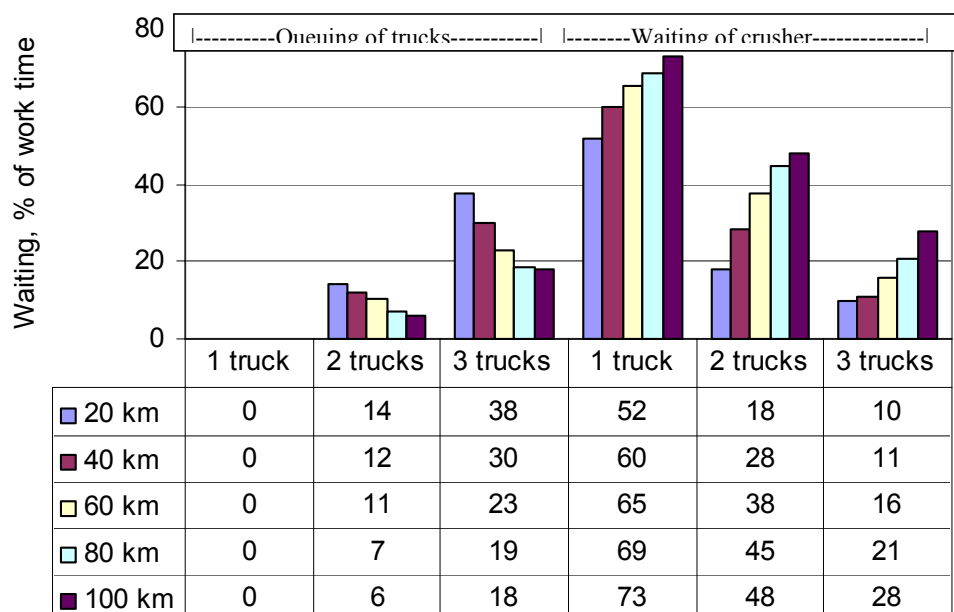
Recently, effective mobile crushers suitable for the comminution of stumps have been introduced. Crusher would be used in a same manner as mobile chippers for logging residue and small diameter tree chipping. They move from landing to landing and chips are transported to the end user by trucks with a semi trailer or full trailer. The aim of this study was to find out optimal number of trucks at different transport distances in a crushing at landing – truck transport of chips supply chain.

In this study a discrete event simulation model was programmed by using Witness simulator to find optimal setups for supply chain of chips made of stumps at different road transport distances. Simulation model was based on continuous supply of chips from landings to a CHP plant. In the beginning of each simulation experiment a set of 46 stump storages were generated. Their average volume in terms of energy content was set to 200 MWh and standard deviation to 100 MWh. The average moving distance between storages was set to 50 km.

Productivity of the crusher was 60 MWh/E0-h. Crusher had randomly occurring breakdowns on average between 9.5 hours and their average duration was 0.5 hours. Crusher unloaded the chunks directly to the truck's trailer. If there was no truck at the landing, crusher had to wait. Load volume of semi trailer trucks was 70 MWh. Indirect loading time of trucks including preparing for loading and moving during chipping as 12.5 min with SD of 3 min. Unloading time of trucks was 30 min with SD of 6 min. Trucks had randomly occurring delays so, that the total delay time was 10% of work time. In the simulation experiments average transportation distances were 20, 40, 60, 80 and 100 km having SD of 10 km and number of trucks varied from 1 to 3. Thus, 15 different experiments were conducted with 5 replications.

It was found out that already at 20 km the use of two chip trucks is competitive (Figure 1). If only one truck is used, the crusher has to wait very large part of its work time. In the systems having two trucks the queuing time for trucks is always below 20% of work time. After 80 km third truck should be introduced in the system. Because the hourly cost of a crusher is 2-3 higher than that of chip trucks, the minimizing of crusher's waiting leads to lowest system costs, too.

The results are in agreement with earlier studies concerning supply systems for logging residues, where chipping is done at landing (see e.g. Asikainen 1995)



**Figure 1.** Queuing/Waiting of trucks and crusher.

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*Key words:* modelling, bioenergy, simulation, comminution of stumps



# The simulation of new operations models of logging contractors in central-Finland

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Due to the decline of round wood import to Finland, there is urgent need to increase the domestic round wood cuttings. In addition to that, the growing fuel use of wood chips stresses also the forest biomass supply and utilization in Finland. In order to prevent the shortage of wood supply to mills, power plants and bio-refineries, new operations models is needed to the wood supply system as a whole.

The aim of this study was to investigate the possibilities to improve the cost-efficiency of logging contractors by developing the logistics and economies of scale in logging operations of merchantable wood. More closely, operations models to be studied were: A. Multi-contracting to three big wood purchasing companies instead of one company, B. Supplying the machine relocation services to other logging contractors and C. Operating with bigger machine performance annually by using double-shifts. A discrete-event model was constructed for simulating the mechanical round-wood logging operations with different scenarios of operations models. Three different cases of logging contractors were chosen (contractors with one, two and three harvester-forwarder chains). In each case, contractor had its own machine relocation truck. Real logging data of 2003–2004 was used as an input matrix to the simulation.

Compared to the initial operations model of the contractor with three harvester-forwarder systems, the biggest savings in logging expenses were 3.3 % in multi-contracting and 2.0 % in increasing the machines' annual use (double-shift work). In the combination scenario, having all cost saving operations models simultaneously active, the total cost-efficiency improvement was 7.2 % compared to initial situation.

# Agreed documents – tools for comprehensible and solid contractor agreements in forestry

- Reporting from parallel work in progress in Norway and Sweden

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## Agreed documents

Agreed documents are by juridical definition industry-specific, standard agreement, settled between buyer and seller. Typically, these are formulated by a committee, including buyer and seller representatives from major companies or organizations of the business. By referring to this set of standard formulations in every specific contract, the agreed documents are held legally binding. Agreed documents typically consider matters such as liability, cancellation, damages on third party, delimitations on warranties, right of interpretation and actions undertaken in case of dispute.

A set of agreed documents is often found in industries where contracting processes are undertaken in a quite repetitive way and where products or services sold are *relatively* homogenous. Standardizing and thereby rationalizing the otherwise quite extensive purchasing work as such, is of course an overall purpose, combined with the aim to minimize costs within the buyer-seller system, created by experienced uncertainty. Facility management, construction, transportation, manpower leasing and software subscriptions are examples of industries all using a well established set of standard agreements.

## Agreed documents in Forestry?

Possible benefits of standard agreements are now investigated also in the business of forestry. Contractors are carrying out the major part of forestry operations (both in silviculture and logging), and structure of the forestry services market is similar to other entrepreneur-based businesses, see above. In both Sweden and Norway, work is progressing towards a set of forestry-specific agreed documents.

## Norway

In Norway, The organization Standards Norway is responsible for all standardization areas within the country except electro-technical and tele communication. This includes administration and ownership of several sets of agreed documents. Therefore, a Norwegian set of forestry-specific agreed documents is developed and hosted within the framework of Standard Norway, on demand from a committee representing the forestry. The committee includes representatives from buyers and sellers of forestry services<sup>1</sup>. Jørgen Birkeland, Stand-

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ard Norge, is secretary and project manager. A first set of agreed documents (*Alminnelige kontraktsbestemmelser for skogsdrift*) have been developed during 2007-2008, a hearing is set out during fall 2008. The standard is probably executed shortly after.

### Sweden

The corresponding organization to Standard Norway, SIS, does not handle agreed documents. Agreed documents are more likely to be found and administrated by a sector-specific association. Hence, the initiative of agreed documents in forestry and the development project of the same are found at Skogforsk. In addition, the administration of the decided standard is suggested to be continuously within the responsibility of Skogforsk. In Sweden, an executive committee is formed including representatives from buyers and sellers of forestry services<sup>2</sup>. The aim of the project outcome also includes agreement on a set of standardized templates to describe the services traded. All of these will be put forward to the business in a web-based application. The process will continue during the latter part of 2008, aiming to have a set of agreed documents (*Allmänna Bestämmelser Skogsentreprenad*) executed in early 2009. The templates (starting with logging services) will be finally decided upon during fall, as well as the technical solution.

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<sup>2</sup> Committee representatives from SMF (The Association of Forest Contractors), Stora Enso, SCA, Södra, Mellanskog, Norrskog, Norra skogsägarna, Skogssällskapet, Holmen, Korsnäs and Sveaskog.

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# Forest-Industry Research School on Technology (FIRST) – A joint Swedish-Finnish initiative to strengthen competitiveness in forestry

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In order to stay competitive on the global market up to 2020/2025 it is estimated that the overall productivity in Nordic forestry must be raised by minimum 50% compared to the present performance level. This includes improvements of the present cut-to-length system, the need for mechanization in silviculture, systems engineering, and development in the field of forest energy operations. The present shortage of research capacity will hamper further strategies of improvements and advanced development and is a serious threat to the long-term progress of the Nordic forestry.

Finnish and Swedish parties of interest have discussed a program of high priority for capacity building in forest technology with the aim to establish a joint Swedish - Finnish Forest Industrial Research School on Technology (FIRST). The Swedish part of FIRST is owned by the forest faculty at SLU, and the Finnish part of University of Helsinki and the University of Joensuu. In Sweden, the associated partners are the research institute Skogforsk and a number of host companies in Swedish forestry. In Finland Metla is involved. The Swedish and Finnish part, respectively, will have somewhat different financing situations. *This paper describes the Swedish part of FIRST.*

In this industrial PhD- program 6-8 researchers will be educated to take on *future key positions in the Swedish forest research society as well as in the operational business sector*, thus providing research- and purchasing competence for the future. The co-operation with operating enterprises as industry hosts in thesis work and practice will enhance the relevance and application strategy of the effort. Furthermore, setting up a research school will boost creativity within the research field enabling research ideas and methods that would not likely have been brought up in the normal situation of today.

To strengthen the Nordic-Baltic co-operation in Forest Technology the Finnish-Swedish initiative FIRST will offer education possibilities for a certain number of additional PhD-students from other Nordic countries as well as the Baltic countries.

The Swedish part of the steering group has had its inaugural meeting 18th of April 2008. The group includes representatives from SLU, Skogforsk and the forest sector. The role of the steering group is *to secure scientific quality according to the university's standards and the relevance according to the forestry sector's needs.*

Operational management of FIRST will be carried out by a programme manager (Magnus Thor, Skogforsk) and a scientific coordinator (Tomas Nordfjell, SLU). The operational man-

agement reports to the steering group.

The PhD projects are specified in close cooperation with the forestry sector, based on needs with the horizon “*advanced application in the year 2020/2025*”. A hearing with a gross number of host companies has been carried out in which the needs were specified and potential host companies were targeted.

Based on the project areas, projects are more clearly defined together with the specific host company and the group of supervisors. In cases where SLU does not possess enough in-field supervisory competence, assistant supervisors with specific knowledge will be recruited from other universities. The intention is also to include assisting supervisors from the Finnish part of FIRST for all PhD students. The recruitment of PhD students to each of the projects will be carried out in either of the following two possibilities: 1) Advertisement of vacant PhD positions within FIRST, with a specification of the project. The student must fulfil the basic qualification criteria, normally an M Sc in Forestry or in Mechanical engineering, Physics or equivalent, all depending on the project. 2) Enrolment of a person already employed by the host company. This person must meet the qualification criteria as set up by SLU and FIRST, just as in case one.

The area of forest technology is by tradition dominated by men. Efforts will be made to get an equal gender distribution within the group of PhD students. The employment is for a special project of 5 years with the host company as employer. After the project is completed, the door will be open to a continuation within science or in the forestry sector. Ideally, about half of the doctors-to-be will continue within academia after the research school is finished and half will continue as technical strategists in the forestry sector.

In addition to research work and courses, each PhD student should go through, in total, *one year of advanced professional practice at the host company*. This practice is divided into a number of thematic blocks scheduled during the 5-year period.

Courses, in total 60 ECTS credit points, are of three types: General PhD courses, FIRST-specific PhD courses and individual PhD courses, adapted to the specific PhD project.

An important dimension in FIRST is the international aspects. The purpose is threefold; 1) to apprehend international views and knowledge and; 2) to form connections to the international society and; 3) to market the Scandinavian approach in the science of forest technology. This will be achieved by international conferences, study tours and Scandinavian workshops-seminars. At least three FIRST study tours will be organized to areas of interest concerning the development of different forest technological approaches during the project: East (e.g. Russia, the Baltic countries or China), North (Canada, US) and South (probably Brazil).

One of the most important parts with FIRST is to create an international scientific environment and strengthen the international network. Even though FIRST does not represent a big research school, it will be the largest group of PhD students in the area of forest technology worldwide. This will give a long-lasting impact on the international society, and a possibility to be the lead partner in international cooperation's in this area for a long time.

A substantial share of the international researchers in forest technology will be engaged as opponents or evaluation committee members, at the end of FIRST. Also this is a good opportunity to create more international contacts, and cooperation.

# GIS-based decision-support program for short-wood transport in Russia

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## Objective of the program

Objective is to develop a GIS-based decision support program for the planning and analyzing short-wood transport at the logging company level for Russian conditions. The program should give the logging company comprehensive information about the benefits and limitations of different short-wood transport options. A logging company should get sufficient information to make sound short and long term decisions.

## Material and methods

Problem in the short-wood transport is to define delivery plans, which allows maximizing wood removals and rationalizing the usage of short-wood truck fleet in a logging company. Decision support program has been constructed in MapInfo environment using Map Basics for coding and Microsoft Excel for reporting.

Data required for planning and analyzing short-wood transport include:

- Road maps in MapInfo format
- Location of logistic management units (cutting areas, customers, railway stations, garages)
- Characteristics of logistic management units

Cutting areas: the start date of logging; the type of cutting site (winter, summer, the whole year round); the type of producible assortments and their characteristics: tree species, size, and quality class; the average production of daily logging; the growing stock by assortments: the actual cut and allowable cut; the possibility to use heavy trucks with trailer; the possible customers for each assortment.

Customers: the type of the customer (local customer means that direct delivery by truck is possible, whereas remote customer means that trans-shipment from trucks to railway wagons is needed); distance from railway station to remote customer; the type of used assortments and their characteristics: tree species, size, quality class; the monthly contracted deliveries by assortment.

Garages: the number of registered trucks; the characteristics of each truck: model, trailer or semi-trailer availability, registration number, carrying capacity, average time for loading and unloading.

Railway station: name, code; costs of trans-shipment from trucks to wagons via terminal per m<sup>3</sup>

- Wood transporting costs and trans-shipment costs at the terminals are taking into account when searching optimal routes.

## Testing

The efficiency of the developed program was tested in real logging process. Three delivery plans were compared for a logging company operating in the Republic of Karelia. The company provided forest inventory and infrastructure information and thus following map layers

were created: roads, forest stands, and cutting areas. The “basic” delivery plan (Plan 1) was done in a traditional way without program support. Two “advanced” delivery plans (Plan 2 and Plan 3) were done with the program. The difference between the second and third delivery plan is that in the third plan (Plan 3) the trucks change the drivers on the route without re-tuning to the garage every shift.

The delivery plans were created for four adjacent working days using two shifts per day for the same conditions of logistic management units (cutting areas, customers, routes, fleet etc). There were five trucks based in one garage, four cutting areas, and four customers (three sawmills and one wood terminal). Capacities for short-wood trucks were 50-52 m<sup>3</sup> depending of the model (Sisu, Volvo, Scania). Daily outputs in cutting areas were 140-420 m<sup>3</sup> depending of the site, the actual cut per cutting area was 5000-15000 m<sup>3</sup>.

### Results

Comparison of the results between delivery plans when applying the basic method (Plan 1) and the program (Plans 2 and 3) are made. Optimization of the schedule using the program according to Plan 2 shows that the total delivered wood volume increases by +9 %. The total run is the same, but the total working time decreases by 17 %. The required fleet is the same, 5 short-wood trucks. The fleet utilization rate decreases slightly (-4 %), the index of loaded distance increases by 22 %, the total volume of transported round wood per km increases by 9 %.

Optimization of the schedule using the program according to Plan 3 shows that the total delivered wood volume increases by +10 %. The total run and the total working time decrease by 22 %. It reduces the required fleet from 5 to 4 trucks. The fleet utilization rate increases by 19 %, the index of loaded distance increases by 30 %, the total volume of transporting round wood per km increases by 42 %.

### Conclusion

Extraction of short-wood from the harvesting processes is becoming common practice in Russia. Logging companies are faced with a large number of options for short-wood transport, but they have limited knowledge of the potential in logistics. Developed GIS-based decision support program is a tool to assist the logging companies to make comprehensive decisions on organizational options for short-wood transport most beneficial for them. Application of the program allows to increase efficiency when introducing cut-to-length technology in Northwest Russia, to decrease wood transport costs, to improve utilization of short-wood truck fleet. Testing of the program and comparison of alternative delivery plans show that the efficiency of short-wood transport can be increased by 40%. Program could be used also for other applications, like for road planning, fuel supply or logistics in silviculture, and also provides an excellent opportunity to convey knowledge gained in research to the companies by practical and understandable means.

### Acknowledgements

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# Forest fuel supply chain management using advanced optimization based decision support system

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The growing use of forest fuels for energy production increases the need of effective planning systems for management of the forest fuel supply chain. It includes decisions of how, when and where to comminute the forest residues, when and where to store it and how to transport it to terminals and heating plants. Also, the procurement cost at harvesting sites and price level at customers have to be taken into consideration.

During several years Skogforsk has been working with FlowOpt. This is a Decision Support System (DSS) for strategic and tactical management of round wood procurement developed by Skogforsk and has been used in many case studies at Swedish forest companies. It has been used to find optimal solutions of the wood procurement and versions of the DSS have been implemented at companies. FlowOpt covers different planning situations on a long term level in the forest supply chain. The main questions to be answered concerns allocation of timber, back hauling possibilities, location of train terminals and cooperation between companies. FlowOpt can use different transport modes in the optimization such as truck, train and boat. The system is based on a GIS interface which is connected to a database where all data used in the analyses is stored. Each case is given a unique set of data files used in an optimization model which solves the specific problem while taking all constraints into account and minimizing the total cost. The system uses the Swedish National Road Database when calculating distances between supply and demand nodes.

During the last year Skogforsk has further developed FlowOpt into the system FuelOpt in collaboration with Holmen Skog AB and Sveaskog AB to include procurement of forest fuels. Forest fuel procurement comprises more variation in the supply chain than round wood procurement since there are extra decisions to be made. The optimization model used in the system has been extended to manage the various decisions that are needed for forest fuels. The decisions include when and where to comminute the forest residues and what kind of system for comminution that should be used. Given the choice of system there are constraints on capacity for both comminution and transportation. Also, the new model comprises costs for purchasing residues and the value of the product when it is delivered to the customers. The objective is to maximize the profit while keeping the costs low for the forest fuel company.

The optimization model is an Integer Programming (IP) problem whereas the original FlowOpt model is a Linear Programming (LP) model. The reason to include integer variables is that the decision to use a specific system at, for example, a harvesting area is modeled with binary (values 0 or 1) variables. The problem is modeled using the modeling language AMPL. The problem can be solved using any IP solver and we make use of the cutting edge CPLEX optimization system.



There are several systems for comminution available and each system has to be described with possible activity, for instance, chipping or compacting. For each activity, the cost, performance per hour and capacity constraint needs to be defined. The original FlowOpt system manages all data regarding the transportation activities and computes distances between all nodes in the network.

Due to the high amount of possible actions for purchasing, comminuting, transportation, storing and allocating the forest fuel it is very difficult to manually even find a feasible solution and in practice the time required to establish a plan is very long. Therefore, a system that provides optimal solutions in short time is very valuable.

The result from the model will present an optimal solution showing

- where to purchase the residues
- which type of system to use for comminution or bundling at each harvest area and terminal
- if and where some assortments should be stored and related volumes
- what transportation system to be used
- which customers the forest fuel should be allocated to
- catchment areas for each terminal

The case study has been performed together with Sveaskog which handles approximately 2 TWh forest fuels every year. The planning horizon covered one year of forest fuel handling in the middle of Sweden where supply was grouped into 400 supply points with 800 MWh forest fuels. There are eight 8 assortments used. The demand at 21 heating plants in the area amounted to at least 600 MWh with the possibility for Sveaskog to deliver more if profitable.

The machine systems used in the case were forwarder-mounted chippers, bundlers, truck-mounted chippers, modified forwarders and large mobile chippers placed at terminals.

The case objectives were to maximize the revenue for Sveaskog and find out the best allocation of train terminals, catchments areas for the different customers and which types of machine systems should be used.

The optimization model for this case included about 65,000 decision variables and 5,000 constraints. All data processing and solving using CPLEX took less than one minute.

When writing this, the results from the optimization have not yet been verified by Sveaskog. However, the results give us the total cost, catchments areas, allocation of train terminals and the optimal use of different machine systems. Verified results will be presented at the conference.

During the development there are parts in the system which is not automatically generated and during 2008 we are working on making it a stand alone and user friendly DSS for direct usage at companies.

# Integrated procurement of forest, fossil and wood waste fuels of energy mill

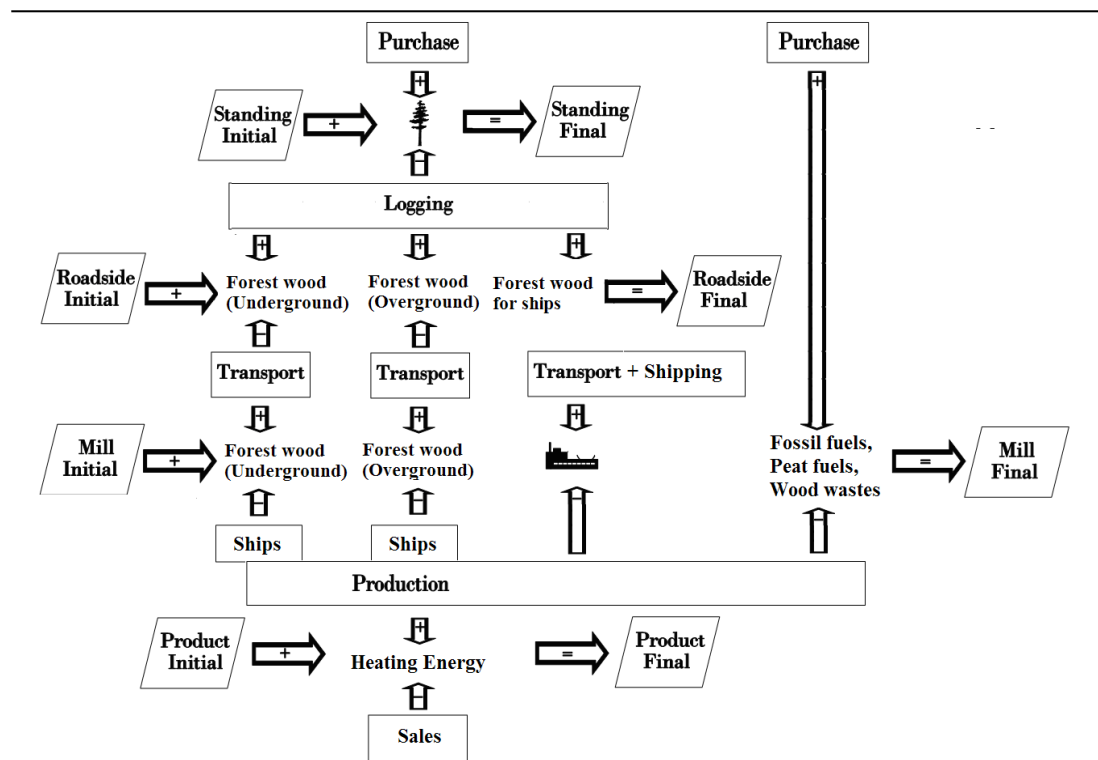
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In this paper, a large-scale industrial fuel procurement scheduling problem is considered. The problem includes the allocation of number of fossil, peat and wood-waste fuel procurement chains with release and due dates into a heating mill. The decision-making environment is further complicated with sequence-dependent procurement chains of forest fuels (Figure 1).

Different properties of the decision-support system and methodology are discussed and illustrative “Putting a price on carbon dioxide emissions” -examples based on real-life industrial data are presented. A dynamic linear programming (DLP) model was used to describe the scheduling task. However, due to the complex nature of the problem, the DLP-based material flow model cannot directly be used to solve the integrated system with industrial relevance. Therefore, the energy flow model was used to describe the combinatorial complexity.



**Figure 1.** Dynamics of energy resource inventories in a heating mill: Vertical arrows describe sequence-dependent effects of system; Horizontal arrows describe time-dependent effects of system.

The reformed energy flow model proved to be more effective than the models developed by Palander (1995) and Palander et al. (2004), because in the new model, the forest fuels delivering could be taken in consideration more precisely. This resulted from the fact, that forest fuels shipping were modeled with the separate variables in the reformed model. Problems occurred only with the determination of the fossil, peat, and wood waste fuels. The material flow method (Palander 1995), used also in the model by Palander et al. (2004), did not pay attention to the profitability of integrated procurement of energy fuels. The material flow method allocated the cubic meters (solid m<sup>3</sup>) of the forest fuels and ensured that the best possible forest fuel alternative was in the model, but it did not ensure that it was profitable. Therefore some of the delivering alternatives presumably decreased rather than increased the quality of manager's tasks, the energy fuel mixes. This was avoided using the method of this study, because the energy flow model allocated the megawatt-hours (MWh) of the fuels for all energy fuel assortments.

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# Forest chip production and CO<sub>2eq</sub> emissions in Finland in 2015

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A lot of discussion about the CO<sub>2eq</sub> emissions of different fuels has been presented. The importance of monitoring and reducing greenhouse gases is a general subject for further development. However, there are only few comprehensive calculations of CO<sub>2eq</sub> emissions in the production of forest chips. Metsäteho Oy undertook a study on the CO<sub>2eq</sub> emissions in forest chip production in Finland. The fuel consumption of production machinery was determined, as well as forest chip supply system alternatives related to targeted amounts was described.

CO<sub>2eq</sub> emissions were calculated with the updated Emissions Calculation Model by Metsäteho Oy. The model has about 15 years of history with traditional wood procurement and long-distance transportation, as well as silviculture and forest improvement activities. Also occasional calculation related to the forest energy systems and CO<sub>2</sub> consequences have been carried out (for example Korpilahti in 1998). Nowadays; production of forest chips has been included to the model with full weight.

Emissions calculation has to continue to provide information that is vital for the future development. In Finland, the comprehensive forest work studies of mechanized felling and forest haulage was carried out in the 1980's and 90's, and for the moment deep understanding of production of forest chip technology is needed, as well as realistic alternatives of forest chip supply chains in the future.

In this study, the CO<sub>2eq</sub> emissions were determined for different raw material flows (chips from small-sized thinning wood, logging residue chips, and stump and root wood chips), and for various supply chains (i.e. chipping at roadside landings, at terminals, and at power plants). As significant part of the study a sensitivity analysis was performed to point out the influence of different kind of parameters and to underline the importance of data management behind the emissions calculations. Emissions are calculated by supply chain combined with realistic long-distance transportation methods. Also silviculture and forest improvement activities are included into the model.

In Finland, 3.04 million m<sup>3</sup> (6.1 TWh) of forest chips were used in 2007. Targets have been set for the future use of forest chips in Finland. It has been estimated that the stock of techno-economically harvestable forest chips is around 10–15 million m<sup>3</sup> (20–30 TWh) annually. In 2007, commercial fellings of industrial roundwood were 53 million m<sup>3</sup> sub and it has been targeted to be 72 million m<sup>3</sup> in 2015. This study case gives an estimation of forest biomass supply sources, supply chains and machinery, as well as CO<sub>2eq</sub> emissions related to the target for 2015 (7.5 million m<sup>3</sup> i.e. 15 TWh).

It has been estimated that a total of 1,100 machine and truck units are employed in the production of forest chips for energy plants in Finland. If the consumption of forest chips by

energy plants in 2015 reaches the target, then the requirement of forest machines and trucks will be over 1,700 units.

In the case, the target will be reached, the estimation of the proportion of the **supply sources** in 2015 are following:

- |                    |      |
|--------------------|------|
| - logging residues | 53 % |
| - small-sized wood | 29 % |
| - stump wood       | 18 % |

In the case, the target will be reached, the estimation of the proportion of **comminution methods** in 2015 are following:

- |               |      |
|---------------|------|
| - at roadside | 42 % |
| - at terminal | 22 % |
| - at plant    | 36 % |

In the case, the target will be reached, the estimation of the proportion of **long-distance transportation methods** in 2015 are following:

- |                                |      |
|--------------------------------|------|
| - truck from roadside to plant | 63 % |
| - truck from terminal to plant | 11 % |
| - train                        | 4 %  |
| - barge                        | 3 %  |

If this estimated forest energy supply will be reached in 2015, the total CO<sub>2eq</sub> emissions will be around 130 000 tons. Proportion of forest chip harvesting from that is 68 %, long-distance transportation 22 %, silviculture and forest improvement 2% and production of diesel and fertilizer 9 %. In this study, the supply chain with lowest emissions was logging residues with chipping at the plant. Conversely, the highest emissions came from stump wood when operating with chipping at terminal.

The differences of emissions are due to the productivity and fuel consumption of different kind of technology, but also because of realistic combination of supply chains and available machinery. We have to look at the whole production system, hence there is no sense to compare supply chains without realistic, comprehensive boundaries. It is possible to do these comparisons with Metsäteho's Emissions Calculation Model which is based on actual data.

*Keywords: CO<sub>2</sub> emissions, Supply chains, Forest chips, Small-diameter wood, Logging residues, Stump wood, Finland.*

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