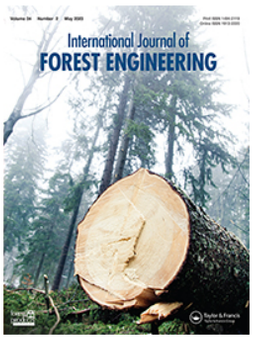

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The role of harvester measurement in the wood supply chain

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ABSTRACT

Forest industries manage their wood supply chains for sustainability, efficiency, and value creation. Roundwood measuring is a crucial part of wood procurement to achieve the best total value and sharing of benefits between business partners in the supply chain. Industrial measurement is the dominant measuring technique used in Sweden, but the use of harvester measurement has gained increasing interest over the last decade. In this study, we analyzed how harvester measurement affects the wood procurement process regarding operations, supplier relationships, and total costs. The data was gathered through interviews with the analysis being supported by theoretical frameworks of lean thinking, supplier relationship management, and total cost of ownership. Harvester measurement has the potential to increase incentives for the purchaser to preserve the value created and improve control of the supply chain, thus leading to more efficient resource use. It also improves supplier relationships due to a simpler price list, which ultimately increases transparency. Lastly, forest industries may increase their profitability levels and competitiveness due to increased supply chain surplus and reduced total costs. Further research on quantitative measures is required to assess the significance of these effects, as well as the entire sustainability impact on the wood supply chain.

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Forest industries; operation management; supplier relationship; supply chain management; total cost; wood procurement

Introduction

Forest enterprises are facing the challenge of constantly improving and coordinating the efficiency of wood supply chains (United Nations Department of Economic and Social Affairs 2021). Wood procurement is a key part of these supply chains, where measurement, inspection, and valuation of the roundwood are crucial components. Different measuring techniques can be applied to determine the roundwood value at different points in the procurement process, either at the industry such as sawmills of biorefineries, or in the forest (Wilhelmsson et al. 2019). Measurement in the industry is a common method in many countries and is the dominant model in Sweden to use as a payment basis for both log-to-log and pile measuring. However, outside the Nordic countries, measuring standing timber for sale within the forest is the typical business model wheremeasurements are taken before harvest and not at the industry (FAO, ITTO, and U.N. 2020).

In Sweden, interest in using harvester measurement as a payment basis has increased over the last decade. Harvester measurement refers to using the harvester head measurements to determine the value of the roundwood to settle the supplier's payment. Industrial measurement refers to using measurements taken at the industry to determine the roundwood value (Wilhelmsson et al. 2019). An important difference between the two measuring points is that industrial measurements refer to an assortment price list, containing different prices for different dimensions and log qualities. Meanwhile, harvester measurements refer to a stem price list where the price is calculated as per unit volume, such as SEK per cubic meter under bark. However, the effects of choosing either of these measurement techniques as a payment basis are not yet fully understood in terms of operations management, supplier relationships, and total costs.

The industry is seeking to streamline wood procurement practices given that they contribute to two-thirds of sawmill costs for their final products, and the raw material is also an important component of the end products. Wood procurement management is consequently vital for sawmills and other forest industries to remain competitive (Gustafsson 2006; Helstad 2006; Lindström 2020). Malladi and Sowlati (2017) highlight the importance of operational planning related to product flow, storage, pre-processing, and vehicle scheduling within forest-related supply chain management. The authors also suggest that just-in-time management should be increasingly applied in forest supply chain planning. However, despite its importance, the wood procurement process has not seen much change or implementation of new practical, operational, or managerial techniques (Keipi 1978; Harstela 1997; Sikanen 1999; Helstad 2006; Scholz et al. 2018).

Björheden and Helstad 2005) highlight that the roundwood procurement process is vital for further processing stages and ultimately for the supply chain's value creation and competitiveness. Industry measurement use obsolete price lists which may not allow for maximum value creation during bucking, if the harvest is performed long after the contract is settled. However, harvester measurements allow for more flexible bucking since the stem price list does not affect the supplier's received payment. Helstad (2006) demonstrates that harvester

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measurement leads to improved management of information flows, logistics flows, and better supplier relationships, which leads to improved competitiveness.

The use of harvester measurement as a payment basis does not affect the measuring accuracy. However, it can increase the customer value, improve logistics flows, reform lead times, and redefine the risk a supplier takes when selling wood (Wilhelmsson et al. 2019; Helstad 2006). Despite the promising benefits of using harvester measurement as a payment basis for wood procurement, there is a lack of studies that have identified and mapped the operating differences between a procurement process for harvester measurement and traditional industrial measurement (Kremmerer and Labelle 2020). Prior research in the field has not investigated how harvester measurement influences operations management, supplier relationships, and total costs, resulting in a knowledge gap.

Therefore, the aim of this study was to identify differences between a wood procurement process where industrial measurement is used, to a procurement process where harvester measurement is used. The project aimed to identify the differences through analyzing activities, information flows, lead times, and cost drivers in both processes. This was undertaken to demonstrate how the operational management, supplier relationships, and total costs are affected when using harvester measurement instead of industrial measurement.

To provide an overview of roundwood management, the following sub-chapter details the key features of wood supply chains. The approach, conceptual framework, and methods are developed thereafter. In the results, the specific implications of harvester measurement are reported with comparisons to industrial measurement. The paper ends with a brief discussion and the conclusions of the study.

Forest industries wood supply chains

A typical supply chain for wood and wood-based products includes the forest operations, transport of raw material, processing, and further distribution to a secondary processing unit, or wholesale and retail facilities (Figure 1).

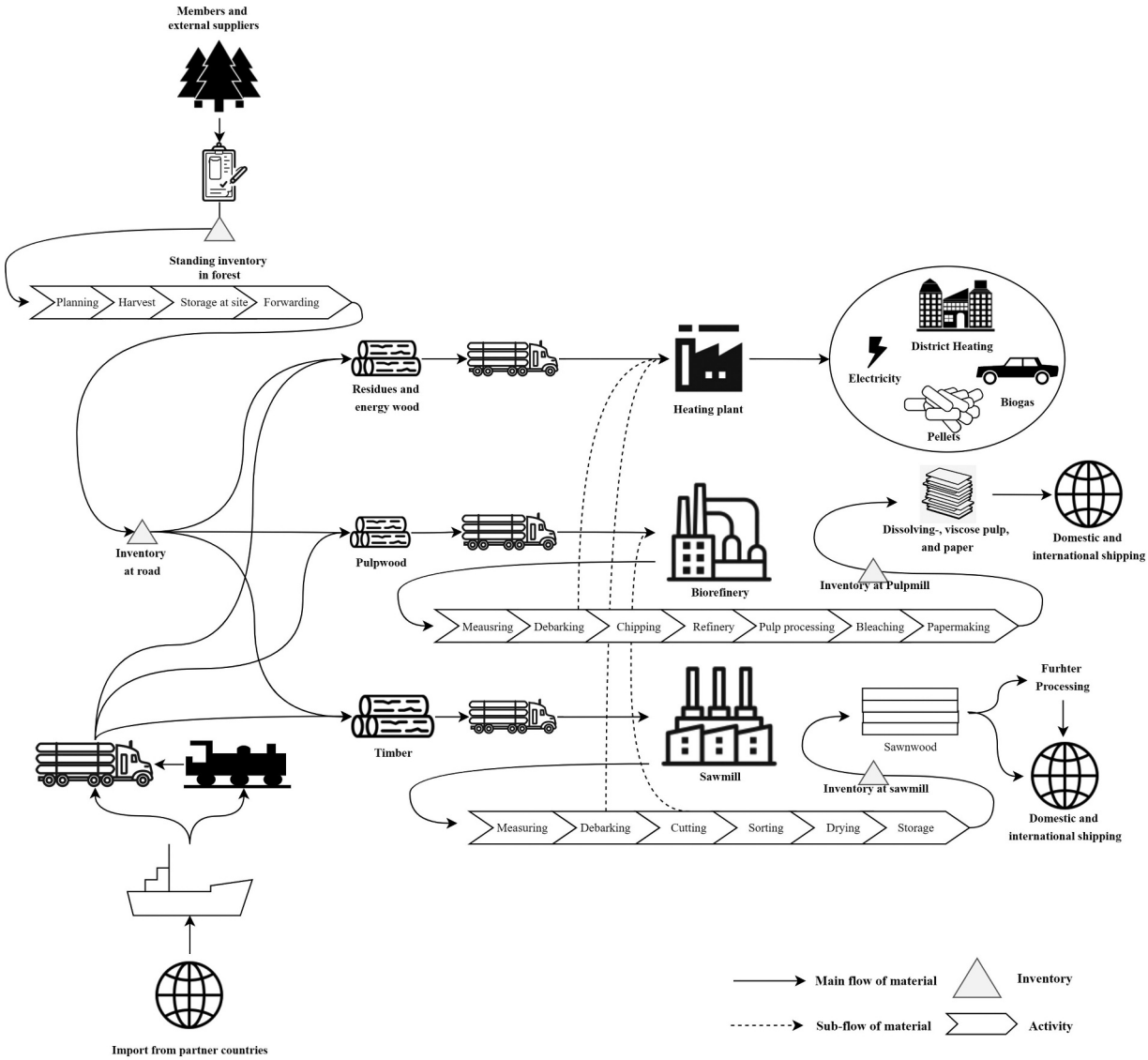

Figure 1. A typical wood supply chain from the supplier's raw material to the end customer's final products.

In the first step, a contract is typically formed between the supplier and purchaser. Then there is a harvest operation and forwarding to the inventory at the road, with the destinations being three main receiving facilities, namely sawmills, biorefineries, and heating plants. The Swedish industry is highly export-oriented, and a considerable number of wood-based products are sent for international shipping. The boundaries of this study were set to research the procurement process, from the time that a contract is formed until the roundwood arrives at the industry. In addition, this study only considers the cut-to-length system since that is the dominant cutting technique in Sweden.

The typical wood procurement process comprises a supplier who usually receives guidance and harvest propositions from a wood purchaser who coordinates the forest operations. The final felling and thinning are the operations that generate a flow of roundwood to the industry and income for the supplier. Figure 1 illustrates the key participants in the process with whom the purchaser must coordinate. A crucial dimension in these procedures is being transparent, reliable, and effective to gain the supplier's trust (Schnackenberg and Tomlinson 2016). These factors are important to consider when choosing, coordinating, and monitoring roundwood measurements to meet the suppliers' demand for fast and reliable payment. Not meeting the suppliers' demand may lead to considerably higher procurement costs or not being able to procure any material in the future.

Materials and methods

This study's approach included three stages, namely the selection of key theories and concepts, the identification of business processes, and analysis of the business process. A conceptual framework of key theories and concepts including lean management, the total cost of ownership, and supplier relationship management were constructed to support the analysis.

Conceptual framework

Lean management principles were used in the study framework because they conform to identifying less wasteful practices and represent a practice-oriented framework to study the key processes and work routines (Krajewski et al. 2013, p. 246). Womack and Jones (1996) define the concept of "lean" through four key principles related to defining value, mapping the value stream, achieving a pull system, and pursuing perfection in the system. Womack and Jones (1996) further argue that perfection is achieved by constant improvement of the organization and the removal of waste. Common types of waste are those described in the context of the lean concept of "muda." Muda is the Japanese word for wastefulness and describes waste in terms of overproduction, waiting, transportation, processing, excess stock, unnecessary motion, mistakes, and defects (Hines and Rich 1997; Heizer et al. 2017). The lean concept states that there are three types of activities in a process, namely value-adding, necessary but non-value-adding, and non-value-adding activities, while organizations should focus on removing the last type (Monden 1994). In this study we also assessed the cost structure and how costs are affected when harvester measurement is implemented. The concept of the total cost of ownership categorizes all the associated costs in a procurement process and was, therefore, included in the conceptual framework (Ellram 1993, p. 49–60).

The third theory of relevance for this study was the supplier relationship management (SRM) theory (Mitrega and Pfajfar 2015, p. 193–203; Forkmann et al. 2018, p. 4–16). Given that the costs for forest industries comprise procurement costs to a considerable extent, the price and supplier relationship have an impact on business success. Combining cost reduction and management of supplier relationships can improve competitiveness for all the partners in the supply chain. Promoting collaboration to create value for all parties may result in lower costs, reduced risk, greater efficiency, better quality, and improved access to innovation (Forkmann et al. 2018, p. 4–16). Including SRM in this study is essential to assess how harvester measurement influences the supplier relationship between the wood procuring organization and the forest owner.

Research approach

This study was a qualitative case study since this approach enables an understanding of processes and interactions, which lies in the focus of this study (Barratt et al. 2011). Qualitative methods are also more suitable where previous research findings are scarce and the field is relatively unexplored (Barratt et al. 2011; Yin 2011). This research used value stream mapping and activity-based costing (ABC) analysis to examine the key processes and cost implications (Kotzab et al. 2010). As shown in Figures 1 and 2, value creation encompasses several key operations and actors, whereas this study focuses on the processes from contracting until the roundwood arrives to the industry.

Data collection

Data was gathered from two main sources, Biometria and Södra Skogsägarna (Södra). Biometria is a central forest organization in Sweden set up by the Swedish government to ensure that the industry's measurement accuracy fulfills the necessary legal requirements. Södra is the largest forest owners' association in Sweden and has 22 local offices across southern Sweden. The local office for this study was Långasjö. These two organizations were chosen based on their experience of harvester measurements and traditional industrial measurement methods, their willingness to share primary data, and the organization-bound relevance for efficient procurement transitions. Biometria contributed with technical and system specific information regarding harvester measurements, and the forest owners' association, Södra provided detailed operational experience on harvester measurements. Both organizations were also given informed consent to use the data that they shared.

The data were collected using the semi-structured interview guide presented in Appendix 1, which was used in online interviews with the respondents. Collecting data using semi-structured interviews is a common method within case studies where there is a need for flexibility and adaptation (Robson 2011). This was necessary in this case given that previous

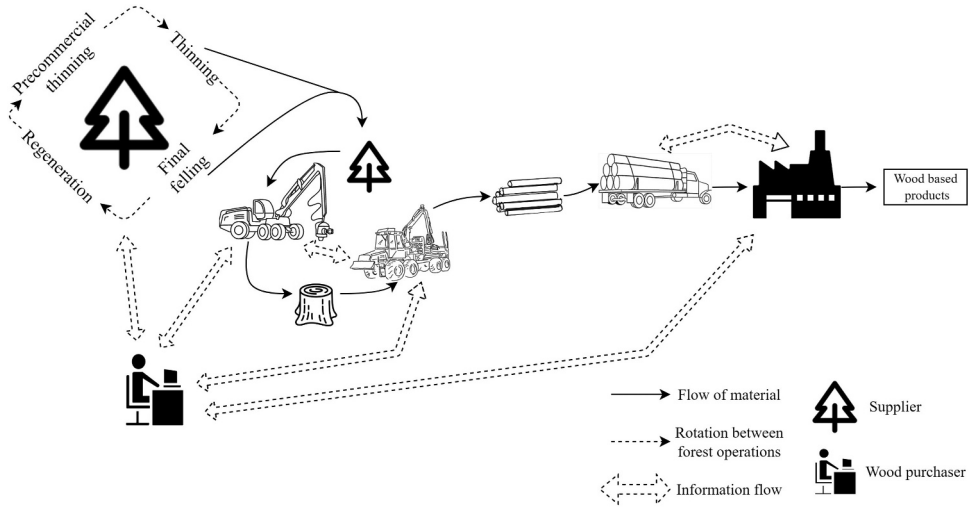

Figure 2. The typical procurement process from the standing forest to operation, transport, and further processing.

research on harvester measurement is relatively scarce. The interview guide was designed to encompass six themes related to the aim and conceptual framework of the study with open questions. The questions were formulated in an open way to increase the chance of obtaining any unknown information on procurement processes. Direction during the online interviews was moderated to help the respondents to stay on the topic, which was necessary given that open questions can cause the respondents to move away from the topic (Robson 2011). Overview of collection of data from each interview is presented in Table 1.

Respondents were selected using a non-randomized approach and four criteria for participation were selected to ensure the reliability of the data being collected. To be selected the respondent had to be involved in the procurement process and have knowledge of costs and cost drivers within their area of work. The third stipulated that the respondents had to be aware of the time required for each activity within the process. The respondent also had to be willing to participate in the interview, in terms of formalized informed consent.

Five respondents were selected at Södra with the help of a project leader. Three respondents from the Långasjö local office of Södra were elected due to their relatively lengthy experience with harvester measurement. Two respondents were selected from the Södra Industry to obtain more detailed information about the last steps in the procurement process. One respondent from Biometria participated because all the data on roundwood measured in Sweden needs to be transferred through their systems. Validation of the data was undertaken by sending back any observed contradiction, uncertainty, or any other type of question in the empirical material to the respondents for them to either clarify or confirm that the information had been presented correctly.

The online interviews were conducted over a relatively short time and only reflects the state of the procurement process at that particular time.

Methods for analyzing the empirical data

Value stream mapping (VSM) is a lean management tool meant to create a visual map of all the necessary components in a process (Hines and Rich 1997; Krajewski et al. 2013, p 251–254). Based on the collected data, two VSM's were created to give an overview of the procurement process with estimated lead times from the respondents and the total time required for one process cycle. The first VSM described industry measurement. In lean terminology, this map corresponds to the initial, "as-is" VSM. The second VSM is defined as a "to-be" VSM. The two VSM depictions can then be compared concerning the evaluation criteria.

VSM was created for the current, "as-is" procurement process based on industry measurements. The processes underpinning a potential harvester measurement were described in a "to-be" VSM displaying the differences in activities, information flows, and lead times between processes.

An activity-based costing (ABC) analysis was performed to present the differences in terms of cost drivers between wood procurement processes. The purpose was to enable reasoning whether harvester measurement brings benefits in terms of the total costs to the procurement process. The ABC framework used for the analysis in this research is illustrated in Figure 3.

Table 1. The time and date of the interviews, the respondents' position, and the date when the validation was sent.

Respondents' position	Office or area	Date and duration	Validation date
Forestry inspector	Södra district office Långasjö	2021–04-09 (1:h)	2021–04-28
District manager	Södra district office Långasjö	2021–04-09 (45: min)	2021–04-28
Production planner	Södra district office Långasjö	2021–04-12 (45: min)	2021–04-29
Project leader	Södra industry	2021–04-12 (1:h)	2021–04-29
Bucking specialist	Södra industry	2021–04-13 (45: min)	2021–04-30
Head of development	Biometria	2021–04-15 (2:h)	2021–04-30

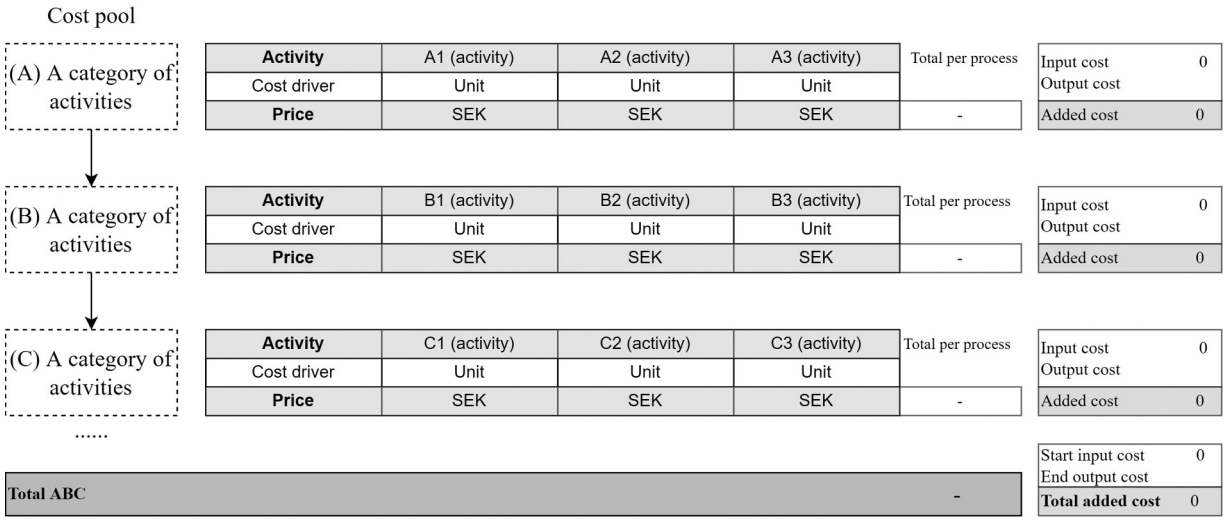

Figure 3. The ABC framework constructed for the cost analysis within the procurement processes, based on the framework by Kotzab et al. (2010, p 836).

The ABC analysis was performed by categorizing the key processes into cost pools. The cost drivers were then assigned to each activity within each cost pool. The total number of activity-related costs within each process was counted, and the corresponding cost of each could then be estimated. In this study, price values were not acquired from the interviews due to the observation unit's confidentiality terms and values were instead estimated based on public data. Costs for contracting, planning and final invoicing were estimated by calculating the hourly cost from Södra's Annual and Sustainability Report (2020); costs for harvest, forwarding, and transport were collected from the statistical database of the Swedish Forest Agency (2021). The estimated cost within each cost pool was summarized to present an estimated difference between industrial and harvester measurements (Kotzab et al. 2010).

Research quality assurance

This study relies on the four principles of trustworthiness to assure the quality of the research. The four principles of trustworthiness as described by Guba and Lincoln (1994) are credibility, dependability, confirmability, and transferability. The meaning of these principles and their application in the study are presented in Table 2.

Quality assurance ensures the trustworthiness of the research. Despite the quality assurance, the introduction presents prior knowledge about the topic in which the author must take a stand on when deriving the key conclusions. Thus, the study may be subject to subjective implications to some extent.

Results

The results include three stages: (1) VSMs of two value streams, "as-is" and "to-be," (2) Identification of differences in terms of activities, information flows, lead times, and cost drivers, (3) analysis of how the differences affect operations management, supplier relationships, and total costs.

Value stream of the process "as-is" with industrial measurement

The first "as-is" VSM analysis displays the procurement process when industry measurement is used as a payment basis. The mapping revealed seven main activities, five participants, thirteen information flows, and five stages of inventory during the process. Figure 4 presents the VSM, followed by a detailed explanation of the process in reference to the respective subprocess number in brackets.

As shown in Figure 4, a contract is established between the buyer, the forest inspector from the local office, and the supplier who is the forest owner. The encounter involves negotiating the contracting terms and management advice given by the inspector to the forest owner. After the contracting process, an inventory phase can be noted where the forest sites are contracted, and the trees are still standing.

Table 2. The four principles of trustworthiness, their meaning, and application in the study.

Principle	Meaning	Application in this study
Credibility	Respondents and their contributed empirical material must be correctly retold.	*Validation of the collected data.*
Dependability	Research must be independent of the researcher.	*Transparent respondent selection procedure and providing the interview guide in the appendix.*
Transferability	A complete and transparent accounting of all different steps within the research should be made to make extrapolation possible.	*A thorough description of the background of the project, aim, theory and method.*
Confirmability	Any researcher should ensure that no preconception has affected the result of the execution of the research.	*Strengthened by the applied theories and methods used, their origin and relevance for the study are argued for.*

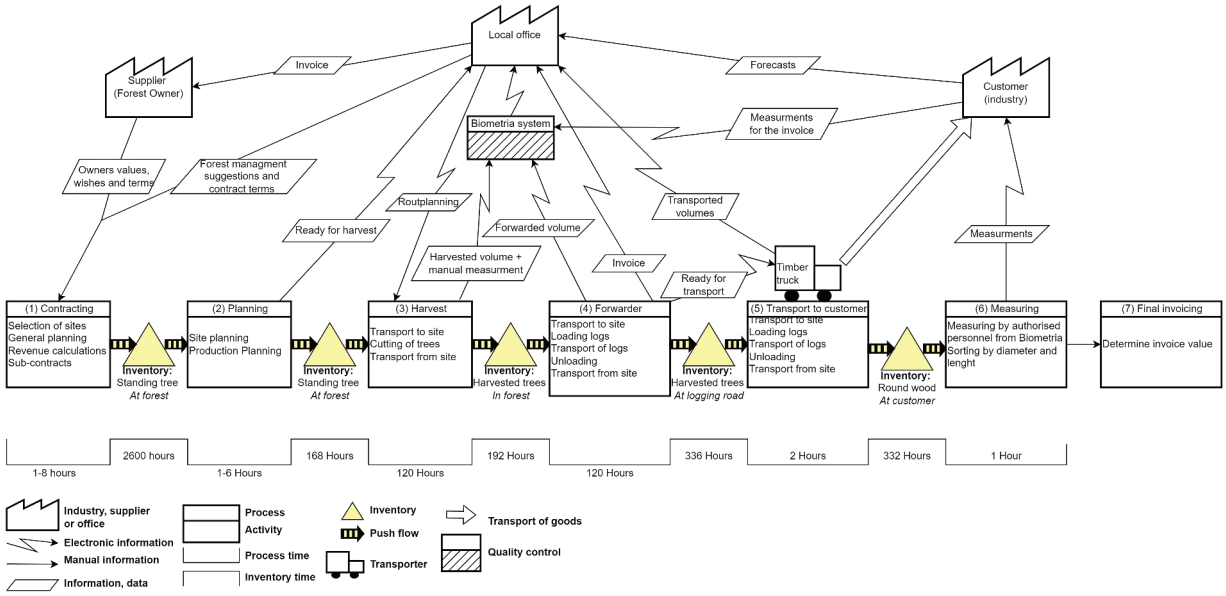

Figure 4. Value stream of the wood procurement process with industrial measurements. Each activity is numbered in brackets.

The contracting process (1) is followed by a planning process (2) where the forest inspector sets out the borders and routes for the harvest operations. Once the planning has been completed, the forest inspector sends a digital message to the production leader at the local office to notify them that the site is ready for harvesting. The inventory remains the same, although it may now be harvested at any time.

Once the harvest team has received the route planning information from the local office, the harvest process (3) begins followed by a period in the inventory where the harvested trees are stored at the site. The harvester operator takes one manual sample measurement per day to ensure accuracy of the measurements. The main information sent by the harvester comprises production data and volumes, assortment, and the manual measurements. Forwarding (4) begins during, or shortly after the harvest (3), and the harvested trees are then stored by the roadside and transported by truck to the industry. The forwarding operator sends data on the forwarded volumes to the local office. Once the process has been completed, an invoice is sent by the harvester team to the local office. Roundwood road transporters then receive a signal from the harvester team that the roundwood is ready for transport (5) to the industry. At the industry, the roundwood may be stored at the site before being measured, or it can be offloaded at the measuring station.

With industry measurement, the last operational step is to measure (6) the roundwood at the industry's measuring station before processing. This is also the point where ownership of the timber is transacted. The quality and value of the roundwood are determined, which then becomes the basis for the payment according to the contract's terms. Once the local office has received the data from the industry, the production leader can combine the invoice from the harvester team with the value of the roundwood received by the industry and carry out the net payment (7) to the supplier.

Value stream of the "to-be" process with harvester measurement

Figure 5 displays the corresponding VSM "to-be" procedure when the harvester measurement is applied as a payment basis in the procurement process.

Although the general process structure in Figure 5 is in line with that of Figure 4, there is some divergence. Contracting (1) is performed with a stem price list instead of an assortment price list. The harvester (3) operator must take two manual measurements per day instead of one measurement to ensure accuracy. The duration of the inventory at the logging road between stages (4) and (5) is normally longer because there are no stress to push the roundwood to the industry. No measurements at the industry (6) are needed to determine the payment to the supplier. Final invoicing (7) is done immediately after the forward (4) operation has been completed. The following sub-chapters highlight the differences in terms of the activities, information flows, lead times, and cost drivers.

Differences in terms of activities

Contracting (1) with harvester measurement as teh payment basis leads to fewer questions from the supplier since a stem price list is easier to understand than an assortment list. The stem price list is based on the volume measured and not the harvested assortments compared with the assortment price list. Harvesting (3) requires more manual measurements by the operator to ensure the measuring accuracy in the harvester head. The higher precision requirements are imposed since these measurements now determine the supplier's payment. Given that there is no assortment list that needs to be adjusted with changing demand from the industry, the bucking instructions can be instantly changed.

The final invoicing (7) occurs earlier since the cost from the harvesting and forwarding operations are known, as well as the

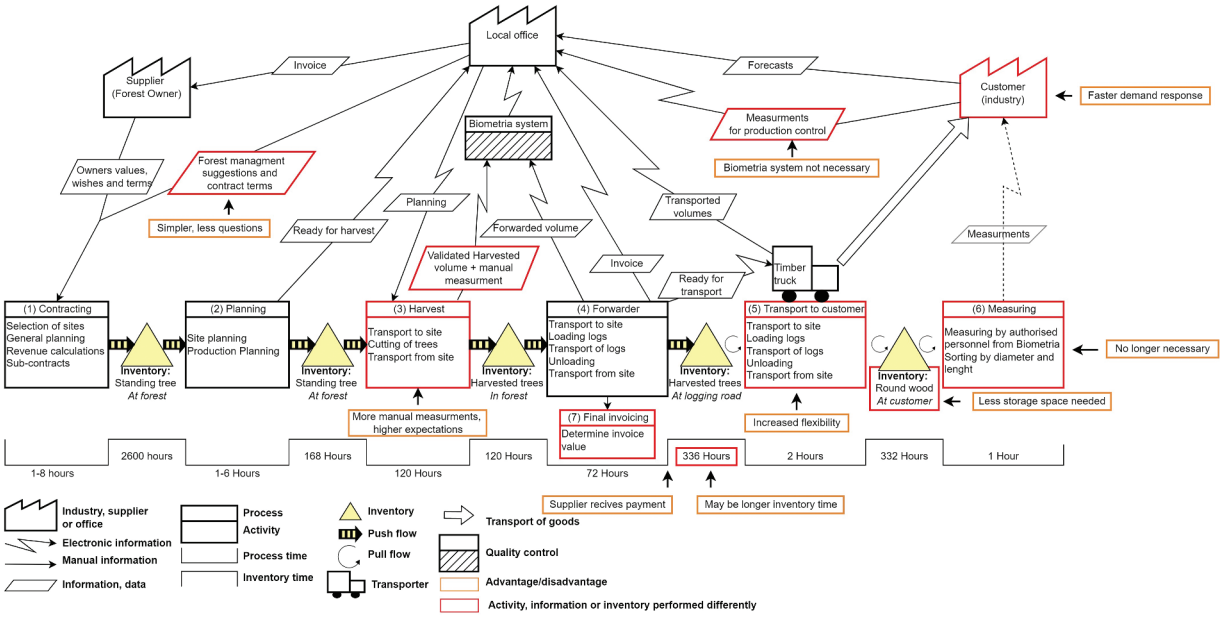

Figure 5. Value stream of the wood procurement process with harvester measurement. Each activity is numbered in brackets.

roundwood value. Therefore, the production leader can construct the invoice earlier and let the inspector send the payment to the supplier immediately after the forwarding (4) has been completed. The supplier also does not have to worry about reducing the value of the roundwood on its way to the industry. As an effect, the buying industry's officers receive fewer phone calls from the supplying landowners.

Differences in terms of information flow

The bucking instructions from the local office to the harvester (3) operator work more efficiently when harvester measurement is used given that there is no need to construct a more complex assortment list. The information can then be sent faster with a stem price list and also adjusted faster according to demand from the industry.

The information flow between the industry and the district office does not have to go through Biometria because the volumes are manually reported and are not used for the invoice to the supplier. No data is obtained for this process at the measuring station (6) to pass on to the industry. The manually transferred information from the purchaser to the supplier then becomes simpler. This is because there is no need to explain the assortment price list which is more difficult for a supplier to grasp compared to a stem price list. There are also fewer questions asked during the harvest because the roundwood has already been measured and the payment to the supplier has already been settled. Therefore, they are not affected by anything that may happen to the roundwood further down the supply chain.

Differences in terms of lead times

The local office mainly monitors time from contract (1) to harvest (3), time from harvest (3) until the supplier receives payment, and time from forwarded roundwood (4) to transport (5), to ensure a preferred safety inventory and to maintain a positive relationship with the supplier. There seems to be no difference between the two procurement processes concerning the time from contract (1) to harvest (3). However, there is a time difference from harvest (3) until the supplier receives payment and time from forwarded roundwood (4) to transport (5).

The time from forwarded (4) roundwood being at the road to transport (5) is likely prolonged given that there is no stress to reach the lead time for the payment to the supplier because it is not dependent on when the roundwood arrives at the

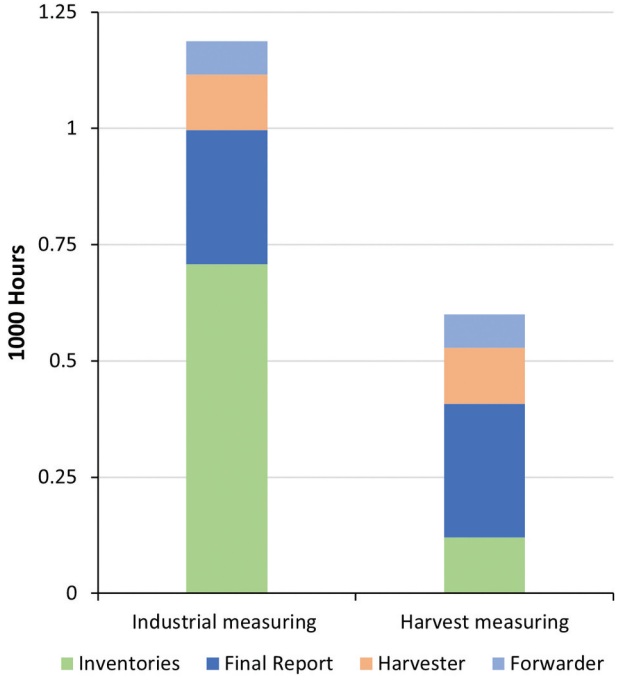

Figure 6. The lead time from the harvest to the point when the supplier receives payment.

industry. The time from harvest (3) to the supplier receiving payment is reduced from eight to four weeks (Figure 6).

(7) is that the invoice can be completed without having to wait for the measured volumes from the measuring station. The production leader must only wait for the reported costs from the harvester (3) and the forwarder (4).

Differences in terms of cost-drivers

The ABC framework illustrated in Figure 7 summarizes the cost drivers found within the procurement process with industrial measurement. The cost pools of the analysis are represented by the process activities, and the cost drivers for each of the respective activities were identified during the interviews. Due to confidentiality, only the number of cost drivers for each cost pool are presented in the figure and not the actual cost figures.

When industrial measurement is applied in the procurement process, a total of 23 cost-drivers were identified: four from contracting (1), three from planning (2), four from harvesting (3), four from forwarding (5), four from transport to the industry (6), and one cost-driver in the final invoicing (7).

Harvester measurement leads to several changes in the cost structure (Table 3). Measurement at the industry (6) is the only cost pool that completely disappears when harvest measurement is applied given that the measurements have already been completed during the harvest. Within the cost pool of final invoicing (7), adjusting the invoice becomes non-value adding and disappears since there are no volumes from the measuring station for these adjustments. Transport (5) flow to the industry can be arranged differently since there is no need to separate loads from different suppliers. Therefore, less distance may be required due to better flow planning. Contracting (1) changes slightly since less time is spent explaining the price list. There seems to be no change within the planning (2) activity. There was also no apparent change in the forwarding (4) activity. Harvesting (3) changes given that there is more

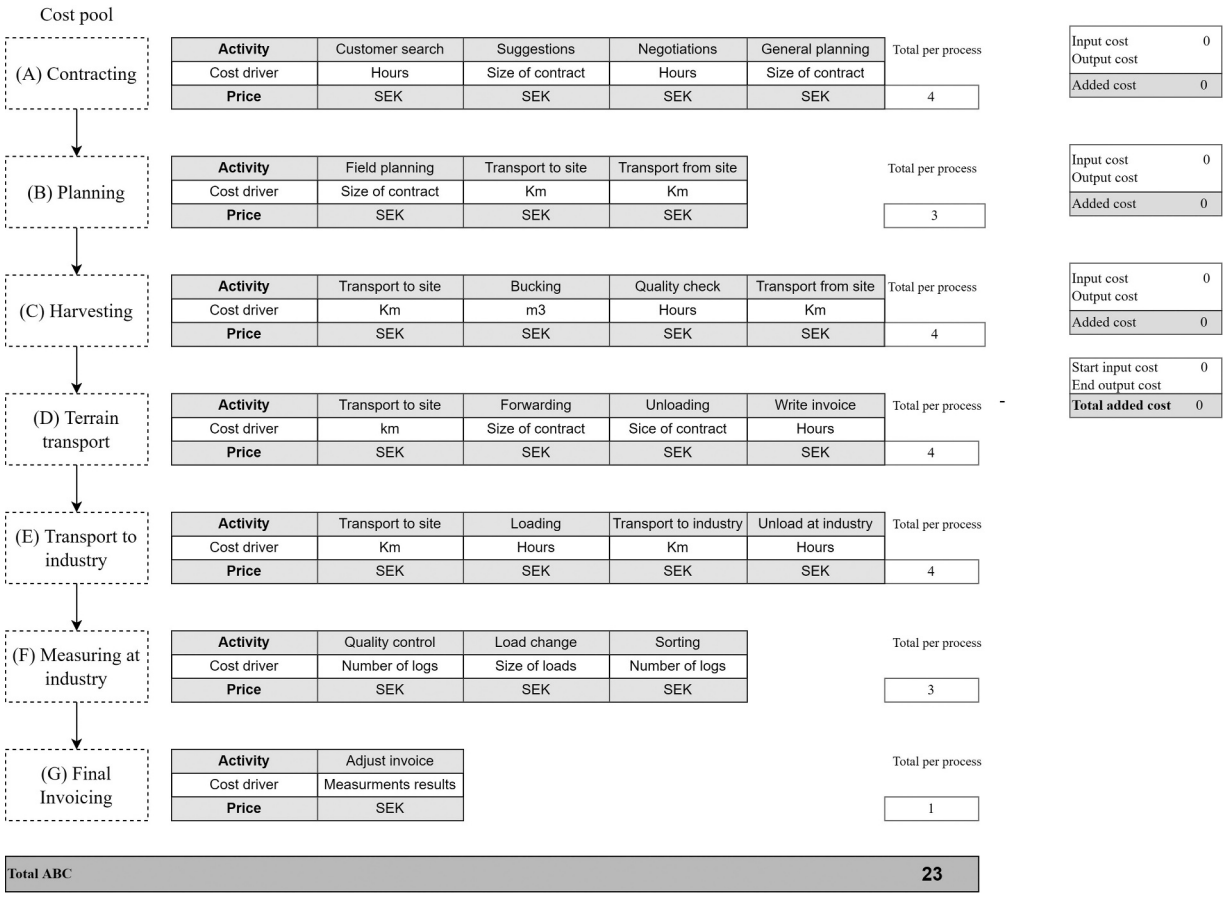

Figure 7. The ABC analyses include the cost pools, activities within the cost pools, the drivers of cost within each activity, and the total number of cost drivers.

Table 3. Differences in the activity-based costs in the procurement process when harvester measurement is used compared to industrial measurement.

Cost pool	Activity	Difference
Contracting	Suggestions and negotiations	Less time is required to explain the price list since stem-price is used
Planning		None
Harvesting	Quality control	More time is required for quality controls
Forwarding		None
Transport to industry	Transport flow	Less distance might be required to and from the site due to better flow planning
Measurement at industry	All	Disappears
Final invoicing	Invoice adjustments	Disappears

time spent on quality control. The operator performs two quality controls when using harvester measurement instead of one as with industrial measurement.

The total number of cost drivers is reduced from 23 to 19 when harvester measurement is applied. All three cost drivers, namely quality control, load change, and sorting from the measuring at industry (6) disappear, as well as the invoice adjustment in the final invoicing (7). This indicates that the supply chain surplus increases since there are fewer steps and less cost drivers in the process.

The effect on operations management

The **change of ownership** occurs earlier within the procurement process when harvester measurement is used given that the final invoice can be sent immediately after the forwarding has been completed. This influences how the management of the operation can be performed and most types of muda waste reduction as described by Heizer et al. (2017) can be identified.

Waste in terms of processing and waiting is reduced given that no measurements are required from the measuring station in the industry. Transportation waste may be reduced when using harvester measurement given that transport becomes more flexible. Transport planning can be undertaken without having to consider the lead time from harvest to supplier receiving payment. The transport flow can also be arranged differently since there is no need to separate the roundwood from different suppliers, whereas transportation waste in terms of time and fuel may be reduced.

The unnecessary motion of the production leader adjusting the invoice is reduced given that there are no reported volumes from the measuring station to use for the adjustments. According to the respondents, seven out of ten invoices must be re-calculated and adjusted. The respondents also mention that there is no need for the invoice to be reviewed by the production leader before it arrives at the inspector who sends it to the supplier. Lastly, when the forest inspector does not have to explain the assortment price list for the supplier, unnecessary motion is saved since the inspector does not have to take additional time to explain it.

Since the value of the roundwood has already been determined during the harvest, there is no need to measure it again in the industry for the procurement process. Furthermore, there is also no need to separate roundwood from different suppliers in the inventory since it is now owned by the buyer. Therefore, there are no loads to separate at the sorting station, increasing the sorting capacity by an estimated 15% according to the respondents.

The effects on the operation management regarding **inventories** was also observed due to these differences. Within the inventory at teh logging road, there is improved flexibility in the transport flow, improved usage as inventory, and a longer inventory time. The flow from the logging road becomes more flexible since the wood does not have to reach the measuring station at a certain time to fulfill the desired lead time and, therefore, becomes a pull flow. The flow from the logging road can also be adjusted better to match the industry's demand for the same reason. Inventory use may increase in terms of there being a longer inventory time to ease the stress on the inventory in the industry.

The effect on supplier relationship

With industrial measurement, the supplier takes all the risks in the value stream since he owns the roundwood until it reaches the measuring station. Therefore, everything that happens between the harvest and the measuring station will affect the payment to the supplier. In contrast, the buyer takes all the risks with harvest measurement since he owns the roundwood after it has been harvested. Therefore, the purchaser may be motivated to compensate for the increased risk by further improving the harvester technique to ensure that the maximum value is generated.

Due to the earlier change of ownership with harvester measurement, there is no risk of forgotten, stolen, shrunken, or biodegraded roundwood taken by the supplier. They also do not take any risk if the operator cuts the trees with a margin of error, if a harvester cuts to the wrong price list, if the roundwood is not separated correctly at the industry, if the forwarder separates faulty assortments at the road, or if there are any administrative mistakes in the value stream. Furthermore, the earlier change of ownership also generates improved cash flow for the supplier since he receives the payment approximately four weeks after the harvest with harvester measurement, instead of eight as is the case with industrial measurement. In contrast, the cashflow is worsened for the purchaser. And lastly, the stem-price list ensures that the supplier will not be affected if the operator has a margin of error when cutting trees since he is being paid per cubic meter and not by assortments.

The effect on total costs

Contracting, planning, and final invoicing may all be regarded as the acquisition cost. The differences observed indicate that less time is spent on contracting and the final invoicing due to a simpler price list, fewer phone calls, and there being no need to adjust the invoice. It is likely that the total time saved from all these activities is one hour per procurement. By applying published data (Södra 2020), the total costs for these three activities are estimated to decrease from 37.7 SEK/m^3ub to 36.7 SEK/m^3ub with harvester measurement. Harvest and forwarding costs are laid onto the supplier and should be regarded as sales costs. These activities are then estimated to increase from 106 (Swedish Forest Agency 2021) to 107.7 SEK/m^3ub.

Transport and measurement in the industry are transport and logistics-related acquisition costs when industrial measurement is used, though this changes to ownership costs when harvester measurement is applied since the change of ownership occurs earlier. Transport costs should reduce due to less waste in terms of overprocessing. It is estimated that 0.5 SEK/m^3ub is saved due to increased flexibility in how the transport flow can be arranged and due to the reduced overprocessing. Measuring at the industry is removed completely when harvester measurement is used. Table 4 presents the estimated procurement costs with industrial measurement compared to harvester measurement.

Table 4. Estimated cost per m^3 for industrial measurement compared to harvester measurement.

Activity	SEK/m^3ub Industrial MS	SEK/m^3ub Harvester MS
Contracting, planning, and final invoicing	37.7	36.7
Harvest and Forwarding	106	107.7
Transport	89	88.5
Measuring the industry	6	0
Total	**238.7**	**232.5**

The cost analysis revealed that the supplier sales cost are slightly higher with harvester measurement compared to industrial measurement. The total acquisition cost for the purchaser including contracting, planning, transport, measuring at industry, and final invoicing is 7.5 SEK/m^3ub lower. The analysis does not include all the differences identified and reduced waste given that these are complex and require more data and analyses for estimations to be made.

Discussion

The results from this research have shown that there are differences in terms of activities, information flows, lead times, and cost drivers when comparing the wood procurement process where industrial measurement is used, to the process where harvester measurement is used. According to the results, harvester measurement generated less waste, reduced the supplier's risk in addition to an improved cash flow, and reduced the acquisition cost for the purchaser. Therefore, the research showed that these differences affect the operations management, supplier relationships, and total costs.

Results suggest that the use of harvester measurements causes the change of ownership to occur earlier and reduces waste in the procurement process. In addition, bucking instructions are more flexible and do not affect the payment to the supplier. Therefore, the results indicate that harvester measurements bring more control to the process. Sawmills with superior control over their procured roundwood will have a substantial competitive advantage as well as increased profitability (Björheden and Helstad 2005). This research has highlighted that harvester measurement could increase the competitiveness of the forest industry due to improved operations management in terms of increased control of the supply chain.

Additional effects of the earlier change of ownership when harvester measurement is implemented, are a more flexible transport flow that changes from a push to a pull flow. Prompted by the industry measurement model, enabled a longer inventory time on the road and eased the stress on the industry inventory. Malladi and Sowlati (2017) highlighted that just-in-time management could be considered within forest supply chain planning, with the suggestion that optimization of product flow, storage, bucking, and vehicle scheduling is necessary to improve forest supply chain planning. The results from this study suggest that harvester measurement provides a solution for optimizing supply chain planning and further improving operations management due to these factors, whereas it may also enable just-in-time management.

Given that the stem-price list, followed by the usage of harvester measurement, contains fewer elements compared to an assortment price list, the transparency against the supplier is likely to increase. Furthermore, the findings from this study demonstrate that the supplier will receive his payment twice as fast with harvester measurement compared to industrial measurement, thus increasing efficiency for the supplier. Lastly, it is arguable that the reliability of the procurement process from the supplier's perspective, is considerably increased. This is due to the change of ownership of the roundwood occurring earlier in the process, thereby reducing the risk taken by the supplier and increasing the risk taken by the purchaser. Schnackenberg and Tomlinson 2016) suggest that transparency, reliability, and effectiveness are crucial in gaining the trust of the supplier. Therefore, according to this study, the improvement of these factors due to the use of harvester measurement is likely to increase the trust of the suppliers and improve the supplier relationship with industry.

Using harvester measurement in the procurement process leads to a reduced number of inputs and seems to have a limited effect on the outputs. There is less input given that the measuring at the industry is no longer necessary, there is less administrative work, and less storage space may be needed at the industry. Therefore, the results from this study indicate that the supply chain surplus increases. An increased supply chain surplus is an indication of increased profitability levels (Lambert and Cooper 2000; Chopra 2019). Therefore, harvester measurement may also have the ability to increase profitability levels for forest industries due to the increased supply chain surplus.

The study provides total cost suggestions for harvester measurement, which was also requested in Kremmerer and Labelle's (2020) research. This research found that the harvester operator must take more manual measurements when harvester measurements are used as a payment basis, increasing the supplier sales costs by 1.7 SEK/m^3ub. However, there is no need to measure the roundwood in the industry, the transport flow becomes flexible and there is less administrative work for the procuring organization, which seems to reduce the buyers' acquisition cost by 7.5 SEK/m^3ub. The study findings also indicate that one of the largest cost drivers for the buyer is the time spent on the procurement process. To reduce this, a digital contracting and planning process could potentially be implemented.

This research was limited to the first business flow between the procuring organization and the supplier, thus the results from this study do not cover the effect of harvester measurement on the entire wood supply chain. In addition, this case study is context bound and therefore cannot be generalized. However, this context bound case study offers ground for an extended application of the results for the reader. Further

research needs to be conducted on the second business flow between the procuring organization and the industry to determine how the use of harvester measurement affects the entire wood supply chain. One of the main cost drivers within the procurement process is time. Finding ways to further digitalize the procedure could further reduce the costs. These research findings suggest that using harvester measurement in the wood procurement process improves control of the supply chain, strengthens the trust amongst suppliers, and reduces the total costs. This research also suggests that it enables increased competitiveness and profitability levels for forest industries, although further research on quantitative measures is required to assess its importance.

Conclusions

This research has shown that the usage of harvester measurement in the wood procurement process can change the incentive structure, increase control of the supply chain, improve supplier relationships, increase supply chain surplus, and reduce total costs. The incentive structure changes since the value of the roundwood is determined, and the change of ownership occurs, earlier in the process, thus increasing the incentives for the purchaser to preserve the value created, leading to more efficient resource use and improved value creation. Additionally, the purchasers increased control of the supply chain due to the earlier change of ownership may also contribute to more efficient resource use. The supplier relationship improves due to usage of a price list with a single price per m^3 and payment being received earlier, which ultimately increases transparency in the supply chain. Lastly, the increased supply chain surplus due to reduced input to the process, in combination with reduced costs, may also lead to increased profitability levels and competitiveness for forest industries. However, this study did not consider the *market* effects of implementing harvester measurement, such as the effect on roundwood prices; nor did it consider effects on the second business flow between the procuring organization and the industry, for instance, whether the incentive structure changes for that business flow as well. Further research on harvester measurement's effects on the roundwood market and the second business flow between the procuring organization and the industry is necessary to determine the effect on the entire supply chain. Further research on quantitative measures is required to assess the significance of these effects, as well as the entire sustainability impacts on the wood supply chain.

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Appendix 1. The interview template used in the study

Theme	Question	Connection to the aim
General	How long have you been working at Södra Skogsägarna? What are your main tasks?	• *General*
The procedures: activities, lead times and cost drivers	Could you describe what activities occur within wood procurement, from contract to measuring at the industry? What activities are you involved in? What happens during these activities? How long do these activities usually take? What is the determining factor that affects the cost? E.g. hectares, time, volume.	• *Identify activities and their content to enable a reasoning whether they are value, or non-value adding* • *Identify lead-times and cost drivers*
Information flows and lead-times	What information (input) do you need to perform each activity? Where do you get the information (input) from? How long does it take to receive the information from the point where you need it? Why is this information necessary? What is its purpose? What kind of information (output) do you send to the next person in the process? And to whom? Why is this information (output) necessary to send?	• *Identify information flows, the purpose of the flows, and the lead times within the flows*
Difference in the procurement when harvester measurement is used	How is the wood procurement process affected today by applying harvester measurement as the payment basis instead of industrial measurement? Can any activity be performed faster? Why? Does any collected information (input) become unnecessary? Does any information (output) seem unnecessary? Why? Can the cost in any activity be affected by harvester measurement? Why? Are there any operational difficulties of using harvester measurement today?	• *Identify activities, lead-times, information flows and cost drivers in wood procurement when harvester measurement is used* • *Identify differences within activities, lead-times, information flows and cost drivers between wood procurement with harvester measurement compared to industrial measurement*
Possible improvements in the wood procurement process	What are the main advantages and drawbacks of using harvester measurement? Do you see any direct cost benefits? Is there anything else you would like to mention regarding harvester measurement?	• *Identify possible improvements in the wood procurement process*