Abstracts from the NB-NORD workshop on Big data from forest machines: Ongoing and possible future R&D activities for forest operations

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A researcher's perspective on Big data from forest machines

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Big data has quickly become a buzz-word and the usefulness of Big data is being investigated and developed in most sectors of society and industry. It has become a driving force behind the ongoing waves of digital transformation, including artificial intelligence, data science and, ultimately, the Internet of Things. There is still no commonly accepted definition of the Big data-concept, which is still evolving and being reconsidered.

The term Big data describes the large volumes of real-time, streaming data generated by a business on a day-to-day basis, although, in my opinion it is not the amount of data that is important – more the mode of capture and how data are coupled together. The data may be both structured and unstructured and can be analysed for insights that lead to better decisions and strategic business moves. Such analyses may reveal patterns, trends, and associations, especially relating to human behaviour and interactions.

In mechanized 'Nordic' forest operations, the machine communication standard *StanForD 2010* provides Big data-opportunities. Data generated from machines can be combined with other data sets, e.g. the digital terrain models from ALS scans of the terrain, depth-to-water maps, road network databases or digital GIS records of ancient monuments etc. Actually, data from machines in work are already being used in combination with data from other sources, for a number of purposes. Examples are logistics and transports, follow-up of performance and production, various financial transactions, updating of forest inventory records, improved production forecasting, stand choice and harvesting sequencing, machine state monitoring, decision support, e.g. for reduced environmental impact, identification of operator training needs and much more. Thus, as in other industries, we are already seeing the power of Big data. The possibilities seem almost endless. In short: Big data is a powerful tool to improve the efficiency and precision of operations. Improved efficiency, i. e. a more favourable relation between input and output of production means that the net margins of forestry and forest operations are increased – with more to share between the stakeholders. This is also the goal of applied forest operations R&D.

But although Big data may yield unprecedented insights and opportunities for development, it also raises concerns and questions that must be addressed:

- Data privacy – Big data often contains personal or business sensitive information.
- Data security – if we approve for someone to have our data for a particular purpose, can we trust them to keep it safe?
- Data discrimination – is it acceptable to discriminate, based on data? We use credit scoring to decide who can borrow money. Insurance is heavily data-driven. We can expect future analyses and assessments of ever increasing detail and care must be taken that this will not become an obstacle for development.

Addressing these challenges is important and failure to do so can leave individuals as well as businesses vulnerable, in terms reputation, legally and financially. Most of the issues are connected to ownership and rights to access the data from forest machines in operation. There are many stakeholders claiming such rights (Figure 1), and no commonly accepted agreement exists in the Nordic-Baltic area, although preliminary agreements are, at least partially in place. It seems likely that the machine owner will be identified as the full owner of the data generated by the machine, but at the same time, the owner of the forest where the machine is working, and the buyer of the produce are entitled to relevant parts of the information. To efficiently support the sector, also the machine manufacturer and researchers are in need of data generated, and a number of authorities also claim access rights. In addition, it can be foreseen that agencies and NGOs with an interest for environmental monitoring will demand that parts of the data are made public. The number of entities with an interest in data generated by forest machines will probably increase.

Figure 1. There are many stakeholders in Big data from forest machines and the number is likely to increase. The questions of ownership and rights to access must be sorted out.

To conclude, I personally consider the Big data approach is a megatrend where much development made in other sectors will become useful and available also in forestry. The combination of machine generated data with other data sets - ultimately in an “internet of things” – provides opportunities for development of the same dignity as did mechanization. The inclusion of Big data procedures in forestry will increase the value of forestry for the growing bio-economy and increase output as well as sustainability and profitability. It may also increase the status and attractiveness of the sector.

But a successful launch of Big data including machine generated data in forest operations presupposes a speedy solution to the different problems related to data ownership, data security, personal and business integrity and possible misuse of data.

If these issues are constructively resolved, Big data provides a forest of opportunities for our sector.

The influence of driving distance on the forwarders' average speed in mid Sweden

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Background

There are indications from previous studies that forwarder's driving speed is affected by the driven distance (Nurmi et al. 2006; Gullberg 1997; Kumazawa et al. 2011). These indications are assumed to have several different causes. Longer driving distance stimulates for better work planning and establishment of strip-roads with better conditions. Operators may also feel stressed and drive faster as driving distance increases. Moreover, average driving speed theoretically should increase with increasing driving distance as the proportion of accelerations and decelerations (and other possible constants) decreases with increasing driving distance. However, it has been very resource intensive to collect large follow-up datasets on forwarders' speed and distance, and the relations between them.

The resent development in onboard computers and software has enabled new ways to study forwarding (e.g. Manner et al. 2016). This is also something that enables a more in-depth study of the relationship between forwarder's driving speed and a given distance driven during a specific work element. Large datasets can be collected automatically without affecting operator's behaviour during the data gathering, i.e. reduction of so called observer-effect.

This extended abstract presents preliminary results for the relationship between the distance driven and the work-element specific driving speed (load-level arithmetic average speeds, observed when speed > 0 km/h).

Material and Methods

This study used the time study dataset of Manner et al. (2016). The data was collected between March 2011 and October 2013. The dataset was collected by TimberLink software installed on the onboard computers of two JD 1910E forwarders while operated by nine operators in total. For more detailed descriptive statistics readers are referred to the original article of Manner et al. (2016). The observations were further filtered by removing loads with unusual work and possible measuring errors. Individual observations that were deemed to have an unrealistic large impact on the analysis was also removed, i.e. when there were hundreds of meters to the nearest observation. These individually removed observations were not assumed to be caused by measurement error, but rather by a lack of observation in extremely long forwarding distances. This filtering meant that the 8868 loads was reduced to 4400-4500 loads (the number varies between the work elements) that were used in the analysis.

These loads were then analysed with correlation analysis and least square regression analysis to investigate the effect of driven distance on the driving speed during the work element: driving unloaded, loading, and driving loaded.

Results

The correlation between unloaded driving speed and driving distance was relatively strong, while the correlation between loading and loaded driving speed and distance was weaker. Drive distance was clearly associated with driving empty and driving while loading speeds in the regression analysis. While, similar association was not found driving loaded (Figure 1).

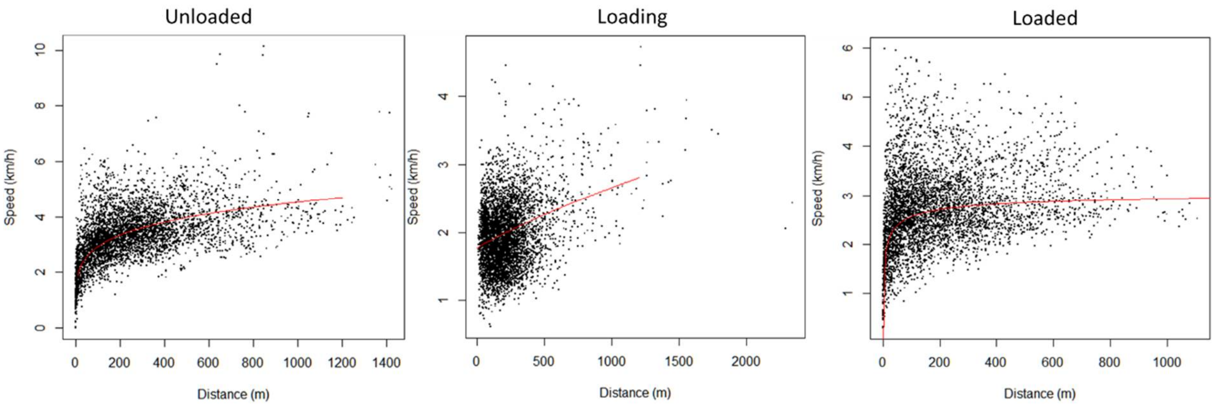

Figure 1. Effect of distance driven on forwarders' driving speed during driving *unloaded*, *loading,* and *loaded*.

Discussion

It is quite evident that driving distance have an association to forwarders' driving speeds (Figure 1). It is also clear that the effect is quite dominant for unloaded drive speed and less dominant for loading drive speed. While, the analysis has difficulties explaining the relationship between loaded drive speed and distance. This difference is quite obvious as there are more factors affecting the loading drive and driving loaded speeds than the driving unloaded speed. Loading drive speed is affected by number of loading points, the distance between loading points, and the harvesters work (e.g. is the piles well-made or not), which mean that distance should explain a smaller part of the variation. Driving loaded speed is on the other hand effected by load size which will vary somewhat between loads and distance should therefore have a larger effect (c.f. driving empty and loaded speeds). Differences in load size could explain the decreasing variation in loaded driving speed with increase driving distance. Small size loads are not desirable on longer distances, and a small load size will also increase the maximum driving speed as well as reduce the acceleration time.

It is not possible from our data to conclude why the distance effects the forwarding speed, but it is likely that it is a combination of relatively more driving on better strip roads, stress put on the operators of the long distance, and/or reduced effect of acceleration and retardation in Nordic conditions. However, they are interesting for further studies.

Our results can be interesting to use in simulation of forwarding work and in optimisation of forwarding routs. We also suggest based on our results that work element-specific distance is included in investigation of forwarding speed, when possible. A combination of distance, ground condition, slope, whether condition and load size should be able to predict forwarding speed better than current functions are capable.

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StanForD2010

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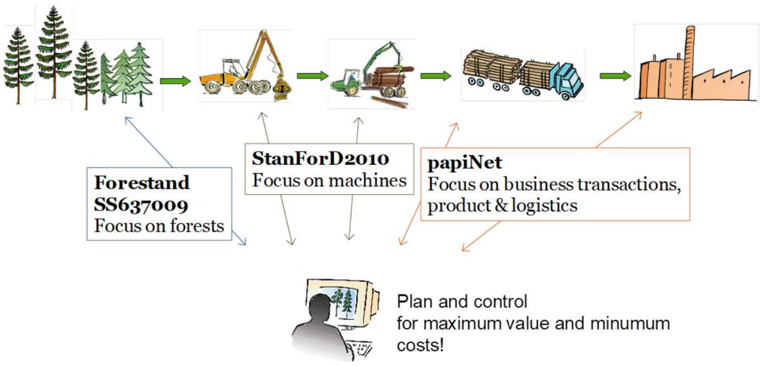
Introduction to standardization

Data is needed from all nodes in the forest to industry supply-chain in order to maximize the value and minimize the costs. Common languages, i.e. data standards, are needed to communicate and understand these data.

Today there are three different parallel data standards existing in Sweden, Forestand, StanForD and papiNet (figure 1).



This presentation will focus on StanForD2010 in order to give a basic understanding of the standard, it's possibilities and the development trends.

StanForD2010

The old StanForD "classic" focused on minimizing the amount of data needed to be transferred due to technical limitations regarding memory and communication capacity. This meant that aggregated data was usually communicated. A very important principle when developing the new StanForD2010 was to avoid aggregated data, which means that the receiver of data is now responsible for calculating all different types of key figures. This gives much more flexibility and less needs for updating the standard with new calculated data. An additional important focus area has been to simplify frequent (per hour or shift) reporting of data from the forest machines. The new standard has also been improved with new possibilities to register coordinates, time stamps and unique identities.

New possibilities!

StanForD2010 gives several new possibilities to improve the efficiency of our supply chain. The fact that we frequently register coordinates and time stamps as well as globally unique identities opens up a large number of new possibilities.

Large dataset from normal work situations

Historically we have in many cases been forced to use manual data collection when analysing different types of logging operations, by including the time of felling it is now possible to use normal production data from harvesters (hpr) to analyse productivity. Skogforsk is presently involved in a project to develop a new model for paying contractors based on hpr-data in combination with other data sources such as terrain models based on LIDAR. The basic data for this type of analyses is illustrated in figure 2 where the productivity per stem from a large number of final fellings.

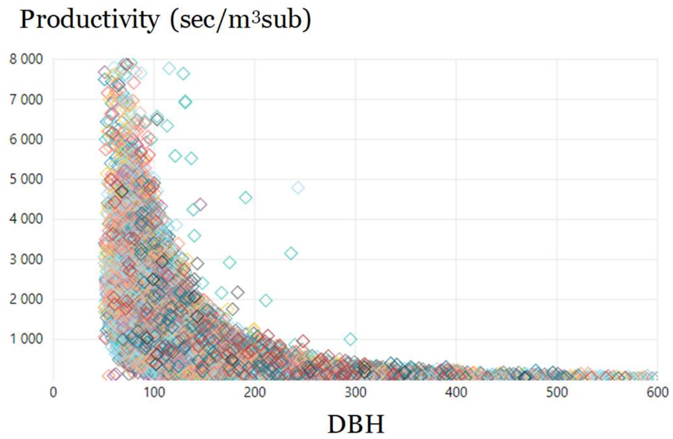


Figure 2. Productivity (sec/m3sub) per DBH for 855 000 stems (23 harvesters in final fellings).

Combining hpr and hqc data

The new globally unique identities for individual machines, stems and logs makes it possible to match normal production data (hpr) with e.g. measuring quality control data (hqc). Skogforsk is working on a project to develop new tools for improved monitoring of harvester measuring where we extract information related to speed of feeding, reverse feeding etc. from the hpr and combine this information with measuring accuracy (figure 3).

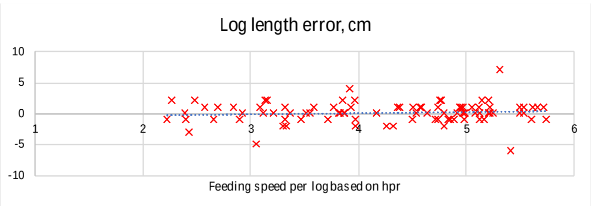


Figure 3. The log length error calculated from an hqc-file vs the feeding speed per log as extracted from an hpr-file.

All harvester parameters are known

The fact that all bucking optimization parameters are included in the normal production reporting means that it is always possible check whether the machine is using the correct settings (figure 4) as well as whether the settings have been implemented correctly.

	140	160	180	200	220	240	260	280	300	320
370	5	5	15	15	15	5	5	5	5	5
400	0	0	0	0	0	0	0	0	0	0
410	50	50	0	0	0	0	0	0	0	0
430	0	0	20	20	20	15	15	15	15	15
460	15	15	15	15	15	15	15	15	15	15
490	20	15	15	15	15	20	20	20	20	20
520	0	0	20	20	20	20	20	20	20	20
550	10	15	15	15	15	25	25	25	25	25

	140	160	180	200	220	240	260	280	300	320
370	5	5	15	15	15	5	5	5	5	5
400	0	0	0	0	0	0	0	0	0	0
410	50	50	0	0	0	0	0	0	0	0
430	0	0	20	20	20	15	15	15	15	15
460	15	15	15	15	15	15	15	15	15	15
490	20	15	15	15	15	20	20	20	20	20
520	0	0	20	20	20	20	20	20	20	20
550	10	15	15	15	15	25	25	25	25	25

Figure 4. Illustration of changes done to limitation matrix during harvesting at a harvesting object at where the red cells indicate that a specific length and diameter combination is not allowed to be cut. The blue cells indicate that a log can only be cut manually.

Trends – Where are we heading?

Historically StanForD has mainly been used and developed by Nordic actors. An increased global interest in utilising StanForD is notable. This means both going back to basics in order to clarify for example volume and bark calculations as well as including new types of operations such as tree-length operations (feller-bunchers, skidders etc.) into StanForD.

A number of additional detailed machine data have been included in the standard during the last years such as:

- Possibilities to include tracking coordinates in production and operational monitoring files

- Possibilities for operator to register so called stem-codes, e.g. to include information about high stumps, retained stems, cultural heritage sites .

- Possibilities to create so called “user-defined-data” which means that a flexible questionnaire can be defined by forest company or contractor and sent out to the forest machine. The filled in questionnaire can be reported back.

- Possibilities to do a quality control of existing forwarder scales in order to make certain that the weight scaling used for reporting is correct.

Most of the present GIS-applications are primarily used as a one way communication of a static map as drawn before harvesting was commenced. These GIS applications are usually more or less totally independent of the other softwares in the control systems. Several manufacturers and forest companies have started looking at a new generation of gis-applications which are more integrated with the control systems as well as services for continuously updating the interface based on already reported data. There will be a need to continuously update the gis-application regarding route optimization, results from thinning following-up and product quality parameters. Another important aspect is to open up possibilities for operator to manually add gis-information tio be sent back to both forest companies and machine owners.

Automated stand delineation and strip road generation based on harvester location data

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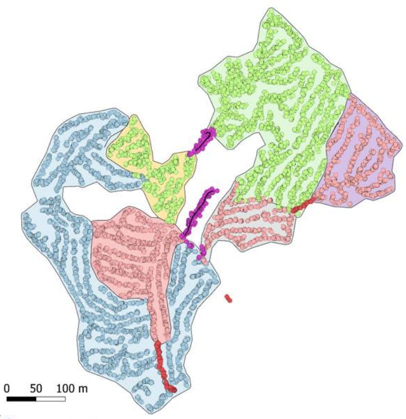
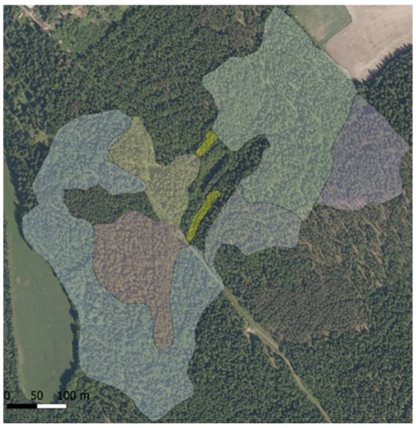
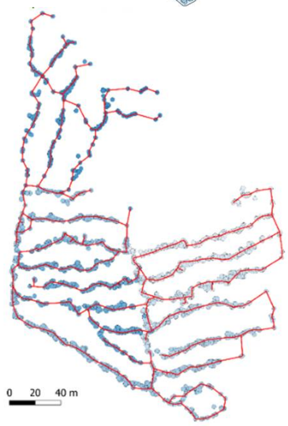
In Finland, tree stem data is collected from over one million felled trees each day (Melkas & Hämäläinen 2015). Harvesters offer significant potential to update forest resource information based on operations and to collect reference data for the remote sensing purposes. The harvesters produce stemwise location and diameter data during operation (StanForD 2018). If collected on a large scale, the location data offers promising possibilities to reliably update the forest inventory data on a much shorter timescale than currently with laser scanning. When the diameter data is fitted for the Laasasenaho (1982) stem curve, the volumes of the whole harvested trees are obtained, and when combined with the stand delineations, the harvester dataset serves as ground truth data for remote sensing studies. The location data can also be used for quality purposes of the harvesting work.

In this work, a test set of harvester location data (n = 635 350) was used to develop an automated method for boundary delineation of harvested stands. The method handles one harvesting object at a time. It separates the stands from the striproads that lead to the stands, then creates the stand boundaries, and cleans the overlapping boundaries between several adjacent stands. In addition, the striproad network inside the stand was automatically generated, and can be further used for calculating the striproad length, area and intervals for indicating the quality of the work.







The results of the automated stand delineation were compared with two reference datasets: stands digitized from aerial images, and stand boundaries determined by walking around the harvested area with accurate GPS receiver. In general, the locations and areas of the automated stands correspond with good accuracy to the reference stands. The automated striproads result in expected length of striproad per hectare as well as the striproad intervals for different harvesting methods (thinning, final felling).

The study was conducted as part of *Wood on the move and new products from forests* – project, which is one of the Finnish governments key projects 2016 – 2018. Finnish Forest centre is also integrating the system to their own systems.

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Single-tree positioning using harvester: Experiences from an operational implementation

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Accurate positioning of single trees registered automatically during harvesting operations opens up new possibilities for reducing the field sampling effort in forest inventories utilizing remotely sensed data. Traditional field measurements on field sample plots required by remote sensing based forest inventories are expensive; however, georeferenced single-tree data collected during regular harvest operations can substitute or supplement traditional measurements. As part of a large project, we developed and implemented an integrated accurate positioning system based on real-time kinematic global satellite positioning. The system was based on a modified and extended version of the DigPilot positioning system developed by the Norwegian company Gundersen & Løken AS. A cut-to-length harvester was equipped with the system and the system was running for about two years. In addition, a low-cost global navigation satellite system (GNSS) receiver was mounted directly on the harvester head. A number of challenges occurred when running the system operationally. However, we were able to collect georeferenced single-tree data for more than 55000 trees. Positions of harvested trees were evaluated and compared to coordinates obtained using a total station. At the single-tree level, the mean error for the integrated positioning system was 0.9 m. The low-cost GNSS receiver mounted on the harvester head yielded a mean error of 7.0 m. The sub-meter accuracy obtained with the integrated system suggests that data acquired with a harvester using this positioning system may have a great potential as a method for single-tree field data acquisition.

Utilization of high resolution harvester production data for improved pre-harvest planning and follow up

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Introduction

Detailed standardized production data (hpr- or pri-files) is collected by all modern CTL harvester computers during harvesting. All data are stored in standardized StanForD files (Anon 2013, www.skogforsk.se/stanford2010). This data can be utilized in order to improve forest management and operations, feedback to operators and forest owners.

There is a large number of new implementations based on harvester data under introduction, including follow up of machine productivity and reliability, automatic thinning evaluations, regeneration planning after final felling, predictions of wood inner quality, forest residue estimation etc. The objective of this presentation is to present some of the latest fields of applications based on harvester data.

Detailed harvester data

Measuring data for each stem and log are registered continuously, including e.g. dimensions, species, coordinates, time, operator decisions etc. These data can be used in order to re-construct the trees and the forest that was felled (figure 1 and 2). When reconstructing stems a number of filtering algorithms has to be implemented in order to e.g. handle stem breakage. Algorithms has been developed (Bhuiyan et al, 2016) in order to calculate the harvested area using coordinates of the stems as well as segmenting the site into sub-areas with more homogenous trees based on the dominant height.

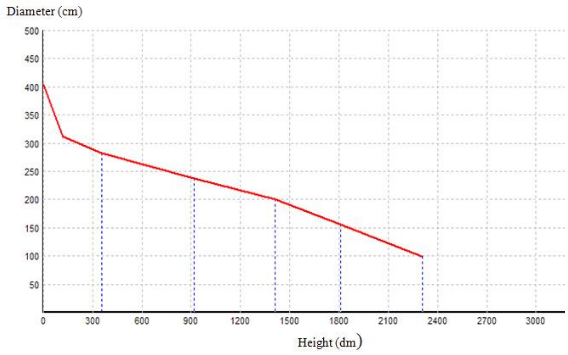

Figure 1: Harvested stem with 5 logs

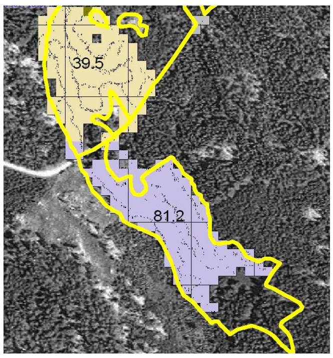

Figure 2: Site segmented into 2 separate sub-areas based on variation in dominant height.

It is possible to calculate a receipt on the harvested volume and the value, area, average stem size, DBH distribution, damage frequency etc. when the harvesting operation is completed. Today modern software versions have functionality for automatic hourly production reporting which means that tools using harvester data are almost working as real-time applications.

Case 1. Improved pre-harvest planning (yield estimations)

Implementation projects are carried out by Skogforsk together with three major Swedish forest companies in order to develop a new pre-harvest planning/assessment system for improved yield estimations (Möller et al 2017). The system is based on calculating a number of key figures per harvested sub-area (figure 2 and 3).

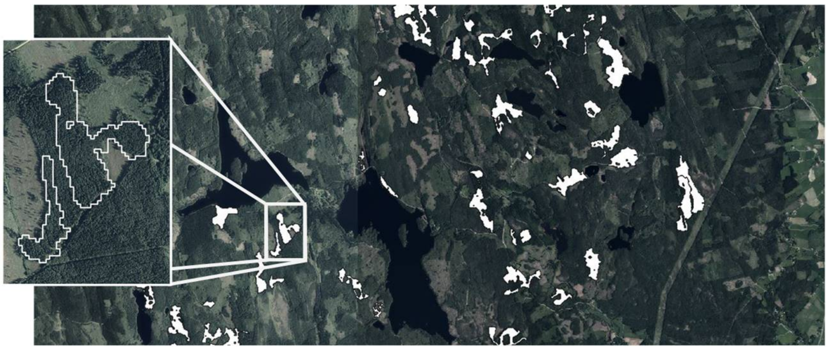

Figure 3: Examples of harvested sites used in imputation to find harvested sites as similar as possible to planned sites that are not yet harvested.

When planning a new harvesting site the same key figures are collected using field measurements, remote sensing and existing stand inventory data. Using an imputation method (Söderberg, 2015) the most similar harvested sub-areas are selected. The results from the imputation can then be used for predicting the outcome of the planned site based on what was harvested on other sites (figure 4) or a new synthetic stem database can be created in order to make bucking simulations. Test with the imputation method have given good results.

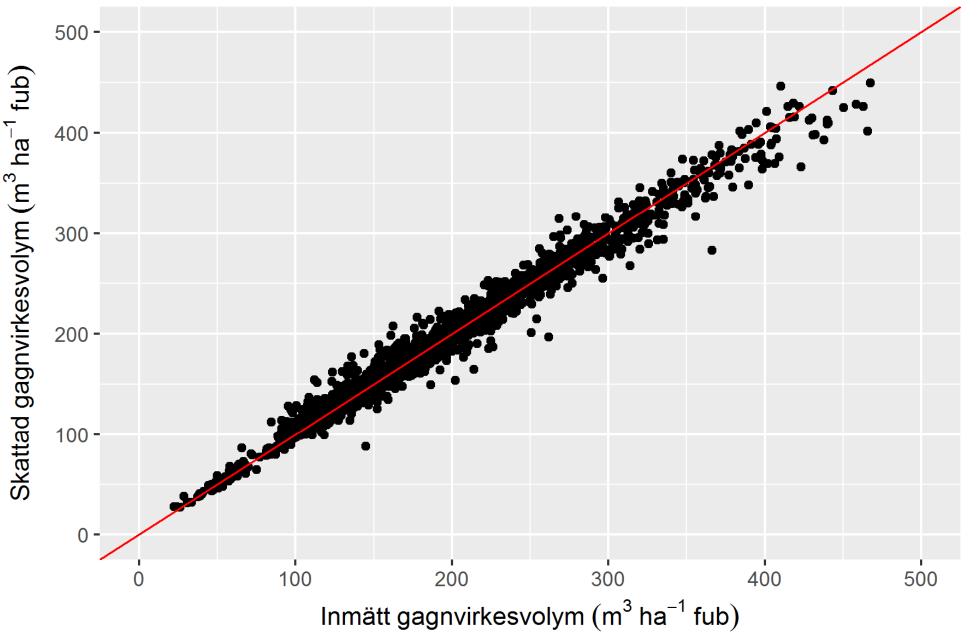

Figure 4: Imputation results from tests with 2000 different harvesting sites in Sweden. The result describes the estimated volumes based on an imputation from 5 calculation areas (similar stands) copared to the harvested volumes as measured by the harvester. Imputation based on basel area, Diameter och height. The figure come from real control measuring based on harvester data (Möller et al 2017).

In average there was no systematical error in the study (0,1 %) and the standard deviation was 6,8 %.

Case 2 Automatic thinning follow up

A model has been developed in order to calculate key stand data after thinning based entirely on standardized harvester data. The model has been evaluated for all types of sites in Sweden using more than 10 different thinning harvesters.
The objectives of thinning follow-up on a stand level are to monitor thinning operations, making it possible to update databases for forestry planning systems, increase thinning quality, decrease costs and increase total productivity. It is important to focus further development on giving the logging teams more rapid updates as well as increasing the quality of the estimations of the remaining stand.

Figure 1: Thinning harvester felling strip road trees.

Material and methods

Skogforsk has developed a model for calculating key stand level data, based on harvester data (Möller m. fl. 2011, 2015). The model has been extensively tested in practice. A demonstration software for use in harvester computers has been developed, giving operators feedback on important thinning quality parameters and data for the remaining stand (Figure 2). A total of 60 different thinning stands from all over Sweden have been evaluated.

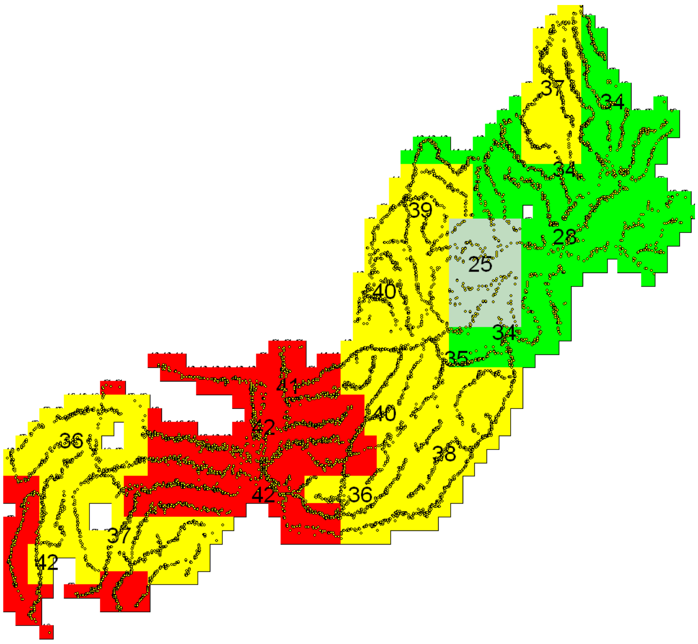

Figure2: Degree of thinning (felled basal area / pre harvest basal area) calculated based on harvester data, example of user interface in harvester. Red color indicates very intense thinning (>40 %), yellow indicates intense thinning (35-40 %), green normal (25-34 %) and light green a low degree of thinning (<25 %). Black dots indicate harvester positions when felling.

Results

Comparisons of manual field measurements of thinning intensity to the automated follow-up by harvester data showed a good correspondence with a standard deviation of 2.8% (Hannrup et al 2011, 2015). The study also showed that strip road trees can be identified using crane angle data and thereby making it possible to estimate the thinning quotient with high precision. This means that the thinning quotient can be continuously monitored in an automatic system, which has not previously been possible.

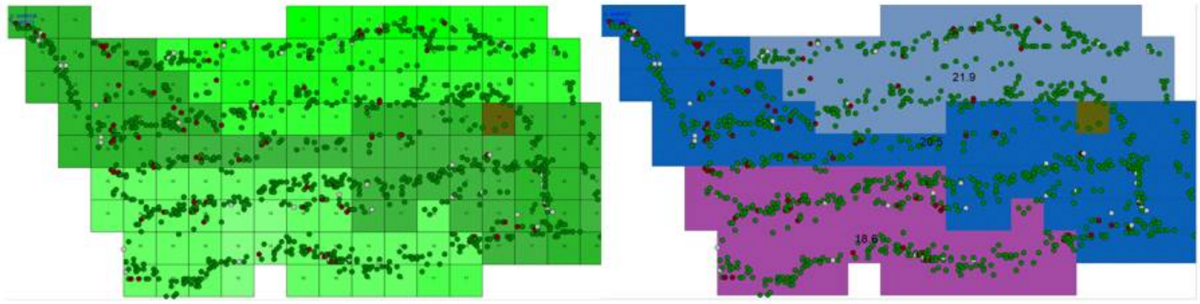

Figure 3: Automatic segmentation of harvesting site based on dominant height as measured by harvester, illustration to the left. Estimated basal area (m^2/ha) after thinning based on harvester data, figure to the right. The basal area is estimated for each segmented sub-area.

The systematic deviations for stand parameters like basal area, volume, DBH, number of stems and dominant height were small (<2.2 %) when comparing manual reference measurements with the figures estimated based on harvester data (Hannrup 2015). Standard deviation for the differences between reference measurements and harvester-based estimations were 12-13 % for basal area and volume after thinning. The corresponding values for basal area weighted DBH and dominant height were four and eight percent, respectively. Also the results for number of stems also gave a quite low standard deviation (15%). The species distribution based on harvester data corresponded well with the reference assessment on approximately 85% of the stands. Significant deviations regarding species distribution occurred in cases with dramatic differences between the distribution before thinning comparing with what was harvested (e.g. if all trees of a certain species were felled).
The precision of harvester-based estimation of basal area and volume was on the same level as earlier noted for inventories carried out with areal laser scanning (Naesset 2007). The most significant differences in precision between these methods are probably when estimating basal area weighted DBH and species distribution where both of these parameters can be estimated with a significantly higher precision using harvester data.

Conclusion/Discussion

Today basically all new StanForD2010 compliant CTL harvesters are able to report detailed production data. This means that the harvesters are sending the same data that are actually measured in the machines, consequently the receiver of data has full flexibility in analyzing the data. It is worth pointing out that this is basically the only time from planting to and industrial use that we measure each individual stem and log.

There are few limitations in the possibilities of improved utilization of harvester data as long as we limit ourselves to the present measuring techniques. However there are some important factors that always needs to be considered when planning to upgrade information systems:

- Control system software need to be regularly updated
- Mobile communication solutions that can handling quite large amounts of data
- Operator skills/experience and training has to be at the right level
- Measuring system needs to be well calibrated and continuously controlled

Taken together our studies indicates that the methods for estimating stand variables and to forecast assortment yield based on harvester data is of general usage and can be expected to give a high precision in practical forestry under most normal conditions that occur in Swedish stands. Based on these studies it is concluded that the methodologies have been sufficiently validated and that the methods can thus be widely implemented by Swedish forestry.

Both methods have been implemented by forest companies in Sweden. Other methods are tested as well and will most likely be taken in use in the nearest coming years.

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Improving forest-to-industry integration through digital descriptions of wood properties based on harvester data

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Introduction

What is done by forest inventory, harvesting decisions/agreements, production and logistic planning stand selection and bucking instructions is decisive for the start of several parallel value chains starting operationally by all CTL-harvesters responsible for producing roundwood products on one, or commonly several customers demand. At the planning stage, before harvesting a bucking simulator producing hpr-files (e.g. Skogforsk Aptan) based on total height, diameter and stem form of individual trees can be extracted by ALS or other forest inventory methods (Barth et al 2014). HprProp is a program module operating on ordinary harvested production files (.hpr), produced by all modern CTL-harvesters according to StanForD 2010 (Arlinger et al 2012). In addition to the hpr-file a complementary input of the number of annual rings at breast height (i.e. breast height tree age) of an average tree per species recorded for the entire harvesting object, selected parts of objects or even individual trees if available. The operational parts of the program are based on the diameter and length measurements performed by ordinary harvester felling heads, models for predicting the number of annual rings along the stem based on stem tapering (Wilhelmsson 2006), and some scientifically published models (Wilhelmsson et al 2002; Moberg 2006; Moberg et al 2006), some technical publications (Ekenstedt et al 2003; Hannrup 2004; Wilhelmsson & Moberg 2004) and some additional unpublished models for predicting stem, wood and fiber properties of industrial relevance.

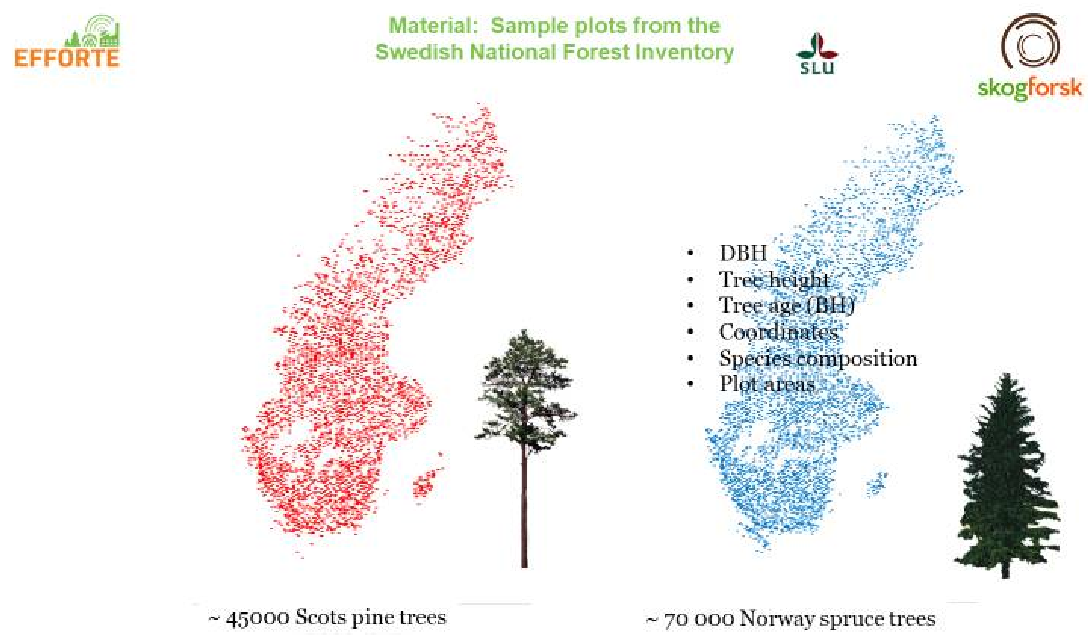
A CTL harvester felling head measure diameter and length continuously during stem processing. When tree age (today stand or calculation area averages) is added the wood and fibre properties of Scots pine and Norway spruce listed above (and some additional properties) can be predicted.

Materials and methods

Ordinary CTL harvester of all brands(colours) can produce hpr-files and consequently also producing suitable input for the Hpr programme modules including HprProp for predicting wood and fibre properties. The list above is continuously expanded with additional property models of industrial relevance and is also of interest for development of new property prediction models and machine learning systems for integrating harvester measurement, new measurement technology in harvesters and sawmill scanning frames (Including x-ray).

SpcsGrpName	SpcsGrpInfo	DBH	Lat	Long	Alt	Log Key	Assortm	Assortm Name	Destination	DiaToOb	DiaToUb	Length	VolPrice	VolOb	VolUb	DiamOb	Dens	HeartDiam	HeartPercent	Bark	Latewood	AnnGrRing	FiberLength	FiberWall	KnotTypePercent	MaxKnotDiameter	GreenDensity	BarkDensity	MinAnnGrRing	MaxAnnGrRing	LogPrice
Tall	1	294	60,26	17,75	51	1	SSTE:0218	SkinnsbS	Mottagn:	257	246	550	0,26	0,3493	0,2952	281	435	161	39	22	25	76	278	330	0	22,724	873	558	68	86	0
Tall	1	294	60,26	17,75	51	2	SSTE:0118	KastetSe	Mottagn:	229	222	520	0,2001	0,2425	0,2255	244	407	139	35	9	23	64	286	294	0	25,996	887	747	59	68	0
Tall	1	294	60,26	17,75	51	3	SSTE:0118	KastetSe	Mottagn:	200	193	415	0,1199	0,1446	0,1351	215	394	116	31	7	23	55	282	280	0	26,3197	896	773	50	59	0
Tall	1	286	60,26	17,75	52	1	SSTE:0118	KastetSe	Mottagn:	239	228	521	0,2111	0,3056	0,2557	270	430	153	38	22	25	74	277	329	0	22,2607	879	555	64	86	0
Tall	1	286	60,26	17,75	52	2	SSTE:0118	KastetSe	Mottagn:	221	213	416	0,1461	0,1725	0,1592	230	402	128	34	9	23	61	284	293	0	25,7231	893	743	58	64	0
Tall	1	286	60,26	17,75	52	3	SSTE:0118	KastetSe	Mottagn:	177	170	413	0,0931	0,1257	0,1169	201	392	105	29	7	23	51	279	279	31	26,0845	902	773	44	58	0
Tall	1	286	60,26	17,75	52	4	SSTE:1000	BM U-F	Mottagn:	120	115	428	0,07	0,0761	0,07	152	386	68	21	6	22	37	263	265	100	22,7552	907	789	28	44	0
Tall	1	286	60,26	17,75	52	5	SSTE:XXX	-	Mottagn:	13	10	430	0	0,0243	0,0221	91	384	27	9	4	22	21	228	247	100	14,4049	886	820	5	28	0
Tall	1	307	60,26	17,75	52	1	SSTE:0218	SkinnsbS	Mottagn:	280	264	461	0,2502	0,336	0,2797	298	438	172	40	25	25	77	278	333	0	22,5631	863	523	72	86	0
Tall	1	307	60,26	17,75	52	2	SSTE:0118	KastetSe	Mottagn:	236	228	522	0,2111	0,2693	0,2488	259	410	150	36	10	24	66	288	296	0	26,4317	878	725	59	72	0
Tall	1	307	60,26	17,75	52	3	SSTE:0118	KastetSe	Mottagn:	194	187	413	0,1126	0,1469	0,1371	216	391	116	31	7	22	53	283	280	30	26,6732	894	768	46	59	0
Tall	1	307	60,26	17,75	52	4	SSTE:0118	KastetSe	Mottagn:	147	141	374	0,0578	0,0846	0,0782	172	385	82	24	7	22	40	270	267	100	21,9154	903	779	34	46	0
Tall	1	307	60,26	17,75	52	5	SSTE:XXX	-	Mottagn:	39	35	374	0	0,0307	0,0279	113	383	40	13	5	22	25	242	252	100	13,3027	895	805	9	34	0
Gran	2	154	60,26	17,75	49	1	SSTE:1020	GM U-F	Mottagn:	81	76	525	0,0686	0,0766	0,0686	135	425	86	44	7	27	60	279	282	10	14,753	849	813	27	86	0
Gran	2	101	60,26	17,75	50	1	SSTE:1020	GM U-F	Mottagn:	78	74	406	0,0266	0,0297	0,0266	94	443	56	39	5	31	64	269	281	0	17,9207	881	840	41	86	0
Tall	1	225	60,26	17,75	51	1	SSTE:0118	KastetSe	Mottagn:	195	184	413	0,109	0,1599	0,131	215	439	118	36	20	26	75	267	326	0	20,0741	910	584	64	86	0
Tall	1	225	60,26	17,75	51	2	SSTE:0118	KastetSe	Mottagn:	161	155	520	0,0976	0,1244	0,1135	179	407	94	30	8	24	56	273	287	0	23,7649	919	762	48	64	0
Tall	1	225	60,26	17,75	51	3	SSTE:1000	BM U-F	Mottagn:	120	115	493	0,0718	0,078	0,0718	143	394	65	22	6	23	41	262	268	58	22,8583	919	795	33	48	0
Tall	1	225	60,26	17,75	51	4	SSTE:1000	BM U-F	Mottagn:	54	51	396	0,0248	0,027	0,0248	95	389	31	11	4	22	25	236	251	100	17,0387	901	827	14	33	0
Tall	1	270	60,26	17,75	50	1	SSTE:0118	KastetSe	Mottagn:	242	230	433	0,1774	0,2484	0,2064	261	440	147	38	23	26	76	274	332	0	21,4067	886	549	69	86	0
Tall	1	270	60,26	17,75	50	2	SSTE:0118	KastetSe	Mottagn:	202	195	521	0,1544	0,1983	0,1822	223	409	125	34	9	24	62	282	294	0	25,1978	899	743	54	69	0
Tall	1	270	60,26	17,75	50	3	SSTE:0118	KastetSe	Mottagn:	156	150	491	0,0861	0,1177	0,1087	181	392	91	27	7	23	48	274	276	45	25,2908	909	776	39	54	0
Tall	1	270	60,26	17,75	50	4	SSTE:1000	BM U-F	Mottagn:	81	77	450	0,0459	0,0501	0,0459	127	386	51	17	5	22	31	252	259	100	20,8633	906	805	19	40	0
Gran	2	210	60,26	17,75	51	1	SSTE:0120	Heby Kv1	Mottagn:	191	181	525	0,1338	0,176	0,1587	203	414	143	55	11	25	72	291	288	0	20,5336	822	778	64	86	0
Gran	2	210	60,26	17,75	51	2	SSTE:1020	GM U-F	Mottagn:	146	138	493	0,0971	0,1087	0,0971	171	407	110	46	9	24	53	292	281	1	23,2789	819	791	42	64	0
Gran	2	210	60,26	17,75	51	3	SSTE:1020	GM U-F	Mottagn:	81	75	510	0,0495	0,0562	0,0495	120	402	63	31	8	24	33	276	267	100	18,5577	814	811	22	42	0
Gran	2	98	60,26	17,75	52	1	SSTE:1020	GM U-F	Mottagn:	70	66	467	0,028	0,0313	0,028	89	443	52	37	5	31	62	267	280	0	17,7992	881	841	35	86	0
Gran	2	95	60,26	17,75	51	1	SSTE:1020	GM U-F	Mottagn:	72	68	470	0,0271	0,0303	0,0271	88	445	51	37	5	32	63	267	280	0	18,2181	884	841	39	86	0
Tall	1	262	60,26	17,75	50	1	SSTE:0118	KastetSe	Mottagn:	234	222	413	0,1587	0,2212	0,1819	253	439	142	38	23	26	76	273	332	0	21,0438	890	551	68	86	0
Tall	1	262	60,26	17,75	50	2	SSTE:0118	KastetSe	Mottagn:	201	193	413	0,1199	0,1502	0,1373	218	410	121	33	9	24	62	281	295	0	24,9113	902	738	56	68	0
Tall	1	262	60,26	17,75	50	3	SSTE:0118	KastetSe	Mottagn:	164	157	432	0,0827	0,1132	0,1047	184	394	94	28	7	23	50	275	279	25	25,1288	910	773	43	56	0
Tall	1	262	60,26	17,75	50	4	SSTE:1000	BM U-F	Mottagn:	96	92	528	0,0693	0,0754	0,0693	136	387	57	19	6	22	34	257	263	100	22,4726	910	798	23	43	0
Tall	1	268	60,26	17,75	49	1	SSTE:0118	KastetSe	Mottagn:	231	219	521	0,1947	0,2717	0,2273	255	436	144	38	21	26	75	275	325	0	21,8831	888	574	65	86	0
Tall	1	268	60,26	17,75	49	2	SSTE:0118	KastetSe	Mottagn:	196	189	413	0,115	0,1427	0,1314	215	404	118	33	8	23	59	281	289	0	25,2328	902	752	53	65	0
Tall	1	268	60,26	17,75	49	3	SSTE:0118	KastetSe	Mottagn:	152	146	522	0,0866	0,1239	0,1143	176	391	87	26	7	23	46	272	273	53	24,2196	910	776	38	53	0

Above, a copy of parts of an ordinary output from HprProp, also including unique stem and log ID:s showing measured information, harvester operator's forced cuts (caused by stem faults/irregularities) and predicted wood and fiber properties of each log. Additional properties as carbon content, distance between branch whorls and predicted MOE/MOR have also been described (Wilhelmsson et al 2011).



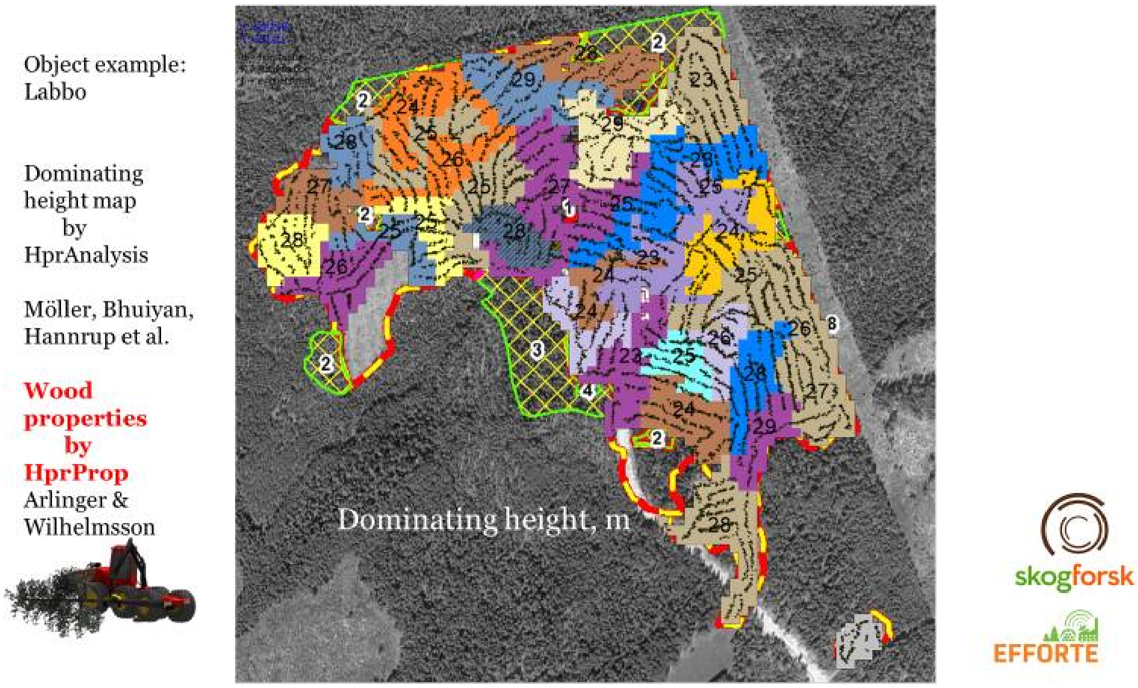
The Swedish National Forest Inventory (SLU) is a valuable source of detailed tree plot measurements distributed over all Sweden. In this analyses plots from 5 years inventory 2005-2009 have been analysed.

Simulated harvesting

A large number of measured trees from the National Forest Inventory plots (including individual tree age measurements or estimates) from stands mature for final felling have been virtually harvested by our bucking simulator (Skogforsk, Aptan). The produced hpr-files (simulated production) and added variance to cover the random variance component of individual trees not explained by the explainable fixed effects of the wood property models (Mixed models referred to in introduction). Based on detailed National inventory of specific sample trees, frequencies of inventory detected damage and faults were analysed.

Real harvesting

The same kind of analyses can currently be performed for objects with fair stand age estimates. Means and models for predicting stand age by height and site fertility and image analyses of log ends are also under development. The real harvester production files include al detected rot, forced cuts and downgrading decisions made by the harvester operator. Based on access to hpr-files from forest companies, Skogforsk are developing a large database of real hpr-files currently being processed to provide information on harvested trees and logs over all Sweden. More information is given by Möller et al (in these proceedings).



Example of detailed object information from harvester production as a basis for within object analyses of wood variation. In this case average breast height tree age was 56 years for 11% of the produced volume (higher fertility, pure spruce compartment) while it was 86 years in the remaining 89% of the produced volume.

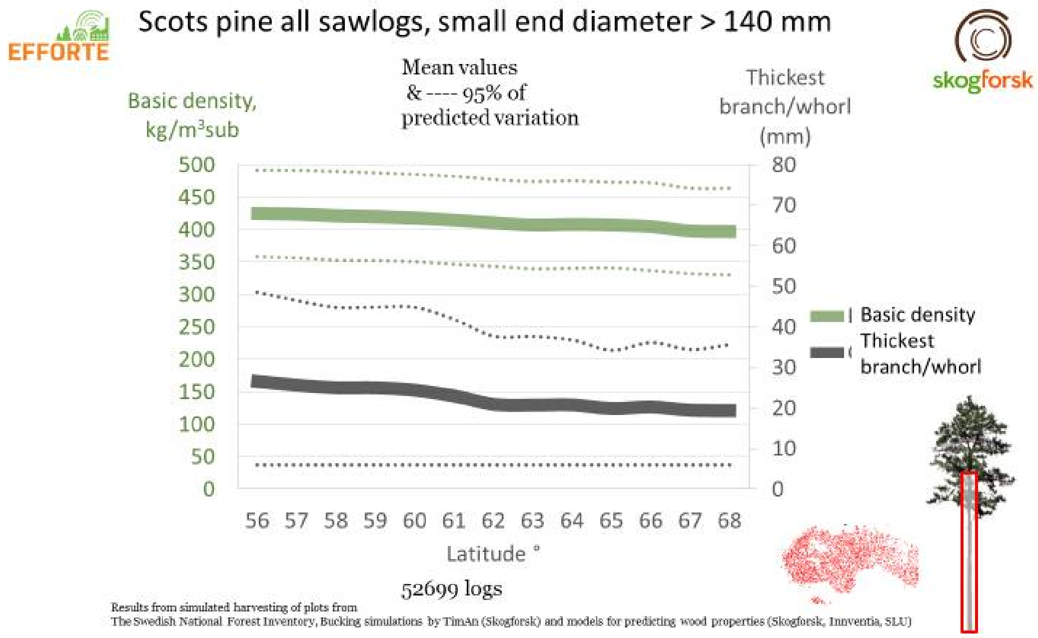
Results

In this short communication a series of slides shows different results based on analysis by the tools described above.

Simulated harvesting

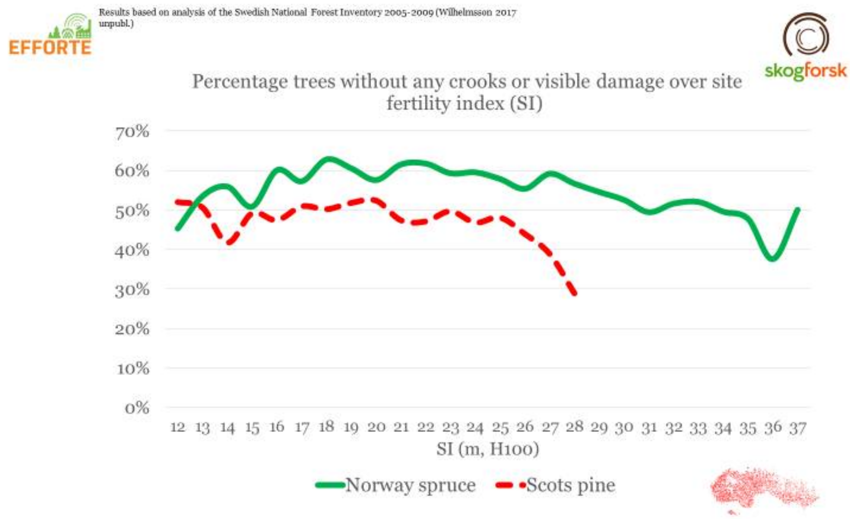
Example of results from simulated harvesting of Plots from the National forest inventory

The following results are examples from the simulated harvesting of plots from the National Forest Inventory. More examples of results are given in the slide presentation.



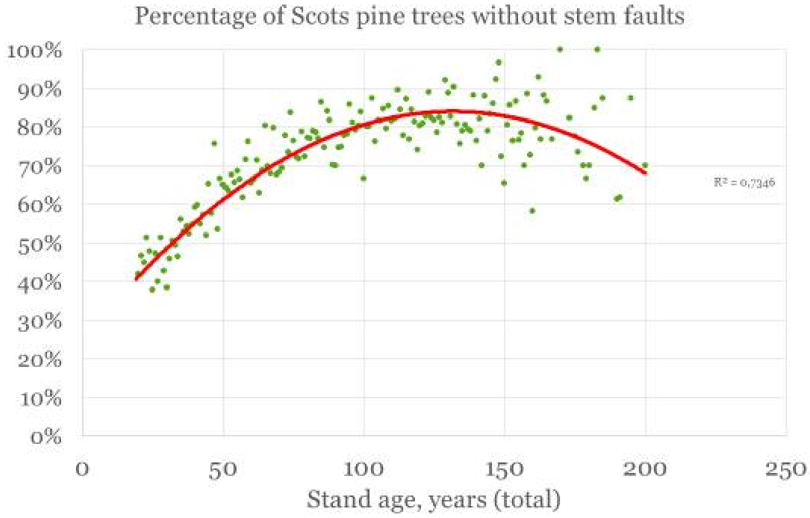
The "big picture" of averages and variation in predicted basic density (left) and thickest branch/whorl (right) over latitudes from southern to northern Sweden. Including predicted fixed and random effects (Wilhelmsson et al 2002 and Moberg 2006 respectively).

Analysis of inventory data on damage and faults detected during inventory of sample trees

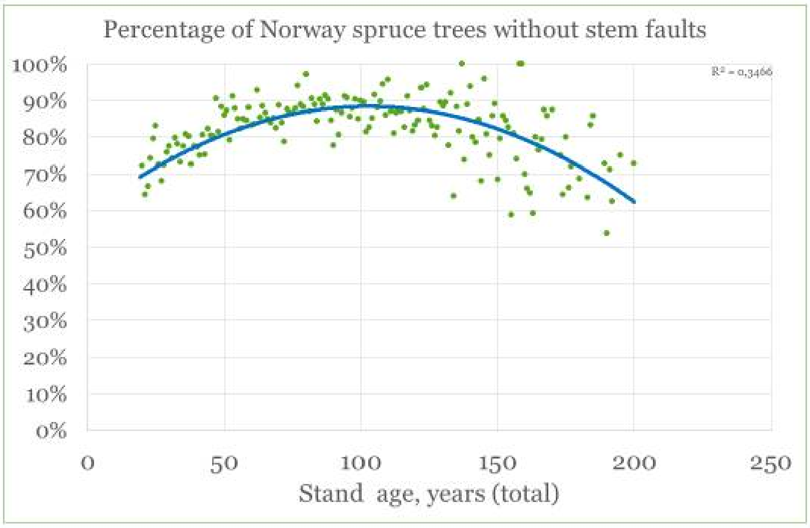


Compilation of Species and Site Index (SI) averages showing frequency of sample trees (National Forest Inventory) free from "non-acceptable crooks or visible damage up to 5-10 m from ground level depending on specific property.

Results based on analysis of the Swedish National Forest Inventory 2005-2009 (Wilhelmsson 2018 unpubl.)



Results based on analysis of the Swedish National Forest Inventory 2005-2009 (Wilhelmsson 2018 unpubl.)

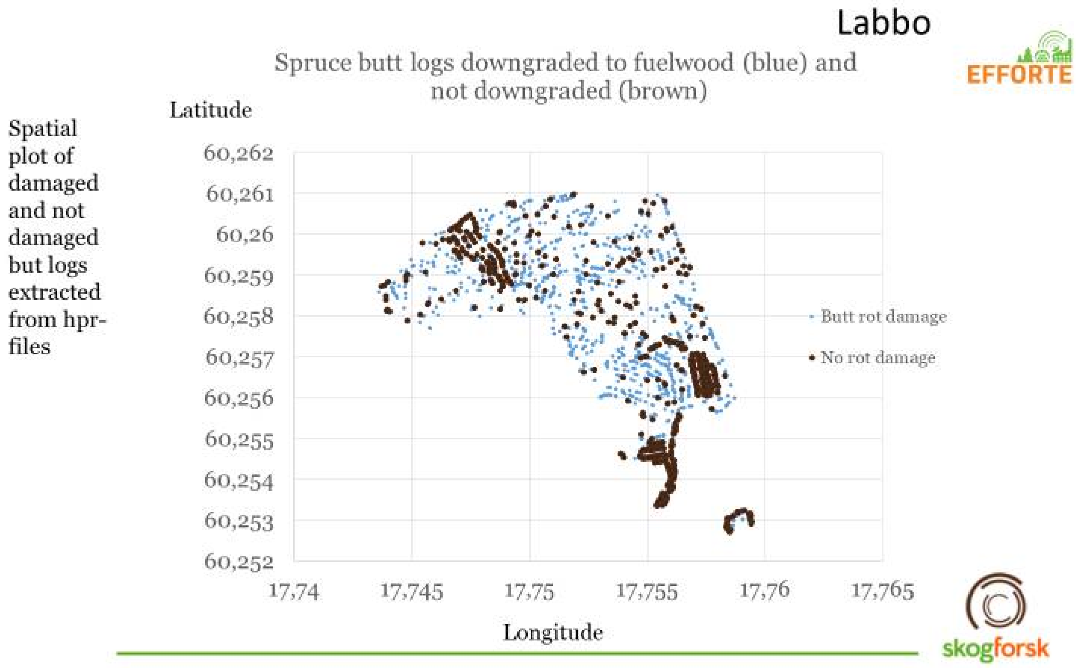


Compilation of relationships between stand age and observed frequency of sample trees free from visible stem faults (National Forest Inventory) including all ages of harvestable stems of Scots pine and Norway spruce respectively.

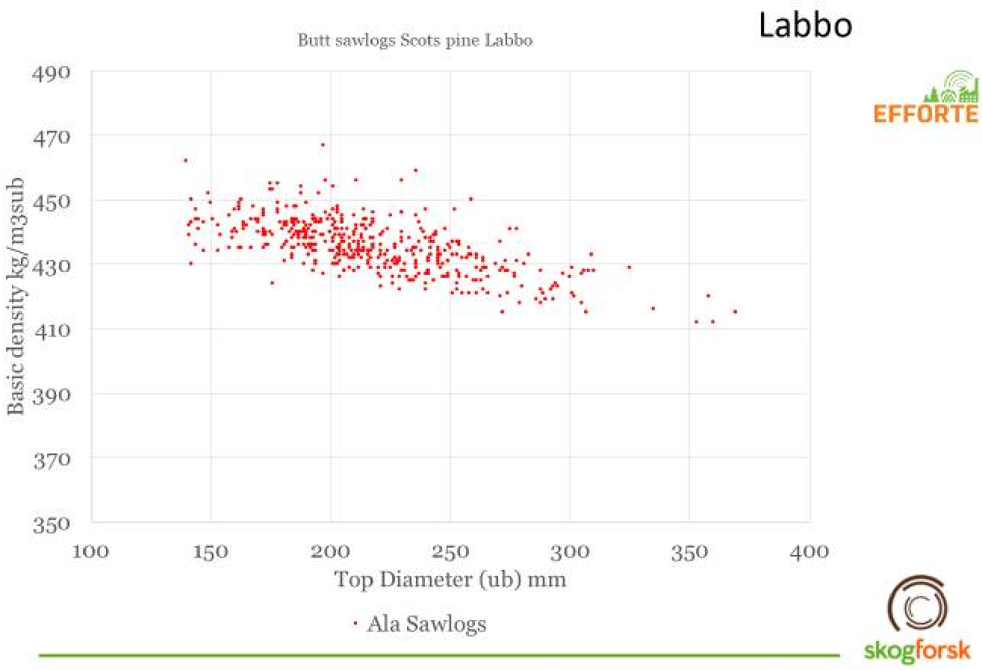
By detecting relationships between common averages and variations concerning stand variables and detected damages this can be analysed in relation to actual percentages of forced cuts from large scale statistics from harvester production. This possibility is included in another r Skogforsk project

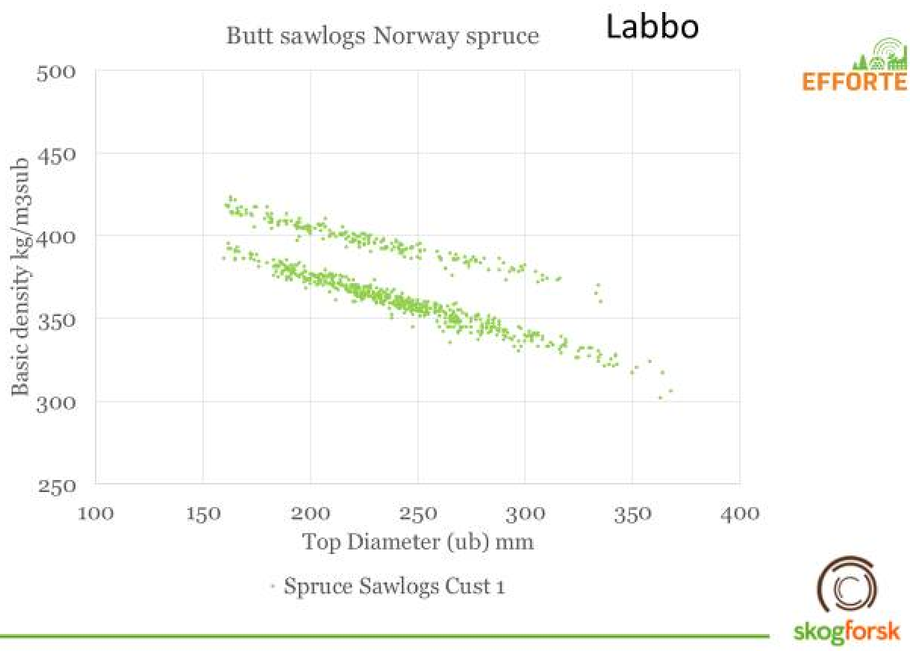
Real harvesting

Example of results from the Labbo harvesting object



Labbo object. Spatial distribution of downgraded Norway spruce butt logs dominated by the cause of butt rot and not damaged butt logs of spruce. White fields indicate pine or birch dominated areas without spruce. The frequency of damaged vs total frequency of spruce trees can be compared with other similar objects by imputation but also compared with reference levels based on the sample tree registrations by the National Forest inventory.





Predicted basic density of one sawlog assortment (fixed effects by HprProp, based number of annual rings and log end diameters) of Scots pine (One sawlog assortment) and one of Norway spruce. Labbo object.

Conclusion

Harvester production files can be used to present measured properties like log end diameter and tapering, height from ground and tree dimensions also relative to neighbouring trees. By HprProp and stand/tree age at breast height a considerable number of different properties can be predicted with medium to good accuracy at the individual log level and good average and deviation results at assortment and diameter class level. A new field of possibilities occurs when imputation of individual trees and harvester production files from "most alike objects" (See Möller et al in these proceedings) and combinations with sawmill scanning technology. "Big Information" may provide a small revolution in integration between forestry and industry, also including possibilities to calculate benefits and costs for different bucking regimes and logistic solutions.

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The potential and use principles of harvester production data as forest resource information

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1. Background

Harvesters are constantly producing large amounts of data of felled trees during the logging operations. Accurate measurement data of the stems together with GNSS location is a huge potential in generating detailed information describing tree stock properties and harvesting site conditions as well as in updating the forest resource information. In Finland the objective is to utilize the existing information of harvesting and other forestry operations in keeping up the public and open forest resource information provided by Finnish Forest Centre. Harvester data plays an important role in that. Forest companies also see the potential of the harvester data especially in describing and estimating the stock properties of the new harvesting sites. Harvester data can also be combined with other information sources, like ALS and TLS/MLS inventory data, x-ray measurements of sawmills and various type of stand and forest management history information. A key interest here is in developing models, which could be used in estimating the internal wood quality characteristics on either stand or tree level.

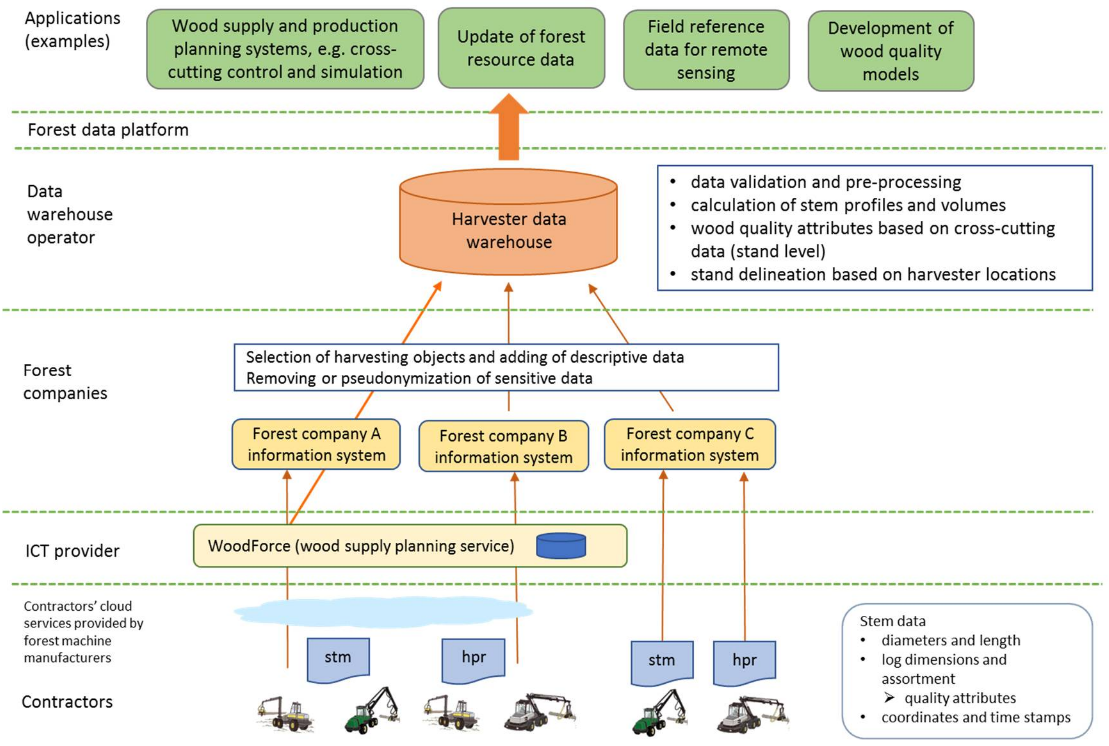
2. Harvester data warehouses

Implementation of StanForD 2010 data communication standard in the ERP's of the forest companies, in the planning and control services of harvesting workforce management and in the measuring systems of the harvesters makes it possible to acquire harvester measurement data efficiently and based on standardised data format. Main content of the harvester warehouses ("stem banks") is in the hpr files (or stm files of the old standard): stemwise measurement and log data and coordinates of the cut trees. However, saving the stem profiles and positioning is not a default setting in all the harvester systems.

Next is described how the harvester database can be constructed and maintained for the productional use based on the methods developed in the pilot project of Metsäteho. In the system development operational and business models of wood supply and existing IT systems need to be taken into account. Primarily harvester data warehouses are supposed to be company-specific, but especially for forest resource information purposes a third-party data repository can be created, provided that there will be a common agreement on the use and management principles of it. A prerequisite for it is that the data content of the database is restricted to the minimum and business sensitive and personal data is not included.

Acquisition of the harvester data to the database requires that there is an agreement on it between the contractor and the forest company defining also the data ownership and access rights. Collecting and saving the data should be as automatic as possible or at least the needed tasks in the machine must be instructed clearly. The data is transferred from the machines using mobile data communication services. For example, in WoodForce™ service this is a basic functionality and should not cause any extra actions for the operator. It might also be possible to transfer the files from the cloud service of a machine manufacturer, but for time being those services have not been used in Finland. To secure the transfer process, the size of the hpr files should be restricted.

Management and processing of the data can be done either in the IT system of the forest company or alternatively in a separate external service. This kind of tailored service or software does not exist yet in the market. However, the aim in the pilot project is to specify, build and test a cloud service based platform which would contain the database and the methods to process the data for it. Before the data is saved in a database, its quality (e.g. missing values or data errors) should be checked. The data is pre-processed with specified algorithms in order to save the stem profile information in a form of a taper curve function. New stemwise features (e.g. tree height and stem section volumes) and size class or site-specific key figures (e.g. sawlog percent or average quality grade breaks) can be calculated from the original data.



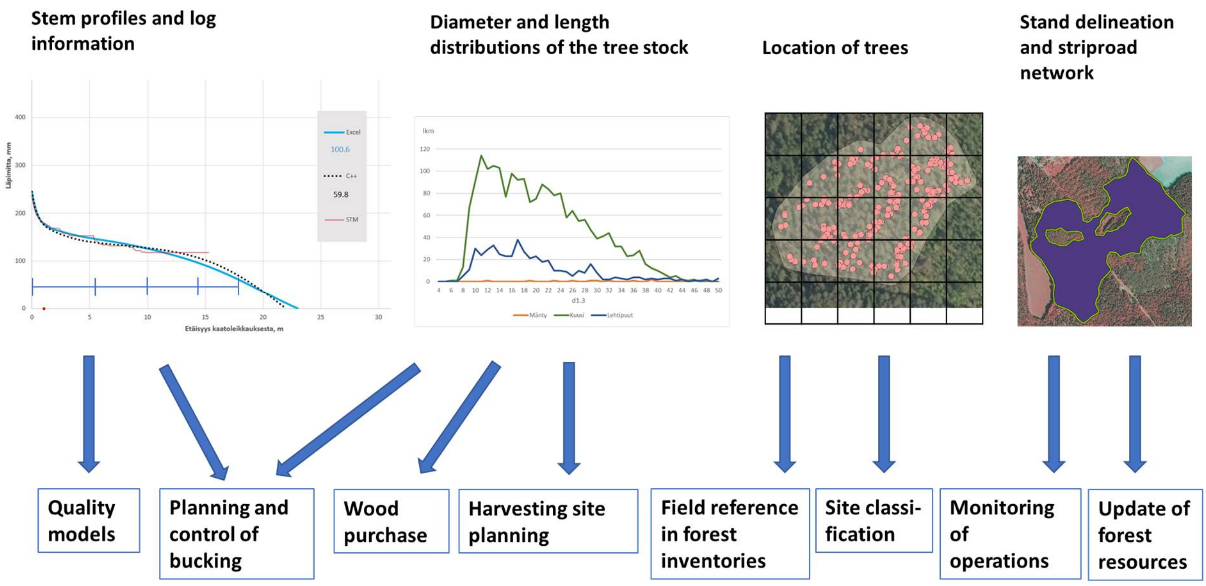
Picture 1. Different paths of the data from the harvester to the data warehouse and use applications.

3. Potential use areas and applications of harvester data

From the point of view of forest companies the system development focus is now in how harvester data can be applied in wood procurement planning, especially in making tree stock estimates of the new harvesting objects and in planning and control of bucking. This means preparing optimal bucking instructions (pin files) for different type of harvesting objects. A new planning service and tools are being developed which are based on the demands of the mills concerning log dimension and quality distributions as well as on bucking simulation of the estimated trees at the harvesting objects. Aim is to provide an precise tree-by-tree set with quality estimates of the harvesting object for the simulation process. Methods for this are being studied and tested. There is also a special interest in big data analytics and other data-based methods which could be applied in classifying the harvesting objects based on the stock attributes. Large amounts of harvester data combined with other information sources (e.g. x-ray data of logs or aerial laser scanning data) offer also possibilities to analyse the similarities of the harvesting objects based on big data methods and tools.

There is a particular interest in updating the open forest resource information offered by The Finnish Forest Centre by data of harvested stands *(described in presentation by Melkas and Riekki)*. This data could be transferred to the forest resource information management system or to the user applications via a specific forest data platform which also is under development in Finland.

One potential utilization area of stemwise harvester data is to use it as a field reference data in forest inventories. Traditional sample plot measurements could be partly substituted by “harvester sample plots” on the condition that the location of the tree data is accurate enough. This seems to require that the coordinates of the cut trees can be registered based on the position of the harvester head. Results from the studies that have been carried out recently have been promising, but shown also that there is a need for a post-calculation of the raw coordinate data that can derived from the harvester.



Picture 2. Potential forest information that can be derived from harvester production data.

4. Recommendation for common forest machine data use principles

A prerequisite for the wide use of the forest machine data is that the use principles have been discussed and agreed between the business parties involved in wood supply. Therefore, a recommendation for common forest machine data use principles has been prepared and published in Finland in 2017.

The joint recommendation of forest companies, machine entrepreneurs and machine manufacturers describes the general principles of ownership and use of forest machine information. The purpose of the recommendation is to clarify the rules of ownership and use of data and to promote the construction of applications and services based on forest machine information for the purposes of sector operators. Use of forest machine information most often calls for agreements between the owner and the user of the information, agreeing in detail on the production and use of data. The recommendation has been drawn up taking into account the requirements of competition legislation, and the purpose is not to harmonise agreement practices. Along with data ownership and use rights it takes into account the new requirements of the EU data protection regulation (GDPR).

5. Acknowledgements

Metsäteho has studied and developed the methods to utilize harvester measurement data in “Harvester data warehouse pilot” project (2016 – 2018) which has been conducted as part of research program “Forest information and digital services” of the Ministry of Agriculture and Forestry in Finland. Partners in the project are Tampere University of Technology, University of Helsinki and Finnish Geospatial Research Institute FGI.

Big Databases in forest planning and operations – New lidar campaign in Sweden

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Background

EFFORTE is a research and innovation project (BBI, Horizon 2020) providing the European forestry sector with new knowledge and knowhow that will significantly improve the possibilities of forest enterprises to assemble and adopt novel technologies and procedures.

The project aims at enhancing the efficiency of silviculture and harvesting operations; increasing wood mobilization and annual forest growth; increasing forest operations' output while minimizing environmental impacts; and reducing fuel consumption in the forest harvesting process by at least 15%.

The project is based on three key elements of technology and knowhow:

1) Basic understanding of fundamentals of **soil mechanics and terrain trafficability** is a crucial starting point to avoid soil disturbances, accelerate machine mobility and assess persistence of soil compaction and rutting. The key findings and recommendations of trafficability related to EFFORTE can immediately be adapted in all European countries.

2) Due to decreasing Cost-competitiveness of manual work and maturity of technology it is now perfect time to realize the potential of **mechanization in silvicultural operations**. EFFORTE pursues for higher productivity and efficiency in silvicultural operations such as tree planting and young stand cleaning operations.

3) 'Big Data' (geospatial as well as data from forestry processes and common information e.g. weather data) provides a huge opportunity to increase the efficiency of forest operations. In addition it adds new possibilities to connect knowledge of basic conditions (e.g. trafficabillity), efficient silviculture and harvesting actions with demand and expectations from forest industries and the society. Accurate spatial information makes it possible for forestry to move from classic stand-wise management to precision forestry, i.e. micro stand level, grid cell level or tree-by-tree management. EFFORTE aims at achieving substantial influence to the **implementation and improved use of Big Data within Forestry** and through this increase Cost-efficiency and boost new business opportunities to small and medium size enterprises (SME) in the bioeconomy.

EFFORTE researchers will develop and pilot precision forestry applications that, according to the industrial project partners, show the greatest potential for getting implemented immediately after the project. The project consortia include members from Finland, France, Sweden, Scotland and Switzerland.

One initial task was to review existing and future Big Data sources for forest planning and operations. This review is summarised in this abstract together with the plans for a new nationwide lidar campaign in Sweden as lidar data is considered as one key Big Data source for forestry planning and operations.

Material and Methods

Review of Big Databases in forest planning and operations

The focus on big datasets are linked to the objectives of the EFFORTE project, i.e. support to terrain trafficability, silvicultural and harvesting forest operations. The review process was performed natiowide with experts on geospatial data for forestry applications (Willén. et. al 2017). The current state of the art varies in each country and this was partly reflected in each country table.

This review includes:

- Existing data sources (country wise) of relevance for planning and wood supply in the forest industry. Everything is identified and described with regards to current and future accessibility, data quality, level of standardisation, and existing and future fields of application.

-Potential future data sources (country wise) are identified and assessed with regards to feasibility.

- A SWOT analysis (country wise) of all existing and potential future data sources.

- Conclusions including the outlook and the European dimension based on the experiences in Sweden, Finland and France. **This section is presented in the abstract.**

New nationwide lidar campaign in Sweden

The first nationwide laser data campaign in Sweden is almost finalised and a new initiative was started with representatives from the Swedish Forest Agency, SLU, Lantmäteriet and Skogforsk during 2016. The idea was to try to start a new nationwide lidar campaign as the first one covered almost all forested areas 2010-2015 and started to be outdated.

A meeting was set up in February 2017 with Forest Managers from all major forest companies, Lantmäteriet, SLU, The Forest Agency and representatives from the Swedish government. One incentive was possible co-funding from the industry if the laser scanning would start very soon. A steering group and a project team was selected from the interested organisations.

During the spring of 2017 several meetings was held, including detailed planning for a campaign starting 2018, including detailed technical specifications based on the experiences from the first nationwide scanning. It included cost assumptions of about 400 SEK/m^2 for a lidar coverage with about 1 lidar point/m^2. All results were communicated with the Swedish Ministry of Industry.

Results and Discussion

Review of Big Databases in forest planning and operations

Based on the country reports some common key datasets are identified for use in R&D to develop operational methods and tools in forestry for the Efforte objectives, table 1. They are not yet available in detail and nationwide in all France, Finland and Sweden, but may likely be soon.

The level of maturity and European dimension describes both the availability in European countries and the status in operational implementation. Further efforts are generally needed to exploit how the datasets may be utilized in forest operations and for the objectives in the Efforte project. Applications relating on forest machine data, VHR imagery and mobile laser scanning are candidates to potential future datasets that requires with both additional R&D in data collection and how to be utilized as decision support in forest operations.

Table 1. Key data sources identified for forest operations and planning

Datasource	Justification	Level of maturity and European dimension
Detailed digital elevation model[1]	A detailed digital elevation model is the bases for most terrain trafficability maps and a key parameter to avoid soil disturbances, accelerate machine mobility and assess persistence of soil compaction and rutting.	Available today in many European countries.
Lidar based forest estimates	Forest estimates such as timber volume or diameter is important in forest planning and wood supply. It is also a key factor in harvest operations and to perform detailed production planning, e.g. in terms of rutting. Lidar based forest estimates may be based on the same lidar collection as the detailed digital elevation model. New technique in data collection, e.g photon scanning will most likely make it faster and cheaper.	Available today in some European countries.
Soil maps	Soil maps may be further utilized in forest operations and for silvicultural operations and trafficability mapping	Available today in many European countries, but with varying spatial resolution that need further studies for implementation in forest planning.
Weather data and models	Weather maps and models plays an important role for the bearing capacity and could play an important role for more detailed planning of forest operations to avoid soil disturbances and for improved productivity in forest operations.	Available today in all European countries, but not included in forest operations models or decision support.
Road databases	For logistics, the road databases play an important role to plan wood allocation to industry, but also in getting access to planned forest to cut where roads conditions such as buoyancy is critical.	Available today in most European countries, but with different details.
Forest machine data	Current forest machines start to gather lots of data from machine condition, harvest and forwarder statistics. Other information, e.g. on trafficability may also be included and all together these datasources will play an important role to collect reliable and up-to-date information on forest operations.	Available today in some European countries. To be further studied in how to include in forest operations models or decision support.
VHR imagery (or UAV for more local analysis)	VHR imagery from satellites/aircrafts have the potential to both be used as imagery and produce digital surface models and then for forest estimates. The coming VHR initiatives, possible with a new business model, may produce far more frequent data than current sensors and may therefore be a potential important data source.	Available today in all European countries, but not included in forest operations models or decision support.
Mobile laser scanning (future applications)	Laser scanning produce reliable data in forest applications and more details may be captured with mobile laser scanners. Details may include both ground conditions as well as details from the stems.	Available today in most European countries, but only tested in R&D.

New nationwide lidar campaign in Sweden

In September 2017 the national budget for 2018 included funding for a new laser scanning campaign. 10 MSEK is allocated yearly. The tendering process ended up with a cost of about 210 SEK/m^2 indicating a possible nationwide coverage in 7,5 years and shorter if co-funding from the forest

[1] Spatial resolution 1-5 meter

industry are included. The preliminary planning was performed for a 5-year coverage, but still indicate the scanning order covering most of the forested parts of Sweden, as shown in figure 1. End May 2018 the final instructions were delivered from the Ministry of Industry as part of the new national forest programme and the scanning started.

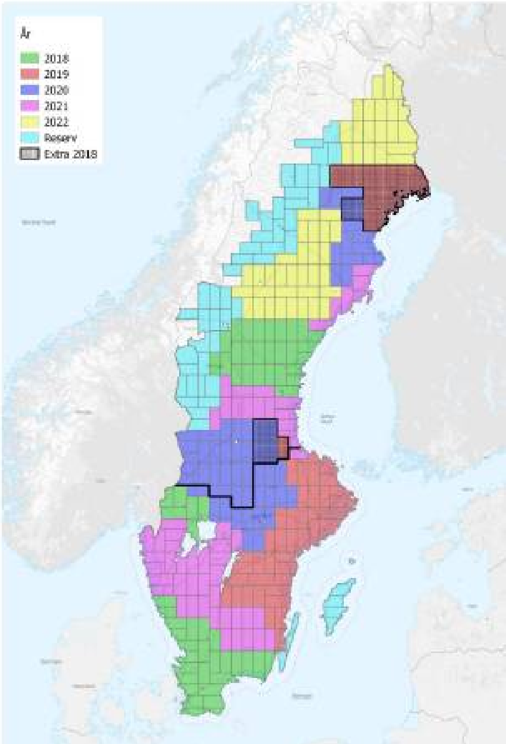

Figure 1. Preliminary order for the nationwide laser scanning campaign in Sweden.

The new coverage with forest estimates give the opportunity to map forest and forest growth in detail, but also the possibility to include the high quality forest estimates in recurrent forest planning at forest companies.

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Harvester head position data – how precise is it?

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Background

Data recorded at single-tree level can make a considerable contribution to improving tree growth models and biomass estimates at a larger scale. ALS data already provides the basis for most forest inventories in the Nordic/Baltic countries. However, accurate estimates of the position of the harvester head provide the key to linking ALS based estimates of tree volumes to what is actually measured and recorded in the StanForD files. Lindroos et al. (2015) provide a review of the need and potential for gathering improved estimates of the head position, while Hauglin et al. (2017) carried out tests with various GNSS configurations and compared the accuracy against those obtained from a measuring station. StanForD provides variables to hold data on the base machine position, machine heading and crane angle, and these are used in estimating the harvester head coordinates. Auxiliary information such as number of satellites and an estimate of GNSS precision is also stored. This data is largely dependent on the accuracy of the estimates of the base machine.

Material and Methods

We used standard information from the StanForD file data to estimate the accuracy of the conventional system on a Komatsu 911 harvester after clearcut harvesting. All slash covering stumps was cleared and the area was photographed using a DJI Phantom 4 UAV. A semi-manual procedure was first used in matching trees in the StanForD file with the stumps visible in the orthorectified aerial photographs after which the deviation was calculated. Secondly, a procedure was used to reposition the base machine onto the visible skid trail and the position of the stumps recalculated using heading and crane angle. Finally we fitted a Piksi Multi GNSS receiver coupled to a base station to the machine in order to get RTK fixed positional estimates on the harvester, and used these as the basis from calculating the position of the trees.

Results and Discussion

Results of both tests will be presented in a later version of this abstract and at the workshop.

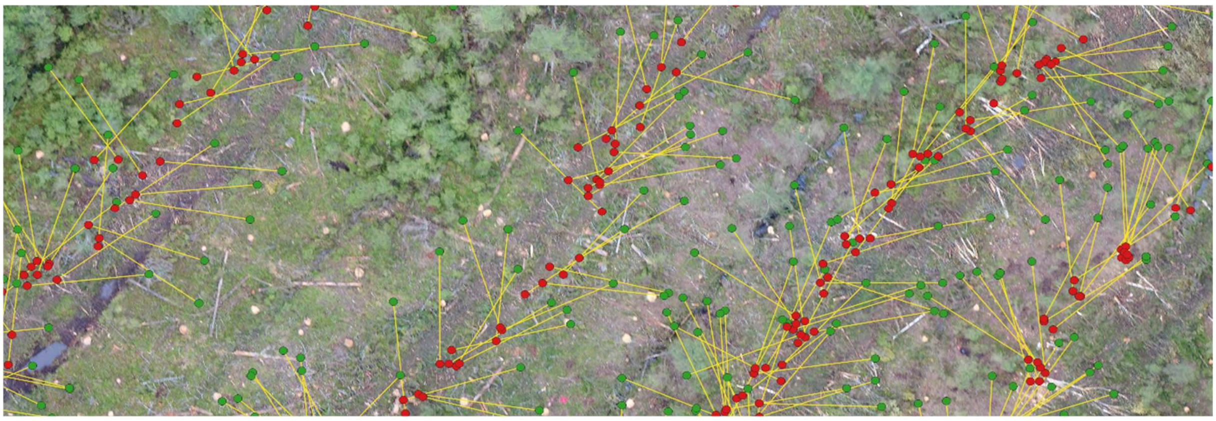

Figure 2 An example of how the tree positions (green dots) are calculated from the position of the base machine (red dots).

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