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Precision Forestry Symposium
Stellenbosch, South Africa
1 to 3 March 2010

Developments in Precision Forestry since 2006

Proceedings
(Extended abstracts)

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Developments in Precision Forestry since 2006

Proceedings of the
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1 - 3 March 2010

Edited by P A Ackerman, H Ham & C Lu

Preface

On behalf of the Symposium Scientific Committee, I am privileged to provide the introduction to this volume of proceedings. These proceedings represent scientific contributions to this Precision Forestry Symposium titled “Developments in Precision Forestry since 2006” held in Stellenbosch, South Africa, from 1 to 3 March 2010. The symposium was jointly organized by the Department of Forest and Wood Science, Stellenbosch University (the host) and the Chair for Forest Work Science and Applied Informatics, Technische Universität München (TUM).

The objective of this symposium is to provide details of research results and promote communication and information sharing on precision applications in forest operations. This symposium is the culmination of a number of events and initiatives, not only in South Africa, but also in Europe and North America. The initial idea of presenting the First South African Precision Forest Symposium in 2003 and the formation of the Precision Land-use and Management working group were initiated by events at Washington State’s Precision Forestry Cooperative’s initiative and their presentation of the First international Precision Forestry Cooperative Symposium in 2001. In addition, precision developments in Africa made researchers at Stellenbosch take note of the enormous potential which precision based forest operations offer the forest industry. These events and initiatives led to a close relationship between Stellenbosch University and TUM in the presentation of both symposia and extensive collaborative research activities. Without this partnership much of what has happened over the past few years would not have been possible.

I would like to thank all those who were involved in the organization of this symposium for their significant contributions to the success of this event. We are also indebted to the authors of the extended abstracts included in this volume as well as attending delegates. I would also like to thank our sponsors; Southern Mapping Company, Stihl, Husqvarna, FAO, MTO and Optron Geometrics for their generous financial contributions to this event. Lastly my appreciation to the members of the Department of Forest and Wood Science – Hannel Ham, Poppie Gordon, Cynthia Lu, Anton Kunneke, and Martin Ziesak for their organizational work in the background.

These proceedings are reproductions of extended abstracts submitted to the symposium with editing to achieve consistent format. No attempt was made to review or verify results, although the abstracts were reviewed for suitability by members of the symposium scientific review committee as set below.

The following experts served as extended abstract reviewers for the International Precision Forestry Symposium 2010 in Stellenbosch, South Africa:

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March 2010 Pierre Ackerman

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KEYNOTE ADDRESS

New Sensor Technologies and Analytical Tools for Precision Forest Management

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There are currently about 3.9 billion ha of forests on this planet and they cover one quarter of the Earth's land area. Each year we are losing about 10 to 15 million ha of natural forests to other land-uses and gaining 2 to 4 million ha of planted forests. About 2% (72 million ha) of the world's forests are fast growing commercial plantations. These plantations currently provide about a third (635 million m^3) of the industrial roundwood harvest demand while the remaining 3.8 billion ha of forests provides the other two thirds.

The global forest industry faces many challenges including:

- Growth in the world's demand for wood. If we continue to use wood at the rate per capita, the annual demand by 2050 will be about 6 billion m^3. The current estimated supply is 3.5 billion m^3 and another 0.5 billion m^3 could come from natural forests and existing plantation forests. The 2 billion m^3 shortfall will have to come from new plantation forests.
- Global competition. Competition is coming not only from other wood producers around the world, but also from raw materials producers (e.g. concrete, steel, aluminium, plastics) and from alternative uses for the forest owners' land. If forestry does not yield a high enough return for the forest owners they will look for other uses for their land.
- Sustaining environmental values. While meeting growing global demands for wood and aiming to be globally competitive, we have to remember that there are other values that are equally important to sustain – such as fisheries, clean water, wildlife habitat, recreation, and site productivity.
- Interest in forests as renewable energy sources. To meet the expanding market for new energy products, new forests, new tools, new equipment and new systems will have to be developed and managed by foresters and forest engineers around the world. Who knows how big the demand for wood fibre will be if the world truly embraces forests as renewable energy resources?
- Markets are becoming more demanding and complex. To improve their own competitiveness, mills are becoming much more specific in their requirements. Mills want to be sure that they are getting the right quantity of the right product at the right price at the right time.
- Shortage of skilled and willing workers. In some parts of the world this is due to an aging workforce and forestry being viewed as "low-tech" industry with no career path.

The term precision forestry means different things to different people. As Bill Dyck (a keynote speaker at one of the earlier Precision Forestry conferences) noted, "to a geneticist it probably means precisely matching the genetics of a tree species to the site to maximize growth. To an industrial forester it might mean precisely managing a forest to match what the market needs. But to a conservationist it probably means being able to precisely manage a forest to optimize environmental benefits." One only has to look at the topics covered by speakers at this conference, and earlier precision forestry conferences, to see that precision forestry does indeed mean different things to different people. Regardless of the meaning, hopefully the precision forestry approach to forest management will help meet the challenges that the global forest industry faces.

As the website for this conference notes, "precision forestry uses high technology sensing and analytical tools to support site-specific, economic, environmental, and sustainable decision-making for the forestry sector supporting the forestry value chain from bare land to the customer buying a sheet of paper or board."

Jon. S. Wilson in the Preface to his Sensor Technology Handbook writes, "The first decade of the 21st century has been labelled by some as the "Sensor Decade." With a dramatic increase in sensor R&D over the past 15 years, sensors are poised on the brink of a revolution similar to that experienced in microcomputers in the 1980's. Tremendous advances have been made in sensor technology and many more are on the horizon."
New sensor technologies are improving our ability to determine with greater precision, such things as, what do we have in the seedling-to-customer forestry supply chain, where is it located, how is it changing with time, who is producing it, and what are the impacts of altering its form. While the introduction of sensor technologies into operations may involve additional costs, the resulting benefits may include lower overall operating costs, greater management efficiency, increased safety, improved and more consistent products, and reduced negative environmental and ecological impacts.

One of the outcomes from applying new sensor technologies is that we are able to rapidly gather data in huge quantities. For example, a single mechanized harvesting machine working three shifts per day in eucalypt plantations in Brazil would be gathering close to 100 million measurements of stem taper annually. As another example, a terrestrial LIDAR scan of a single inventory plot will require about 150 megabytes of computer disk space. Two of the challenges that forest managers now face are, "how do we make sense of so much information?", and "how do we ensure that the data has been correctly measured to start with?" – 100 million measurements from a poorly calibrated piece of equipment is unlikely to lead to precision forest management. New analytical tools for pre-processing the data and new approaches to data management, ensuring accuracy, availability, and security are required.

Given that high technology sensing can provide us with good quality forestry data, a plethora of tools are required that will help forest managers to meet the global challenges our industry faces. Tools that will: help forest managers to produce increased quantities of wood with the right properties to meet the world's markets and demands, reduce impacts on the environment from all activities along the seedling to customer supply chain, ensure that wood is a globally competitive product, enable forests to contribute sustainably to the world's energy needs, and ensure that those people who want to work in our forests can do so productively and safely in a "high tech" industry with a definite career path. A review of the abstracts for this conference convinces me that precision forestry analytical tools are being developed that will help meet these challenges.

Session 1:

Non-destructive wood quality assessment and wood quality modelling

Integrating terrestrial laser scanning based inventory with sawing simulation

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The forestry and wood processing industries more often than not operate as two separate players on the market. A major reason for the disintegration between these industries is the lack of information flow from the wood processing industry to the forestry industry and vice versa. While material flow is from biological production to conversion in the sawmill, information flows in both directions. Thus, potential for optimization along the forest-wood timber value chain is not realised.

In our approach we attempted to fill this knowledge gap with a feasibility study. The objective of our study was to establish the stem form and taper of standing plantation trees with a terrestrial laser scanner (TLS), model the stem form in three dimensions (3D), and subsequently input the resultant stem models into a sawing simulator.

Thirty *Pinus pinaster* trees in a stand in the Western Cape plantation of South Africa were scanned with a TRIMBLE FX laser scanner. This terrestrial phase shift scanner provides a distance resolution of 1 mm at 15 m distance on 90 % reflectivity of the target with a maximum scanning rate of 175.000 points/s. Due to smaller reflectivity rates of trees, accuracy was likely less but still produced sufficient results of our purpose. We scanned the stand from four different positions to reduce shading and measure the position of all trees with a total station in comparison. Tree and knot whorl heights were measured with a vertex hypsometer.

Based on the TLS data we extended the study to determine 3D taper in a way that it also detected sweep and the cross sectional stem form, based on an section wise adaptation of splines to the TLS derived point cloud (Fig 1.). Stem sweep was extracted by approximating circles to horizontal stem sections. Branches were detected and filtered based on the noise they induced at the whorls while fitting the circles. A 2D spline was fitted for each section to approximate the stem surface within this section. For stems which were scanned only from one side or were partially shadowed, additional guide points for the spline were derived from adapted circles to avoid swinging of the splines. Difficulty was however experienced with smaller shadow induced gaps. Figure 2 shows two horizontal sections of a stem with the approximated splines. The method produced good results for stems that were fully captured without shading of one side and less precise, but still acceptable results, for stems that were only scanned from one side.

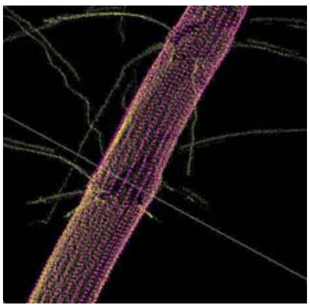

Figure 1: Detected points on the stem surface for spline interpolation from TLS data.

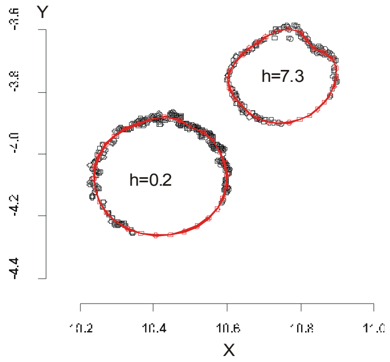

Figure 2: Horizontal stem sections in different heights (0.2 m and 7.3 m) with the stem from approximated by cyclic splines (splines red, laser data black). These data were used to create spatial representations of stems that were then sawn with the sawing simulator SIMSAW 6 (Wessels *et al.* 2001) like seen in Figure 3.

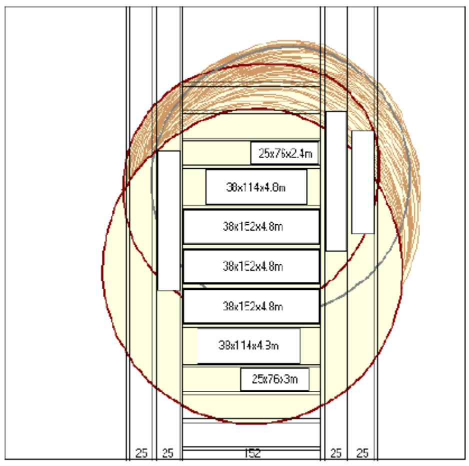

Fig 3. Output of a sawing pattern generated by SIMSAW 6

The results were very promising and showed the feasibility of the method for inventory of stands which provides direct information regarding potential saw timber recovery from a stand. However, the method still has to be referenced with sawn timber under real industrial conditions.

The application reveals several application fields: (1) Data created stands can be scheduled for harvesting according to the buyers demands (tailor made allocation). (2) If TLS inventory is available in younger stages, thinning and pruning regimes can be adapted to optimise the quality of the stand based on a cost-benefit analysis. (3) Precise information on the timber output and probable harvesting costs can be acquired before felling. Timber output reports from the simulation software can be especially useful for sawmill production planning purposes.

This is an example where precision inventory information, linked with latest ICT techniques and a rigorous model approach to emulate conversion along the forest wood chain can contribute to improving the production in forestry.

References:

Wessels CB, Dell MP, and Price CS (2001) SIMSAW 6 User Manual. CSIR Report ENV-D-I 2001-11. Durban, South Africa.

The non-destructive determination and modelling of knotty core sizes of pruned *Pinus patula* on a compartment basis

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The objective of this study was to develop and assess the methodology of using tree ring measurements in standing pruned *Pinus patula* for modelling the knotty cores of the pruned section of a tree. A total of 170 trees from 17 compartments on a wide variety of growth sites from the Mpumalanga escarpment were selected and destructively sampled. Sample trees were selected to represent the productive timber volume available from the compartments using stratified sampling. Sample discs were removed from breast height (1.3m) and at 6m. After drying and sanding, discs were scanned on a normal document scanner and ring widths were measured using an image analysis program. A preliminary study using 30 discs was undertaken to ascertain the appropriate number of radii to measure per disc. A comparison between the results of two radii as opposed to four radii showed that the mean ring width difference was not significant. In practice, this means sampling on standing trees will involve two breast height increment cores from opposite sides of a tree. Ring width measurements were also used to determine whether annual growth at 6m could be predicted from growth at breast height. It was shown that cumulative growth at 6m can be predicted using cumulative growth at breast height, site index, and cambial age at breast height as independent variables with sufficient accuracy (R^2 = 0.96). Ring width measurements at breast height can therefore be used to predict growth in the upper pruned section which in turn can be used to reconstruct the internal knotty core through the full pruned section of the log.

Analysis of variation for the entire data set from ring width measurements showed that there was far greater variation in knotty core percentages (the percentage of diameter occupied by knotty core) between different compartments than within compartments. Within a tree, the knotty core percentages between three stem sections 0-2.4m, 2.4 – 4.8m, and 4.8-7m, differed significantly. The knotty core percentages were found to increase from the bottom section (49.1%) to the top section (65.4%).

A single log from the pruned section of each tree was removed and processed into sawn timber at the sawmill. After drying of the boards, a sub-sample of boards from 17 logs, one from each compartment, was selected and reconstructed into log form. From the reconstructed log the actual knotty core size at a specific height was determined for each log. A comparison of the actual knotty core sizes and the modelled knotty core sizes of a sub-sample of trees showed only a modest relationship (R^2 = 0.62). Reasons for this might be variability in pruning quality, inaccurate pruning records, nodal swellings, and the methodology used to measure the actual knotty core sizes.

Knowledge of knotty core sizes can be used for many different purposes. The two applications that were assessed and found to be useful include decision support for cross cutting logs and for sawmill production planning purposes. Sawmill simulation software was used to evaluate value and grade recoveries under different scenarios. It can be concluded that the methodology proposed to reconstruct knotty cores from tree ring measurements has the potential to be used as a decision aid in the forest and forest products industries.

Session 2:

Forest operations simulations

Simulation of Wood Harvesting Processes in the Virtual Forest

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Discrete event simulation is used in industrial applications as an effective information system to support decision-makers, especially in logistics of manufacturing processes. Evidentially, this method can also work in forest operation planning while accepting the challenges of the huge variety of forest conditions. Based on the preliminary works of Bruchner (2003) and Hemm (2006), this contribution is about the illustration of wood harvesting processes in discrete event simulation software.

The base model used by this simulation tool is the Virtual Forest, developed by the state of North Rhine-Westphalia NRW in Germany. Intended as a central database, the Virtual Forest includes novel fundaments of information, planning and orientation for the located forest business. Amongst others, the model contains topography, soil, roads, building and forest stand data up to the attributes of the single tree. Remote sensing technologies such as aerial survey with stereo camera and laser scanning, or infrared satellite pictures are adopted to attain this goal. These data are complemented by maps of properties and selected location attributes. In the next few years, the total forest area of NRW should be recorded this way while constantly advancing the implemented algorithms.

The accurate transformation of the real environment offers the possibility of close to reality simulation in step with actual practice. The simulation tool retains this exactness by using single tree events as its control mode. Depending on the attributes of the tree, time consumption of the applied resource takes place, in turn, assured by results of scientific time studies. After choosing the stand and trees to harvest, the operator defines the favoured assortments and the resources which should work in the scenario. The user can watch the simulation proceed in real time within the 3D-Model of the Virtual Forest or he can immediately access the results of the simulated scenario. The analysis shows all relevant output values to support further decisions.

One main challenge is the development of an automatic routing system, which allows the logical procedure of the harvesting resources in different scenarios. This problem cannot be solved perfectly. While handling the travelling salesman problem, this routing system must also deal with collision avoidance, unidirectional trafficability of inclined skid roads and many other restrictions. Therefore, an iterative method was favoured that provides good solutions of routing in the vast majority of scenarios. After defining the workstations by allocating trees to the adequate skidding road, these points of interest are clustered. The edges are weighted and one simple rule type allows the resource to find its way through the scenario.

The assignment of the current project is to increase the reliability of simulation results by consolidating the performance data of harvesting resources. On their own, single case studies cannot cope with the diversity of forest conditions. Therefore, the automatic monitoring systems running with modern machines should be used to collect data on a big scale. The preconditions are exact cognition of the applied algorithm and the statistical preparation of these data.

Discrete event simulation – an advanced method for analyzing complex logging operations

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Recently, the interest of using simulation as a operations research (OR) method has increased within the fields of forestry operations and supply chain systems of forest biomass research. Studying the system behaviour through simulation is justified particularly when studying the real system is too expensive, time consuming, and difficult to observe; or if the system does not exist in the real world.

The operational environment in the Scandinavian CTL-logging system is complex and diverse, therefore imposing challenges on modelling the system in the simulation environment. The machine operations are partially guided with the work-shift scheduling and with the changes of the system. The harvester and forwarder are interlinked to the harvesting unit with continuous interactions. The productivities within machines vary according to the site characteristics and other logging conditions. Productivity also varies between machines resulting in rescheduling of the operations or waiting/idle times of the machines. Controlling and managing several harvesting units and their machine relocations to new sites concurrently increases the number of functions and interactions in the simulation model.

Nevertheless, modelling and simulating the logging operations at a certain scale are nowadays easier and more precise, owing to the deeper understanding of operations, more detailed knowledge of machine performances in varying conditions, more precise historical data of harvested sites, and better programming packages for building the simulation models.

This paper is presenting the basics of simulating discrete-event systems. Furthermore, the paper expresses the essential elements of concern while designing and building a simulation model for mechanised CTL-loggings.

Operational efficiency of the year-round CTL-harvesting on sensitive sites in Finland – A simulation study

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Shorter winters and more varying weather conditions make access to peatlands, steep slopes and rain sensitive silt and clay soils more difficult and can cause increased costs and uncertainty for the wood supply. Both technical and logistical solutions are needed to ensure year-round supply from more difficult harvesting conditions on sensitive sites.

In the western part of Finland, where the share of peatland forests is over 40 % of all forested land, logging has been mainly done during the winter when the ground is frozen. Due to the seasonally fluctuating employment of logging fleets and operating personnel together with the trend of milder winters, the common aspiration has been to develop year-round logging on sensitive sites. The solutions, which decrease the ground pressures of current logging machines, such as band tracks, wider tires and extra axles, give better opportunities to the machines and operators for year-round employment. Even though there are machine concepts currently in use on sensitive sites, there is no clear picture of cost efficient and environmentally sound practices while operating in areas where the share of peatland forests is high.

The objective of the study was to identify and quantify the most cost-effective options in machine modifications, operating methods and site selection through discrete-event simulation, while harvesting in areas with a high share of peatland forests. The logging simulation model was compiled with WITNESS process simulation software. The logging sites and logging contractors were selected for the simulations from the large and precise logging history data contributed by large forest companies. Three logging contractors (abbreviated as A, B and C) were selected for the simulations. The simulation model consists of three harvester-forwarder units and one low-bed truck for machine relocations. Latest work studies of mechanized CTL-harvesting were utilised for compiling upgraded time consumption models for the logging machines. One of the three harvester-forwarder units was used for soft soil harvesting. In order to increase the flotation of machines, this logging unit was modified with building band tracks for soft soils in summertime.

Simulation scenarios were categorised into four main sub-scenarios: the share of peatlands; duration of the winter (frozen ground) season; amount of logging sites available for logging during summer season; and the modification class of the logging unit operated in soft soils. Between scenarios, the share of peatlands varied from 10 to 50 % of the total cutting removal. “Normal winter” and “short winter” were used to discover the cost effects of possible milder winters. The amount of available logging sites during the unfrozen season had two choices, normal and low. Four modification classes in terms of the maximum ground pressures of the machine concepts were created for the soft soil logging unit. Machine modifications varied from each other with different installations of band tracks for soft soils available in Scandinavian markets (Figure 1). Modification classes are synchronized to the soil bearing capacity classes which have been defined in recommendations for peatland logging during summertime. Machine modification classes were as follows: “improved bearing” (≤ 50 kPa), “high bearing” (≤ 40 kPa) and “extreme bearing” (≤ 30 kPa). The “basic” class of machines results in ground pressures over 50 kPa. Primarily, the forwarder was the machine to be modified for attaining enough low ground pressures. Adapted time consumption formulas and the filling degree of the load space within different modification classes were customized for the soft soil logging simulations based on the interviews of highly professional machine operators. Every scenario was simulated by five replications; the duration of each replication was set for one year. For the scenario comparison the unit costs (€/m³) were calculated with up-to-date cost factors for the machines and modifications.

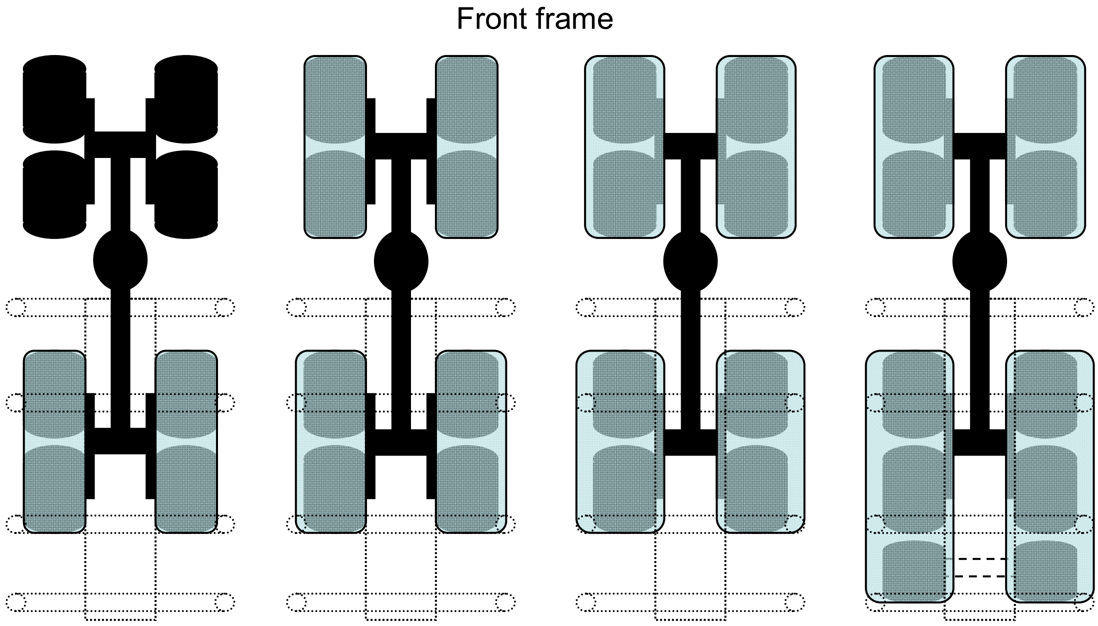

Figure 1: Sketches of the different modification classes for forwarders used in soft soil logging. "Basic" was equipped only with basic band tracks on rear bogie. Class B "Improved bearing" was equipped with basic band tracks on front bogie and wide band tracks on rear bogie. Class C "high bearing" was equipped with wide band tracks on front bogie and extremely wide band tracks on rear bogie. Class D "Extreme bearing" had the same tracks on front bogie than the class C plus the extra axle behind the rear bogie with extremely wide band tracks.

Unit costs varied from 9.61 to 17.24 €/m³ depending the scenario and the case contractor. Mean productivity in peatland logging during winter was 12.0 m³/h, whereas during the summer, the productivities with modification classes of "improved bearing," "high bearing" and "extreme bearing" were 10.5, 10.7 and 10.9 m³/h respectively. Regardless of the higher logging productivity during winter in peatlands, the limited amount of logging sites during the unfrozen period favoured harvesting some of the peatland logging sites during summer. This increased the logging opportunities, decreased down-time of machines and lowered unit costs for the whole year. For example, in the scenario of contractor A (peatlands 25% share of the total removal), where all the peatland forests were possible to harvest either only during the winter or year-round, the most economical was to purchase soft soil installations and to modify one logging unit for peatland loggings during the summer. Depending on the modification class of the peatland logging year-round, the decrease of unit costs was 2 to 4 % compared to peatland logging only during the winter. When the share of peatland logging increased to 30 % or more, there was a compulsory need to modify one logging unit for soft soil logging during summer.

As a general comparison, none of the modification classes were clearly better when compared in monetary terms. It seemed that if the share of peatlands with lowest bearing capacity classes increases to a high level and peatland logging was to be done all summer, it is most economical to invest for the "extreme bearing" modification class. However, the most cost saving method is to schedule peatlands to the right cutting order in terms of the bearing capacity classes of the sites. Site classes with the lowest bearing capacity should be harvested during winter time when the ground is frozen and the best bearing site classes with higher performance level during summertime.

An evaluation of skyline systems in Norwegian conditions using discrete-event simulation.

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Large volumes of spruce-dominated forests established on steep terrain are maturing in western Norway. The level of harvesting needed in utilising these forests calls for investments in cable yarding, processing and transport systems, and updated knowledge on the appropriate technology for Norwegian conditions. In the yarding-processing-truck transport operation, the processor cannot operate if the cable yarding system does not supply trees at a sufficient rate or when the buffer storage becomes full. As a result, the productivity of the whole system is often substantially lower than those of the individual parts in the system. Discrete-event simulation has been applied successfully in the analysis of a wide variety of wood harvesting and transport systems, where the productivities of different parts in the supply chain are interlinked (Asikainen 1995, 1998, 2001, Talbot *et al*. 2003, Myers and Richards 2003, Väätäinen *et al*. 2005).

In this study a discrete-event simulation model was programmed to find optimal setups for the timber yarding-processing-truck transport system in Norwegian conditions. The simulation model is based on dynamic operation using a logging site and transport distance database as the input. The model estimates the expected values and their distributions for the setup times, productivities, and machine failures of the yarding-processing unit and truck transport system.

The work of a yarding-processing unit was divided into two main operations: moving and setting up the cable yarding system, and yarding and processing the trees. The direct relocation time is calculated by dividing the moving distance by the moving speed; and the set up time depends on the yarding distance, the direction, shape and steepness of the slope (Stampfer *et al*. 2006). Yarding and processing of wood is affected by the yarding distance, volume of the trees, and steepness and difficulty of the slope (Stampfer *et al.* 2003). The variables describing each logging site are drawn from probability distributions that are based on the stand data records. Available skylines differ in terms of investment levels, set up times, and load capacities.

The timber truck with a trailer was modelled for the road transport of timber. In the dynamic simulation experiments the average transportation distances are 20, 40, 60, 80, 100 and 120 km, with a SD of 10 km. Additionally, the number of trucks varies from 1 to 4. The yarder stacks processed timber onto the landing. Once the buffer is full, the yarder has to wait. The trucks enter the model on the road leading to the landing. As the truck arrives at the landing, it first loads the timber in the buffer storage and then waits (if necessary) until the yarder processes enough timber to fill a load. When the truck is fully loaded, it leaves the landing, drives to the mill and unloads. If there is more than one truck in the system, queuing can take place at the roadside landing and at the receiving terminal. The trucks and the skyline system have randomly occurring machine failures.

The alternate skyline system solutions are compared and the optimal technology for different stand categories is recommended. In addition, the optimal number of trucks and size of the buffer storage between processing and transport at different transport distances is estimated

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Aspects of modelling time for simulators of harvesting operations

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"Although it is easier to sell pictures, pictures will not produce data, but reliable data are necessary to produce moving pictures. That means: a fan of harvesting simulators should from time to time still take his rubber boots to look what is going on outside in the woods."

1. Work study results to feed harvesting simulators

The single grip harvester is a good example to use in discussing the potentials and limitations of simulating harvesting operations. At an early stage of our harvesting simulator project, the sponsors did not expect too much effort to develop a simulator of single grip harvester operations out of already existing training simulators. Interestingly, there was a belief in a certain intrinsic problem solving power of moving pictures. Visualisation and representing geometries and technical parameters of machineries are basic elements of training simulators.

However, actual training simulators for harvester operators have two crucial shortcomings. First of all, the simulated interaction between machinery and environment is very simplified and insufficiently based on real life data - that are e.g. effects of stand structure, tree shape, branches, friction between harvester head, tree and remaining stand, between tree or machine and terrain, possible assortments. In addition, the training simulator is still geared by the operator. Yet, a simulator of harvesting operations has to produce reliable planning figures representing decisions and behaviour of staff on different scales. The necessary scientific discipline to solve such questions is called "work science." The substantial task is to model process steps by describing the variation of time consumption quantitatively.

Indeed, a true causal determination of processes would need sensationally deep knowledge about man - nature - machine interactions. Even more detailed work studies are necessary in order to feed models into simulators of harvesting operations. That of course includes the use of future high resolution on-board-computer data about machine activities. As well as others, our simulator of harvesting operations has been constructed based on models, parameters and experiences about harvesting processes gained in many field studies.

2. Potential precision of predicted time per single tree

In reality, a rather high variation of time consumption per tree was observed in time studies even under easy conditions (e.g. case studies in even aged spruce stands in flat terrain, single operators). The statistical models of time consumption using timber volume of the processed trees (piece volume) explain between 30 - 70% of the variance. The standard deviation of residues roughly ranges between 0.2 an 0.4 minutes per tree.

It is necessary to define what kind of precision is aimed at within reasonable ranges of operational parameters. For example, in absolute values, precision of time per tree does not change very much depending on piece volume. Therefore, the relative precision per tree tends to be lower in processing small trees. On the other hand, absolute precision of productivity is higher in processing small trees, whereas time per m^3 and therefore costs per m^3 do vary widely in early thinnings. Including more parameters, a limited further reduction of variation is possible. But even models based on precise on board computer data about the time consumption per log of a harvester head still leave a remarkable rest of unexplained variance.

Up to now, many important influencing parameters still have to be recorded manually. It is suggested to test the use of diameter gradients of trees and roughness of stem surface. Parameters like crown lengths and diameters may be automatically recorded in order to derive future models for time consumption in (semi-) automatic time studies - using on board computers for time measurement. Even if a certain technical state of machinery is presumed, and machinery, terrain conditions and operators do not change; it will have to be expected that the complexity of interactions of many factors will set clear boundaries for the precise prediction of single tree time consumption.

3. Expectations for the precision of predicted figures for whole operations

The step from short case studies to changing harvesting operations produces additional categories of variation. Despite a high variation of residuals, the analysis of about 1800 daily records of timber production under varying conditions is promising. It was possible to predict rather reliable productivity levels by using basic parameters of operation. It especially worked out to include machine parameters as technological indicators into models for time consumption. A continuous detailed analysis of local parameters, process steps, machine movements, and operators decisions, along with long term observation results, contribute construction material to reliable and flexible harvesting simulators. New tools for automated data collection about machine activities and external influencing parameters of stand structure will enhance the further development of methodology for scientific work studies.

Multi-stem mechanised harvesting operation analysis – application of Arena 9 discrete-event simulation software in Zululand, South Africa

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This study focuses on a recently introduced multi-stem mechanized harvesting and transport system. A time study (191.1 h of observation) examined the system working in a seven-year-old Eucalyptus pulpwood operation. Using the time study data a simulation model was constructed using Arena 9 simulation software (System 1). Two further simulation models (Systems 2 and 3) representing hypothetically improved multi-stem systems were built and tested for potential productivity gains and cost reductions. The simulation models constructed in this study were dynamic (consider time), stochastic (consider randomness of observations), discrete-event (activity-oriented) models. The model was set to run for a simulated period of 10 months (each month was a replication).

The real world system represented by System 1 produced an average of 475.2 m^3 of pulpwood delivered to the mill (40 km lead distance) per 11 h daytime shift. System 1 comprised the following equipment:

- 1 Tigercat 720D drive-to-tree wheeled feller buncher with continuous disc saw.
- 1 Tigercat 630C grapple skidder with dual arch bunching grapple.
- 1 Volvo EC 210BLC excavator with Maskiner SP650 delimber-debarker head.
- 1 Volvo EC 210BLC excavator with Maskiner SP551 delimber-debarker head.
- 1 Hitachi Zaxis 200 excavator with Maskiner SP650 delimber-debarker head.
- 1 Volvo EC 210BLC excavator with Tigercat slasher deck.
- 3 Volvo FM400 6x4 rigid trucks with drawbar trailers.

System 2 is a hypothetical system which employs exactly the same equipment as System 1 but differs in specific operating procedures. It was constructed primarily to simulate potentially advantageous alterations to System 1's operating procedures with the aim of improved equipment balance, productivity, production and cost. Some of the more significant practices identified were:

- Fuelling and greasing bottleneck equipment outside of scheduled work hours.
- Providing operators with more, shorter scheduled rest periods.
- Feller buncher presentation of bunches for the skidder needed to be consistent and clear of obstacles.
- Skidder log recovery grapple mounted on the skidder blade for collecting stems dropped in previous cycles.
- Skidder collection of bunches at an angle of 90° to its takeoff direction
- Minimal time delay between felling and debarking required for reduced bark adhesion.
- Larger stock buffer between the delimber-debarkers and the slasher, meaning less slasher movement, less skidder indexing cycles, higher slasher productivity and increased volume payloads per truck.

System 3 simulates the potential of replacing the delimber-debarkers with delimber-debarker-slashers. It is comprised of the following equipment:

- 1 Tigercat 720D drive-to-tree wheeled feller buncher with continuous disc saw.
- 1 Tigercat 630C grapple skidder with dual arch bunching grapple.
- 4 Volvo EC 210BLC excavators with Maskiner SP650 delimber-debarker-slasher heads.
- 1 Volvo EC 210BLC loader/excavator with Rotobec grab.

- Volvo FM400 6x4 rigid trucks with drawbar trailers.

In System 3, the feller buncher and grapple skidder operate in a similar manner to System 2. Subsequent to timber extraction by the skidder, four roadside processors delimb, debark and cross-cut the full trees to 5.5 m lengths. Following this, the cross-cut timber is loaded onto trucks by the loader and transported to the mill.

All simulation models were cost using standard cost inputs (Hogg *et al.* [in print]), results taken from simulation runs, and working hours and days taken from simulation model parameters.

Outcomes of the study, based on the objectives, were as follows:

1. In System 1 the simulation model acceptably represented reality on every level, with the real world and the model differing by an average of 0.85% in overall production over 40 simulated months. System balance was improved most noticeably in the decrease of feller buncher waiting time from 43.1% of its total scheduled work hours (System 1 with three trucks) to 26.2% (System 2 with four trucks). Production improvements were clearly evident with simulated timber over the weighbridge/month increasing by 31.1%. Cost reduction was also realized, with the cost/m3 of timber decreasing by 12.5% with System 2. System 3 resulted in lower costs than system 1, but not to the extent as with System 2 (4.5% vs. 12.5%).
2. Several beneficial operation and application practices were identified in System 2, which led to the successes mentioned above. Not all changes made in this study, however, would necessarily produce the same positive result in other multi-stem operations. Improvements were gauged according to the studied harvesting operation under specific conditions. Applicability of these operation adjustments to improved operation in other systems would therefore be expected to vary to an extent with system configurations and operating environment.

The ultimate test of the appropriateness of the simulation results will be through applying the improved system scenario in reality and monitoring the outcomes. This requires implementing simulated adjustments (the changes made to System 2 with four trucks in this case) into the real world system and running further time studies to evaluate how accurately the model forecasted reality.

Session 3:

Remote sensing and mensuration

Determining stand value and log product yields using terrestrial LiDAR and optimal bucking algorithms: Experiences from Oregon, Australia and Ireland.

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Good metrics of the quantity, quality and location of timber resources within forests are essential for ensuring that wastage is minimized, harvest and volume growth increments are balanced, log products are optimally matched to markets, and the value of the forest is maximized at the time of harvest. Terrestrial LIDAR is a new approach for gathering detailed descriptions of individual stems and their location.

Four trials were undertaken in plantation forests. All forests were LIDAR scanned and their stem profiles automatically detected.

- Ninety-three plots were established in 16 sitka spruce stands in Ireland. Stem profiles were gathered on over 4000 trees using terrestrial LiDAR. A sub-sample of 140 stems from 12 of the stands was used to compare LiDAR volume estimates with volume measurements from a harvester; LiDAR volume was within 4.5% of harvester volume. The LiDAR plot data was then linked to biomass expansion factor models and used as the basis for a case study that looked at optimal bucking and optimal allocation of wood fibre to conventional and bioenergy markets that included 13 processing plants. The study demonstrated that terrestrial LiDAR data could be used to determine stand product yields and value in sitka spruce plantations.
- Nine plots were established in three Douglas-fir stands in Oregon. Stand ages ranged between 20 and 67 years. Stand values and log product yields for two log markets were estimated, using optimal bucking algorithms. Estimates for LiDAR derived data were compared with estimates based on post-felling, manually measured stem profiles. Overbark diameter was underestimated by an average of 6 mm. Stand volumes were underestimated by an average of 4%; ranging from -1% to -6%. LiDAR based stand values were within 9% of value estimates based on optimal bucking of manually measured stem profiles. Stand and undergrowth density and tree size affected the accuracy of automated stem detection and stem profile measurements. Differences in volume and value estimates were noted between stand types (based on age) and markets.
- Eighteen plots were established in three Radiata pine stands in South Australia. Stand ages ranged between 27 and 41 years. Tree values and log product yields were estimated, using optimal bucking, for the terrestrial LiDAR derived data and compared with estimates based on mechanized harvester and manual stem profiles after felling. LiDAR stem diameter profiles and manual stem profiles differed by less than 10 mm up to a height of about 20 m. Based on a sub-sample of 117 trees taken from the three stands volume was LiDAR derived volume estimates were 1% higher than estimates from manual stem profiles. LiDAR value estimates were about 2% higher. Differences were noted between stand types. Harvester diameter, volume and value estimates were not as accurate as LiDAR estimates; this was mainly due to underbark diameter calibration issues with the harvester.
- Sixteen plots were established in four Radiata pine stands in Western Australia. Stand ages ranged between 18 and 33 years. Tree values and log product yields were estimated for the terrestrial LiDAR derived data and compared with estimates based on MARVL standing tree inventory procedures and on mechanized harvester and manual stem profiles after felling. Compared with the manual measurements of harvested logs, LiDAR estimates were 5.6% lower for total volume and 3% higher for total value. LiDAR value estimates were about 2.5%

higher than MARVL inventory estimates. Plot preparation and tree characteristics affected the accuracy of automated stem detection for and stem profile measurements from LiDAR data.

The four trials in three different parts of the world have demonstrated that terrestrial LiDAR data can be combined with optimal bucking algorithms to estimate stand volume, value and product yields. Factors affecting the accuracy of the estimates depend on species; stand conditions, plot preparation, and experience with the technology.

Using high-resolution satellite imagery and double sampling as a cost-effective means of collecting forest inventory data – the case of Hans Kanyinga Community Forest, Namibia

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The purpose of this study is to evaluate the use of high-resolution satellite imagery in forest inventory of the open savannah woodlands of Southern Africa. The study was carried out in Hans Kanyinga Community Forest, north-eastern Namibia. A two-phase (double) sampling design was used to estimate the variables of interest namely stand volume, stand density and diameter distribution. QuickBird satellite images were used to extract auxiliary variables, such as photogrammetric crown diameter and number of stems, using visual interpretation and measuring tools offered by Erdas 8.7 geographic imaging software. Field inventory data were used to obtain the terrestrial data. The relationships between auxiliary and terrestrial variables were described and regression models constructed.

According to the results of the stepwise regression procedure with the Mallow's Cp statistic as the selection criteria, photogrammetric stand density and a combination of the photogrammetric crown area with photogrammetric stand density were the best candidates for predicting stand volume. The stand volume model explained 56% of the variation. Photogrammetric stand density was found to be highly correlated to terrestric stand density with the resulting model explaining 81% of the variation. Photogrammetric crown diameter was found to be correlated with the diameter at breast height and the resulting model explained 43% of the variation. All models were validated using standardized residuals and the coefficient of determination.

Cost-efficiency assessment of double sampling with regression estimators showed a considerable reduction in inventory costs by up to 24% compared to a traditional forest inventory method in Hans Kanyinga Community Forest. Double sampling was found to be cost-efficient when the proportion of variability of the models was higher than 27%. The inventory concept showed potential in providing information required both at the higher and lower levels of forest management. The results of this study are valid for Kavango region or any other region with a similar set of physical and environmental conditions. Caution must be exercised in implementing these results elsewhere under different physical and environmental conditions. Follow up research is required.

Forest modelling from earth observation data in forestry plantations

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Optimised forest management requires a superior understanding and knowledge of forest science and extensive optimisation and decision support systems. However, knowledge and systems, without relevant and accurate input data will not provide optimised solutions and may even lead to making inferior decisions.

Data collection is expensive and the perceived benefits of good data have to be weighed against the cost. In order to mitigate this dilemma, whilst improving data quality and quantity, conventional data collection methods have to be executed more cost effectively, or one has to find alternative, more efficient ways of obtaining data. Remote sensing is being increasingly used in forest management with many positive benefits, but to date little success has been shown in obtaining tree biophysical data from Earth Observation (EO) sources suitable for supplementing or replacing more conventional field-based measurements.

The proposed service, which is based on the use of ALOS PALSAR data, consists of two main components:

- Generation of thematic and change maps;
- Inference of biophysical parameters such as tree height, DBH, basal area, and timber volume.

This work shows the application of Synthetic Aperture Radar (SAR) L-band imagery in such a way that clear relationships were established with field-based, geo-referenced plot level standing volume, average tree height, average DBH and basal area. The number of trees per plot could not be directly estimated from EO, but the TPH of the plot was mathematically derived from the basal area/DBH/TPH relationship. The coefficient of determination (R^2) is typically around 80% between plot parameters and the radar backscatter. Over the range of data available (up to 400 m3/ha bole volume) there is little evidence of saturation, although the relationship is non-linear and tending to an asymptote probably around 500 m^3/ha. This would correspond to the generally accepted limit for this technique of a saturation around 200 t/ha biomass (equivalent to 500 m^3/ha at timber specific gravity of 0.4, typical for softwoods), but this does not appear to be operationally limiting in the context of these sub-tropical softwood plantations. Moreover, by analysing multi-temporal data acquired every four months, it was possible to identify over the whole concession forest: cover changes (mainly logged compartments), the status of fire breaks, the effective forest area at compartment level, and heterogeneities within the compartments.

The EO derived biophysical relationships were extrapolated to all pixels within and averaged by compartment. Thus a comprehensive set of biophysical data was provided at compartment level, over large areas within a relatively short time frame. This data set was made available in a text format for importing into York's existing forest management system for further downstream processing.

The field data used to establish the above relationships was collected in two pine plantations of York Timbers in the Mpumalanga province of South Africa, using conventional forest inventory methods. Sampling covered a wide range of age-classes, silvicultural states, terrain, climate and altitude and was limited to the three main pine species prevalent in this area. The field data was processed through York's forest growth and yield system. Results indicated that the relationships are largely independent of region or species, but were strongly influenced by terrain, silviculture (thinning, pruning) and age. The EO obtained results for DBH and height are encouragingly good, so much so that supplanting the EO DBH measurement with field-measured DBH degraded the accuracy of the results. Using EO derived biophysical variables as inputs into standard volume equations showed the best results for standing volume estimation. This implies that at minimum only DBH, height and basal area need to be estimated from EO data in order to derive acceptably accurate volume estimates.

Several benefits, other than pure cost reduction, were identified. These benefits include the potential for all forest compartments to be mapped and measured simultaneously, and providing forest managers with a regional geospatial estimate of forest biophysical data and timber volumes. With this independent and repeatable source of biophysical data, there is also the potential for field inventory teams and resources to be more tactically utilized. For example, the intensity of field data sample plots can be increased prior to harvesting to further optimise harvest planning and mill utilisation. Finally, the transparency and independent nature of remote sensing data makes it an ideal source of geospatial forest inventory data for forest certification.

Overall, this project clearly demonstrated that SAR L-band images can be a viable tool in reducing costs, without compromising data quality, while increasing data transparency with potential improvements in efficiency in forest management.

Incorporating Fibre Attributes into Canadian Forest Inventories

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Canada's forests are highly diverse: at the national scale, eight distinct forest regions are recognized; and at regional and local scales, considerable diversity exists in species composition, stand history, site occupancy and site quality. For industries that rely on the forest as a source of raw material, this diversity is both a blessing and a curse. On the one hand, diversity in raw material supports the potential for a wide range of forest products. On the other hand, mills must often deal with highly variable fibre supplies, and high quality fibre may end up in low value products. There is growing recognition that, in order to increase forest sector competitiveness in Canada, the allocation of fibre supply to end product uses must be optimized.

Implementing forest sector value chain optimization requires that timber inventories include attributes that support the estimation of fibre value. Although there have been technological advances, the general approach to forest inventories in Canada has not changed significantly since the 1940s. Interpreters delineate stands from aerial photographs, and with the aid of ground-check plots, assign tree species composition, stand height, site quality, and site occupancy attributes to the stands. This information allows the coarse estimation of timber volume, but not of timber value. Additional attributes that define product potential, such as tree diameter, branchiness and fibre properties, must be incorporated into inventories to support the estimation of value.

The Canadian Wood Fibre Centre (CWFC), a division of FPInnovations, is leading research directed at adding fibre attributes to forest inventories. The CWFC is developing and implementing remote sensing technologies that provide more information about stand canopy and tree crown characteristics, and it is investigating relationships between these characteristics and wood fibre attributes. The remote sensing technologies include airborne LiDAR, high resolution digital photography, and algorithms for semi-automated interpretation of digital imagery.

Two general approaches are being used to estimate wood fibre attributes from remotely sensed data. At the stand level, statistical relationships are being developed between LiDAR point cloud variables and stand characteristics. These statistical relationships provide accurate estimates of stand top height, average height, basal area, quadratic mean diameter, gross total volume, and biomass, as well as the within-stand variability of these variables. Complete LiDAR coverage of a forest allows accurate stand estimates to be rapidly aggregated to entire forest management units (~1,000,000 ha scale), providing finer resolution inventory information and incorporating attributes that were not previously available. More detailed and higher resolution information on variables such as stand volume and quadratic mean diameter are particularly valuable at the operational level, and will support optimization of timber harvesting and transportation, using software such as FPInterface (developed by the Forest Engineering Research Institute of Canada division of FPInnovations).

At the individual tree level, semi-automated interpretation of aerial photographs is being used to carry out individual tree classification (ITC), with the goal of identifying tree species and crown dimensions. Automation of species identification and polygon delineation will make the production of current forest resource inventories more objective and efficient. Functional and structural relationships are being developed to link remotely sensed individual tree crown features with wood quality characteristics including tree diameter, branch diameter, sapwood width, and the distribution of ring area, specific gravity, and microfibril angle. For example, it is possible to estimate tree maximum branch diameter from crown width, tree height, and stand basal area with a root mean square error (RMSE) of about 0.3 cm. Initial analyses indicate that tree DBH can be estimated from these variables with RMSE of 2 to 3 cm. Coupling remotely sensed crown data with structural-functional relationships between crowns and fibre attributes is creating the foundation for a next-generation forest inventory that provides fibre attribute information at the individual tree level.

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Testing new methods to predict response to vegetation control using remotely sensed leaf area index in *Pinus taeda*

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Traditional methods (hardwood basal area, cover index) of quantifying competing vegetation were not well correlated with growth or vegetation control response in *Pinus taeda* in the southeastern United States. We hypothesized that nitrogen (N) uptake from killed competing vegetation could be used to predict vegetation control response.

We calculated competing vegetation N uptake from leaf area index (LAI), foliar nutrient concentration and specific leaf area and estimated vegetation control response. We measured competing vegetation LAI retrospectively. Pine leaf area increases little while deciduous vegetation leaf area increases rapidly from winter to early spring. Consequently, differences between spring and winter LAI values were predominately increases in competing vegetation leaf area. We calculated LAI in winter (leaf-off) and spring (leaf on) by applying the Flores *et al.* (2006) equation to Landsat TM imagery. We subtracted winter LAI values from spring LAI values to estimate deciduous competing vegetation LAI. Foliar nitrogen concentration and specific leaf area estimates for the primary competing vegetation species were from the literature (Jose & Gillespie 1997; Porter 1997; Mewborn 1997; Reich *et al.* 1999).

We used two methods to estimate pine growth response to vegetation control. In both, we estimated nitrogen available from competing vegetation as:

[1] NUSE (kg ha-1) = NCONC (%) ÷ SLA (cm2 g-1) * C * CVLAI,

where NUSE was the nitrogen used to produce competing vegetation foliage, NCONC was foliar N concentration, SLA was specific leaf area, C was a scaling constant and CVLAI was Landsat estimated competing vegetation LAI. Method 1 estimated eight year volume response to vegetation control based on the volume response function for fertilization in Fox *et al*. (2007). This function was adjusted by scaling the slope using estimated N uptake efficiency of 25% based on N15 uptake studies (Hangs *et al*. 2003; Blazier *et al*. 2006). Method 2 estimated annualized incremental vegetation control response, based on the volume growth per unit of nitrogen uptake response function from Albaugh *et al*. (2008). Additionally, for Method 2, we adjusted NUSE downward based on the proportion of competing vegetation killed by the vegetation control treatment.

The pre-treatment competing vegetation LAI ranged from 0.24 to 1.33. Primary competing vegetation species included *Liquidambar styraciflua*, *Liriodendron tulipifera*, *Acer rubrum*, and *Quercus spp*. with the corresponding estimated N use per unit of LAI of 14.5, 16.9, 10.5 and 15.8 kg elemental N use ha-1 yr-1. Method 1 reasonably estimated eight-year vegetation control response for two of four sites while Method 2 reasonably estimated at least one year of vegetation control response from six of nine sites (Figure 1).

The methods showed promise; however, response was poorly estimated in some cases, likely related to competing vegetation LAI estimation, and the availability of specific leaf area and nutrient concentration data for the competing species observed. The variation in competing vegetation LAI was, in part; due to use of imagery with partial cloud cover from outside the preferred measurement dates. Competing vegetation LAI estimates were only available pre-treatment. Method one only needed pre-treatment estimates. Method two could use subsequent competing vegetation LAI estimates but they were not available because treatment plots were smaller than the image pixels; preventing calculation of competing vegetation LAI in later years. Specific leaf area and foliar nutrient concentrations were from the literature and, consequently, not site specific. The nitrogen use estimate was only for the primary competing species, which represented 27-76% of the total competing vegetation.

Other methodological limitations include unknown nitrogen uptake from fertilizing and from eliminating competing vegetation. Method one assumed a 25% N uptake while Method two used an inherent variable N uptake to a maximum of 53%. Actual N uptake is unknown and likely varies across sites due to environmental conditions at application and time since application with greater uptake for longer assessment periods. We did not observe increases in vegetation control treatment foliar nitrogen concentrations suggesting that crop trees may not have readily acquired N from killed vegetation. Both methods assumed all N freed from the killed competing vegetation was immediately taken up by the crop trees. Improvements in matching competing vegetation to the time of interest, site specific foliar nutrient concentrations and specific leaf area for extant species, and a better understanding of the fate of nutrients no longer taken up by killed competing vegetation would improve estimates from both methods.

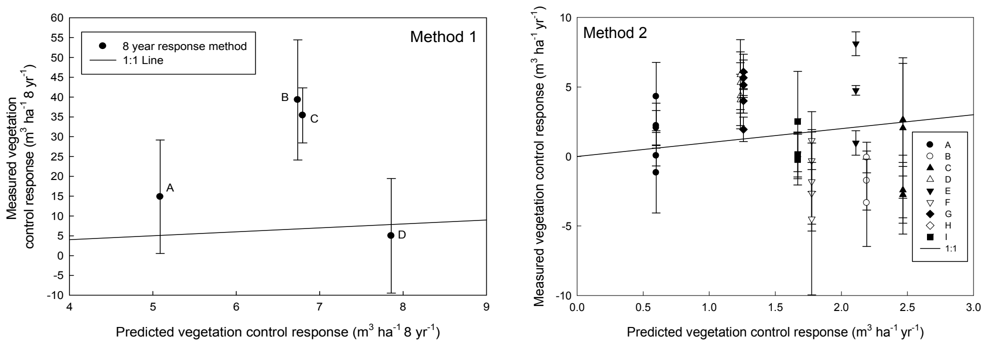

Figure 1: Predicted and measured volume growth response to vegetation control in *Pinus taeda* in the southeastern United States.

LiDAR for Operational Forestry – a Detailed Evaluation

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The potential for airborne LiDAR to significantly improve a wide range of forest mapping and inventory functions has been widely acknowledged. However, actual use of LiDAR by forestry organisations in Australia and New Zealand has been largely experimental, project-based, or small-scale. Most organisations do not have the necessary in-house skills and experience to evaluate, let alone operationalise, LiDAR technology.

Earlier studies by Forestry Tasmania have found that access to LiDAR data and LiDAR-derived products led to improved quality outcomes, but were rarely financially viable except in small, high value operations (Bennett 2005). It was proposed that it could be made feasible if a more holistic approach was taken to adoption of LiDAR-based technology, with integration into as many business processes as possible to obtain maximum value from acquisition. To this end Forestry Tasmania has just completed a LiDAR Feasibility Trial that investigated the technical and financial feasibility of applying LiDAR across its entire forest estate. LiDAR data was obtained over a 300 square kilometre study area of native forest and plantations, and used for a series of large-scale comparative trials in forest management applications ranging from harvesting to road engineering. These trials compared cost and quality of the outcomes with and without the assistance of LiDAR-derived products. Trial results were overwhelmingly positive, showing that LiDAR results in better, cheaper outcomes, and that its implementation is financially justifiable for Forestry Tasmania.

Some of the major findings from the trial were:

- Access to LiDAR derived products resulted in average reductions of 15% in the time taken to plan forest harvesting, with larger reductions for more difficult operations, and enabled planning staff to more efficiently identify site limitations and problems during the planning process, and resulted in better quality forest harvesting plans;
- LiDAR-based timber volume models provided substantially better estimates of total timber volume than existing inventory, with lower requirements for field measurement, resulting in substantially reduced costs. Additionally, LiDAR-based inventory provided information on timber distribution consistently at multiple resolutions, from sub-coupe through tactical to strategic level. This allowed for more efficient planning at all levels, and eliminated the disconnect between operational and strategic volume estimates;
- Effective integration across the whole business could make broad scale investment in LiDAR capture a financially feasible proposition that is cash positive in the short to medium term.

As a result of the Feasibility Trial, Forestry Tasmania is investing in LiDAR across the majority of its State forest, with approximately 700,000 hectares being captured in 2010, and a further 1.2 million ha planned for the next two years.

Method for estimating forest biomass potentials for Central Finland with biomass maps and GIS analysis

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Accurate and up-to-date biomass estimates are needed because of increased interest in the use of forests for bioenergy due to changing climate policies. The recent improvement of biomass models in Finland has opened up the possibility to estimate biomass resources accurately and to give more precise information about procurement costs. These estimates help bioenergy operators and politicians in planning courses of action. Our objective was to develop a method to estimate spatially explicit theoretical, technical, and economical biomass potential of forests.

The main idea of the method was to locate the final felling (FF) and the early thinning (TH) stands by segmenting satellite images, and to give estimates of the forest attributes for those stands using thematic maps. These raster maps were produced applying the k-NN method in combination with NFI data and satellite images from the study area. The biomass estimates for each NFI plot were modelled with advanced tree height and crown ratio models. These models take into account the variation of the tree size distributions and crown lengths of individual trees. The biomass estimates included aboveground and belowground biomass components. Both FF and TH stands were selected randomly so that the harvesting levels were equal to the maximum sustainable harvesting levels. The estimate of the fuel wood removal for FF stands was a sum of the stands logging residues and stumps. The fuel wood removal for TH stands was estimated with thinning models. For the estimation of biomass potentials national road and street network was laid on the stand map with the locations of the power and heat plants. This enabled the estimation of the plants procurement costs for the forest biomass. The resulting potentials were considered as theoretical, technical and economical with integration of different kind of technical and environmental constraints.

The results give distributions for different biomass components for each municipality. In addition, for each plant the procurement cost distributions for forest biomass are given.

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Session 4:

Equipment monitoring and management

User guide for the selection of onboard technology in Australian harvesting operations

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Management of harvesting operations using onboard technology has been highly developed overseas, particularly in Scandinavia, but is still relatively in its infancy in Australia. Overseas experience has identified productivity gains of over 30% in some areas and expectations of further significant gains. On the basis of this overseas experience, the CRC for Forestry Program three has examined the range of onboard technology available and commenced to identify and trial equipment across a variety of Australian forest harvesting conditions (natural eucalypt forest, blue gum and radiata pine plantations). Equipment is being trialled for 12 months to ensure the full range of operating conditions and to allow completion of a number of cycles of identification and implementation of operational improvements.

The main output of this project will be an interactive guide to match user's harvesting systems, stand and site characteristics and current issues with suitable onboard computing systems and methods. Associated guides will assist with implementation and data analysis.

A number of onboard computing systems, with the potential to be used to examine harvesting machine performance, were identified in an initial study. Three case studies are being established to trial the most promising of these onboard computing systems across a range of Australian forest harvesting systems and forest types. The case studies cover natural eucalypt forests and radiata pine plantations producing sawlogs and pulp logs, and blue gum plantations producing pulp logs only.

The natural forest harvesting system is located in the Central Highlands of Victoria and consists of a harvester with a felling grapple head, grapple skidder and two excavators with log grabs and cut-off saws. Tree lengths are skidded to a central landing for processing and haulage. The harvester and skidder each had a Multidat (FPInnovations, formerly FERIC) and Garmin 276C GPS installed (for display purposes). One of the excavators had a Multidat installed. Each Multidat had an internal GPS unit. The skidder had a high-precision GPS unit (SX1) whereas the other two machines had low precision GPS units (Garmin 15).

The radiata pine harvesting system is located in the south-east of South Australia and consists of a single grip harvester, two forwarders and an excavator used to load trucks. Trees are bucked at the stump and logs are forwarded to the roadside for haulage. The harvester had an existing Dasa 4 onboard computing system and one of the forwarders had a Dasa forwarder computer installed with the optional GeoInfo GIS/GPS. A Multidat has been installed in the excavator.

The blue gum plantation harvesting system is located in the south-west of Western Australia and consists of four single-grip harvesters, two forwarders and a roadside chipper. Tree lengths are forwarded to the roadside to be chipped directly into trucks. The onboard computing units had not been installed at the time of writing, as negotiations were ongoing with the new owners of the company. The intention is to install RouteHawk systems in a harvester, forwarder and chipper.

Machine performance data will be collected from each case study and transferred to the author at least once every two weeks for further analysis and reporting. Reports will be sent back to the participating organisations and will be discussed with equipment owners and operators to identify areas for improvement. Subsequent results will be used to estimate the magnitude of any change in performance. The findings of the trial will be used to create an onboard computing selection guide that will enable harvesting machine owners to select the most appropriate onboard computing system for their requirements.

The data to be collected will depend on the capabilities of each onboard computing system. All three studies will collect machine utilisation, delay length and GPS positional data. Other data that may be collected

- Production against productive time
- Fuel use against production
- Delay causes
- Idle time
- Utilisation separated into travel and work time

The GPS data is being used to examine machine performance such as the number of trips and average haul distance of the skidder and forwarders and also to examine the potential for using the GPS to warn machine operators of the proximity of a boundary. Marking coupe boundaries in natural forest is an expensive and potentially hazardous exercise. All three forest types also have “no go” areas within logging coupes such as hazards (steep areas, powerlines, etc), habitat areas or research trials.

The project is still in the establishment phase with only the natural forest onboard computing systems installed and producing results at the time of writing. The radiata pine onboard systems had been installed and were awaiting testing. The blue gum onboard systems were not installed at the time of writing.

Average utilisations (excluding delays) for the harvester, skidder and excavator in the natural forest case study were 47%, 56%, 70%, respectively. The low utilisation of the harvester and skidder compared with the excavator pointed to a bottleneck at the log landing. Further investigation showed that the excavator could spend almost half its time loading trucks, thus reducing the time it could spend processing tree lengths into sawlogs and pulp logs. A spare excavator, previously used in case of a breakdown of the main machines, will be used in future by truck drivers to load their own trucks. Truck drivers currently already load their trucks outside the harvesting crew’s working hours. The ramifications of this change to the haulage requirements are also being considered.

Common measures of skidder performance include number of trips and average haul distance. These measurements are usually made by on site observations though GPS (McDonald and Fulton 2005, Cordero *et al.* 2006). Processing of GPS data is often done using a semi-automated approach that has required manual delineation of the log landing. An automated approach was trialled with the natural forest case study data whereby turns of 180o ±30o were identified in the GPS data which were assumed to represent the end points of the skidder’s path. Estimates using this technique were within 10% of the results from manual processing of the GPS data. Major sources of error were the result of the skidder operator stockpiling logs in the coupe and working on or near the landing, for example, debarking stems. These activities should be reduced when the flow of logs increases through the landing.

In the natural forest case study, the low precision GPS used in the harvester lost accuracy under marginal conditions in gullies with errors over 20 metres whereas the high precision GPS in the skidder maintained its accuracy (errors mostly under 5 metres). The drawback of the high precision GPS is that it costs an additional CA$700. These preliminary results suggest it may be possible to use the GPS as an adjunct to normal coupe marking in steep areas, but at this stage it is unlikely to replace it. A related issue is the accuracy of the base mapping of roads and streams commonly used to define natural forest coupe boundaries. Errors have been detected in the past where roads and streams were not correctly marked on maps and hence coupes were incorrectly located in the forest.

Acknowledgements:

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Path tracking for autonomous forwarders in forest terrain

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Automation in the agriculture sector has been subject to intensive research for many years, resulting in several farming systems operating with various levels of autonomy. In comparison, automation in forestry is far behind agriculture. This is mainly due to the difficulties involved in navigating unstructured forest terrain, where operation paths are rarely straight or flat and obstacles are common. In forestry, the forces driving mechanisation and automation are a lack of workers, amounts of hard physical work involved, aspiration to conduct forestry operations year-round and for more hours per day and the desire to reduce costs and lead-times between logging and industrial processing (Sundberg 1978, Silversides 1997). Moreover, human performance can limit work efficiency. For instance, the technical potential is not fully used in many machine movements as humans have difficulties to precisely guide machines or machine parts at high speeds for long periods of time (Hellström *et al.* 2009, Pilarski *et al.* 2002).

We have evaluated a system designed to autonomously follow previously demonstrated paths in a forest environment, which is seen as a partial solution in the development of fully autonomous forwarders. The evaluated system consisted of a Valmet 830 forwarder equipped with a high-precision GPS system to measure the vehicle's heading and position. A gyro was used to compensate for the influence of the vehicle's roll and pitch. On a clear-cut forest area with numerous stumps and other obstacles, two different tracks where selected. One track was 74 m long and almost level. The other track was 85 m long with an almost circular shape that made the vehicle travel down, parallel, and up the main slope direction. The vehicle was able to follow the two tracks, four times each, with a mean path tracking error of 6 cm and 7 cm respectively. The error never exceeded 35 cm, and in 90% of the observations was less than 14 cm and 15 cm, respectively. This accuracy is well within the necessary tolerance for forestry operations. In fact, a human operator would probably have a hard time following the track more accurately. Hence, the developed systems function satisfactory when using previously demonstrated paths. To reduce soil damage, increase traction, and reduce fuel consumption it is important to reduce the amount of wheel slip. To determine the amount of wheel slip for different ground conditions a method using the difference between GPS and wheel velocities was developed. The resulting slip on asphalt and gravel ground was almost zero. On loose sand, slip values up to 80% was detected. The conclusion is that the proposed method can be used in future studies of wheel slip in forest terrain.

In the future we will challenge the studied system with additional conditions normally found in the forest work environment. In boreal forestry, machinery must be able to function under tree canopy, in slippery slopes, in snow and in temperatures far below 0°C. Moreover, it is essential to evaluate the system's performance when carrying out its actual work; to transport logs. With the basic functionality of system granted, vehicle load and its effect on vehicle dynamics will be evaluated. The ultimate aim of future studies would be to contribute in the development of a forwarder that is not dependent on initial operator guidance to find its path. For example, a path to pick up log piles with a forwarder can be automatically generated based on the harvester path and locations of the left piles. Regardless of how a suitable path is generated, a method like the one presented in this paper, it is still required to guide the vehicle along the wanted path.

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The accuracy of positioning forestry vehicles under canopy

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GPS systems are commonly used in forestry vehicles but the accuracy of these systems can vary greatly, especially in forests with dense canopy or on north facing slopes, where signals from satellites are unable to reach the receiver. Therefore, the accuracy of vehicle positioning is often within a range of several meters. But a high accuracy positioning system for forestry vehicles is essential for a number of purposes, such as:

- Navigation of forestry vehicles
- Documentation of the movements of forestry vehicles
- Supervision of forestry vehicles (e.g. certification, laws)
- Logistics (position of assortments, movements, optimization of movement)
- Science (automatic time studies)
- Forest management planning

The goal of these research projects is to develop, construct and build a good and practice-suitable system for tracking the position of forestry vehicles within a permanent accuracy range of less than 1 m. Maintaining a high precision position with dGNSS as a standalone technology in the forest is not possible. Therefore, a combination with other systems and the determination of the accuracy is necessary. To reach this goal some research projects have undertaken the following:

- Using odometry sensors to measure steering angle and wheel rotation in combination with an inertial sensor system to follow the vehicle position independently from satellite signals
- Adaption of a high precision local radar system (‘Symeo’) in the forest to reach the required accuracy
- Testing of different GNSS-Systems to measure the dynamic precision of a vehicle under canopies
- Determination of the GNSS-accuracy of a working harvester in comparison with precise terrestrial measurement

The results of these research projects will be shown in the presentation.

FPSuite: An Integrated Process Control Platform for Forestry Operations

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To meet the challenges of the current economic conditions, the forest industry must be able to adjust quickly to new market conditions with a very flexible supply chain. For example, accurate knowledge of how much wood is available at different phases of the forest operations is critical. In Canada, there has usually been a lag between execution of the operations and obtaining the information on what was done exactly because of factors like widely scattered operations, long distances and difficult communications. In recent years, FPInnovations has developed various precision forestry tools to improve this situation, including a set of tools called FPSuite.

FPSuite is a set of software and electronic tools forming an integrated process control platform for forestry operations. The four FPSuite modules aid in harvesting and transportation planning, scheduling, logistics, monitoring and optimization along the value chain, improving the efficiency and reducing the costs of forest operations:

- FPInterface, a GIS-based software tool, is used to simulate and plan operations at the tactical and operational levels. Working directly with forest maps, it contains modules to simulate and predict harvesting, transportation, road, silviculture and biomass supply costs. It can also be used to plan for customer (mill) demands, and prepare operational calendars. Additional modules have been developed to optimize harvesting and transportation schedule, to determine backhauling opportunities and to calculate the net value of products generated at the cut block level (difference between supply costs and expected products market value).
- FPDat is an electronic/software application used to collect operational data in forest equipment. A successor to the highly-successful MultiDAT also developed by FPInnovations, the FPDat can collect data on machine utilization, track machine displacement using GPS, and acquire data from the machine through electrical channels and links to the electronic engine. Specific machine configurations are being developed for various applications of FPDat.
- FPCom is the communication link of FPSuite, and two versions have been developed. FPCom Satellite is a modem used to transfer data between the field and the office based on the Iridium satellite network. This modem provides reliable two-way communications for situations without cellular coverage. FPCom Mobile uses short-range modems to collect data from machines to a computer installed in a light vehicle. This computer acts as the data carrier and cellular link is used to move data to or from the computer and the office or back to other machines.
- FPTrak is the integrated performance management and production reporting module of FPSuite. Using data collected by MultiDAT or FPDat units, as well as data coming from other sources (e.g. other machine computers, weigh scales, etc.), it provides the user with production summaries and key performance indicators. The reporting information can be accessed through a web platform by both operations managers and forest contractors. FPTrak can loop back actual performance into FPInterface’s planning module to enable re-adjustments to the planning or the schedules.

The four FPSuite modules can be used independently, in conjunction with other data streams, or all together in an inclusive process control platform. When used together, the modules of FPSuite allow for efficient monitoring of the operations and feedback to the planning phase, which in turn helps to accelerate reaction time to deviations or new customer demands.

The right tools, software and intelligent systems specifically adapted to conditions in forest operations, will help the forest industry to better manage the value chain. FPSuite is an attempt to build a comprehensive solution that covers all the elements of the forest supply chain. The benefits for managers of using FPSuite include improved control of all phases of forest operations, optimized net value from the forest resource and performance monitoring information supplied to managers and contractors in real-time.

FPInnovations is currently in the final phases of development and early stages of implementation of FPSuite on Canadian forest operations.

Side effect of strip road compaction

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The motor-manual technology of wood production is more often being replaced by fully mechanized technologies. The degree of mechanization is gradually increasing and timber harvesting and hauling machines process an ever-higher percentage of the annual cut in the Czech Republic. The timber logging and hauling machines are mainly farm tractors, harvesters and forwarders (wheeled, tracked and/or combined) in the Czech Republic. However, the use of these technologies entails soil damage hazards, too.

The compaction of soils closely relates to the formation of ruts that later develop into water-bars and initial places for the formation of erosion rills if the transport line is led improperly. The risk of water erosion also connects with sod stripping by skid timber or by the lower frames of machines. The risk of water erosion, after the previous sod stripping due to insufficient adhesion of skidding mechanism wheels, is clearly evident at a slope angle of 33%.

The impact of machine travel on soils (especially fine-textured ones) started to be studied some 20 years ago and the results of these studies are generally known. The employment of harvesters and forwarders entails a risk of soil disturbance namely on water-logged, clay soils in which the passing machines disturb the soil structure by compressing large pores. In general, the compression of pores unfavourably affects the soil structure, gas exchange and water movement in both horizontal and vertical directions. Uncontrolled soil erosion occurs on hill slopes. The machine affects the soil by its weight, i.e. by static pressure, but also by dynamic effects (impacts) that may be far more dangerous in terms of soil disturbance.

The goal of the work was to assess a possibility for using the portable falling weight deflectometer, penetrologger and permeameter for measuring the bearing capacity and compaction of strip roads.

The measurement was made by using a portable falling weight deflectometer Loadman II USB, an Eijkelkamp penetrometer (penetrologger) and a permeameter. The diameter of the reaction base plate was 132 mm and the calibration module of elasticity was chosen to be E 160 as advised by the manufacturer. The penetrometer was equipped by a cone type with 3.3 cm^2 cone base area and 60^o top angle. The penetration rate was ca. 2 cm per second. All measurement results were stored in the instrument's memory under different locality identifications.

The transport line was segmented and the measurements taken each 5 m starting from the centre of line towards both sides and ends in the stand. The sample plots were every 50 cm. Due to the time demanding measuring procedure, the measurement by the permeameter was made each 10 m segment on three plots i.e. in the centre of line and on the wheel tracks. The sample plot where the measurements were taken was subsequently subject to the soil sampling by means of physical Kopecky metal rings in order to detect the actual soil moisture content. Wet soil samples were weighed in laboratory conditions with the accuracy of grams and inserted into an oven where they were dried at a temperature of $103C^0$ (+/- $2C^0$) for 17 hours. Then the soil samples were weighed and the moisture contents of soils in the individual sites were calculated.

For comparison with standard conditions 20 plots randomly distributed in the stand were measured by penetrometer and deflectometer.

The common width of a strip road is 4 m in the Czech Republic. It was predicted that the highest compaction on strip roads was on the wheel tracks, however, the centre of the strip road was affected too, but with lower intensity. From the wheel track towards the edge of the strip road compaction slowly decreased. 50 cm from the edge of the strip road the compaction was still visible on each plot. One metre from the edge, compaction was visible only in cases when the wheel track was on the edge of the strip road.

From the measurement it is visible, that circa 1 m of soil on both sides of the strip road is still affected by machinery and is compacted. This definitely results in potential production losses. Fully mechanised technology requires strip roads every 20 m hence circa 15% of soil if affected. To ensure sustainable forest management, it is necessary to apply such systems which minimize strip road construction. If a strip road is constructed it is necessary to minimize the number of passes for assuring recoverability of soil.

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Wander factor for skid distance estimation in pine thinning

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Skidding production equations often require average skidding distance to estimate skidding production or cycle time. The distance usually applied is an estimation of a straight line average distance multiplied by a wander or winding factor to account for realistic travel routes or actual skidding distances. Straight line distances may be affected by slope and by other logging variables (e.g. skid trails, stream crossings and other natural obstacles, etc.) that may alter the skidder path during operations and result in longer distances. A skid distance wander factor is the ratio of the actual skidder travel distance to the straight line distance. These distances can be calculated with the use of precision technologies, more specifically Global Positioning System (GPS) and Geographic Information Systems (GIS), based on machinery positional data, logging productivity information, and stand mapping information. The objective of this study was to use skidder GPS positional data and GIS techniques to calculate a wander factor from long term production studies. The resulting wander factor may be applied to assess skidding productivity from estimations of the actual skidder travel distance.

This study was conducted using GPS data, mapping information, and harvesting productivity information of three logging crews performing thinning operations on pine plantations in Alabama. The crews were composed of one loader, one feller buncher, and one or two skidders. Data were collected from 24 harvest units of loblolly pine plantations totalling 256.6 ha. A harvest unit was the area harvested to one logging deck or landing. The GPS and the productivity data were collected using Multidat data loggers installed in the machines. The data loggers collected information on machine operating hours for all the machines and GPS data from the skidders and feller bunchers. The data set represented a total of 115 days of harvesting operations. Data were processed and analyzed using Excel spreadsheets, the Multidat Software, and ArcGIS Version 9.2.

The GPS data from the skidders were exported into point shape file format to be processed and analyzed in ArcMap. The GPS receivers collected a point every 4 meters travelled by the skidders. For most stands the original shape file of the area was provided by the landowner. For the remaining stands the shape files of the areas were digitized using Digital Ortho Quarter Quads (DOQQ). The GIS analyses conducted for each harvest unit consisted of 2 steps: calculation of the actual skidder travel distances using GPS positional data (total skidder travel distances in km/harvest unit); and estimation of the straight total skidder travel distances (km/harvest unit) using the Spatial Analyst Extension for ArcGIS.

The actual skidder travel distances were the sum of all the distances between GPS positional points (in UTM coordinates) in a harvest unit. Distance between points was calculated using Euclidean geometry. To estimate the straight total skidder travel distances the harvest unit shape files were converted to raster format so that each cell represented the area that supplied one skid load of wood. The number of raster cells per harvest unit equalled the total harvest volume divided by the estimated skid load size. Straight travel distance was estimated by assuming that the skidder would travel a straight round trip between each raster cell and the centre of the logging deck. The Spatial Analyst distance calculator calculated the straight line distance from every cell to the centre of the deck. The Zonal Statistics tool on the Spatial Analyst Extension calculated the minimum, maximum, average, and total straight distance. The straight skidder distance travelled during the harvesting was equal to twice the calculated total straight distance (round trip distance). The wander factor (w) was calculated as the ratio of actual skidder travel distance and the straight distance (w = actual/straight).

An average harvest unit had an area of 10.7 ha and 946 tonnes of wood removed (88.4 tonnes/ha). Skidder mean productivity was 32 tonnes per productive machine hour (PMH) and overall utilization rate (UR) was approximately 53%. The straight distances were on average shorter than actual skidder travel distances (12.94 km/ha and 15.64 km/ha, respectively). The average wander factor for the harvest units ranged from 0.70 to 2.11 and averaged 1.22 (SE = 0.0655). The average wander factor was used to adjust the straight distances to reflect the actual skidder travel distance. When the average wander factor was applied to the harvest data, the ratio of actual travel to estimated distances ranged from 0.55 to 2.81 and estimated distances were on average 15% shorter than actual distances.

Variability in the wander factor was not highly correlated to other harvest unit variables, but could be expected due to harvest geometry, harvest planning, and operator efficiency. Sources of error in the estimated wander factor were skidder travel distance for non skidding functions (e.g. landing clearing) and the skidder production assumptions (e.g. uniform volume removal and average skid load size) made to calculate the straight line distance.

Reduction in unloaded log transport mileage using route optimization

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Coordinated log transport is becoming more common in the US Southeast, replacing the individual logger-controlled approach that has been in place for many decades. As coordination of log transport increases, the application of optimization techniques to lower delivered wood costs becomes more feasible and more attractive. A practical impediment to the adoption of optimized truck scheduling, however, has been the lack of demonstrable savings to offset the additional cost and complexity of implementing an optimization scheme. In this study, we compared optimal routing solutions generated using a transport model previously developed to actual route schedules observed for a single log transport company. The objective of the study was to determine if an optimized routing schedule could reduce unloaded mileage beyond the savings already achieved using the coordinated transport system, and be feasible in the sense that the calculated shortest route would have a high likelihood of delivering all loads on any given day.

Routing information was collected for a 6-day workweek of a log delivery firm operating in the state of Alabama. The company delivered 257 loads from 5 logging operations to 9 wood consuming mills over the week. They coordinated their trucking through a dispatcher but did not use any type of optimization in assigning routes. Trucks typically began and ended their day at a central dispatch yard, but sometimes ended the day loaded. In those cases the trucks usually ended the day at some other location, presumably home, and delivered the load first thing the next morning.

A routing schedule to deliver the same set of loads was generated for each day using a combinatorial model of total delivery mileage that was minimized subject to numerous constraints that set the behaviour of the system (e.g., a load moved from a logger to a mill, and not vice versa, and total delivery time for each truck was limited). The optimal schedule was generated using a simulated annealing approach that employed a simulator of the entire delivery system to compare alternative solutions.

Two forms of the delivery model were optimized, the first looking strictly at intraday movements of the trucks and ignoring what happened at the beginning or end of the shift. In sending some trucks home loaded at the end of the day, the human dispatcher was taking advantage of additional information to schedule across days and, presumably, to reduce total delivery mileage. This extra information was not available in generating the optimal solution. In order to make the comparison between the two approaches on an equal footing, it was decided to ignore this aspect of the actual trucking operation and compare movements within the day only. A second form of the routing model was also used that constrained the final route segment of some trucks to arrive at a specific logger. This form was used to represent those trucks ending the day loaded and was also compared to the actual delivery system.

The basis of comparison between the two delivery schedules was predicated on two hypotheses concerning the form of an `optimal' solution to the routing problem. First, it was presumed that a feasible schedule minimizing total mileage would tend to reuse a small set of relatively short routes among multiple trucks. Second, it was presumed these short routes would ordinarily serve multiple logging operations.

Total unloaded intraday mileage for the actual trucking operation averaged 1537 km, resulting in a 57% utilization (loaded mileage) rate. The optimal routes, on the other hand, averaged 1024 km daily unloaded for a 66% utilization rate. Optimal routes tended to be more uniform in length, with an average standard deviation between trucks of 69 km versus 90 km for the actual delivery system. Optimal routes also tended to deliver loads from multiple loggers on any given day. Trucks delivered loads from a single logger 75% of the time in the actual system, compared to 2 or more in 70% of routes for the optimal system. The distribution of number of route segments (a segment being one logger-mill trip combination) was fairly uniform in the range of 3 to 9 for the actual delivery system. For optimal routing the number tended to be concentrated at 6 or 7 segments per day per truck, indicating that the routes were more uniform in length. When including end-of-shift operations, the daily utilization rate dropped by about 4% in both systems.

Results appeared to confirm that adding route optimization would decrease total mileage and increase utilization of trucks over the current dispatch system employed by the trucking firm in this study. In fuel alone, it was estimated that these efficiency increases could save as much as $45K USD annually. The optimal route generation system does not, however, include timing information explicitly in the solution method and the feasibility of the schedules has not been confirmed in practice.

An electronic device to map tree seedling locations while hand planting

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A central tenet of site-specific, or precision, management in agriculture has been that variability among individual plants is expressed at spatial scales finer than the field and that understanding the variability can improve decision making about resource inputs. This same understanding may or may not translate to the practice of forestry. The finest scale at which an agricultural field can be managed corresponds to the level of a single tree in a forested stand and it is unclear if tending stands as a population of individuals would be either feasible or worth the effort. Nevertheless, it is an interesting technological problem to consider if trees can be identified and monitored individually over time.

A very practical constraint on management of individual trees would be the effort required to gather information on them. To help overcome this problem, a device was developed to map trees as they were planted. In the US South, intensive forest management typically involves contracted regeneration crews hand-planting bare root pine seedlings using dibbles or hoedads. The planting data collection device, known as the 'Smart Dibble' (SD) provided two benefits for site-specific management: a method to identify and map individual stems with little additional effort or cost, and a means of documenting the work of a tree planting crew. A study has been conducted to evaluate the spatial accuracy of the device in mapping seedlings and to determine its practicality in monitoring the efforts of planting crew workers.

The tree-planting monitor used an accelerometer to detect motions of the planter's dibble. The accelerometer electronics were housed in a small cylinder bolted to the dibble shaft and included a wireless communication link to relay data to a recording device carried by the worker. The recording device filtered acceleration data from the dibble and logged the highest observation during each 1-second interval. Also, at 1-second intervals the device stored the location of the worker based on Global Positioning System (GPS) readings.

An experiment was conducted in which four workers from a planting crew were sequentially outfitted with the device and told to complete planting of all seedlings they were carrying, from 400 to 800 trees. When finished, data from the recording device were downloaded to a host computer. The data points (easting, northing, acceleration) were filtered first to determine which points corresponded to impacts of the dibble with the ground (basically those with relatively high acceleration), and these points were further reduced to a sequence of locations each one of which represented the position of a single seedling. The estimated seedling locations were compared to a true position established for the seedling using a Real-Time Kinematic (RTK) GPS.

Results showed the device was capable of detecting the number of seedlings planted within 2.5% in 3 out of four tests, and within 7% in the fourth. Accuracy of the seedling locations was comparable to, but greater than, that of the GPS itself - about 4.5 m average deviation in estimated versus true position. Several sources of error in position were identified. For example, tree locations were established based on GPS location, which was mounted on the shoulder of the worker. As they planted, the workers tended to stand to one side of the beds, introducing a fairly consistent bias. Another main source involved errors in the assignment of dibble impacts to specific trees. A final seedling location was calculated from the average position of the multiple dibble impacts required to plant a single tree. Associating an impact with the wrong tree tended to bias the final tree location. Another source of error was missed or extraneous dibble impacts. The ground in which the seedlings were planted was quite soft and the threshold for which an acceleration value was deemed an impact with the ground was necessarily relatively low. There were instances in which a legitimate dibble ground impact was missed because the ground was too soft to register a change in acceleration, and there were instances in which an impact was detected but not one for which there was planting activity. These tended to happen when the workers walked between trees and used the dibble to steady themselves.

The SD system could also be used to monitor time productivity of the workers. Comparison of videotaped estimates of planting rate to those calculated from the dibble data were complicated by sampling strategy. It was impossible to match an individual planting event in the video and SD data sets, so intervals of 30 events were sampled from the complete data sets and compared. For some intervals and some workers, there was no significant difference between the video and SD mean planting times. In other cases, the differences were significant (by about 30% to 40%). The cause of these differences was not clear, but when entire data sets (video and SD) were compared, mean planting times were statistically the same. This implied that some characteristic of the activity during the sampling intervals had varied, perhaps because of ground condition. It was surmised that differences in estimates of planting rates were more sensitive to working and operator conditions and that the SD method could, if properly applied, provide accurate measurements of worker productivity, at least over a long enough period of time.

Profor: the development of an Integrated Equipment Management System (IEMS)

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In the recent decades, mechanisation has brought a substantial propagation of self-propelled forest machines like harvesters, forwarders, loaders etc. Therefore, forestry following the principle of sustainability has to consider the risk of negative effects to the soil caused by such heavy machinery.

The ProFor planning software helps match forest machines to sites in such a way that critical soil damage, which may be caused by passing over forest soil, can be avoided. A given machine configuration is determined by the tyre setup, including its inflation pressure, the machine weight and the payload.

Modern forwarders offer the option to adjust and control the pay load precisely through electronic scales (E-scales). In addition, central tyre inflation control systems (CTI systems) give further flexibility for ideal fine adjustment. As the load carrying capacity of a tyre is depending of its inflation pressure an integrated approach to control both variables – pay load and inflation pressure – makes it possible to really operate the machine under optimum conditions: which is the maximum payload with the ideally matched minimum inflation pressure for the given site condition. The software which is procuring this service needs to run on an on-board computer with life hardware links to both the CTI system and the E-scales. After matching the site conditions with the machine configuration, the computed ideal inflation pressure gets adjusted and the operation can start. The E-scales will then monitor the loading cycles and ensure that neither tyre critical nor soil damaging overloading will occur.

Furthermore, it should be mentioned that a data logging option gives the opportunity to monitor and evaluate the operation. Contractors and forest owners thus can proof correct, sustainable machine operations, which are not violating sustainability conditions concerning soil aspects. Under the aspect of growing general awareness of sustainability this may become an important further facet for keeping the standards in the chain of custody.

Finally, this integrated equipment management approach offers even more benefits next to the mentioned soil and tyre gentle operation. Combined with other linked devices a like a GPS or a speedometer, several further applications become feasible which will ensure ideally tuned machine operations.

Session 5:

Supply chain optimisation

Reducing transportation costs through the application of performance based standard and hybrid technology, and optimal truck scheduling systems

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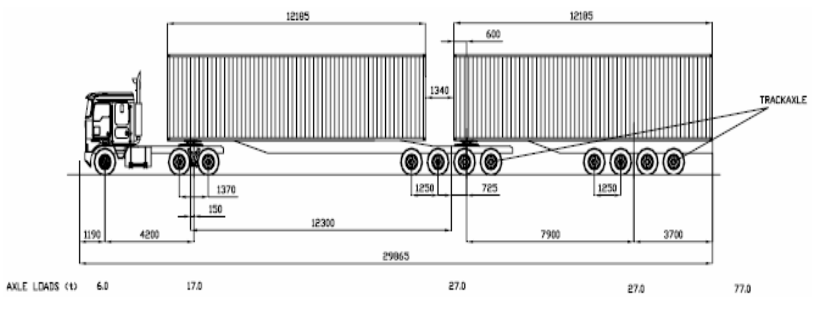
Transportation is an important cost, representing about 15% of the total wood value. One of the greatest opportunities to reduce transport cost is through technologies to reduce fuel costs and increase payload, where every kilogram increase in payload saves $5 to $10 per year and also decreases fuel use and carbon emissions from a fixed freight task by 3% to 5% for every tonne increase in payload. Also, given that trucks are expensive and operational costs are high, it is important to organise log and chip transport efficiently so the trucks are not standing idle or travelling unloaded any more than necessary.

The CRC Forestry Harvesting and Operations program in Australia is working to improve truck payloads and reduce fuel costs within current best practices and with the application of Performance Based Standard (PBS) and diesel/electric hybrid technology. Also, to improve dispatching decisions and better organise forestry fleets for log and chip facilities, a truck scheduling system called FastTRUCK has been developed. Savings well over 15% are expected to be obtained by the implementation of these technologies and decision support systems.

Performance-Base Standards (PBS):

In 2007, the National Transportation Council (NTC) put forward the framework to allow the introduction of new configuration to the Australian transportation landscape through the use of performance based standards (PBS). PBS opportunities made the introduction of vehicles capable of transporting higher loads without compromising the safety or the public infrastructure possible.

The forest industry is exploring three new PBS configurations for access to routes currently limited to semi-trailers and/or B-doubles. One of the configurations is a quad B-double configuration with level 2 route access that would have a per tonne cost 18% lower than the current B-doubles with the 30% increase in payload. The other two configurations are based on new trailer designs using steerable wheel technology; an 18.75 m configuration with 1 route access and a 26m configuration with level 2 route access. The combination of these configurations reduces costs up to 27.7% and fuel savings to 22.2%.

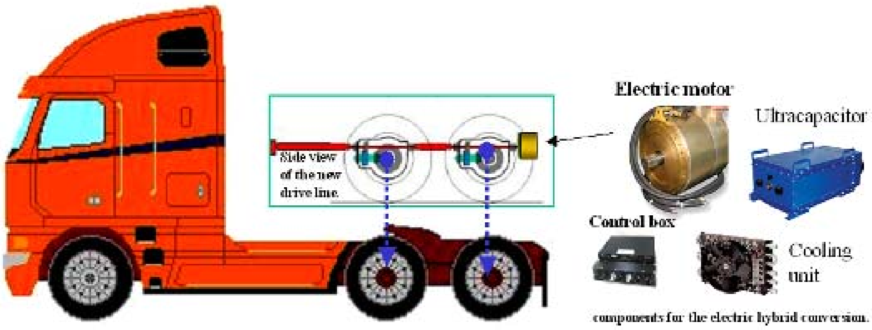


Hybrid technology:

In the face of global warming and increased fuel costs, efforts to reduce fuel use in all operations are of interest. One emerging technology that appears to offer great opportunity in this area for heavy vehicles working in a start-stop application is diesel/electric hybrids with regenerative braking capabilities.

A unique hybrid solution has come up in Australia that offers most of the benefits of other hybrid solutions but can be implemented at a much lower cost by converting existing diesel vehicles. In looking at the forest industry there are three applications that show promise in using the new hybrid technology including normal haul trucks, forwarders/skidders and shunt vehicles.

In the case of the shunt trucks, it is a true stop-start application that could stand to gain significant fuel efficiency form hybrid technology. The diesel truck has been fitted with a supplementary electric motor at the front axle, which will power the vehicle at times of extra load – such as at start-up or going up hills – improving vehicle efficiency. Tests on the prototype are expected to show cost and greenhouse gas emission reductions of 10 – 25 percent. Shunt trucks each use more than 80,000 litres of diesel per year at a cost of more than $112,000. A conservative reduction in fuel use of 10 per cent due to the hybrid technology would equate to at least $11,200 and 21,600 kg carbon dioxide saved.



FastTRUCK – a computer-based truck scheduling system for the Australian forest industry

Just a few companies in Australia use manual or computerised systems to schedule and dispatch trucks. Decisions are made by experienced dispatchers based on log stock information provided by loader drivers, orders from customers, and knowledge and experience of the transport operation. Dispatching is a very stressful job as order information changes constantly throughout the day, and the dispatcher must make instant decisions which often turn out to be sub-optimal.

To facilitate the decision making process during dispatching and to help forestry transport managers organise their fleets and plan log and chip facilities, a truck scheduling system called FastTRUCK has been developed for the Australian industry by CRC Forestry. FastTRUCK is a Windows-based logistic system that creates the schedules by a simulation and a metaheuristic (simulated annealing) process aiming at minimising the number trucks required and the waiting times at origins and destinations. The second version of this decision support system is now being tested by several Australian companies and an extended version is planned based on industry feedback.

Piloting wood tracking system in Ghana

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The Government of Ghana and the European Union initialled and ratified the first ever Voluntary Partnership Agreement (VPA) in 2008 and 2009, respectively. The VPA which forms part of the EU Forest Law Enforcement, Governance and Trade (FLEGT) action plan aim at ensuring that all wood products from Ghana entering into the EU market are verified legal wood that have respected material sourcing and minimum compliance requirements under the forest laws of Ghana.

One of the key Chain of Custody requirements under the VPA is the establishment of an electronic-based wood tracking system (WTS) to improve upon the existing paper-based WTS by the end of 2010. Consequently, the Forestry Commission (FC) of Ghana acting under Ministry of Lands & Natural Resources has contracted HELVETA Ltd. of UK to develop an electronic-based WTS to be deployed by FC. The WTS will operate on HELVETA's CI World software platform and use hardware components such as handheld computers and tagging devices (barcodes) for data capture and transmission to a central database where data reconciliation, validation and other information will be managed.

Timber and associated financial flows to be monitored and tracked starts from the source of timber until export control or domestic market sale point. The main flow types identified are Timber Utilization Contract (TUC) flow, other timber sources flow, timber transport and processing. In the WTS pilot phase, the TUC timber flow from national forest reserves in Ashanti and Western regions, and also involving four companies will be tested. Functional specification prepared for the pilot phase and experiences from field testing of the WTS scheduled for December 7-18, 2009 will be shared at the symposium.

Ghana's WTS is expected to improve upon the regulatory control and governance in the forestry sector by reducing illegal logging and maximizing revenue capture in the forest business process.

Optimal allocation of the forest resource to match raw material with industry needs

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The development of forest utilization concepts relies on modern techniques which are spatially precise and actual, considering both the forest structures and the industrial demands. The proposed paper will provide an approach for a product specific allocation of round wood and the following logistics concerning harvesting and transportation. It will discuss the design and layout of the Forest Warehouse, a GIS-supported management and decision support system, which will help to identify and specify forest stands considering the requirements and demands of wood processing. The cutting volume, timing of intervention and harvesting method should be aligned to the requirements and demands of the industry in the sense of a “Forest Warehouse.”

The Forest Warehouse is the interface between the forest resource with its natural diversity and heterogeneity and the uniform product lines in the wood industry and allows providing a product oriented round wood supply to the wood industry. Besides the quantitative supply with the required raw material, precise information about the wood properties is essential for an optimal product and production design. The concept of this “Forest Warehouse” allows the assessment of cutting volumes and the corresponding wood quality with respect to the stand conditions.

The objectives are the development of concepts and instruments for accomplishing a product-specific allocation of round wood. This includes logistical issues and aspects like the selection of suitable harvesting methods and systems stack management or routing. The added value for the forest owner and for the wood industry can be increased. Data basis are customer specific requirements concerning wood properties, the forest management planning data, the forest enterprise inventory data and spatial information (GIS data, DTM, DSM). Furthermore, these data are used to select suitable harvesting methods and systems depending on site, terrain and soil conditions. In addition, concepts and IT-tools like laser scanning, routing or stack management are involved for gathering more precise information on forest stand level and for optimizing the supply chain management to ensure a just-in-time delivery of round wood to the wood industry.

For an optimized design of the wood supply chain, the Forest Warehouse requires a database that contains a concise description of the stands regarding the overall composition of tree species and of those to be harvested, the wood quality, the existing grade composition and the quantity. Here, laser scanning technology leads to an improvement in the description of quality and grades. The results of the combination of two different inventories are entered in the database: the precise evaluations of the sample plots from operational inventory but without exact geographic reference on the one hand and the estimates of forest management with exact spatial reference on the other. The geographic location of the stands is stored in a GIS as a polygon.

In the planning phase of the supply chain, the harvestable stands are being compared with actual customer needs. The necessary movements of the harvesting machines can be minimized through cluster algorithms in spatial networks and the operational harvesting of timber can be managed more efficiently and more cost-effectively through the analysis of these spatial networks. Furthermore, the optimized sequence of the harvest operations in different groups relates to the common travelling salesman problem. An optimal routing on the forest road network is the basis for these calculations and the subsequent transportation of the timber to the customer. The forest roads are therefore stored in a hierarchical network in GIS together with the public road network.

By receiving round wood with wood properties matching the particular product lines, the wood industry will profit by minimized quality failings, sorting procedures, culls and breakdowns. The forest enterprises will improve their effectiveness and efficiency and increase their net profits.

Think outside the box – new approaches to optimise forest fuel supply chains

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Increasing cost effectiveness and thus lowering costs of forest fuel procurement is a key issue in the research of forest fuel supply chains given that there is a substantial gap between technically harvestable and economically available forest fuel potential. In order to address this challenge a holistic approach is required, taking all parts of the supply chain into account. Up to now, research in the field of bioenergy related forest technology was mainly focused on assessment of new machinery and, due to their importance for the overall procurement costs, different transport and logistic chains. What has not been taken into consideration so far are high labour costs caused by inefficiently structured work organisation.

The aim of this study was to investigate the structure of existing supply chains and to examine their shortcomings. Furthermore, the supply chains were optimised using methodologies and tools commonly used in modern business management but that have not found their way into the research of the forest energy business. The objective is to utilize the synergy potential within the supply chain; namely to improve the interplay of the partners and communication and data exchange. Furthermore, the administrative and non-productive work phases shall be minimized.

In a first step, an IT supply chain management tool was examined in order to determine if its use is beneficial in terms of the economics and overall efficiency of the supply chain. The conducted cost benefit analysis showed substantial savings. In the investigated Finnish forest owners association the net present value of the system was 156 763 € at an interest rate of 4% over a time span of 10 years and an annual turn over of 150 000 loose m3.

The second step of the study aimed to determine what processes actually make up a forest fuel supply chain by using process mapping methodology. For the mapping, four different supply chains in different countries are investigated. The first case was a medium scale supply chain in the East of Finland. The mapping revealed an overall number of 110 processes and 29 data sets and documents which are exchanged between 6 functional units of the supply chain. Several bottlenecks and weak points were discovered, which seem to be costly but could be eliminated easily by rather simple changes in the work organisation.

During the data collection for mapping it appeared that most of the workers involved in the supply chain were not aware of what processes actually make up their job. Thus, they are also not aware how their work depends on other members of the supply chain and how those depend on them. Lacking this knowledge, it is almost impossible to optimise work organisation towards more efficiency on the supply chain scale. The process maps made in this study can be used to create the necessary awareness and as basis for rethinking the existing work organisation in order to find more efficient, less time consuming ways to perform work.

Currently the process mapping of a Scottish small scale supply chain is in progress. So far 81 processes and 11 data sets exchanged between 7 functional units were identified but it is expected that more will be added as the examination continues. Substantial structural differences between the Finnish and the Scottish case became visible mainly because of different raw material sources making the material acquisition more complex in Scotland. Mapping of further supply chains is planned for medium scale supply chains in Germany and Canada.

Reducing pulp mill wood variation by including wood properties in harvest scheduling decision-making

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Pulp mills aim to make pulp and paper products with uniform characteristics. To do this, they could adjust processes to produce a more uniform output, or they could adjust the input (i.e. wood). If wood with more uniform properties enters a mill's process, the processing will be easier, processing costs will be reduced, and the product will be more uniform. However, wood is a variable resource and its properties vary with; *inter alia*, age, species, and the site index and altitude of where the stand is grown. This means that a stand of trees may be highly suitable for a certain process and end-product, and unsuitable for another. For mill operations which produce a particular end-product, it would be ideal to allocate the most appropriate wood to the product and to ensure that wood property variation over time is reduced.

This paper first reviews studies which aimed to reduce the variability of the wood entering a pulp mill by sorting logs based on their properties, with an emphasis on plantation forestry. In all of the sorting studies, the harvesting decision had already been taken, and it was found that wood properties needed to be considered when deciding which stand to harvest, and to which process it should be allocated. Forest harvest scheduling systems and timber allocation systems were then reviewed to ascertain if wood properties had been included in the harvesting decision. Only short-term timber allocation systems were found. The impact of allocating timber to different processes is then discussed.

Studies which assess the impact of log sorting based on wood property, process and end-product variation were reviewed. Ten such studies where found, which were reported in the literature between 1994 and 2007. They analysed the effect of sorting on various species in New Zealand, Sweden, South Africa, Europe, Australia, Canada and Brazil. In all of the studies, timber was sorted after the harvesting decision had been made, and the sorting reduced the variability of the wood. In one of the studies, the anatomical wood properties of *Pinus patula*, which was grown in plantations of KwaZulu-Natal, South Africa, were assessed and predictive wood property models created. The fibre collapsibility of the wood (a function of the fibre's cell wall thickness and cell diameter) was deemed to be the most important property for the pulp mill's two processes (thermo-mechanical and stone groundwood processes). A field study was then undertaken to grade the wood according to fibre collapsibility, with high and low collapsibility wood being processed in different processes. As a result, the process and product variability was reduced in each process. In a follow-up study, the stands destined to be harvested in the tactical timeframe were analysed each year, for six years. The fibre collapsibility model was applied to each stand's wood and based on the process's volume requirements and the wood's fibre collapsibility the wood was allocated to the two processes. This model reduced the variation of fibre collapsibility of the wood which was to enter each process for each year. However, the average fibre collapsibility for each process varied from year to year, implying that if a more consistent raw material is to be supplied to the pulp mill, wood properties need to be included in the harvesting decisions and harvesting decisions need to be made over the long-term.

A literature search then reviewed forest harvest scheduling and timber allocation systems which could be used in plantation forestry applications. Over 25 such systems were reviewed, but no systems were found which made harvesting decisions based on wood properties. However, several timber allocation systems were found which included wood properties. These systems were designed for use at an operational (short-term) planning horizon. Some of these systems included transport distances and costs; this is important to be able to assess the cost of supplying what the mill needs.

As a long-term forest harvest scheduling system including wood properties was not found, one has been specified. This system also takes into account the transportation distances and costs. In the analysis phase of the system specification process, the forest-to-mill supply chain was analysed to see how segregating timber in plantation compartments would impact on operations. Timber would have to be kept separate during transportation and in storage (depot/siding and mill yard). In order to ensure a consistent supply of wood to a pulp mill, wood properties need to be included in the harvesting and wood allocation decisions over the long-term.

A GIS-based model for evaluating supply chains of forest biomass for energy

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The increasing use of bioenergy has resulted in a growing demand for long-distance transportation of energy wood. For both biofuels and traditional forest products, the importance of energy efficiency and rail use is growing. A GIS-based model for energy wood supply chains was created and used to simulate the costs for several supply chains in a study area in eastern Finland. The model integrates supply-site-specific cost calculation of the different work phases of harvesting with a network analysis. Forest data, transportation networks and end-use-facilities are needed in GIS as input data. Cost curves of ten supply chains for logging residues and full trees based on roadside, terminal and end-use-facility chipping were analyzed. Railway transportation was compared to the most commonly used truck transportation options in long-distance transport. Additionally, for a selected combined heat and power plant, a map indicating the optimal supply chains within a province was created.

Raw material supply for sustainable pellet production in Europe

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Wood pellets have become an important fuel in heat and power production across Europe. The largest benefits associated with pellets are their high energy content and compact size, which are advantages in storing and transportation compared to other wood fuels. This paper is highlighting some current developments in pellet markets and innovative solutions to secure future pellet supply particularly in peripheral areas.

Pellets have become popular in many countries, especially in Europe, where the pellet market has become a large business. The pellet market and supply structures are currently undergoing rapid development. In some countries, the supply side is even growing faster than the domestic use, while others need to import pellets to satisfy the growing demand.

In the case of pellets, the quality of the raw material has a large effect on the properties of the final product. Today, the main raw materials used are by-products from the wood industry such as cutter chips and sawdust. At the moment these resources are utilized so efficiently that alternative raw materials are needed in order for pellet production to keep on growing. In the future, the potential development of pellet production will be determined by the availability of raw materials.

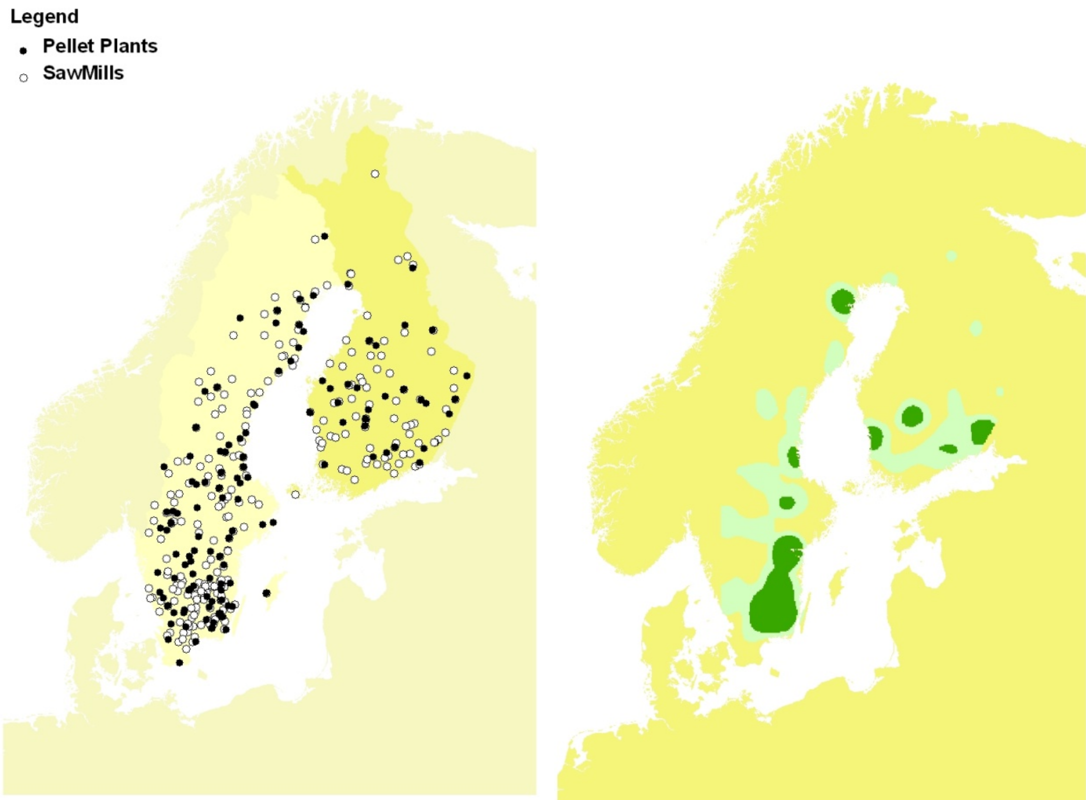

Figure 1: Location of sawmills and pellet plants in Sweden and Finland (2007). Darker areas show the largest difference between the aggregated sawmill and pellet production capacity, and thus the highest potential from the point of view of the raw material supply. (Mola-Yudego 2009)

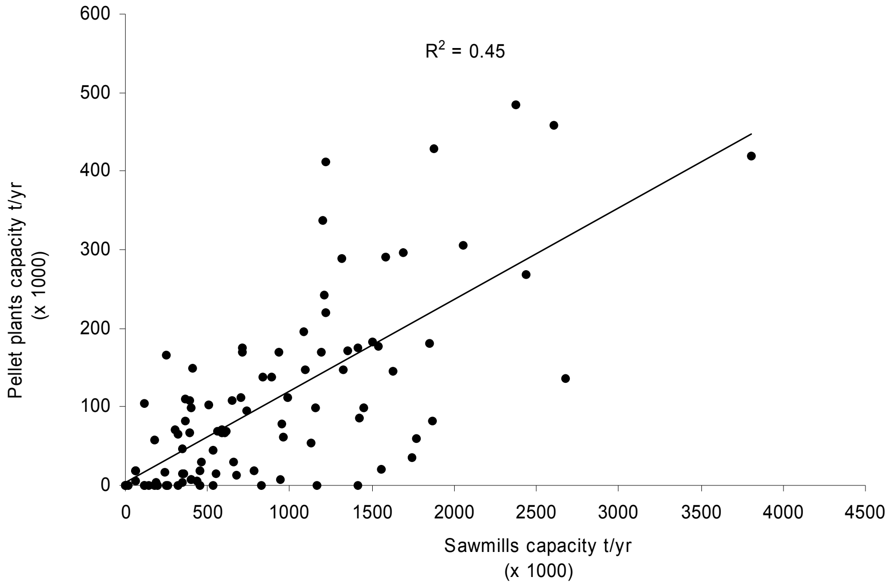

Figure 2: Correlation between aggregated sawmill and pellet plant capacity using a systematic grid and a radius of 80 km in Sweden and Finland. (Mola-Yudego 2009)

This paper studied the existing pellet production and supply structures in different Nordic countries. Furthermore, spatial analysis of existing pellet plants and raw material sources in Finland and Sweden using GIS systems are a major outcome of this study. Finally, new logistical solutions have also been identified and analyzed. When using alternative raw materials and supply structures, these tools are essential to identify new pellet market areas that can be developed further in the future.

Modelling traceability in the wood supply chain – does it pay?

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This paper builds on findings from the recently finalised work package 3.9 of the EU Indisputable Key project. Three institutes cooperated in developing intricate models spanning from the standing tree to the dispatch yard of a Swedish window manufacturer. Numerous timber properties were assigned to RFID tags, applied to the log at felling by a specially adapted harvester head. Logs were allocated to each of seven sawmills according to their timber properties using an LP based optimisation procedure. Simulation was then used to compare the fate of traced timber throughout the production lines of one of the sawmills and its downstream manufacturers.
Some of the parameters that can be estimated at varying degrees of accuracy during a pre-harvest inventory include:

- Theoretical assortment yield to log classes and dimensions
- Internode length (distance between branch whorls)
- Log cracking potential
- Log twisting potential (spirality)

During the actual felling and processing of the tree (i.e. felling, delimbing and bucking) it is further possible to provide information on:

- The top diameter of the log (automatically captured from harvester head)
- The length of the log (automatically captured from harvester head)
- Species – usually spruce vs. pine
- The heartwood content of the log (visually estimated by the operator)
- Allocation to general quality categories (on the basis of rot or discolouration, excessive taper, sweep or knottiness, physical damage).

The costs of gathering information, marking the logs and monitoring or utilising the data were assessed against the benefit of accruing the information at each stage of the chain. Through a number of repetitions, the principal elements contributing to value added were identified for individual segments and for the overall chain. Separating the allocation problem from the process model (simulation) provided an opportunity to analyse the effect of sub-optimal roundwood deliveries on downstream processing, the level of value-adding, and the potential to pass gains upstream to the harvesting entrepreneur or forest owner.

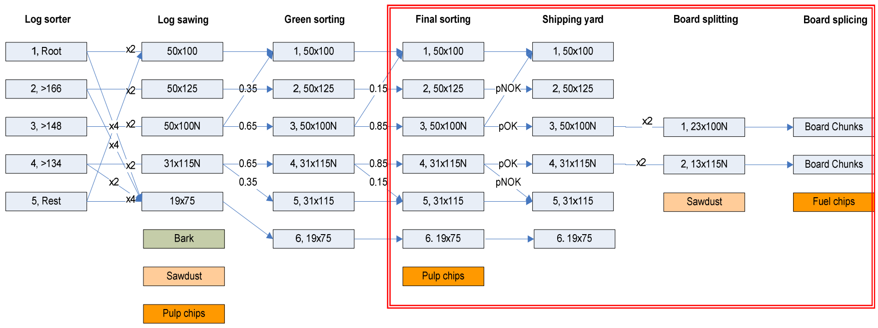

Figure 1: An overview of the simulated product flow from the log yard to board splicing at the secondary manufacturer. The red rectangle indicates the most crucial processes in ‘tailor-made’ supply

In the simulation, the sawmill stipulates that only a limited range of log diameter classes should be marked for this customer. This is due to the fact that the customer requires only 50x100 mm and 31x115 mm boards, an order which can be most advantageously met through the sawing patterns predetermined for log diameter classes 134-148 mm and 149-166 mm. Using the product flow indicated in Figure 1, the output from green sorting and final sorting was as given in Fig. 2.

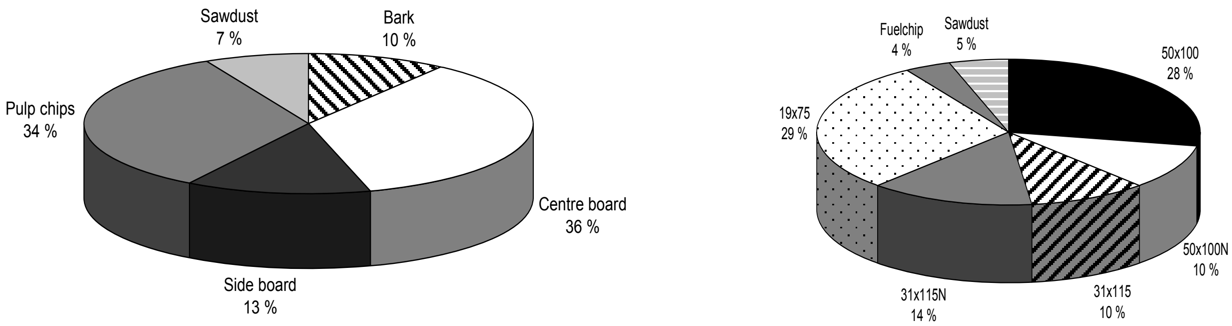

Figure 2: Product flow output after green sorting (left) and final sorting, after drying, on the right. Apart from fuel chips and sawdust, the final sorting only yields boards of varying dimension.

Green sorting was done on the basis of meeting some minimum criteria on wood density, heartwood fraction, and a stochastic downgrading probability, to cover a range of generic parameters that weren’t made explicit in the model. The importance of possible green sorting on the basis of these parameters comes from the fact that they can be used in optimising the drying process. Knowledge of the density, heartwood content, and the position in the log (and tree) the board comes from (twist potential) can be used in manipulating temperatures and drying times in achieving a better product. The concept of deriving and using a ‘value added’ sorting function, offers players a tool for price negotiation, but also for optimising product flow to areas that ensure the highest returns generated on a supply-chain wide scale.

The simulation model developed is able to report on a number of Key Performance Indicators, which cover product distributions, economic yield and environmental impacts. A web version of the simulation is publicly available on the internet

A new solution approach to include wood properties in integrated bucking, sorting and transportation planning

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The efficiency and quality of production at sawmills depend on the properties of the saw logs delivered. Quality or properties can be measured in many ways. We can evaluate quality based on visual properties such as length, diameter, knot sizes and different type of damages. In addition, we can measure quality based on density, fibre length and wood age. Sawmills typically do not have the same requirements as they are focused on different end products e.g., window frames, beams, construction boards and floors. Each of these products require/prefer different raw material. Preference can often be expressed in terms of "must be" and "would be good." This can be divided into one class of hard and explicit requirements ("must be") and one class where we prefer, with some evaluation, some properties. The planning period is tactical i.e. we consider destination of logs from harvest areas to industries. Today sawmills order saw logs from the assortment sawlog without any specific quality requirements. This means that sawmills must accept and make the best use of the saw logs that are delivered. Having said that, we do note that sawmills can specify that the bucking at harvest areas should be focused on a particular dimension e.g. a specific diameter or length class (or combination of). This can be achieved by using a specific price list in the bucking computers used in harvesters. However, this limits the flexibility of the overall logistic planning as there is a need to link specific harvest areas with given sawmills.

Planning of the logistic system involving harvesting activities and transportation is, in general, based on using specific assortments. If a sawmill asks for specific properties, there is a possibility to include an additional assortment with a given specification. However, as sawmills would have different requirements, it would lead to a very large number of assortments. In addition, this would result in that each assortment would only be possible to use at one sawmill. The result would be very stringent transportation planning where the supply and demand could be difficult to balance.

An alternative is to make additional sorting within assortments based on properties. For example, we could sort the assortment "pine sawlog" into three piles based on three different diameter classes e.g. "pine sawlog, 20-30 cm;" "pine sawlog, 30-40 cm;" and "pine sawlog, over 40 cm". Each pile can be used to satisfy a demand of "pine sawlog" but they can introduce more flexibility to satisfy a demand where the requirement is a diameter class of at least 30 cm. A problem with this approach is that we may end up with just too many piles if we have many different requirements on properties. Many piles will result in much higher costs in the harvesting, forwarding and transportation operations. The harvester needs to produce many more piles on the harvest area. The forwarder must then use more routes to pick up all piles and sort them into many piles adjacent to the forest roads. The logging truck must make more pickups of smaller piles to get a full truck load. Therefore, it is important to keep the number of piles low. The logistic problem is to integrate harvesting, forwarding and transportation into one planning problem. Although we integrate different parts, we still use local optimization for the bucking and forwarding operations.

Another issue is how to model the transportation problem. When using assortments, we have implicit requirements, and we can formulate the problem in a Linear Programming (LP) model. Such a model does not need to include specific properties. If we apply different sorting rules, we will end up with different values of the properties. This problem is similar to production planning at refineries where different production modes correspond to sorting. These models are nonlinear and are hence much more difficult to solve.

In summary, we have two aspects to consider in the modelling process. We want to avoid many piles and we want to avoid a nonlinear model. In this paper, we propose a solution approach and model which handles these two aspects. First, the model is linear. Second, we can reduce the number of piles sorted in practice by selecting sorting alternatives in the model which minimizes the number required. The model includes hard constraints on the required properties. For the preferred, but not required, properties we make use of a flexible evaluation. In practice this means that each sawmill can state their preference and what increased value this would have for its efficiency and result. An important part of the model is the flexibility in how we can describe the different sorting alternatives. The development reported is done within the EU project Indisputable key and computational results based on a case study with real production data are presented.

The use of RFID in round wood logistics

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The use of Radio Frequency Identification (RFID) in the timber supply chain has been one of the main research focuses at the chair of Forest Work Science and Applied Computer Science for several years. The basic idea is to use automatic identification to detect single logs and to support the information management in timber procurement. Therefore, the logs are marked with RFID tags. The unique number on every tag individualises the logs in transit.

The scope of a recently finished research project was to show that ultra high frequency technology (UHF) can be a feasible alternative to other RFID-spectrums like high frequency (HF), which had already been tested for these applications. The main focus lies on control of incoming logs at the sawmill. The high read range of UHF-systems provides bulk reading over long distances. This range allows detecting single logs on a truck by passing a RFID-gate. In fact, only a few UHF-tags are suitable for this application. The performance of different tags can strongly be influenced by the surface of the marked object. So the performance of various tag types attached to hardwood was first tested under laboratory conditions. The tests proved the extremely negative influence of fresh beechwood on the achievable reading distance of most tag types. Tag constructions with isolation or distance between the transponder inlay and the application surface showed best results.

After the laboratory tests, a field test with the 4 most promising tag types, and overall 1000 tags, was done to demonstrate the practicability under realistic conditions. The beechwood logs were marked with UHF-tags at the forest road. The identification number was saved to the corresponding timber data on a handheld computer. All timber data was then transferred to a trial database. In the course of timber transportation to the sawmill, the trucks passed a RFID-gate consisting of 8 antennas at the entrance of the sawmill. Tags on the logs were read out while the trucks were slowly passing the antennas. Identification numbers were transferred to the trial database and then matched to the timber data. The truck drivers had no further loading instructions or special limitations. In this field test, the best tag-type had a total read rate of 92 %. In fact, a complete identification of all logs was possible in several loads.

Currently, the timber industry controls the completeness of incoming timber using random sampling. Thereby, the numbers on plastic number plates are checked manually by the gatekeeper and then compared to the bill of lading and the timber inventory. This procedure is time and cost-intensive. Use of RFID for an automatic control of incoming goods would be a huge improvement compared to the current method.

Further developmental work is needed with regards to tag design and methods, for fixing and reading, for a practical use of RFID technology in the timber supply chain. Regarding the type of fixation on the logs a decision between an on-way tag construction and reusable tag types has to be made. Loading instructions for the different trucks could improve read rates at the sawmill.

Session 6:

Landscape assessment and planning

Opportunities, Current & Future, for Precision Forestry Application in South Australia.

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This presentation describes the existing application of precision forestry in the Green Triangle Region of South Australia and Victoria and proposes a future vision for the development of high precision integrated plantation forestry systems for radiata pine management. Implications are also raised in terms of the carry forward of legacy systems and parameters, and the different statistical methods which will need to be developed to make best use of the available data.

Plantation forestry has been practised in South Australia since the 1870's due to a shortage of commercial timber. The internationally reported loss of productivity in radiata pine plantations established for the second rotation during the period of 1935-1970 instigated the development of site specific silvicultural methods to correct the problem. Consequently, yield data are available to compare long term plantation productivity at landscape and point scales over three successive rotations.

The analysis of existing rotation data demonstrates that despite the correction of productivity decline at a plantation estate level, spatial variability is still evident within planting units that cannot be explained by site or climatic factors. This indicates some further potential exists for improvement in the implementation of operations to achieve more uniform plantation productivity outcomes. The application of precision forestry methods and the uptake of new technology can better control plantation related operations and can achieve more uniform resource productivity outcomes. Examples of precision forestry application are drawn from operational activities including plantation establishment, harvesting and sales to show the current state of implementation in the Green Triangle.

The business case for improvement through the application of precision forestry is fundamental to the financial performance of plantation forestry enterprises by potentially affecting the core concerns of sales price, productivity, cost control and risk management. For example: at the plantation establishment phase, tractors equipped with high precision GPS in combination with precision agriculture methods, such as variable rate technologies, can ensure that herbicides are applied at the specified dose rate across 100% of the target area. The risk of 'double dosing' or inadequate or missed areas of target weeds is minimised. On site weather monitoring stations are used to ensure the risk of inadvertent drift is minimised. Plantation resource data and other spatially referenced data such as rainfall and soil type are available for integrated analysis and use in future strategic, tactical, and operational planning with new data types such as depth to water table and high precision contour maps.

The availability of new sensing, positional, analysis and visualisation technology offers the possibility of a fundamental change in forestry systems and the methods used in them. For example, plantation yield regulation could evolve from sampling theory based extrapolation from point samples (inventory plots) to landscape scale 100% enumeration data using airborne LiDAR, without compromising precision for operational use. New sensor technologies, such as harvester head measurements, allow monitoring of the progress of operations against high precision yield predictions and the prompt analysis and, if necessary, correction of any deviations.

There are some considerable technical and social challenges still to be addressed before the full benefit of precision forestry can be realised. These constraints include: the rate and comprehensiveness of communication technology role-out; culture, expertise and training; resolution of

GPS precision issues under tree canopies; and ongoing use of machinery containing superseded sensor and other technology.

In conclusion, there is considerable forest science and technology available to support the application of precision forestry in the radiata pine plantations of the Green Triangle Region of South Australia and Victoria. So the proposition becomes one of better application of the science and technology that already exists. To be most successful, there will need to be the use of systems design principles to ensure integrated systems are developed that provide a sound basis for decision making.

Influence of the quality of data in forest road planning – a case study from Russia

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In Russian forestry the availability and cost of reliable, accurate and precise data is of major concern. For forest road planning it is a critical issue as forest road construction is a significant investment. The study area is in North-West Russia. 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 forest roads is 3,0 m/ha, but the density of good forest roads (accessible with normal trucks during non-frozen conditions) is only 0,8 m/ha. Comparatively, forest road density in Southern Finland is over 15 m/ha. Because of the poor forest road network, transportation costs are high and only 80 % of the annual cutting plan is profitable to harvest. This study was made in order to quantify the cost (of imprecision) of using very general information, which can be compared to the cost of acquiring more precise data.

In a case study area in North Western Russia the planning of a road network was made using data with three different resolutions. In one case the data was of quarters (≈1x2 km), in another case data for 400x400 m raster was acquired and finally 30x30 m raster data was utilized. One problem of the study is to determine the accuracy of the data. There is an experience that sometimes the forest data is not very accurate. Not every stand is actually visited and measured and the clustering of similar stands may sometimes be quite imprecise. For the raster data a combination of sample plots (measured stands) and satellite data is combined with kNN-methodology to construct a covering data set of high resolution and relatively good accuracy.

If the data used is considered to be accurate, the results show that there are some benefits to be made utilizing more precise and higher resolution data. The interaction between harvesting planning and road planning is a main issue. To be able to do profitable harvesting, roads are a major concern. To be able to do road planning, the harvest plans has to be established. In this study we have defined potential harvesting sites for the next 10 years and optimised the road network according to this.

The study highlights the need to use precise and accurate digital data in road planning as well as for planning harvestings. If Russian forestry is going to change to be more intensively managed it has to incorporate GIS, precise digital data and better planning tools in the future.

Simulations of Forest Landscapes based on knN Data.

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It is universally recognized that there are natural phenomena and planning problems that are not tractable on a forest stand level but need a landscape approach. Cellular automata have proven to be suitable tools for modelling processes where the interactions between the entities within a cell neighbourhood need to be taken into account. However, the heterogeneity of the land owners and the emergent landscape level effects of the actions undertaken by individual owners on the ground remain often overlooked in landscape models, which assume rational decision making aiming at maximization of utilities and neglect the reciprocal influence of neighbours' decisions.

The simulation tool presented here is, technically seen, a cellular automaton aiming at illustrating the development of a landscape, encompassing forest, agricultural and other land, under different management regimes. An area-covering data set is used for the basic description of the landscape. The landscape is depicted by assigning state variables to 25 by 25 m pixels thus yielding a spatially explicit description. Using a Markov-chain type model the development of the landscape is simulated. The temporal resolution of the simulation is 5 year periods.

Due to the explicit spatial nature of the data and the simulator, the system is well equipped to handle issues related to spatial lay-out of for example areas set aside for nature conservation.

The data sets used for describing the landscape are available for the entire land area of Sweden, thus allowing for general use in analyses of landscape development and land-use change issues. Data for forest land is constructed by combining, using knN methodology, information from satellite images with information from sample plots recorded by the National Forest Survey of Sweden. Data for other land use types is obtained from the National Land survey of Sweden.

Structurally, the simulator is designed to allow for inclusion of agent-based components to incorporate, for example, land owner behaviour and decision making into the simulations. In recent years notable advances have been made in applying the agent based approach to land use modelling and we aim at coupling the cellular automaton with a decision model for individual agents.

So far, the system has been used mostly for illustrative purposes and has been proven to be a versatile instrument for example in classes in strategic planning. In most cases it has been used to illustrate landscape development with a time perspective of 50 to 100 years. We see that the model has a potential to be used in, for example, analyses of issues around forest owner response to policy changes and the consequences of these responses on an aggregate level.

In the presentation we will outline the basic structure of the simulator, discuss some aspects of the data sets used and give examples of how the output from the simulator can be used to drive habitat models and visualization modules.

An extraction trail generator using LiDAR data and Tabu search

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The transport of timber from stump to mill relies on a range of machines and equipment for primary (forwarders) and secondary transport (road trucks). This makes optimization of timber transport a complex task which should also consider road planning and construction. Given the complexity of optimizing timber transportation, exact methods are limited by problem size. In this case, metaheuristics is a method proven to give good solutions in reasonable time. Forest operations can be divided in several tasks. For a cut to length system, the tasks are felling and delimbing/bucking/sorting by a harvester and transportation and sorting by a forwarder. For other systems, the order of the tasks can be different. This work describes a computer implementation of Tabu search (TS) for generating good trails for wheel based forest machines using the cut to length system. The implementation uses a digital terrain model (DTM) from remotely sensed LIDAR (light detection and ranging) data as well as raster interpretations of conventional road and soil data.

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

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

The neighbourhood implemented is adding of a part of a trail. In addition, we will use a neighbourhood of deleting whole or parts of a trails, a neighbourhood of moving whole or parts of a trail and a routine for merging of trails. In addition to the DTM, road and soil data, we will use environmental data from registrations of key species. The environmental impact will be implemented either as a penalty to the objective function or as multi objective Tabu search.

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

The method will be tested at a full scale level in a forest in Norway. Firstly, we will compare the estimated cost of harvesting with actually incurred cost at a stand. If the model gives good estimates, it will be useful to the forest owner, who can acquire a better estimate of the cost of harvesting. Secondly, an interesting question is whether we can use LIDAR to identify where a forest machine can operate. We will compare the suggested trails to terrain trails actually created by machine operators, and if the accuracy of the DTM is good enough, the method can be used for generating more efficient trails and reduce harvesting cost. Also, the method will be the basis for further research. An estimation of the trade-off between primary and secondary transport costs could provide the basis for the planning of new forest roads, and the method could also be used in matching harvesting systems to sites.

Session 7:

Growth simulation at single tree and stand level

IVY: An Individual-Tree Growth Model for Complex-Structured Stands

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Forest management in Canada is increasingly emphasizing the establishment and maintenance of complex-structured (mixed species, spatially heterogeneous and uneven-sized) stands (Groot *et al.* 2005). Complex-structured stands represent a challenge for modelling stand growth and development. Whole stand methods are not applicable because a wide range in structural conditions makes it impossible to represent all stand states. On the other hand, individual-tree models are susceptible to aggregation and propagation of error and have greater information requirements (Groot *et al.* 2004).

Use of resource constraints has been identified as an approach to control error accumulation (Groot *et al.* 2004), and the IVY model uses the finite amount of light available for interception by trees in a stand to constrain stand-level growth, helping to control error. IVY is an individual-tree growth model that relates tree volume growth to the amount of light captured by the crown during the growing season. The IVY model uses a ray-tracing algorithm to compute light interception for asymmetric crowns with profiles ranging from neiloid to cylindrical (Groot 2004). Tree position and crown dimensions are required as input variables to determine light capture. Light capture is a conceptually simple measure of competition for individual trees, since it integrates the influence of neighbour trees on light availability. As a result, IVY does not require any competition indices.

The heart of the IVY growth model is the relationship Iv = L x VIE, where Iv is individual tree volume increment, L is light intercepted by the tree crown during the growing season, and VIE is volume increment efficiency, the amount of stem volume growth per unit of intercepted light. VIE estimates have been obtained from field measurements for *Picea mariana* and *Populus tremuloides*. For *P. mariana*, VIE varies strongly among site types (from 0.071 dm3 GJ-1 on poor-quality peatland sites to 0.345 dm3 GJ-1 on fertile mineral soil sites) and is linearly related to site index (Groot and Saucier 2008). VIE decreases with the light capture, possibly because in larger trees there is a greater allocation of photosynthate to respiration and to branch growth.

Since the IVY model is driven by light interception, modelling crown dynamics (height growth, crown radial growth, and crown rise) is a key component. IVY currently uses an empirical model to predict height growth as a function of tree height, site index and diameter increment. An alternative model that predicts height growth as a function of the annual ring area increment in the upper crown is also being explored. IVY operates on an annual (or longer) time step by: (i) predicting volume increment from light interception (ii) estimating height growth and crown radial growth, (iii) updating crown dimensions.

A beta-version of software implementing the IVY model has been completed. The software is programmed in VisualBasic and uses tree lists that can be read from csv files or that can be generated interactively.

The crown-based architecture of the IVY model makes it compatible with advances in forest resources inventory (see Groot and Pitt, this symposium), since inventories that supply tree position and crown characteristics satisfy the input requirements of the IVY model. Furthermore, the IVY architecture makes it well-suited to incorporate relationships between crown features and fibre attributes such as the distribution of growth ring area, wood specific gravity and microfibril angle.

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ComBio – Estimation tool for combined energy wood and pulp wood harvesting

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Over the years, cuttings of small diameter round wood from thinnings have been decreasing due the cut down of Finnish forest industry production capacity. At the same time the utilisation of forest biomass for energy production has been increasing rapidly and the need to find high quality yet cost efficient forest energy is increasing. One solution to ensure young forest silviculture in addition to increasing procurement of forest biomass for energy is to combine pulp wood and energy wood harvesting during first thinning operation by changing diameter, topping and bucking requirements. MS-Excel based tool ComBio was developed to analyse different thinning alternatives and to offer decision support for operations. Based on the input data (tree species, d1.3, h), the ComBio generates stem tapers for each tree, calculates the mass of biomass compartments (stem, branches, needles/leaves, stump and roots) by biomass models, applies crown length and distribution models to estimate crown biomass recovery in relation input to data, and finally, does a fixed-length bucking for the stems according to user input. The results are shown to the user by tables and graphs. This paper presents the models and functions of the tool and preliminary results of its use with sample stands.

Utilizing Stem Level Data to Develop Site-specific Profit and Management Zones

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Geographic information systems (GIS) and remote sensed imagery have been widely applied in forest management, in particular inventory and volume estimation, at a landscape scale. Stands tend to be managed uniformly with sub-stand variability masking a true stand-level characteristic that must be discovered with a properly designed inventory, rather than the variability itself being a valuable source of information for development of optimal treatment regimes. The purpose of this investigation was to use LiDAR and other data, along with a GIS to develop a series of maps illustrating spatial variability in stand and site characteristics. A further objective was to speculate on the suitability of these maps for developing site-specific management plans, as is commonly done in agricultural management. The study was conducted on two pine (*Pinus taeda*) plantations near Auburn, AL, USA, one a 3.6-ha site consisting of piedmont soils (Site 1) and the other a 4.5-ha site consisting of coastal plain soils (Site 2). Tree parameters including diameter at breast height (DBH), location, and elevation were measured for every tree on both sites utilizing hand measurement and a total station. Site 1 had 2302 live trees with a stand density of 638 stems per ha and Site 2 had 2332 trees with a stand density of 518 stems per hectare.

For each stand, LiDAR data were used to estimate tree heights, and applied in calculating individual tree volume and per stem value. Seven methods were utilized to estimate height, three proximity approaches, and four Canopy Surface Models (CSM). The three proximity approaches defined a 1.5m buffer around known tree locations to assign LiDAR based z-values as tree heights by: 1) assigning a height based on the LiDAR point closest (NEAR) to the actual tree position; 2) assigning a height based on the LiDAR point with the largest z-value (MAX) within the buffer; and 3) average the z-values for all LiDAR points within the buffer and assign the averaged value. The CSM method assigned tree heights at known stem locations based on First Return interpolated surfaces. Four different interpolation methods were assessed for the CSM method using a 0.5-m output resolution. These included Kriging (KRIG), Natural Neighbour (NN), Inverse Distance Weighted (IDW), and Cubic Spline (SPLI), all calculated using 3D Analyst within ArcGIS 9.2. On site 1, measured heights in the stand ranged from 9 to 25 m, with a mean of 18.5 m and standard deviation of 2.4 m. Values of r^2 were similar among all methods, but were highest for the CSM methods with the natural neighbour (NN) having the highest (r^2 =0.55). On site 2, measured heights ranged from 9 to 21 m, with a mean of 17.0 m and a standard deviation of 1.5 m. However, on site 2, r^2 values were quite varied among all methods, but were highest for the proximity methods, with the MAX method having the highest (r^2 =0.47). The most likely reason for the difference in results between the two sites was due to the management regime in place for the two stands. Site 2, being less dense, and having undergone an intense thinning, had more voids (open areas), causing surfacing model assumptions to not be met. From this analysis, preliminary conclusions indicate the best method to use for estimating heights is dependent on the management regime that is in place for the stand.

Management zones are widely applied in precision agriculture to link field variability with sub-field management strategies. A contiguous field often has regions within which conditions are sufficiently different that costs can be controlled, or revenues maximized, by tailoring fertility, irrigation, tillage, pesticide, or establishment treatments to highly localized conditions – perhaps even on areas smaller than 1 ha. A further objective of this study was to apply management zone generation techniques typical of precision agriculture in forested stands to assess the potential for sub-stand management in silviculture.

In precision agriculture, management zones are typically defined using many layers of data, including information on historic yields and maps of soil or topographic conditions. Following accepted procedures from precision agriculture, digital elevation models and soil maps were used to analyze site variability and determine characteristics to delineate management zones. The study compared the prevalent characteristics utilized to delineate management zones on piedmont soils to the prevalent characteristics necessary for delineating management zones on coastal plain soils. Stocking levels and volume on a per hectare basis were used to determine the effectiveness of the individual zones.

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