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Balancing the flow of wood and use of machinery in harvesting operations

– New perspectives on how to improve performance in the wood supply chain

Malin Johansson

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Malin Johansson

Faculty of Forest Sciences

Department of Forest Biomaterials and Technology

Umeå

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Abstract

Meeting current wood supply objectives requires a certain flexibility in the wood procurement system. Suitable buffers to generate flexibility include creating a balance between flow and resource efficiency. Research on resource efficiency (e.g. cost-efficiency) in harvesting operations are abundant, but the flow efficiency have not been given much attention. This is somewhat surprising as the constant need for flexibility in practical operations has to be solved by more or less unplanned and intuitive means, or handled by other parts of the supply chain. This thesis therefore aims to improve performance in Nordic cut-to-length harvesting operations by exploring flow and resource efficiency and suggesting new perspectives on how to balance them well. Paper I covers how workloads in terms of produced volumes and worked time vary in harvesting operations. The results revealed differences between contractors' workflows, which could be attributed to number of machines, machine sizes and total workload. Papers II and III explore the trade-offs between flow and resource efficiency by altering staffing levels within and between harvesting groups, and thereby improving flexibility. The results revealed that with a balanced amount of flexibility there could be a potential capacity to adjust wood flow efficiency at the expense of resource efficiency. With flexibility, lead times could be shortened to one tenth, but at an increase in costs of 3.2 - 3.5 % or 1.6-1.8 % if flexibility was enabled within or in cooperation between harvesting groups. Paper IV identifies the perceived drivers and hindrances acting on contractors' flow and resource efficiency while taking into consideration the expectation that harvesting operations also include many other important aspects of performance. The results indicate that incentives given in the business relationship mainly drive resource efficiency and hinder flow efficiency, while involvement from the forest company mainly drive flow efficiency while hindering resource efficiency. A framework was therefore created to improve performance management which is currently surrounded by complexity.

Keywords: buffers, contractor, cut-to-length, flexible resources, forwarder harvester, logging, production management, tradeoffs, wood procurement

Author's address: Malin Johansson, Stora Enso Skog AB, 791 80 Falun, Sweden

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Malin Johansson

Akademisk avhandling som för vinnande av skoglig doktorsexamen kommer att offentligt försvaras i P-O Bäckströms sal, Umeå, fredag den 28 april 2023 klockan 13.00.

Opponent:
Professor Luc Lebel, Département des sciences de bois et de la forêt, Université Laval, Québec, Canada.

Betygsnämnd:
Professor Thomas Purfürst, University of Freiburg, Germany.
Dr Janine Schweier, Swiss Federal Research Institute WSL, Switzerland.
Associate Professor Bruce Talbot, University of Stellenbosch, South Africa.

Reserv:
Dr Lars Sängstuvall, Institutionen för skoglig resurshushållning, SLU, Umeå, Sverige.

Handledare:
Professor Ola Lindroos, Institutionen för skogens biomaterial och teknologi, SLU, Umeå, Sverige, E-post: Ola.Lindroos@slu.se

Biträdande handledare:
Dr Emanuel Erlandsson, Institutionen för skogens biomaterial och teknologi, SLU, Umeå, Sverige, E-post: Emanuel.Erlandsson@slu.se
Dr Thomas Kronholm, Institutionen för skogens biomaterial och teknologi, SLU, Umeå, Sverige, E-post: Thomas.Kronholm@slu.se

Dedication

To my grandparents Karin, Birger, Beda and Valdemar.

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Malin Johansson, Emanuel Erlandsson, Thomas Kronholm & Ola Lindroos (2022). The need for flexibility in forest harvesting services – a case study on contractors' workflow variations. International Journal of Forest Engineering 34(1):13-25.

II. Malin Johansson, Mikael Lundbäck & Ola Lindroos. Trade-offs between flow and resource efficiency in harvesting operations – a simulation-based evaluation of the effect of different numbers of machine operators in a harvester-forwarder system. Manuscript.

III. Malin Johansson, Mikael Lundbäck & Ola Lindroos. Evaluation of cooperation between machine groups to enable improved flow and resource efficiency in cut-to-length harvesting operations. Manuscript.

IV. Malin Johansson, Emanuel Erlandsson, Thomas Kronholm & Ola Lindroos (2021). Key drivers and obstacles for performance among forest harvesting service contractors – a qualitative case study from Sweden. Scandinavian Journal of Forest Research. 36(7-8):598-613.

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The contribution of Malin Johansson to the papers included in this thesis was as follows:

I. Conceived the original idea, leading part in designing the study and choice of method, all of the data collection and analyses, and responsible for article writing, with input from co-authors.

II. Conceived the original idea, leading part in designing the study and choice of method, responsible for model development and simulations, all analyses of results, responsible for article writing with support from the co-authors.

III. Conceived the original idea, designing the study and choice of method, model development and simulations, all analyses of results, responsible for article writing, with input from the co-authors.

IV. Conceived the original idea, contributed in designing the study and choice of method, all of the data collection and analyses, responsible for article writing, with input from the co-authors.

Abbreviations

CTL	Cut-to-length
DES	Discrete Event Simulation
m^3	Cubic meters, solid under bark
PMh_{15}	Productive machine hours (excluding delays and downtimes longer that 15 minutes)
SMh	Scheduled machine hours (including delays and downtime)

1. Introduction

1.1 Background

The procurement of wood materials and products from forests has an important role in the global economy and the transition to a bioeconomy (Ollikainen, 2014). This is of great national and regional importance for many countries. Around the world, about 4 billion m^3 of roundwood is harvested annually to supply wood material and products to the world's population. Half of this volume is harvested for industrial use (FAO, 2022). In order to remain competitive with other sectors and on the global export market, the forest sector needs to increase or maintain the efficiency of all its forest operations. That includes stand establishment and tending, harvesting and extraction to roadside, transport to industry, and logistics (Epstein et al., 2007; D'Amours et al., 2008; Rönnqvist et al., 2015). While constantly pursuing improvements in rationalization, it is also important to meet customer satisfaction and values (Kano, 1984; Grönroos, 1997). For decades the forest sector has made intense efforts to decrease costs and increase the efficiency of individual processes in the wood supply chain. In recent decades, supply chain management has focused on trying to improve the overall performance of the wood supply chain, rather than concentrating on individual processes separately. Academic research has also addressed the interests of the forestry industry (Carlsson and Rönnqvist, 2005, Palander, 2022). Moreover, the customer orientation is now also an important consideration for the forestry industry. For example, wood-flow precision is inherently important in a customer-oriented wood supply chain, meaning that the right kind of products (or raw material) should be delivered to the industrial customer in the right quantity and at the right time. In this way, the customer can maximize its own level of production (Carlsson and Rönnqvist, 2005).

Wood procurement is a complex process due to the geographical dispersion of production, divergent flows of products, and acute sensitivity to weather and climate. This means that wood flow is often and repeatedly affected both by anticipated and unforeseen variations in those factors affecting the flow of produced wood (Audy et al., 2012; Guatam et al., 2013). Further complexity arises from climate change, with more extreme and unexpected weather. Moreover, fluctuating demand from markets may not always align with the most efficient time to harvest standing trees, which has to take into consideration forest management objectives, fire hazard risks, or road and terrain accessibility. Orientating wood supply to current demand, while still maintaining efficiency in every operation and process, is thus a challenge (Hoogstra-Klein and Meijboom, 2021). Forests also have functions other than providing wood material and products for human needs. The role of forests in mitigating climate change has increasingly brought the attention of the public around the world to forest management. Recently, the intensified debate concerning forests as carbon sinks, sources of biodiversity and social welfare, as well as a supplier of renewable energy and products, is changing the policies and priorities of forests and forestry (Ollikainen, 2014). This can affect delivery time, product quality and reliability, as well as the reputation of wood suppliers and their products and, in the end, the customer's perception of the value of forest materials and products.

The challenges facing wood supply management are not likely to decrease, but rather to increase and become more complex. The actors in the wood supply chain are therefore constantly forced to adapt their operations to the increased complexity of current needs and demands. It would of course be interesting to look simultaneously at all the operations in the whole wood supply chain. However, there are still many aspects within specific operations that need further attention. The research in this thesis is therefore focused on harvesting operations in the Nordic wood supply environment; these include cutting and bucking the trees by a harvester, and the extraction of logs to the roadside by a forwarder.

1.2 Wood procurement system and supply chain

A wood procurement system includes planning and execution processes for procuring and delivering raw materials from forest to the mill. That includes procurement of forest stands for supply, harvesting, transporting, and managing roundwood stocks (Uusitalo, 2005; Audy et al., 2012). In most countries, the wood procurement system generally consists of several actors and companies that interact through complex business relationships involving material, information and financial flows (Audy et al., 2012). Thus, the planning and execution processes are not carried out exclusively and internally within one company. Supply chain theory is therefore suitable for the wood procurement system as it consists of several independent actors that are linked together, from procuring wood materials from the forest to its delivery to the mill. Industrialization and globalization have been more advantageous to companies that compete in supply chains than as individual organizations. The term 'supply chain' was introduced in early 1980s and different definitions have been proposed over the years. A supply chain can be defined as a *"network of organizations that are involved, through upstream and downstream linkages in different processes and activities that produce value in the form of products and services in the hand of the ultimate consumer"* (Christopher, 2005:6). A core idea for the supply chain concept is collaboration between organizations to incorporate strengths and streamline operations (Lin et al., 2006). To create an appropriate supply chain is no longer solely an opportunity, it has rather become a survival skill (Rezapour et al., 2014). Based on contingency theory (Morgan, 1986), there is no universal set of options to organize, lead or make decisions that suits all organizations. The optimal conditions that satisfy and balance internal with external needs depends on the environmental context and circumstances. Supply chain management must therefore be concerned with developing alignments within and between organizations in the supply chain, as well as with the surrounding external environment (Lee, 2004).

The environment surrounding wood supply is complex and offers many logistical challenges that differ from those of the supply of goods in other industries, such as mining, plastics or petroleum. With forests as the source of raw materials, instead of sourcing the material from one or few locations and transporting it to several locations next to customers, the raw material has to come from many small locations in the landscape. Moreover, these locations undergo constant change, since decades pass between when a given forest stand is planted and harvested to provide wood to various industries. This is in stark contrast to most other industries that have geographically static supply points. In the wood supply industry, every location (i.e. forest stand) offers different working conditions affecting the felling and extraction of wood from the forest to the roadside, as well as the transportation from the roadside to the terminal or mill. These working conditions also differ over time due to the seasonality of weather conditions affecting the accessibility both of forest stands and roads, as well as the capacity needed to deliver according to demand (Audy et al., 2012). Moreover, the varied purposes and values associated with forests and forestry are of interest to many different groups (Ollikainen, 2014); consequently government agencies, non-governmental organizations, environmental groups, and community stakeholders may all influence how wood material is procured from forests. The mills, as customers of the wood supply chain, need to serve market demands that can change rapidly; they therefore have high expectations for product availability, quality and supply and the logistics involved in its timely delivery. Such a customer orientated wood supply means all parts of the overall supply chain need to match high performance to satisfy the customers' high requirements in terms of quality and flexibility as well as the need and request for timed deliveries. Hence, there are high requirements on *wood-flow precision*, which refers to the extent to which the supply-rate coordinates with the demand-rate (Carlsson and Rönnqvist, 2005).

The actors and structure of the supply chain that harvests and transports wood from forest to mill differs between countries (Audy et al., 2012). In most, contractors normally undertake the harvest and transport of wood for companies that have the main planning processes in-house and which usually own the forest land and/or the mills (e.g. Drolet and LeBel 2010; Eriksson, 2016; Erlandsson, 2016; Mac Donagh et al., 2017; Jylhä et al., 2020). The company responsible for the planning processes can be viewed as being responsible for the management of the wood supply chain and aligning it with customer-oriented needs at the mill and within the context of the prevailing environment (Eriksson, 2016).

In Sweden the wood supply chain handles a fairly stable volume demand over the year. However, there are seasonal variations that affect the operational working conditions (Erlandsson, 2013), as well as other variables within and between forest stands (Audy et al., 2012, Eriksson and Lindroos, 2014). Normally, the winter season (ca December-March) provides good conditions in which to conduct forestry operations without machinery damaging the soil. Harvesting is therefore often intensified during this period and the increased stock levels cover any fluctuation in production causing a decrease in stock during spring. Thawing during the spring (ca April-May) deteriorates road conditions and increases the risk of machinery damaging forest soils. During the summer season (ca June-September), there is a restriction on the time allowed for logs to be stored at roadside landings due to the high risk of fungal and insect attack reducing wood quality (Skogsstyrelsen, 2022). Moreover, production decreases due to vacations. Production increases again during the fall (ca October-November), but must be aligned with rainy weather and wet working conditions (Carlsson and Rönnqvist, 2005; Audy et al., 2012, Erlandsson, 2013). However, climate change has led to more extreme and unexpected weather conditions, which makes the conditions for wood supply in Sweden more uncertain (Keskitalo et al., 2016; Lidskog and Sjödin, 2016). For instance, the risk of forest fires has increased markedly during recent summers and related safety restrictions then limit the operation machinery in forests (Sjöström, 2019; Pinto et al., 2020). Usually, the winters provides good operational conditions, with frozen ground making it possible for machines to drive on many otherwise inaccessible forest locations. This is no longer always the case, since the periods of good bearing capacity of forest soils have been shorter, or even completely absent at some locations, in Nordic countries as winters have become warmer (Jungqvist et al., 2014; Lehtonen et al., 2019). Warmer weather, as well as increased wind damage resulting in fallen trees during winter storms, has led to an increase in the occurrence and activity of European spruce bark beetle (*Ips typographus*) (Marini et al., 2017). Harvesting infested spruce trees (*Picea abies*) can limit the damage, but such harvests do not necessarily align with market demands.

1.3 Buffering for volatility in wood supply

In customer-oriented wood supply, wood-flow precision, meaning the extent to which the supply-rate coordinates with the demand-rate, is inherently important. Raw materials and products should be delivered to the mill as customer at the right quality, right quantity, and right time. In this way, the mill can align its production with downstream needs (Carlsson and Rönnqvist, 2005; Hoogstra-Klein and Meijboom, 2021). To ensure that the mill is supplied with its demanded volumes, the wood supply chain must compensate for the volatility of wood procurements. There is thus a need to manage effectively the risks of any disruptions in the supply chain in order to prevent delays in the timely delivery of materials. Buffering is one of the most commonly used risk mitigation strategies in supply chains and it is related to the creation of slack resources (Mishra et al., 2016). In wood supply, this is most often created by two main principles – by buffering in product stock capacity, and buffering in production capacity (Laestadius, 1990). Both principles are usually used to some extent in all wood supply chains, but there can be differences in terms of which of these main principles is used. This differs between countries, and between harvesting methods and systems (Laestadius, 1990; Audy et al., 2012). A harvesting method is defined by the state of harvested material at the roadside, while a harvesting system is defined by the machinery used to perform the harvesting method (Lindroos et al., 2017; Lundbäck et al., 2021).

1.3.1 Buffering in production capacity

A buffer in production capacity can be used to enable wood production to vary according to current demand. When changes occur in the rate of wood demand or in the working conditions for harvesting operations, production can be adjusted both by changing the rate of productivity and utilizing capacity. This can be achieved by adjusting the workload of production resources, for instance: by controlling volume production by quotas (Ulmer et al., 2004), by engaging machine operators in temporary employments (Laestadius, 1990, Kelly and Germain, 2016), and by hiring contractors on short-term contracts and through spot purchases (Erlandsson, 2013). In most countries, harvesting operations are currently undertaken by contractors, which increases the possibilities of using the latter alternative listed above (Conrad et al., 2018; Erlandsson, 2016; Mac Donagh et al., 2017; Jylhä et al., 2020). If temporary resources are used, there is a risk of having insufficient production capacity when demand increases (Conrad et al., 2018). This can lead to opportunistic behaviors among contractors due to increased bargaining power when the capacity needed exceeds that available on the market, and which can thus potentially increase logging prices (Vining and Globerman, 1999). If resources cannot be found, there is, of course, also a risk of failing to meet the demands from the mills.

To ensure that the mills are supplied with their demands for wood the whole year around, it can be beneficial to secure a large share of the estimated annual capacity needed, on long-term contracts and by using a harvesting fleet that is tolerant to short-term volatilities (Erlandsson, 2016). Multipurpose machines that can be used for many tasks can increase that opportunity (Asikainen, 2004). A practical example is the use of medium sized harvesters and forwarders, which can operate in both thinning and final felling (Erlandsson, 2013). This increases opportunities to adapt harvesting operations to match current supply and demand needs without the same need to adjust resource utilization.

Due to less equipment being needed, the Nordic two-machine system used for CTL-method have relatively low relocation and setup time compared to the harvesting systems used for the full-tree method (Guatam et al., 2013; Lundbäck et al., 2021). Harvesting operations can thus be rapidly relocated to forest stands where working conditions both match the demand for production, and are operationally suitable. Thus, instead of changing the workload on existing resources, production can simply be relocated to another, more suitable, place. The one-machine-system, with a harwarder as a combined harvester and forwarder, enables relocation and setup times even quicker than the two-machine system. The harwarder can therefore be suitable if operating in smaller forest stands and if the machines might need to be frequently relocated (Kärhä et al., 2018; Jonsson et al., 2023). However, although multipurpose machines can increase flexibility, they are often not as efficient as specialized machines for the same type of operation (Ringdahl et al., 2012; Eriksson and Lindroos, 2014). For instance, large sized machines are more productive in final felling than medium sized machines (Eriksson and Lindroos, 2014). Moreover, the time taken to undertake a harvesting operation with a harwarder is usually longer than if using a harvester and a forwarder specialized for their respective tasks of cutting and extracting the wood (Jonsson et al., 2023).

To benefit from specialized machines while still retaining flexibility in harvesting operations, Eriksson (2016) suggested an approach of agile production management. This takes advantage of differences in working conditions between forest stands to steer the wood flow, while each operation is performed by the most efficient resource. The term *agile stand selection* will henceforth be used for this production management principle.

To steer and anticipate wood flow through agile stand selection requires accurate information about the forest to be harvested, about the machines that will be used, and requires accurate productivity models. The quality and speed of gathering such information is currently being rapidly improved by our present ability to collect detailed information directly from the machines actually being used: for instance information about the trees, the machine work, and productivity during harvesting. Therefore, data acquisition and methods to produce models are constantly being refined (Eriksson and Lindroos, 2014; Liski et al., 2020). Nevertheless, uncertainties in production outcome still exist. Even though the increased quantity and improved quality of data provide more reliable predictions, the outcome of a given operation may still deviate due to, for instance, large differences between machine operators (Purfürst and Erler, 2011; Häggström and Lindroos, 2016; Manner et al., 2016) and insufficient information about the forest to be harvested (Gustafsson, 2017; Ulvdal et al., 2022). The ability to handle variations in wood demand by adjusting working conditions depends on the available flexibility concerning which forest stands can be chosen for harvest. This is in turn limited by the forest stands available and their management plans (Gunn, 2009; Guatam et al., 2013). Moreover, due to the divergent flow of many different assortments of wood products from a given stand when applying the cut-to-length harvesting method, it is rather complex to manage and adjust the production of some specific assortments without interfering with the production of others (Carlsson and Rönnqvist, 2005). Thus, any planned outcome in terms of harvested volumes and needs for harvesting resources can be subject to variations due to many different sources of uncertainty.

Consequently, any opportunity to adjust production capacity rapidly, and the associated costs, each depends on the labor and contractor market, the machine fleet available, as well as there being an opportunity to use agile stand selection and having confidence in its reliability (Laestadius, 1990; Audy et al., 2012; Eriksson, 2016; Erlandsson, 2016).

1.3.2 Buffers in stock levels

Stocks of wood can be built up over various intermediate levels within the supply chain, as buffers against fluctuations and imbalances between rates of supply and demand. Such buffers provide both the capacity to manage fluctuations immediately, and time to adapt production rates. Thus, buffer stocks increase the ability of the wood supply chain to overcome uncertainties such as fluctuations in demand, machine breakdowns, weather-related restrictions, and divergent wood flows.

Low levels of buffer stocks can cause poor resilience to any disruptions and risks delays to production and reduced performance (Sessons et al., 2005; Puchkova et al., 2015). However, stock levels that are too high can create a high stock cost, due to money being tied up in the stock. Furthermore, as wood is a biological material, its quality can decrease while held in stock, leading to net losses (Jonsson, 2012). Hence, there is a certain time-sensitivity in the supply of wood, but the level of sensitivity depends on many interacting factors including tree species, weather, season, end-use, etc. By building stocks, the time between harvest and delivery increases, and the risk increases of decreased customer value from the wood. Moreover, wood being stuck early in the supply chain can result in decreased opportunities to store wood at later stages in the supply chain, which may, in turn, result in a failure to meet time-constraints. This can then lead to suboptimal industrial processing and increased costs for the mill, due to higher losses in pre-processing, in grading of final products, in by-products, and from increased consumption of process inputs, like bleaching chemicals (Carlsson and Rönnqvist, 2005). If stocks levels fluctuate, the economic consequences and associated risks become even more unpredictable as well as the delivery service becoming less reliable (Puchkova et al., 2015; Hoogstra-Klein and Meijboom, 2021). It is therefore essential to find the optimum size and distribution of the various stock levels along the wood supply chain.

In the wood supply chain, the wood is stored in yards at the mill or at terminals when delivered. Before that, it is stored at the roadside in the vicinity of the forest stand while waiting for transport to a mill or terminal. When using the Nordic CTL-system with a harvester and a forwarder, there are natural occasions when the wood will be in stock. Thus, there is a stock of logs in the forest, consisting of logs produced by the harvester but not yet extracted to the roadside by the forwarder. The Swedish wood supply chain has a long tradition in managing these three stocks at levels which contribute to buffering the wood flow. The benefits are cost-efficiency with high turnover, an even utilization of the resources, and the ability to secure supplies of wood even when production is limited, or wood flow is disturbed (Laestadius, 1990; Audy et al., 2012).

When using a harvester and a forwarder, a buffer is needed to overcome disturbances to production and the imbalances that occur between their respective productivity rates. The forwarder takes over after the harvester has done its work. Thus, the forwarder is dependent on the work conducted by the harvester (Lindroos, 2012). Therefore, to avoid the forwarder standing idle or, losing productivity due to unfavorable working conditions and other disruptions affecting the harvester, a buffer in wood volume between the two machines can be very useful. Wood that has been felled, but not yet extracted to the roadside, is subject to higher risk of deterioration in quality and/or even loss, than are standing trees or the logs at the roadside. This risk increases with the stock level between the machines and also depends on weather and season. For instance, in winter, logs can be covered by snow and hence difficult or impossible to find, and changes in the weather in any season can restrict the forwarder's ability to access a logging site for long periods. Moreover, at this position in the supply chain when the stock is at the beginning of its potential decline in wood quality, the time it's held in stock affects the possibility of using it as a buffer at later stages in the supply chain, and so maintaining customer value. This calls for small and equal operational stock levels between the machines' outputs. However, a small stock level can potentially reduce resource efficiency of the harvesting operation, both in terms of machine utilization and their productivity (Lindroos, 2012; Lindberg, 2016).

1.3.3 Balancing between flow and resource efficiency

Balancing between using buffers of production capacity and stock levels is directly associated with balancing between flow and resource efficiency. The focus on flow efficiency is on the value-added time on the task in relation to the total lead-time to deliver it. Flow efficiency aims to maximize value-adding time and minimize waiting time on the task eg. a service or product. Thus, flow efficiency is associated with keeping stocks at low and even levels. This is because stocks at this stage are in waiting-time when no value is added to the service or products (Ohno, 1988; Naylor et al., 1999). In harvesting operations, the task is to cut trees and extract them to the roadside. In the two-machine system for the CTL-method, the trees are cut and bucked by a harvester and later grabbed by a forwarder for further extraction to the roadside landing. This work can be seen as the value-adding time of the harvesting operation. The time between the harvester and forwarder operations is waiting-time that is added to the total lead-time together with the value-added time. The total lead-time in harvesting operations can thus be viewed as the time from harvest to when the logs are extracted to road-side landings. Flow efficiency increases as the time-gap between these machines' operations is reduced, and as the value adding times lengthen. With flow efficiency, the opportunities to achieve wood-flow precision increase and the negative consequences of holding wood in stock decrease (Hoogstra-Klein and Meijlboom, 2023).

Wood-flow efficiency does not take resource efficiency into account. Resource efficiency means maximizing production while minimizing use of resources (Eriksson, 2016; Lundbäck et al., 2022), which is inherently important for competitive wood procurement costs (Rennel, 2010; Eriksson, 2016). Resource efficiency can mean low value-adding time, simply due to the high efficiency of operational tasks. In such a case, flow efficiency is negatively influenced, compared to less efficient and hence more time-consuming operations, due to the low value-adding time. The total lead-time is positively influenced by both high efficiency of operational tasks and short waiting-times. However, the time-gap between the machines' operations is usually much larger than the time taken to complete actual tasks during a harvesting operation. There is, therefore, significant potential to decrease lead-times in a harvesting operation by decreasing the time-gap between the machines' respective tasks. Thus, improved lead times relates to improved flow efficiency. However, to achieve the optimum lead-time for harvesting operations, both flow and resource efficiency need to be balanced.

According to Laestadius (1990) the two principles of using production capacity and stock as buffers can be substituted for each other to meet a particular need for flexibility. Stocks buffer for imbalances between supply and demand, and increase opportunities to achieve high resource efficiency. Conversely, buffering production capacity increases the opportunity to achieve high flow efficiency. Which of these balancing strategies between the two buffering principles is used in wood supply chains differs according to the different histories and traditions employed in adapting the wood supply to its demand, together with differences in relative cost of keeping resources and wood idle (Laestadius, 1990; Helstad et al., 2001; Audy et al., 2012, Conrad et al., 2018).

Figure 1 is based on Laestadius 1990:103 which describes the substitutable effect between buffers in production capacity and stocks. In this relationship, there exists an isoquant and isocost line for the optimal mix of the two principles. Here, the isoquant represents all combinations of alternatives that will produce a certain flexibility. The isocost line represents all combinations of alternatives that have the same cost output. If a given balance is below the isocost line, the wood supply chain has a high cost-efficiency. However, the flexibility to produce the right volumes at the right time is insufficient and creates a potential risk of decreasing customer satisfaction. If above the isocost line and below the isoquant, then the supply chain is neither cost-efficient nor has enough flexibility. If the supply chain is above the isoquant in flexibility, then right and timely volume deliveries can be achieved. However, customer satisfaction may be decreased due to costs being higher than necessary. According to the contingency theory, there is no general optimum input mix of the flexibility alternatives that might fit all types of wood supply chain. The necessary flexibility, as well as the relative cost of the substitutes, differs between different contexts in which the supply chain operates. However, for the supply chain to find its optimum, it is important to investigate different combinations of the flexibility alternatives and the respective trade-offs.

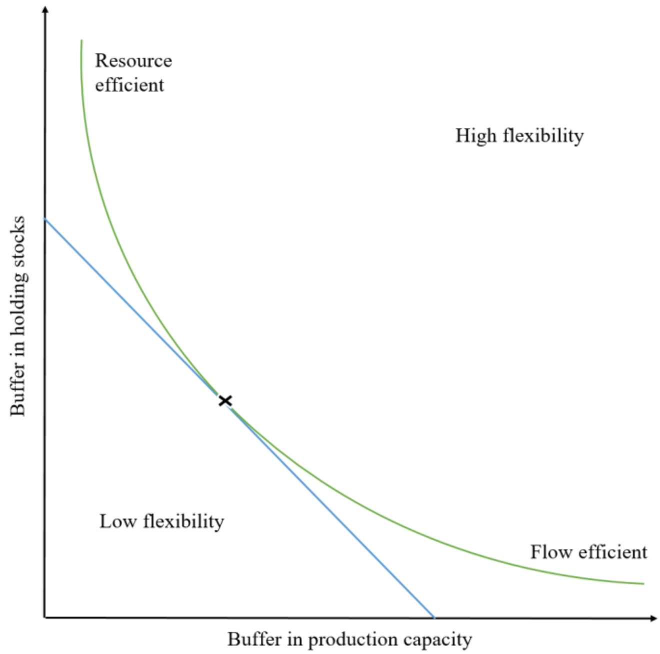

Figure 1. Isoquant (green) and isocost line (blue) for the optimum mix of flexibility in production capacity and holding stocks (based on Laestadius 1990:103), given the relationship between costs of flexibility in production capacity, and in holding stocks.

1.4 Operational planning for harvesting operations

Planning that includes consideration of environmental, economical and social values is essential for sustainable forestry (MacDicken et al., 2015). In operational planning, the decision maker must consider multiple factors when selecting which forest stands to harvest at different times. The selection is made from the list of available stands, often called a *tract bank*, of standing forests that are planned to be harvested but which have not yet been harvested (Nilsson et al., 2013). Factors that affect the choice range from the availability of forest stands in the tract bank, to forest management requirements, production goals, machinery and operators in the resource fleet, weather conditions, and economical results of the operation. Thus, forest stands cannot be selected solely to attain the most appropriate wood-flow and resource utilization at each moment (see section 1.3.1). When selecting a forest stand for harvest, the future availability of forest stands in the tract bank also need to be considered and accounted for. Moreover, the selection must also suit other forest management plans and requirements, for example, some forest stands can only be harvested during certain seasons and weather conditions (Nilsson et al., 2012; Nilsson et al., 2013). This means that there is usually a certain time window when harvesting a forest stand can be accomplished to avoid exceeding its 'best before date'.

The composition and number of stands in the tract bank is inherently important when opting to use agile stand selection (Flisberg et al., 2019). One consideration is the source of the forest stands. If a forest company's tract bank typically comprises a high proportion of its own forest, it is less subject to uncertainties concerning its future, and is likely to have a better chance of stands being selected for harvest at opportune times (Nilsson et al., 2013). In contrast, if a large proportion of the tract bank belongs to non-industrial, private owners, there will be more uncertainty concerning which stands will be felled under contract (Erlandsson, 2013), and more stringent demands from the forest owners concerning when their stands will be harvested (Erlandsson et al., 2017).

Another essential limiting factor in operational planning is the ability of the terrain to withstand the traffic of machinery operating in a stand, together with whether roads permitting access to wood at the road-side landings for onward transportation are passable. The greater the proportion of forest stands there are with terrain and passable roads suitable for harvesting operations to be carried out in all seasons and under a wide range of weather conditions, the better the opportunities for agile stand selection during the greater part of the year (Rowell, 2023).

Despite the complexity arising from the plethora of factors needing to be taken into consideration, planning and decisions regarding forest stand to harvest is largely done manually with help of simple support systems and calculation tools. However, although there has been an intention to optimize the scheduling of forest stands, they have not been implemented in practice to any significant degree (Frisk et al., 2016). Difficulties surrounding the use of such scheduling optimization can be explained by the complexity of harvesting operations, with the many dynamic variables affecting the outcome of any apparently optimal plan, all of which also vary with time, as well as there being questions concerning data reliability. As mentioned above, some examples of these dynamic variables are also subject to variation in operational conditions within and between each stand (Nilsson et al., 2012; Wilhelmsson et al., 2021), in skills and performance among machine operators (Purfürst and Erler., 2011; Häggström and Lindroos., 2016; Manner et al., 2016), in weather and seasons (Keskitalo et al., 2016; Lidskog and Sjödin., 2016), and in forest information (Ulvdal et al., 2022).

Thus, agile stand selection requires a high level of competence in the decision maker. He or she must have a thorough understanding of all the relevant factors that need to be considered, as well as knowledge concerning the local prerequisites relevant to such factors as those mentioned above. As the decisions concerning which stand to harvest affects many stakeholders, including the forest owner, the machine group or contractor, and the mill, it is a challenge to satisfy everyone's demands. If the companies within the supply chain share common goals of competitiveness and commercial success (Lee, 2004), a holistic perspective and collaboration between all the stakeholders could eventually lead to an optimal solution to the supply of wood and management of forests due to decreased sub-optimization of individual stakeholder's desires. As policies change to include forests having extra functional roles as carbon sinks, and as sources of biodiversity and social welfare (Ollikainen, 2014), sustainable forest management becomes ever more important with each forest stand subject to adaptions (Mohtashami et al., 2017). This means further additional constraints on forest management practices, which may limit opportunities to use forest stands flexibly in order to steer wood flow. Adapting to the increasing demands of a customer-oriented wood supply probably means a greater need for flexibility in production capacity as a buffer by varying use of machinery and/or being able to provide more versatile services.

1.5 Contractor performance alignment with the wood supply chain

In Sweden, forest companies (among whom also include forest owners associations) are the main planners of harvesting operations, including sourcing and aligning harvesting resources to the requirements of the wood supply chain (Eriksson, 2016; Erlandsson, 2016). Since the period from 1980-1990, when extensive outsourcing resulted in forest companies offering to sell their machinery to machine operators, the executors of harvesting operations have mainly comprised contractors (Eriksson, 2016). Most contractors are small and medium-sized enterprises (SMEs) with only two, three or four employees and one or two machines. Forest companies therefore often rely on contracts with several contractors to secure the required amount of harvesting operations in a given geographical area (Häggström et al., 2013; Kronholm et al., 2019). To maintain competitiveness and success of the wood supply chain, it is essential that there is alignment between a forest company's needs and the performance of many different contractors (Lee, 2004; Eriksson, 2016).

Performance in harvesting operations is a multidimensional quantity that may be defined by many parameters (Häggström and Lindroos, 2016; Blagojević et al., 2019). This further complicates the ease of alignment between contractors and a forest company. For instance, there are large variations among contractors regarding their profitability (Kronholm et al., 2021; Jylthä, 2020), machine efficiency (Eriksson et al., 2015), and various value attributes of the harvesting operation as a service (Eriksson et al 2015; Erlandsson et al., 2017). This highlights the variation that exists among contractors regarding their ability to align with a forest company's needs, which is consequently disadvantageous for the wood supply chain (Eriksson et al., 2017).

Actions taken by the forest company affect contractor performance (Krause et al., 2000), contractor satisfaction and profitability (Erlandsson and Fjeld, 2017), contractor alignment with a forest company's needs (Eriksson et al., 2015; Eriksson, 2016) as well as contractors' resource investments and business models (Benjaminsson et al., 2019). For a forest company that is aiming to improve the alignment between their contractor fleet and the forest company's need, Eriksson et al., (2015) developed a framework comprising four generic managerial approaches - *Active contractor selection*, *Incentives alignment*, *Supplier development initiatives*, and *Active use of a power advantage*. Because performance varies among contractors, Eriksson et al., (2015) also developed a process by which an appropriate mix of the managerial approaches for each contractor's case could be chosen, depending on the capability of the individual contractor and the contractor's current performance alignment with the forest company's needs. For the process to be effective the contractor must have the means to perform what is required, both regarding their capability and the intended goals of the forest company.

For decades, strenuous efforts have been made to minimize the cost of harvesting operations by improving productivity and cost-efficiency (Eriksson, 2016). That work represents one of the successes for competitiveness in the wood supply chain, as harvesting operations constitute for half the share of the forestry costs involved in wood procurement (Eliasson, 2022). Due to the need to conform to an environmental context and related circumstances (Morgan, 1998), such as traditional practices and opportunities for holding roundwood stock (Ager, 2014), the Swedish wood supply chain has invested heavily in sophisticated and specialized harvesting resources (Nordfjell et al., 2019). Thus, many Swedish contractors now have specialized machines that can only operate in final felling (Kronholm et al. 2021), and which require regular and high work rates to keep logging costs low (Eriksson et al., 2015). Contractors with machinery used in thinning, comprising mainly medium sized, can also operate in final felling (Erlandsson, 2013). However, this is not the most cost-efficient choice because thinning machines are not best suited to final felling (Eriksson & Lindroos, 2014), and because operator skills increase with experience (Purfürst, 2010) with their competency becoming more specialized when mainly working in one kind of operation - thinning or final felling.

Thus, as the harvesting operation in Sweden relies on to utilize resources in a high and even degree, it also applies for the contractors that have the investments in the machines. Therefore, a consistent and high utilization of the machines is important for costs of the harvesting operations (Erlandsson, 2016; Erlandsson and Fjeld., 2017). These high levels of efficiency, productivity and utilization rate are also important to satisfy the forest companies (Eriksson et al., 2015). However, increased requirements for wood-flow efficiency in harvesting operations can result in contractors' machines being utilized at more uneven and unexpected levels during the year. Increased variation in the requirements of harvesting operations also means increased uncertainties and risks in the sourcing process by forest companies. For instance, there are costs that forest companies may have to incur when compensating contractors for under-used machines and manpower according to the common standard for agreements between customers and forest contractors (Skogforsk, 2020). The increased uncertainties and risks can also have negative effects on contractor profitability and satisfaction (Erlandsson and Fjeld, 2017). Therefore, if wood-flow efficiency needs to be increased, forest companies should want to be able to match contractors' flexibility with the necessary flexibility. Based on Eriksson's et al., (2015) framework for aligning performance with customer needs, it would first be necessary to specify the need for flexibility, evaluate its importance, evaluate contractors' current performance, and assess contractors' capabilities to fulfill the need. A suitable strategy for improving flow efficiency in harvesting operations can then be developed.

1.6 Aims and objectives

The overall aim of this thesis is to improve performance in harvesting operations by exploring and suggesting new perspectives on how to balance flow and resource efficiency. This is done in the context of Nordic cut-to-length harvesting operations, where forest companies outsource a large part of the harvesting operation to contractors. The research progresses from investigating the current situation, to analyzing potential improvements, and identifying factors affecting performance in harvesting operations.

Specific objectives of studies I-IV were to:

I. Investigate the level of contractors' workload variation in terms of wood volume handled and time spent on the operations.

II. Analyze how machine use flexibility created by different numbers of operators within a machine group influences the balance between flow and resource efficiency.

III. Analyze how cooperation between machine groups staffed with flexible operators influences the balance between flow and resource efficiency.

IV. Identify perceived drivers and hindrances for contractors' flow and resource efficiency, taking into consideration that harvesting operations also include other important aspects of performance.

All studies presented here were conducted within a case of an integrated forest company operating in central Sweden as purchaser, and the company's contractors providing harvesting services in the region.

2. Materials and methods in brief

2.1 The company in the case-study

This thesis was performed as an industrial doctoral project financed by Stora Enso Skog AB; all empirical data were collected within the boundaries of Stora Enso's harvesting operations in Sweden.

Stora Enso AB is one of the biggest forest owners and wood supply organizations in the world. Globally, Stora Enso owns or leases lands that cover a total area of 2.01 million hectares, of which 1.4 million hectares are located in Sweden. Annually, the company harvest about 6.4 million m^3 of roundwood in Sweden (Stora Enso, 2022) and the operational area is mainly in the central parts of the country, from Bohuslän in the south to Härjedalen in the north.

The largest proportion of the harvesting work in Sweden is performed by contractors. Contractors' agreements normally extend over 1-3 years and there is usually a long-term intent to business relationships thus allowing collaborations to develop over many years. Contractors usually operate a single group comprising one harvester and one forwarder; but the number of machines and groups can vary. A work schedule of two work-shifts per machine per day is standard, but many contractors operate single shifts.

The conditions under which the present study was carried out are similar to those usual in the business relationship between forest companies and contractors in Nordic countries (Eriksson, 2016; Jylthä, 2020; Kronholm et al., 2021).

2.2 Paper I

In order to examine variations in contractors' workflow volumes and times, and to identify differences between contractors, data on contractors' harvesting work during the calendar years 2018 and 2019 were collected from Stora Enso Skog's records stored in its IT systems. The dataset included reported volumes per machine, stand, and date together with information about the type of operation (final felling, thinning or other harvesting work), estimated productivity, and reported time and compensation for other harvesting work. Hourly compensation rates were extracted to enable the derivation of machines' monthly variation in terms of work time. The information in the dataset also included machine size and type, and to which contractor the machine belonged.

To quantify workflow accurately at the machine level, it was important that data derived from the machines operating during the study were reliable. Therefore, to handle the flaw of data errors and so minimize the effect that poor data quality might have on the reliability of results, the original data were refined by excluding machines that did not meet the criteria of three data reduction steps. After the three reduction steps, 77 machines (19%) remained, which accounted for 38% of the total harvested volume, and 36% of the total time in the original dataset.

The analyses focused on two main sources of variation (Performance variation and Workflow variation), and on two main aggregation levels (individual machines and contractor). For analysis at the contractor level, the volume and machine time of those owned by the same contractor were aggregated per month. To derive performance variation, the relative monthly variation for a machine was calculated by comparing monthly values with the mean value over the studied period, for both volume and time, as well as for individual machines and contractors. Workflow variation was defined as the coefficient of variation (CV) of performance variation. Performance variation and workflow variation were normalized to render them comparable between machines or contractors.

2.3 Papers II & III

Discrete Event Simulation (DES) was used to analyze how flexibility of machine use within and between harvesting groups influences the balance between flow and resource efficiency. In Paper II, a simulation model was used to evaluate a standard two-machine cut-to-length system (large harvester and forwarder). The two-machine system was operated by two, three or four operators, making the machinery adaptable to different wood-flow related objectives within the harvesting group. With respect to wood-flow, certain conditions and objectives were included at different levels in the experiment, as well as time consumption as a factor dependent on stand condition, and random periods of downtime. In order to isolate the effect of adapting machine use, stand selection was not used to influence flow and/or resource efficiency.

The model in Paper III built on the model used in Paper II. The more developed model was expanded to include two harvesting groups, with three or four operators each. The two groups also operated simultaneously, with the added possibility that machine operators could not only adapt machine use to wood-flow related objectives within one harvesting group, but also between harvesting groups.

To run the simulations, actual stand-data recorded in final fellings during 2021 were provided by Stora Enso Skog AB. The data included information on harvested volumes as well as on tree and terrain features. The data were used to calculate stand specific time consumptions for the harvesting and forwarding of loads in the stand, as well as the number of full forwarder loads in each stand. Statistics on harvester and forwarder downtimes during 2021 were also provided and used to customize probability functions for downtime intervals and durations in the models. For cost calculations, estimates of cost components for large machines were provided by the forest company according to their costing model in which utilization rates were set according to the follow-up dataset as 86% for harvester and 89% for forwarder. To accommodate differences in machine usage with different numbers of operators, the expected lifetime was set as 9.0, 6.1, and 4.6 years, with salvage values of 15%, 22.5% and 30% of machine investments for two, three, and four operators, respectively. Operator costs were set as the same for both the harvester and the forwarder. Moreover, different machine usage was also expected when there was cooperation between machine groups (i.e. with 7 operators), leading to different lifetime and salvage values. With limited information on how large the effects would be prior to the simulations, the fixed values were set between the values of having 3 and 4 operators per group, respectively.

At the end of each simulation, the resulting datasets were automatically reported and collected in new spreadsheets. The results were further analyzed with Minitab 18 to compare the different combinations of machine operators, machine choice thresholds, and initial gaps.

2.4 Paper IV

For this exploratory study, a qualitative approach with in-depth semi-structured interviews of four production supervisors and eight contractors was used. Snowball sampling, which followed a specific structure, was used to select the study participants in order to identify as much variation in perceptions about performance as possible within a limited sample.

During the interviews, each of the participants was asked to reflect upon different value attributes of the harvesting service and the performance within them. A list of value attributes was provided as examples to help stimulate the participants to consider different value attributes. The participants were also asked to reflect on reasons behind the outcome of the performance to gain insight into which factors drive and hinder contractor performance. For example, production supervisors were asked to identify which factors supported and hindered contractors' performance results, and which of these factors best explained the contractors' performance results. Similarly, the contractors were asked to identify factors that either supported or hindered their own performance.

The interviews were recorded, and the transcripts approved by the participants. All of the transcripts were coded and subjected to content analysis. The identified values relating to harvesting service were categorized according to value attributes, which were in turn sorted into identified attribute groups. Identified factors were organized based on the themes of Capability, Incentives, Commitment, and Involvement, along with External factors. In the transcripts, the occurrence of each value attribute and each factor was counted. Thus, the counting was based on the number of contractors the production supervisors mentioned with each value attribute and identified factor, and how many of the interviewed contractors mentioned each value attribute and factor.

3. Results

3.1 Contractors' workflow variations (Paper I)

Performance in terms of volume produced and worked time varied between months and years for harvesters and forwarders (Figure 2). There was a large dispersion in performance variation over the 24 months within the 77 machines, regarding both volume produced and worked time. Some of this could be attributed to seasonal patterns in most machines performed above or below their mean volume and time values, with performance during May, June and July being notably lower. Significant differences were mainly observed between months in different seasons, but also occurred between months in the same season and between the same month in different years. For example, produced volume and worked time were higher in the May and August of 2018 than 2019. The largest difference in performance between all 24 months was observed between July and August 2018.

The relative performance variation within months of volume produced and worked time for all the 77 machines pooled was positively correlated. However, it was noted that the range of dispersion between volume produced and worked time was considerably smaller for negative values (i.e. when machine performance is below average) compared to positive values (i.e. when machine performance is above average) of relative variation. The dispersion of relative variation decreased when aggregating the machines over the 39 contractors that owned them. Moreover, the dispersion of variation for volume produced was wider than for worked time on data aggregated at the level of both machine and contractor .

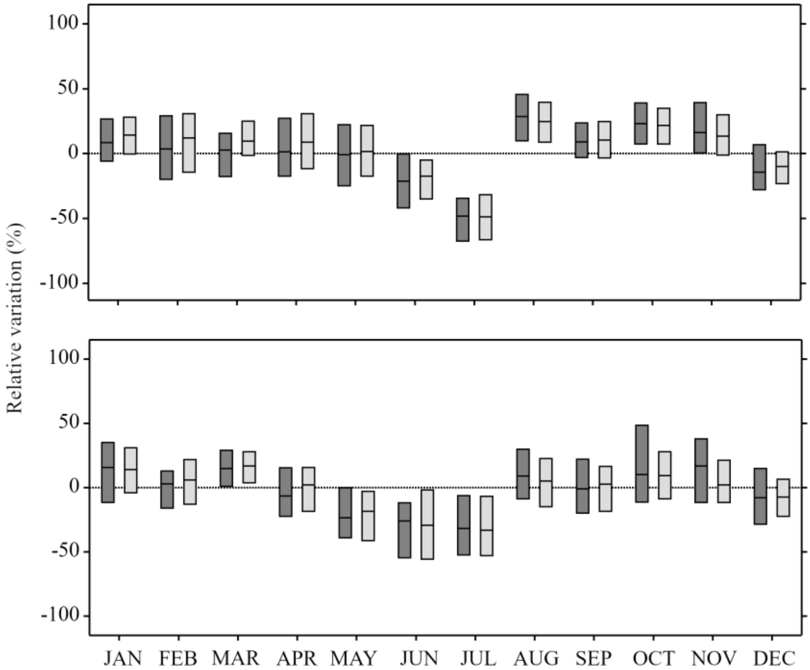

Figure 2. Relative variation in the machines' volume produced (dark gray) and worked time (light gray) over months for 2018 (upper panel) and 2019 (lower panel). Boxes indicate median and quartile values. A relative variation value of 0% indicates that the value for that month was the same as the mean value for the machine's performance during the observed 24 months. The lowest possible relative variation value −100% indicates that the machine had not been used or produced no volume at all that month. N = 77 machines per month.

Individual machine's and contractor's workflow variation in volume produced and worked time was indicated by the coefficient of variation (CV) of their monthly performance over the studied 24 months. In general, there was a strong positive correlation between workflow variation in produced volume (CV_{volume}) and workflow variation in worked time (CV_{time}) at both machine (Figure 3) and contractor levels (Figure 4). But there were also examples of substantial deviations between CV_{volume} and CV_{time} at both levels. Most of the correlation deviations indicated a higher CV_{volume} than CV_{time}. These examples were common for medium sized harvesters and forwarders (Figure 3) and contractors with medium sized machines (Figure

4). This indicates that medium sized machines could have high CV_{volume} while still having relatively low CV_{time}.

The results revealed that a contractor's workflow varies in both volume and time. However, the study also showed that it is not the same for all contractors as the level of unevenness in workflow differed between contractors, which could be attributed to the number of machines, machine sizes and total workload of harvesting services. These results indicate that many contractors demonstrate capacity flexibility that has negative effects on their resource efficiency, and thus, on the costs of the harvesting operation. It seems that contractors with more machines can even out the workload between the machines, resulting in a more consistent workflow at the company level than at that of individual machines.

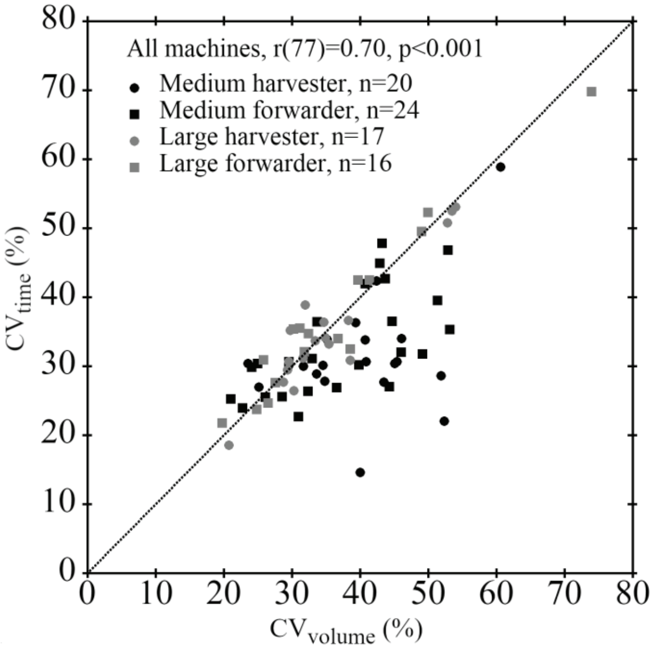

Figure 3. Relationship between the machines' CV_{volume} and CV_{time}, distributed over machine type and size. The closer to the line, the more equal CV_{volume} and CV_{time}. Machines under (to the right of) the line have a lower CV_{time} than CV_{volume}. r = Pearson correlation coefficient. The number in parenthesis represents the total number of machines. n = number of machines in each combination of machine size and type.

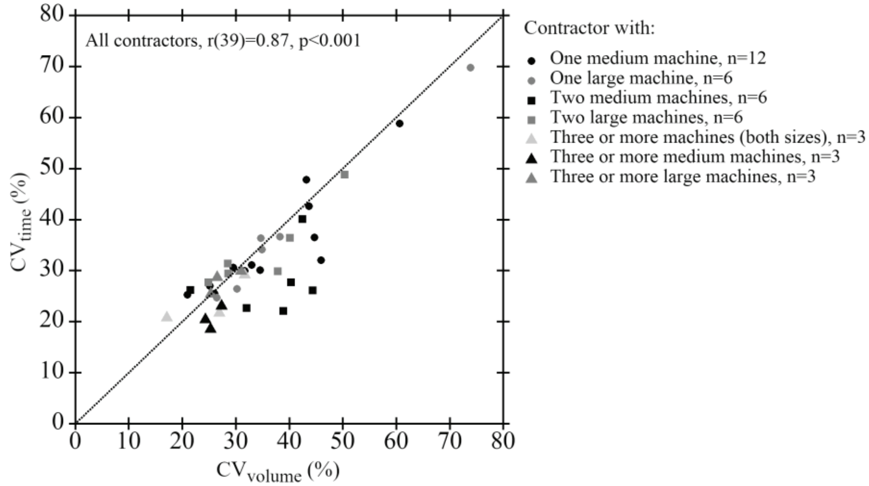

Figure 4. The contractors' machines' CV_{volume} and CV_{time} with information about machine size and the number of their machines. The closer to the line, the more equal CV_{volume} and CV_{time}. Contractors under (to the right of) the line have a lower CVtime than CV_{volume}. r = Pearson correlation coefficient. The number in parenthesis represents the total number of contractors. n = number of contractors in each combination of number and sizes of machines.

3.2 Balancing flow and resource efficiency (Papers II and III)

The results show that there is a trade-off between flow and resource efficiency within harvesting groups. Indeed, flexibility in terms of the production capacity to adjust utilizations on machines according to wood flow objectives was successfully achieved, but at the expense of resource efficiency. To staff the machines with four operators was, in Paper II, related to no flexibility, and provided the best resource efficiency, but low and highly variable flow efficiency. To staff the machine with two operators resulted in complete flexibility, but at the expense of cost efficiency and long lead-times. The best balance was achieved when staffing the machines with three operators, which allocated 33% of the work time to flow adjustment work, which resulted in the shortest lead-times and the smallest cost increases (Figure 5). Compared to four operators, the lead-times were 22% - 91% lower with three operators depending on the initial gap and time-gap threshold for machine-choice, but it came with increased costs of 3.2% - 3.4%.

Cooperation between harvesting groups staffed with flexible operators gave further possibilities to balance the amount of flexibility, both within and between harvesting groups. The result of the cooperation between the harvesting groups, compared to groups working independently, was that the group with four operators attained in average 60-90% lower lead-times and increased costs of in average 1.6-1.8%, while the harvesting group with three operators maintained the lead-time at the same levels but for almost half the costs increase (1.6-1.8%), (Figure 6). The results in Paper III thus show that the need to balance the amount of flexibility, in terms of production capacity, in order to adjust wood flow efficiency, could be done with less loss of resource efficiency if the flexibility adjustment work was done between, rather than only within, harvesting groups.

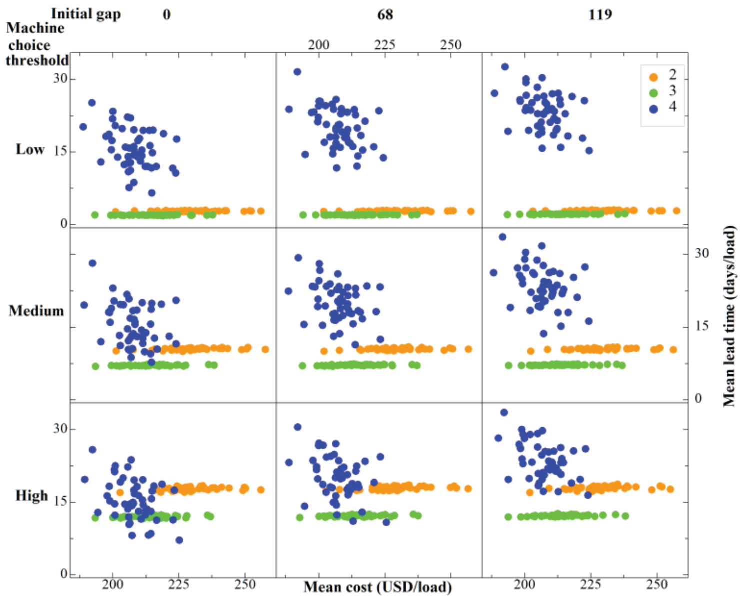

Figure 5. Mean lead time plotted against mean cost per load for all combinations of operators, machine-choice thresholds and initial gap. n = 50 sets of forest stands.

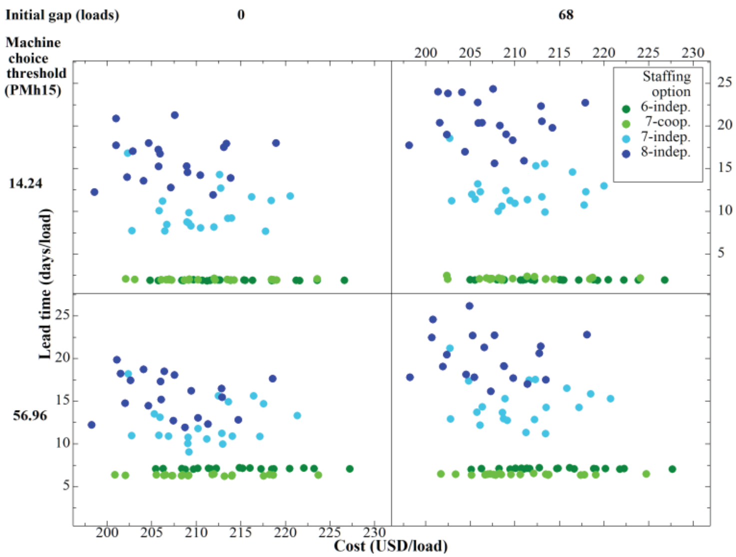

Figure 6. Mean lead time plotted against mean cost per load for all combinations of staffing options, machine choice threshold and initial time-gap. n = 20 sets of forest stands.

3.3 Performance in harvesting operations (Paper IV)

The interviews in Paper IV revealed 18 different value attributes as aspects of performance, which were perceived to be important in harvesting operations. These value attributes were divided into eight groups. Ordered from the most to least the frequently mentioned, the groups were: Adaptability, Operational quality, Delivery, Information, Development, Independence, Stability, and Safety. This shows that performance in harvesting operations consists of many different values that can be perceived differently by production supervisors at the forest company and by the contractors. What constitutes good performance can therefore be assumed to be case specific.

Contractor performance was perceived as being affected by a range of driving and hindering factors. These factors were categorized into five themes: Capability, Incentives, Commitment, Involvement, and External factors. Most factors could exert both a driving and hindering effect, which varied between contractors and depended on the value attributes in question. In total, production supervisors most often mentioned factors in the theme Capability when discussing both what drives and what hinders performance under a value attribute. The contractors also mentioned factors connected to Capability the most when reflecting about what might hinder performance. However, concerning what drives performance, factors connected to Incentives were instead the most frequently mentioned.

The main reason for why Capability was stated most often as being obstructive to performance was because under many value attributes and for many contractors, the factor 'resources', in which there was a lack of machine operators was frequently considered to hinder performance. Production supervisors also frequently mentioned a contractor's competence as affecting performance, both in a positive and negative direction, depending on which contractor or value attribute was being discussed. However, contractors considered their own competence only in a positive light. A mirror image of this pattern was noted for the factors 'collaboration interface' and 'relationship'. These factors were given as examples both of driving and hindering effects by the interviewed contractors, but production supervisors only mentioned these factors when providing examples of what drives performance.

The same factor could have opposing effects on different value attributes. Such opposed effects were found in ‘collaboration interface’ and ‘economy’ of the performance in the groups Adaptability and Delivery, which are values connected to flow and resource efficiency. Most contractors were perceived to perform well in Adaptability according to both the production supervisors and the contractors themselves. The ‘relationship’ and ‘collaboration interface’ factors were mentioned by both business parties as the drivers of good performance in Adaptability. The production supervisors did not mention many hindrances, but many contractors highlighted obstacles to their Adaptability performance being due to ‘economic losses’ and ‘lack of resources’. The economy was instead mentioned as a driver of Delivery (volume production and delivery reliability) that was hindered by the ‘collaboration interface’. Thus, it seems that Incentives drives resource efficiency while hindering flow efficiency, and Involvement drives flow efficiency while hindering resource efficiency.

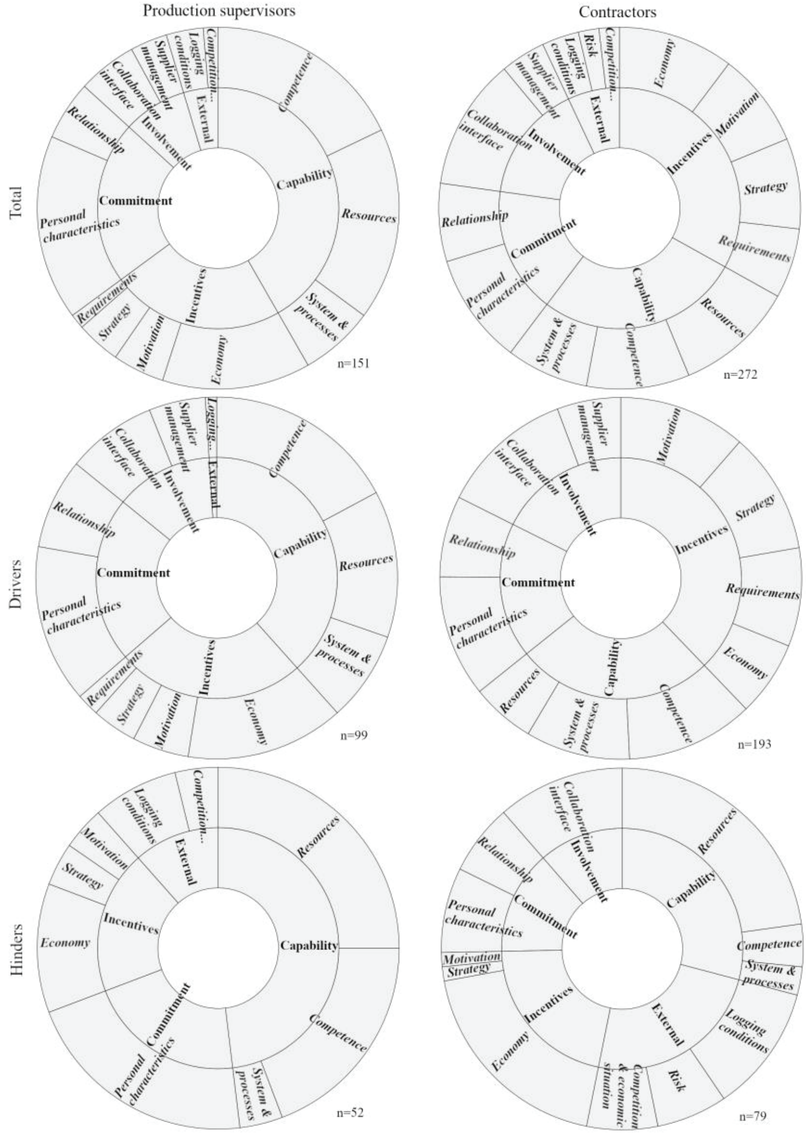

Figure 7. The proportions of the themes and factors within examples given (n) by the production supervisors and contractors, organized as total instances of cases in which the theme/affecting factor was mentioned as an obstacle or driver. The themes and factors are sorted according to frequency, with the theme that was mentioned most often at the top of each circle (frequency of mentions then progresses clockwise in descending order).

4. Discussion

Based on the findings revealed by these four studies, the following sections discuss challenges, potentials, and solutions for managing harvesting operations in a complex operating environment.

4.1 Evaluating flexibility in harvesting operations

Because wood supply is a complex process, it is widely understood that there is a need for flexibility in the wood supply chain. However, wood flow efficiency by buffering with flexibility in capacity rather than with stock levels has not received much attention in either previous research or in the operational practices used in the harvesting operation part of the Swedish wood supply chain, although a few studies did highlight this topic 20 years ago (eg. Helstad et al., 2001; Brunberg, 1999a; Brunberg, 1999b). One reason for this lack of attention may be that flexibility has always been associated with decreased resource efficiency and increased costs. This is anathema to the stringent goals of cost efficiency in harvesting operations. Rennel (2010) emphasized low fiber costs and cost efficiency of wood procurement as being strong determinates of a mill's competitiveness. Harvesting operations constitute more than half of forestry costs and consequently every improvement in cost-efficiency means large savings on the cost of wood procurement (Eliasson, 2022). The history and tradition of holding large stocks of roundwood in floating, and subsequently in road and railway transport, have meant the need to focus on flexibility has been sidelined, with a greater focus instead on making harvesting operations as cost-efficient as possible. In Sweden, flexibility has therefore been left as something to be accommodated by other parts of the supply chain. Hence, the tradition of holding stocks has remained, being considered a more cost-efficient way to buffer fluctuations instead of buffering resource capacity, and thereby keeping costly resource capacity idle (Laestadius, 1990; Audy et al., 2012; Eriksson, 2016).

The lack of research into flexible resource capacity in harvesting operations does not mean that there is no need for flexibility in that part of the supply chain. In fact, that need for flexibility has always happened in Swedish forest operations in one way or another. For instance, one of the perceived benefits of outsourcing forest work in Sweden during the 1980s and 1990s was the opportunity to increase capacity flexibility in harvesting operations (Ager, 2014; Erlandsson, 2016). Outsourcing makes it possible to secure a certain proportion of the required capacity through long-term contracts, and temporary fluctuations in required capacity could be managed through short-term contracts or spot-purchases. However, as argued by Erlandsson (2016), this increases the risk of lacking capacity when it is needed, or of opportunistic behavior among contractors, which can lead to rising prices. Moreover, the control of operational performance decreases (Erlandsson, 2016), which can have negative effects on the wood supply chain (Eriksson, 2016). It is not surprising therefore, that contractors engaged on long-term contracts use flexibility to adjust volume production according to current need - a practice that is highly appreciated by their clients, as earlier demonstrated by Erlandsson et al., (2017) and which was also the case in Paper IV of this thesis.

Capacity flexibility in harvesting operations is obviously needed (e.g. Paper I) but is normally not purposely integrated in either the design of the supply-chain or the contractor's business relationship with their customer. This seems especially true when it comes to adjusting the utilization of resources. It seems that when a need for flexibility occurs, the organizations involved in a harvesting operation adapt to solve a problem with the current situation. That probably means an increase of logging costs, but of an uncertain amount. Despite the potential cost increase caused by flexibility, not much has done to investigate how much flexibility is needed, nor how it can be handled in an efficient way. However, the potential of agile selection of harvesting stands to steer production has been in more focus for practitioners (Eriksson, 2016) and using a combination of a flexible harvesting fleet that can operate in both thinning and final felling (Erlandsson, 2013). The potential is that the need for costly capacity flexibility in harvesting operations can decrease with the amount of volume flexibility that can be managed through agile stand selection.

Agile stand selection can be done using models that predict machine productivity based on the conditions in the stand to be harvested (Eriksson, 2016). The company used as a case study for this thesis used such productivity models to direct wood flow toward satisfying demand, while trying to enable contractors to utilize their resources at a high and consistent level throughout the year (Paper I). Indeed, if that goal is achieved and a suitable business model for pricing of operation is used, it should limit negative effects on contractors' profitability and satisfaction, as Erlandsson and Fjeld (2017) found to be a risk with an uneven workload. For contractors to accept agile stand selection, the pricing of the operation needs to be adjustable for variations in work conditions. Payment per unit work time meets this requirement but might not be preferred by a forest company in many cases. Payment per produced unit, on the other hand, is considered to promote work efficiency. For this pricing model to compensate adequately for variable work conditions, the productivity of harvesting operations needs to be predicted under various work conditions. Moreover, such pricing models also enable work conditions to be matched to the quantities of wood desired, by selecting harvestable stands based on the predicted time it will take for the contractor to harvest the standing volume. Agile stand selection will then reduce the cost of unused machinery and manpower for which the forest company may compensate contractors according to the common standard agreements between the business partners in the harvesting operation (Skogforsk, 2020). Therefore, it is assumed that the produced volume varies more than the time consumption on contractor's machines.

As shown in Paper I, 'volume produced' and 'worked time' are significantly correlated. Thus, agile stand selection cannot fulfill the whole need for volume flexibility without including capacity flexibility. Thus, contractors should assume that the need for flexibility in harvesting operations refers both to volumes to be produced, and working time to produce it. However, according to the results in Paper I, it appears that this assumption depends on whether flexibility is needed to increase or decrease volume production. If the aim is increased volume production, it might be achieved without the same need of flexibility in working time. However, if the aim is to decrease volume production, it would probably also require flexibility concerning decreased work time.

Machine size and type also seem to be important as medium sized machines, especially the harvester, attained larger workflow variations in produced volume than worked time. This is due to medium sized machines being capable of both thinning and final felling (Erlandsson, 2013). As shown by the production models in Eriksson and Lindroos (2014), this affords an opportunity to make large adjustments in volume production without needing to adjust machine working-times. As mentioned above, the difference between relative variation in volume and time is smaller when decreasing than increasing produced volumes. This may be because medium sized machines are normally used in thinning, but when wood demand increases some can be transferred to final felling, so increasing delivered volume without changing working time. However, in final felling, large machines are more productive than medium machines. Thus, using medium machines in final felling often results in higher logging costs. More thoughtful adjustments of machine working-time could create further potential for improvement by selecting stands for final felling by large machines, and for thinning by medium machines.

In Paper I, workflows were more evenly spread at the contractor level than on individual machines. The reason behind this may be that some contractors appoint machine operating staff in such a way that it levels out the available and required work-time between machines. This indicates adaptability over time to the respective, but fluctuating, needs for harvesters and forwarders. In this way, although none of the machines are utilized equally each month, the buffering between the machines effectively manages the need for flexibility and may potentially increase the overall machine system's flexibility. However, further knowledge is required concerning how best to set up such flexible staffing in order to manage the need for flexibility, and to quantify any other potential gains and trade-offs. The next section therefore discusses how harvesting operations can improve flow efficiency by using machine flexibility within and between harvesting groups, and what trade-offs in resource efficiency it might lead to.

4.2 Trade-offs between resource and flow efficiency in harvesting operations

As Paper I indicates, contractors must manage variation both in produced volume and in the utilization of their resources. It should be expected that any increased need for volume flexibility in harvesting operations would not be without a need for capacity flexibility. Thus, a need to increase flow efficiency in a harvesting operation, probably means a decrease in cost-efficiency. How the harvesting operation could contribute to improved flow efficiency in the supply chain, and what trade-offs might exist between flexibility and costs, therefore requires more attention. Moreover, bearing in mind the high variation in contractors' workloads, as shown in Paper 1, managing the need for capacity flexibility and thereby limiting the negative effects and unexpected cost increases it may otherwise cause, should also be examined more closely.

In Paper II, flow and resource efficiency were compared between harvesting groups staffed with different numbers of operators. With the operator numbers, different amount of working time in which the operator can choose what machine to operate occurred. In that way, different capacity flexibility was enabled between machines. With the full crew of four operators, there was no possible capacity flexibility. Hence, flow efficiency differed largely between sets of forest stands. However, flexible capacity was possible with two or three operators due to there being an opportunity to buffer between the machines' fluctuating productivities. With two operators, 100% of the work time was flexible and available for wood flow adjustments, whereas 50% of the work-shifts was available with three operators. Since the sets of forest stands did not result in any differences in flow efficiency for harvesting groups staffed with two or three operators, it can be argued that harvesting groups with this setup are substantially less dependent on the success of agile stand selection to be flow efficient. As three operators in a harvesting group decreases the lead-time more than when there are only two, and lessens any cost increase, the amount of buffered production capacity should not be too large. Based on these findings, it should be possible to allow enough capacity flexibility between machines to provide more reliable and stable lead-times in forest operations.

How the machine group is staffed can therefore be a useful way to enable capacity flexibility in the two-machine system and increase flow efficiency in harvesting operations. However, rationalizing the work of harvesting operations has meant concentrating attention on attaining the highest possible resource efficiency and highest possible cost-efficiency of operations (Ager, 2014; Eriksson, 2016). The baseline is often set at operating each of the machines over two shifts per day. In that way, the fixed costs on the machines is distributed over more hours and volumes, which leads to lower delivery cost as revealed in Paper II. With capacity flexibility enabled by flexible machine use, the utilization of individual machines becomes lower and more uneven. Not surprisingly, this also leads to higher costs in general, as well as large cost-variations between different sets of forest stands. However, considering the costs between different sets of forest stands, large variations were also observed when having the resource efficient group with four operators. Thus, costs can be assumed to be very sensitive to working conditions, irrespective of the flexibility of the harvesting group. This is not surprising since machine productivity differs among stands (eg. Eriksson and Lindroos, 2014; Liski et al., 2020), which also affects costs. Paper III demonstrated how cooperation between harvesting groups can substantially improve flow efficiency, and keep the increase in costs lower than when only flexible machine use is enabled within independent harvesting groups.

Without capacity flexibility in harvesting operations, large stock levels occurred between the harvester and forwarder. Moreover, it resulted in long lead-times for the wood to go through the two-machine system. Thus, even if machines are staffed according to their full potential, it will still be necessary to adjust their capacity. Such an adjustment of machine use also means a level of capacity flexibility that is likely to increase logging costs and add uncertainties. Machine operators may then need to operate outside normal working time on the machine that falls behind in order to catch up with production. However, that also has its challenges and limitations. Labor regulations limit the working time of machine operators, as well as their ability to work between certain hours at night (Skogsavtalet, 2020). Moreover, current difficulties in recruiting and retaining machine operators (Ager, 2014; Kronholm et al., 2021) limits opportunities to temporarily adjust utilization on the machines by adjusting the number of employed operators, or adjusting their working time. This thesis has not included any further investigations into how operators' working conditions might be influenced by increasing wood flow efficiency. Further work in this area would be essential before implementing the results of this study.

It is normally a forest company's responsibility to match production to delivery plans (Audy et al., 2012; Erlandsson, 2013; Eriksson et al., 2017). This was also true for the case studied in this thesis. The delivery demanded of the contractors can therefore be dependent upon what forest stands contractors are instructed to harvest. To steer production to desired levels, the forest company can act according to the principle of agile stand selection. This is a complex task that requires a high level of competence in order to steer production successfully while also considering management plans for the forest. Another challenge is to balance production rates between the harvester and forwarder. With flexible machine use by flexible operators, as investigated in Papers II and III, capacity flexibility buffers interruptions to wood flow caused by fluctuating productivity of the harvester and forwarder. If volume production needs to increase or decrease, it still requires agile stand selection to change productivity. However, because the ability to adjust volume production by agile stand selection is limited (Audy et al., 2012, Guatam et al., 2013), there will probably need to be additional capacity flexibility that will in turn require adjustments to working time both of the machine operators and the machines, in order to increase or decrease produced volume. The challenge of implementing agile stand selection, and the fact that in this case there were potentially larger variations in demand than agile stand selection can manage, probably explains some of the considerably larger variations that were observed in Paper I compared to that generated in the simulations of Papers II and III. It should also be noted that the reality of harvesting operations is more complex than addressed in Papers II and III, which is also likely to have contributed to the differences observed.

Nevertheless, the results from Papers II and III clearly show that the balance between flow and resource efficiency can be improved in the harvesting operation. A first step would be to enable the flexible use of machines by flexible operators within harvesting groups to create capacity flexibility in order to buffer the imbalances that can occur in the two-machine system (as in Paper II). A further step would be to enable cooperation between harvesting groups over flexible machine use, as in Paper III. This would also potentially increase flow efficiency in harvesting operations but with a considerably smaller trade-off loss in terms of decreased resource efficiency and increased costs. However, as discussed below, enabling cooperation between machine groups might also be more challenging than enabling capacity flexibility within machine groups.

4.3 Improving performance in harvesting operations

As Papers II and III revealed, flexibility within and between harvesting groups is key to improving the balance of flow and resource efficiency in harvesting operations. This is in accord with supply chain theory, which states that cooperation networks towards shared goals leads to gains in competitive benefits (Lee, 2004), which are inherently important for the long-term survival of businesses (Rezapour et al., 2014).

However, cooperation in harvesting operations towards shared goals are subject to a range of challenges. One of these is the fact that many contractors in Sweden own only one, or just a few, machines (Häggström et al 2013; Kronholm et al., 2021). To manage flexibility between harvesting groups thus means that cooperation is needed between contractors. As contractors compete for contracts and look to their own interests of profitability and satisfaction, it is naturally unfair if one benefits from the cooperation and the other does not. However, some learnings can be gained from cooperation during the road-transport operations in the wood supply chain. In this last link in the supply chain, cooperation between contractors is the norm as it enables backhauls for better routes and thus better flow and resource efficiency (Carlsson and Rönnqvist, 2007; Frisk et al., 2010). However, cooperation models to improve flow and resource utilization at a holistic level have, to my knowledge, not been applied in Nordic harvesting operations. Palander (2022) pointed out a potential with a franchise concept, in which synchronization of many operations can improve the combined efficiency when compared to the sum of separate operations. By applying a franchise concept, benefits to large contractors' might be achieved when balancing flow and resource efficiency by cooperation between harvesting groups. Thus, the franchise concepts may be a means to align many smaller contractors towards the same goals, but other ways to combine efficiency in a collaborative manner also exist. More research is needed to elucidate how cooperation and business models can be applied to align harvesting operations into the whole wood supply chain. As forest companies are very involved in planning and coordinating harvesting operations to align with supply needs (Audy et al., 2012; Erlandsson, 2013; Eriksson et al., 2017), such cooperative models would probably need forest company involvement.

Another way to enable flexibility between harvesting groups without the need of cooperation between contractors, is to keep harvesting operations in-house instead of outsourced to contractors. Another way is to encourage contractors to expand. Then, cooperation can take place between a contractor's own machine groups. With owners of contractor companies aging and the number of young persons entering the contractor business decreasing (Conrad et al., 2018; Kronholm et al., 2019), those contractors that tend to have their performance aligned with the forest company also tend to be offered larger contract sizes (Eriksson et al., 2015). In Finland Jylhä et al. (2020) found that the size of a business was positively correlated to a contractor's profitability, since larger businesses had capacity to provide large volumes as well as versatile services, power in negotiation, and opportunities for a more cost-efficient harvesting operation within their company. The same tendency has also been shown for the larger contractors in Sweden (Kronholm et al., 2021). Moreover, as the results in Papers I-III show, it is likely that contractors with many machines and machine groups are better able to strike a good balance between flow and resource efficiency.

The potential to improve the balance between flow and resource efficiency as described in Papers II and III requires flexible machine operators who can operate different machines instead of just one. The managerial capability of contractors is therefore extremely important regardless of whether the contractor comprises and manages one or many harvesting groups. The managerial capability and skill in operating a business have been highlighted in many studies as the reason for why some contractors succeed while others struggle (Eriksson et al., 2017; Contrad et al., 2018; Gercans et al., 2021; Kronholm et al., 2021). Good alignment with the forest company is also a key to success (Eriksson et al., 2015). However, such alignment requires not only good managerial skills of the contractor, but also a willingness to collaborate with the forest company and to satisfy customer demands with the harvesting operation (Eriksson et al., 2017). A forest company would therefore benefit from applying a managerial role upon their contractor fleet in order to stimulate collaboration and alignment with the needs of the various links in the whole wood supply chain.

However, performance in harvesting operations is a complex, multifactorial metric, and is very case specific (Eriksson et al., 2015; Häggström and Lindroos, 2016; Erlandsson et al., 2017). Therefore, in addition to improving the balance between flow and resource efficiency, other value attributes within the harvesting operation must also be considered, which can make it difficult to realize what alignment with the supply chain really is.

As the study in Paper IV revealed, contractors are a blend of professionals characterized by a unique mixture of performance achievements across different value attributes. Some contractors perform strongly across many value attributes, while others perform strongly in only a few. Regardless of whether the decision to focus on certain value attributes is conscious or not, this result indicates that different niches and business models exist among contractors. Furthermore, even if a forest company has not considered a certain value attribute, it may still be important. In general, service companies that are one step ahead, and provide unexpected beneficial values, can attain excellent customer satisfaction and gain a better market position (Kano, 1984). Something that should also be true for harvesting contractors. To be one step ahead in terms of innovation and finding niches requires contractors to have an entrepreneurial attitude. As St-Jean and LeBel (2012) concluded, this requires a certain degree of independence from the forest company. Nevertheless, the forest company and its contractors should benefit from any close collaboration aimed at development and innovation, as it increases the chances of better alignment with the whole supply chain (Eriksson et al., 2017).

The results of the study reported in Paper IV indicate that a forest company may be satisfied with contractors due to their good adaptability regarding performance, even if they perform poorly in other value attributes compared to their competitors. Thus, contractors that facilitate and support the work of the employees of the forest company were much appreciated, as well as contractors who adapted to variations and changes that occurred in daily operations. Moreover, as some of the wood supply came from non-industrial private forest owners, contractors that adapted their operation to the special needs of private owners were also much appreciated. As stated by Nordlund and Westin (2010), and Erlandsson et al. (2017), non-industrial private forest owners may have requests that limit opportunities to use agile stand selection to steer wood flow. This can mean an increasing need for capacity flexibility for the contractors as well as increasing difficulties to match production with industry demands (Audy et al., 2012; Erlandsson, 2013). Erlandsson (2016) described the perspective of harvesting operations involving the triad of forest owner associations, forest owners, and contractors. The perspective on performance in harvesting operations differs among these three entities, as well as what satisfies them (Erlandsson et al., 2017). Having a large part of the wood supply from non-private forest owners may therefore make it even more challenging to achieve both high flow and resource efficiency.

As was shown in Paper IV, forest companies appreciate contractors who are highly adaptable due to their ability to make rapid changes in, for instance, the order in which stands are harvested. This indicates that the forest company will be satisfied with adaptable contractors, regardless of whether a problem was caused by the forest company, the contractor, or by external circumstances. Based on these observations, it seems that adaptability is one of the most important attributes for a contractor to master. On the other hand, Erlandsson and Fjeld (2017) report that such adaptability can decrease contractor satisfaction and profitability. It also decreases operational efficiency, which Eriksson et al. (2015) highlighted as being the most important feature of contractor performance. As Paper IV indicated, performance in harvesting operations is complex not only because there are many aspects that different individuals perceive differently, it is also difficult for any one player to excel in all aspects of performance and the associated value attributes, as some can contradict the performance of others. Such is the case for flow and resource efficiency as it clearly means trade-offs, which by definition means that better performance in one aspect is at the cost of another. Therefore, it was not surprising to find that some factors perceived to drive performance in value attributes important for resource efficiency, simultaneously hindered performance in value attributes important for flow efficiency, and vice versa. However, what was notable in the results of Paper IV, was the imbalance and contradiction of Incentives and Involvement on those performances in value attributes that were important for resource and flow efficiency. If the incentives tell a contractor to do one thing and involvement by the forest company to do another, it is obviously difficult to develop performance alignment. Therefore, if both flow and resource efficiency are important in harvesting operations, the different factors affecting performance should be in better balance and synergy with each other. To guide management through the complexity of the myriad factors affecting performance, the section below provides a framework for discussion based on a concept map (Figure 8) of the interactions between many factors that affect performance in harvesting operations.

4.4 Conceptual framework for performance management

Performance excellence emerges from the judicious selection of action at the best level, for each of the many factors that together form a complex matrix. Based on contingency theory (Morgan, 1998), these factors need to be organized in a way that meets the requirements of the environment they operate in. A part of that environment was captured by *External factors* in Paper IV, but there are other contextual factors which are essential and underlie organizational behavior (Johns, 2006). To contextualize the concept map below on a broader basis than just *External factors*, it is presented in the context of *Working conditions, Market conditions, Contractor conditions,* and *Supply chain conditions*. Based on John (2006), interactions exist between contextual factors, as well as on the organizational setting and behavior. Organizational behavior can be many things (Morgan, 1998), but the concept map in this thesis limits it to the themes that were used in Paper IV viz *Incentives*, *Involvement, Contractor capability,* and *Contractor commitment*. In the concept map *Incentives* and *Involvement* are considered as managerial factors executed by the forest company in order to affect a contractor's *Capability* and *Commitment* to performance. Along with interactions within the contexts of *Working conditions, Market conditions, Contractor conditions,* and *Supply chain conditions*, the interactions between these themes leads to the performance outcome (Figure 8). Combined with the concept map in Figure 8, I suggest the use of a four-step process to orientate performance management within harvesting operations (Figure 9).

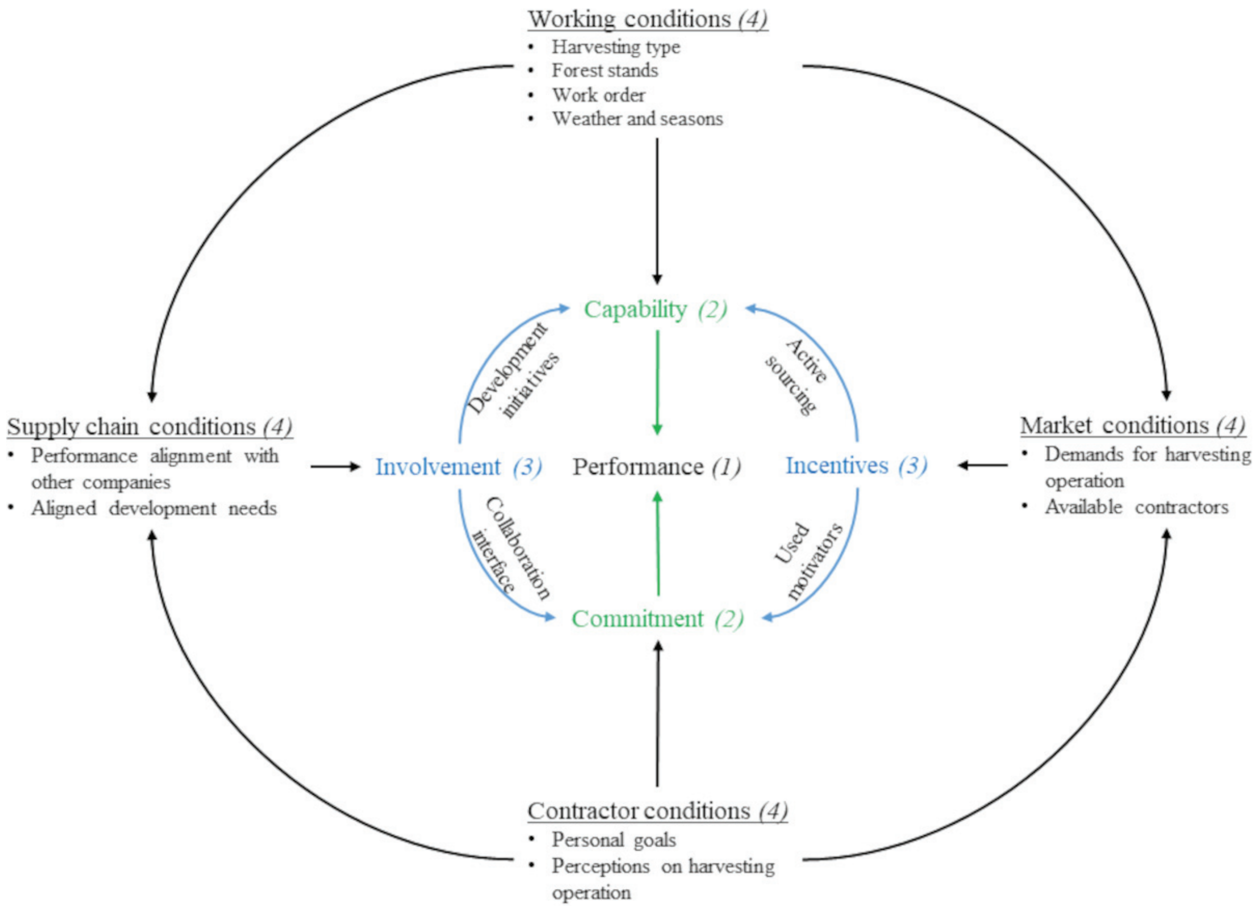

Figure 8. Concept map of interactions between factors affecting performance in harvesting operations. Suggested process for orientating is provided in Figure 9, where the numbers (1-4) indicate the relevant process steps. Blue indicates the forest company, green indicates the contractor.

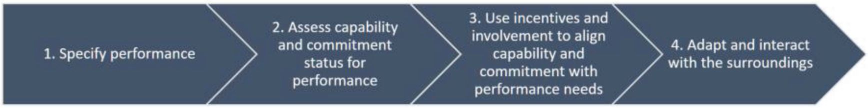

Figure 9. Flowchart of suggested processes for orientating in the concept map in Figure 8, where the numbers (1-4) indicate the relevant themes.

4.4.1 Specify performance (1)

To use the concept map for performance management, one first needs to specify what performance is in harvesting operations. As other studies such as Eriksson et al., (2015) and Erlandsson et al., (2017), along with Paper IV of this thesis reveal, harvesting operations comprises a range of different value attributes. This process step can be made by using the method described in Eriksson et al., (2015), which requires specifying the attributes of service needs together with their importance. Such an approach can be helpful when balancing and evaluating trade-offs between different value attributes. However, there is a risk of an unbalanced focus favoring the value attribute perceived to be most important, with concomitant disadvantages to performance in others. It is therefore suggested that, in the concept map, each attribute also is individually reconsidered as being perceived to have importance in the harvesting operation.

4.4.2 Contractor capability to performance (2)

To deliver a performance required by the harvesting operation, the contractor must be able to actually do so, and do so satisfactorily. According to the resource-base view (RVB) of a firm, resources as tangible and intangible assets are key to performance. Tangible assets are physical resources such as machinery, equipment and financial capital, whereas intangible assets have no physical presence, but exist in the abstract such as skills and knowledge (Wernerfelt, 1984). Tangible assets are easier to copy and procure according to best practices than intangible assets (Grant, 1991). In Swedish harvesting operations, relevant machine types and sizes affect a performance in its various value aspects differently. For instance, larger machines are more productive in final fellings than medium sized machines (Eriksson and Lindroos, 2014), but medium machines are more flexible when there is a need to manage volume production because they can be used both in thinning and final felling (Erlandsson, 2013). Thus, tangible assets, such as using the right machines and equipment for what needs to be performed, are important. However, what often divides successful businesses from their less successful competitors are their intangible assets such as competence and the knowledge held by the firm (Grant, 1991). For instance, the importance of skilled machine operators is often highlighted, as the operator has a great influence on performance in harvesting operations (Purfürst and Erler, 2011; Häggström and Lindroos, 2016). However, for a contractor it is seldom enough to be a skilled machine operator for the business to succeed. For instance, Norin and Thorsén (1998) noticed that good leadership and efficient processes are commonly apparent among high performing contractors. Moreover, Eriksson et al., (2017) emphasized managerial and collaborative capabilities as essential for both business success and alignment with a forest company. Gercans et al. (2022) also pointed out those capabilities as success factors, along with experience in the sector, skillful employees, teamwork, and good contract rates.

It is interesting to discuss capability in terms of the opinions of participants from the forest company in Paper IV. About the larger contractors, they mentioned contractors' leadership skills as a principal reason for performance excellence, whereas an excessive focus on contractors' themself operating machinery was regarded as a reason for poor performance. By contrast, about small contractors they mentioned operational skills (e.g. handling of machines) to positively influence performance, whereas leadership skills were seldom mentioned. To some extent, this may be explained by the nature of the work. Larger contractors have more employees operating machinery. Therefore, the contractor responsible for agreeing contracts will take on distinct managerial roles (both internally and externally), spending more time managing the company rather than operating the machines (Jylhä et al., 2020). This does not mean that smaller contractors do not need leadership skills, but rather that the importance of leadership skills may increase successively with the size of the organization. Forest companies' actions of Incentives and Involvement should therefore benefit from assessing the contractor's leadership and operational skills, as both of these factors are relevant to the performance of the harvesting operation.

4.4.3 Contractor commitment to performance (2)

An individual's commitment to an organization and their own work activities has been shown to correlate with performance, because committed individuals tend to be more likely to meet an organization's demands than those who are less committed (Porter et al., 1974). This also applies to contractors since the most successful contractors are often highly committed to their customers and tasks (Eriksson et al., 2017). Commitment can be based on emotional attachment and a calculative dimension to performing the task (Gilliland and Bello, 2002).

Based on discussions with the participants in Paper IV, the forest company seem to consider contractor commitment to rely mostly on the actions of the contractors themselves. Notably, operational quality was mentioned to be driven by a contractor's enthusiasm and pride in performance. The interviewed contractors also confirmed that their positive attitude drives their operational quality of performance, as they often described their own pride at performing well in these attributes. The relationship was mentioned by both parties, but to a considerably higher degree by the contractors. In the discussions linked to the relationship factor, the participants mentioned a mutual trust between the parties as a driver of performance, with this characteristic especially mentioned regarding adaptability, which included flexibility, collaboration, and where wood procurement might be necessary from private forest owners. Moreover, the contractors commonly judged their adaptability to be beneficial in the development of any long-term relationship with a customer, which also indicated a calculative dimension on commitment for further business opportunities with a forest company. These recorded attitudes are important to take into consideration in the actions of Incentives and Involvement when improving a contractor's commitment to the business relationship, and thus their commitment to providing a good performance in harvesting operations.

4.4.4 Incentives and involvement (3)

Eriksson et al., (2015) suggested the use of *active sourcing, supplier development, incentives alignment* and *use of power*, in order to improve contractors' performance alignments with requirements. They emphasized that any suitable approach would be case specific, depending on the given contractor's capability for performance and how well the current performance aligns with requirements. This thesis takes that framework as its base and adds the dimensions of commitment and the context in which the forest company and contractor operates. Thus, the most appropriate approach depends on contractors' capabilities, their commitment and the contextual setting.

The concept map of this thesis suggests that incentives can be used to improve contractor capability and commitment to improve performance. Incentives can mean actively sourcing a contractor with capability that aligns with the necessary performance required. It may involve increasing contract sizes of current contractors in the business relationship, or contracting new or additional contractors that have the necessary capability. For these contractors to engage in the task that has to be performed to the required degree of excellence, the forest company also needs to deploy motivators to enhance a contractor's commitment. That might include aligning economic incentives, as suggested by Eriksson et al., (2015), to promoting contractors' own returns while simultaneously maximizing customer value (Cohen at el. 2007). However, lifestyle objectives can be more important for contractors as SMEs, than maximizing returns of their business (St-Jean and LeBel, 2014; Erlandsson and Fjeld, 2017; Johansson et al., 2021). Moreover, as Erlandsson and Fjeld, (2017) empathized, contractors' satisfaction is not the same as their profitability. Thus, deploying motivators may include more than economic incentives, such as, for instance satisfaction of needs at different levels of Maslow's Hierarchy which includes physiological, security, social, ego, and self-actualizing needs (Maslow, 1943; Morgan, 1998). 'Use of power' leverage is also an incentive that might be used to commit contractors to performance. As such, the forest company as customer can leverage their dominant position in the business relationship to convince a contractor to act in a certain way (Eriksson et al., 2015). In the Swedish context, contractors who offer harvesting operations have high investment costs in machinery and rely on only a few large companies to make a living (Erlandsson, 2016; Kronholm et al., 2019). Thus, these contractors understand that if they do not provide the required performance then the cost of a potential breakdown in the business relationship will be rather high and they will therefore take this factor into account if they want to maintain the relationship (Morgan and Hunt, 1994; Gilliland and Bello, 2002). However, 'use of power' can cause conflicts, which do nothing to assist the goal of achieving performance excellence. For instance, low levels of trust between the forest company and the contractor, where the forest company is disrespectful towards the contractor, along with unprofessional and dishonest behavior are all attributes of conflictual relationships (Eriksson et al., 2017). This significantly harms commitment and hurts performance excellence (Porter et al., 1974).

Along with incentives, a forest company's involvement with its contractors can improve the contractors' capabilities and commitment to performance. For instance, to improve current contractors' capabilities, the forest company can offer development initiatives, such as education and training programs, that strengthen the contractor's necessary capabilities to perform (Eriksson et al., 2015). In this way, the forest company can promote the development of contractors' capabilities to align with future needs (Krause et al., 1998). If development is left in the hands of the contractors themselves, or to market mechanisms, it can expose the supply chain to risks since contractors' actions as entrepreneurial SMEs may not always align with the rest of the supply chain members' needs (Falkner and Hiebl, 2015). Development initiatives provided by the forest company to help contractors improve their capabilities can therefore be for the common good of the whole wood supply chain (Lee, 2004). However, for contractors to actually follow any development initiatives provided by the forest company, the forest company also needs to engage in the collaboration interface with the contractor. How the forest company interacts in the collaboration interface is inherently important for a contractor's commitment to attain the improvements suggested by the forest company. This includes how the forest company fulfills their part of the assignment, and the consequences of these actions. Moreover, the contractors then receive help and guidance from the forest company when it is needed. Erlandsson and Fjeld., (2017) highlighted this as being essential for contractor satisfaction, and it can also be assumed to be true with respect to their commitment to performance excellence.

4.4.5 Interact with the contextual environment (4)

The contextual environments of *Working conditions, Market conditions, Contractor conditions,* and *Supply chain conditions* affect the capability and commitment necessary for contractors to perform to the required standard, as well as the incentives and involvement a forest company needs to apply when managing the performance of their contractor fleet.

Working conditions directly affect performance capability. It includes the use or availability of machinery that is suitable for the job in hand, since large machines outperform medium machines in final felling while they are not an option in thinning (Eriksson, 2016). This means capability depends on appropriate machinery depending on whether the operation involves final felling only or if thinning is also needed (Erlandsson, 2013). Moreover, as performance differs widely among machine operators (Purfürst and Erler, 2011; Häggström and Lindroos, 2016) it is likely that their skills also differs between harvesting types. Thus, different harvesting groups are likely to differ in their capability to perform thinning, final felling or both. Managing the variations in working conditions between forests stands (Nilsson et al., 2013), as well as according to season and weather conditions (Keskitalo et al., 2016; Lidskog and Sjödin, 2016), also requires certain capabilities.

Working conditions in turn affect the contextual environment of the market mechanism with the demand for harvesting operations varying over time. This gives incentives for using short-term contracts and spot purchases, or adapting capability to more long-term projects (Erlandsson, 2013, Erlandsson, 2016).

Working conditions also affect collaborations along the wood supply chain, as it can mean specific adaptations being made to different parties, which can in turn further affect performance. For instance, the decision of which forest stand to harvest affects not only the harvesting group and the contractor, but also many other links in the wood supply chain, such as the forest owner (Erlandsson et al., 2017), stock levels (Paper II and III), and the mill (Carlsson and Rönnqvist, 2005).

A contractor’s commitment to perform in a harvesting operation depends not only on incentives from and involvement by the forest company, but also the contractor conditions, such as personal goals and perceptions for what good performance is. Indeed, the results of Paper IV indicate that such contractor conditions are perceived to be important for their performance in harvesting operations. Contractor conditions do not only affect their commitment to performance, but also the market conditions. For instance, forest companies should contract contractors with conditions that align with the required performance (Eriksson et al., 2017), but they should also adapt their incentives depending on the contractor (Eriksson et al, 2015). Moreover, if contractor conditions are severely misaligned with market demands, it can lead to the liquidation of the firm (Eriksson et al 2017), leading to fewer contractors on the market.

Contractor conditions also affect collaborations along the wood supply chain, and, in turn, the involvement by the forest company. For instance, if a contractor is willing to participate in aligned development needs, involvement efforts can help struggling contractors to align, or strategically develop their capability and commitment for better performance in the future (Krause et al., 1998; Eriksson et al 2015).

4.5 Strengths and weaknesses

To address the high-level goal of improving performance in the harvesting operation part of the wood supply chain, a combination of quantitative and qualitative research methods was used. In Paper I, large datasets on real-life harvesting operations were provided by Stora Enso Skog AB, so validating the results and their practical relevance. However, the data used suffer the same limitations as similar datasets, in being case-specific as well as containing errors (Eriksson and Lindroos, 2014; Manner et al., 2016). Moreover, the study focused on machines working continuously for the company, so it did not encompass the complete breadth of the various harvesting operation scenarios at the contractor level. The complete range of management flexibility as used by the forest company has not therefore been completely addressed. Nevertheless, the results clearly show the potential of evening out variations when there is the possibility of balancing machine use across many available machines.

Papers II and III focused on flexible machine use within, and between harvesting groups, respectively, and the effects on flow and resource efficiency by using discrete-event simulations (DES). Some of the main advantages in using simulations is that they can mimic a specific bounded real system in a robust way, and the effects of manipulating a system in different ways can be evaluated without carrying out expensive or hazardous physical experiments (Banks et al., 2005). Hence, different levels of machine use flexibility of the standard two-machine cut-to-length system could be evaluated under controlled and comparable conditions. That would be difficult to do as a physical experiment, both due to high costs and the impossibility of making comparisons under identical conditions. Real-life data were provided by the forest company acting as the subject in the case study, thus validating the results and their practical relevance. However, as with all models, the representations of reality and system boundaries had to be simplified. The models in Papers II and III are thus imperfect imitations of the actual complexity of the system. Although variation in forest stands and downtimes were considered, many other variables were not accounted for. The possibility and willingness of operators to work according to the flexible machine-use scheme is the most obvious area to investigate further in future research.

The performance outcome of harvesting operations is surrounded by a degree of complexity that could not be accounted for in the quantitative approaches used in Papers I, II and III. A qualitative approach with in-depth interviews was therefore used in Paper IV. That study was conducted in the context of a real-life case with the forest company and its associated harvesting contractors. The sampling process aimed to identify the maximum variation and diversity of performances in the harvesting operation among the participants in order to reveal the multiplicity of perspectives from a limited sample. This is a common approach in qualitative research (Creswell and Poth, 2016). Paper IV thus explored a broad spectrum of examples comprising a range of different perspectives of factors affecting the value attributes in different aspects of performance in harvesting operations. In contrast to other studies based on surveys (eg. Drolet and LeBel, 2010; Erlandsson et al., 2017), the results of Paper IV were derived from in-depth interviews within a case study. The strength is that new perspectives can be explored after participants have been able to reflect upon their experiences, and the interviewer can thus gain further details and a deeper understanding. Thus, despite the relatively small sample, the results widen the insights concerning the complexity that underlies a successful harvesting operation executed by contractors. However, due to the intrinsic features of qualitative research, it is important to keep in mind that the results are a range of case-specific examples of different perspectives built on a sample of 12 persons and may not represent all contexts or cases. These insights and case-specific examples should therefore be used as indications, rather than conclusive results when researchers and practitioners consider performance in harvesting operation in similar contexts elsewhere.

All four studies within this thesis were conducted within the boundaries of a specific forest company, Stora Enso Skog AB. This cooperation was invaluable, since it gave access to otherwise inaccessible data. The drawback is that the results are case-specific. However, as Stora Enso Skog AB operates in a context that is broadly similar to other forest companies and forest owner associations in Sweden and the Nordic countries, it is reasonable to assume that the results are likely to be relevant in those similar contexts. Moreover, balancing between flow and resource efficiency in forest operations as well as in the whole wood supply chain is of global relevance. The results disclosed by this thesis are therefore likely to be of general interest. Naturally, when the results are further explored in other contexts, adequate adaptations have to be considered.

5. Future research

The results of this thesis indicate that there exists a potential to improve flow efficiency in the harvesting operation part of the wood supply chain. However, improved flow efficiency comes at the expense of decreased resource efficiency, and thus increased costs of harvesting operations. This trade-off must be seen in relation to potential cost savings in other parts of the supply chain, for instance by holding lower stock levels. Future work should therefore focus on evaluating whether flow efficiency in harvesting operations should indeed be increased at the expense of higher logging costs, and if so, by how much it should be increased. Moreover, the contribution from increased flow efficiency in harvesting operations on wood-flow precision also needs to be investigated further in order to evaluate if flow efficiency, with its buffers in capacity flexibility, is justified.

If increased flow efficiency is justified in the harvesting operation part of the wood supply chain, it is probably possible to reach an efficient balance of increased flow efficiency with limited trade-offs in decreased logging costs if flexible operators and cooperation among several pairs of machines can be used to enable flexibility in capacity. For that to be an option, operators need to be able and willing to work according to the flexible machine-use scheme and this is an obvious area to investigate further in future research. Furthermore, an integrated business model that focuses on the combined results of machine operators, contractors and harvesting operations would probably be needed. How such a model should be formed and developed is another interesting topic for future research.

The identified drivers and hindrances of incentives and involvement were perceived to influence the capabiliy and commitment for flow and resource efficiency differently. Future research should also therefore address how to align incentives and involvement in order to work synergistically to improve the balance between flow and resource efficiency, as well as other aspects of performance in which harvesting operations are expected to excel.

6. Conclusions

Contractors currently need to manage considerable variations in workflow in terms both of produced volume and worked time. These variations can negatively affect resource efficiency and, thus, costs for harvesting operations. However, some contractors manage capacity flexibility among their machines, resulting in relatively high variation in workflow for individual machines but a more even flow on their combined set of machines.

A more holistic perspective on workflow could substantially improve flow efficiency in harvesting operations. By enabling flexible machine use within harvesting groups, lead-times decreased by 22 % - 91% with a cost increase of 3.2% - 3.4% compared to having no capacity flexibility, and depending on the time-gap required between the harvester and forwarder operations. Improved flow efficiency therefore comes at the expense of decreased resource efficiency, and thus increased costs for harvesting operations. The negative effects of the trade-off when balancing flow and resource efficiency can be decreased by cooperation between harvesting groups sharing the flexibility. By doing so, the cost increase was only 1.6-1.8 % for a similar substantial improvements of lead-times as was attained within harvesting groups.

Managing performance in harvesting operations is complex with the many aspects of performance making it difficult to excel in them all. The complexity is inherent when balancing between flow and resource efficiency as it clearly means trade-offs that favor one aspect of performance over another. The framework provided here should therefore be considered when balancing flow and resource efficiency, and with respect to other aspects of performance. The complexity surrounding the management of performance is then likely to be simplified by applying a more holistic perspective regarding how incentives and involvement influence a contractor’s capability and commitment to different aspects of performance.

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Popular science summary

Forests are an important source of renewable raw materials, and the forestry industry is likely to play an increasingly key role in the development of sustainable, bio-based societies. Sweden is a country with 69 % of its area covered by forest and is one of the world's largest exporters of forest products into the highly competitive global market. It is therefore important that forest management is carried out in the best possible way in order to supply the demand for renewable raw materials in a socially, environmentally and economically sustainable way. Using forests to produce raw materials poses a number of challenges, not least because of their geographical distribution, but also because of the complexities involved in moving different wood products from a standing tree to where it can be processed in a mill, and the need to work around the further complexities of unpredictable weather and climate change. This places high demands on all parties that play a role in the forest sector to achieve good interactions and relationships between them as wood passes along the supply chain from forest to mill. In Sweden, harvesting work, i.e. the felling of trees, cutting into logs, and transporting logs to the nearest road, is carried out with a system of machines consisting of harvesters and forwarders which normally work together paired as a team. But economics is always a consideration, and even though they work in teams, an important factor is usually to maximize performance of the individual machines. However, the two machines often work out of sync with each other, because their work is affected by different things – for example, the harvester works quickly if there are large trees, while the forwarder works quickly if the road is nearby. Any unbalanced teamwork needs to be managed: one way of doing this is by managing the so-called forest stock, i.e. the wood that the harvester has harvested, but which the forwarder has not yet transported to the road. This forest stock can be used to act as a buffer between the productivity of the two machines so that they can work as quickly as possible. A large forest stock reduces the risk of the machines hindering each other in their work, so working efficiently, and keeping harvesting costs competitive. However, if the forest stock is too large, it can take too long to transport it all to the road and on to the mill, and while it waits, the wood can become difficult to access by the forwarder - perhaps because of poor weather, - and its quality can deteriorate.

The work in this thesis examined how harvesting operations might be improved, by exploring in a suite of four studies if there could be better ways of balancing the use of machinery to improve the flow of wood at the beginning of the supply chain. The first study examined the current situation, the second and third analyzed potential of two different solutions to improve the situation, and the fourth identified those factors that most affect the performance of the harvesting operation as a whole. The first study showed that, currently, the use of machinery in harvesting operations varies a lot from month to month resulting in a similarly variable rate of wood production. This leads to large uncertainties in the expected costs. It is also uncertain how the flow of wood from harvester to forwarder, or from forest to roadside is affected by this volatility. However, the study revealed that flexibility in harvesting operations was necessary to manage the imbalances between the production rates of the two machines. This is currently managed in several different, but not very structured or systematic ways. Studies two and three used simulations that showed how flexible staffing, both within a team and between teams, can help to balance the flow of wood between machines, while controlling the cost of the added flexibility. With certain scenarios it proved possible to reduce the forest stock to one tenth of the level that occurred without flexibility. In Study 2, quite high levels of flexibility were gained if machine groups worked independently, but costs increased by 3.4-3.4 % above that of the machines working without flexibility. In Study 3, potential improvements were made if teams worked together so sharing the flexibility among more machines and operators. When two teams cooperated, they achieved the flexibility needed to balance the differences between machines' productivities and thus kept forest stock low, and at a cost increase of only 1.6-1.8%. Having flexible operators and cooperation between machine teams requires the overall focus to shift to the perspective of collective common goals, rather than simply trying to maximize the performance of individual machines or machine teams. In the last study, interviews with various participants in different sectors of the industry revealed that the performance of harvesting work is very complex. Clients, such as forestry companies, expect contractors and machine operators to perform many different roles to satisfy their desires. This complexity was evident when it came to balancing the flow of wood and use of machinery, as actions and practices that can lead to small forest stocks and short lead-times were often at odds with keeping costs low. A concept map and associated flowchart was therefore devised based on factors revealed by the interviews, that were deemed to influence contractors and operators. This concept map is intended to help clients understand the complexity of the system and how contractors and operators can each be influenced to achieve desired results. One potential route to improvement would be for clients to take a more holistic perspective on how the incentives they provide and the degree and nature of any active involvement they have, fundamentally affects the capability and commitment of contractors and machine operators to achieve the desired results and satisfy the different goals of clients, contractors and operators.

Populärvetenskaplig sammanfattning

Med skogen som förnybar råvara har skogsnäringen en nyckelroll i utvecklingen mot ett hållbart, biobaserat samhälle. Sverige är ett land vars yta till 69 % är täckt av skog och är en av världens största exportörer av skogliga produkter på den högt konkurrensutsatta globala marknaden. Det är viktigt att brukandet av skogen sker på bästa möjliga sätt, för att kunna leverera den förnybara råvara som efterfrågas på ett socialt, miljömässigt och ekonomiskt hållbart sätt. Att bruka skog för att ta fram råvara innebär en hel del utmaningar, inte minst på grund av den geografiska spridningen, dess komplexa virkesflöden och påverkan från väder och vind. Klimatförändringarna gör att brukandet av skogen än mer svårplanerat och komplext. Detta ställer höga krav på aktörerna inom skogsnäringen, för att få till ett bra samspel inom virkesförsörjningskedjan från skog till industri. I Sverige genomförs drivningsarbetet, det vill säga avverkningen av träden till stockar och transporten av stockar från skogen till närmaste bilväg, med ett maskinsystem bestående av skördare och skotare. Dessa två maskiner arbetar i normalfallet tillsammans i lag bestående av en skördare och en skotare. Men trots att de arbetar i lag så är det oftast fokus på att maximera de enskilda maskinernas prestationer. Detta gör att maskinernas arbete ofta är i otakt, eftersom deras arbete påverkas av olika saker - skördaren jobbar snabbt om det är stora träd, medan skotaren jobbar snabbt om det är nära till bilvägen. Den obalans som uppkommer mellan maskinernas produktion hanteras bland annat genom ett så kallat skogslager. Det består av det virke som skördaren har avverkat, men som skotaren ännu inte har transporterat till bilväg. Skogslagret buffrar alltså så att de båda maskinerna kan jobba på snabbt, och ett stort skogslager minskar risken för att de hindrar varandra i arbetet. Ett stort skogslager gör alltså att maskinerna kan användas effektivt, och ge en konkurrenskraftig drivningskostnad. Men det är inte bra med ett för stort skogslager eftersom det då tar lång tid innan virket transporteras ut ur skogen, och sedan vidare till industrin. En lång väntan i skogen medför risker för bland annat att virket kan bli svårare att komma åt för skotaren vid till exempel väderomslag som kraftiga snöfall eller regn, och en lång väntan innan virkes används i industrin innebär risk för att kvaliteten kan försämras.

Denna avhandling fokuserade därför på hur drivningsarbetet kan förbättras, genom att utforska nya perspektiv för hur effektivitet i virkesflöde och i maskinanvändning kan balanseras. Detta är gjort i ett paket av fyra olika studier. I den första undersöks den nuvarande situationen, i den andra och tredje analyseras förbättringspotentialen i två olika lösningar, och i den fjärde identifieras faktorer som påverkar drivningsarbetets utförande i sin helhet.

Den första studien visade att normal drivningsverksamhet innebär stora månadsvisa variationer i virkesproduktion och maskinanvändning, vilket medför stora osäkerheter i vilka kostnader som kan förväntas varje månad. Dessutom är det osäkert hur virkesflödet påverkas av denna ryckighet. Studien visade dock på ett stort behov av flexibilitet för att hantera obalanserna mellan maskinernas produktionstakter. Detta hanteras för närvarande på många olika sätt, men inte särskilt strukturerat eller systematiskt.

Studie två och tre visade att flexibel bemanning inom och mellan maskinlag är effektiva sätt att balansera virkesflödet mellan maskinerna, samtidigt som man har kontroll på kostnaden för flexibiliteten. I simuleringarna som gjordes så visade det sig möjligt att sänka skogslagret till en tiondel av nivån som uppstod utan flexibilitet. I studie två uppnåddes detta genom att maskingrupper arbetade självständigt, vilket gav ganska stora flexibilitetsnivåer och därmed en kostnadsökning på 3.2 – 3.4 % jämfört när maskinerna arbetade utan flexibilitet. I studie 3 så undersöktes om detta kunde förbättras genom att maskinlag samarbetade och delade på flexibiliteten. När två maskinlag samarbetade så fick den flexibilitet som behövdes för att balansera skillnaderna mellan maskinerna och därmed också hålla skogslagret lågt till en kostnadsökning på 1,6- 1,8 %. Att ha flexibla förare och samarbete mellan maskinlag kräver ett ökat fokus på helheten av gemensamma mål, snarare än att maximera prestationen från individuella maskinlag eller maskiner.

Intervjuerna i den sista studien visade att utförandet av drivningsarbetet är väldigt komplext, eftersom uppdragsgivare (som skogsföretag) förväntar sig att förare och entreprenörer utför många olika saker enligt deras önskemål. Denna komplexitet visade sig tydligt när det gällde hur virkesflöde och maskinanvändning balanseras, eftersom åtgärder och arbetssätt som kan leda till små skogslager och korta ledtider ofta stod i motsatsförhållande till möjligheterna att hålla låga kostnader. En konceptkarta med tillhörande flödesschema skapades därför baserat på faktorer som sades påverka drivningsarbetet. Den är tänkt att hjälpa uppdragsgivare att förstå komplexiteten och hur drivningsarbetets utförande kan påverkas för att uppnå önskade resultat. En trolig väg till förbättring skulle vara att uppdragsgivaren tillämpar ett mer helhetsinriktat perspektiv på hur olika incitament och åtgärder påverkar entreprenörers och förares förmåga och engagemang i att uppnå de önskade resultaten.

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The need for flexibility in forest harvesting services – a case study on contractors' workflow variations

Malin Johansson, Emanuel Erlandsson, Thomas Kronholm, and Ola Lindroos

Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, Umeå, Sweden

ABSTRACT

In many parts of the world, contractors account for the main share of harvesting work. Harvesting is characterized by innate complexity and volatility, and this can affect contractors' workflow and ultimately their profitability. Thus, there is certainly a need for flexibility in harvesting service provision and procedures, but our current knowledge about contractors' workflow variations are limited. This study investigates workflow variations in harvesting services by comparing monthly variations between contractors' workload in terms of harvested volumes and the time spent on operations. The data originates from 77 machines belonging to contractors and their harvesting of 6.6 million m^3 of roundwood in Sweden during a two-year period. The results indicate differences between contractors' workflow variations which can be attributed to the number of machines, machine sizes, and the workload in harvested volume and hours. These findings are relevant for guiding both the customer and contractor in this business relationship, and they could also serve as a basis for further research on the need for flexibility to effectively increase and decrease volume production in harvesting services.

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Contractor; business relationship; profitability; supply chain; harvester; forwarder

Introduction

Like many other countries (see, e.g., the work of Drolet and LeBel 2010; Mac Donagh et al. 2017; Jylhä et al. 2020), the main share of harvesting work in Sweden is done by independent contractors hired by forest companies or forest owner associations to cut and transport the trees from forest to roadside (Ager 2014; Eriksson 2016; Erlandsson 2016). In Sweden, the main part of harvesting work was outsourced by forest companies during the 1980s and 1990s, aiming for increased capacity flexibility and decreased fixed capital in machinery for the service-buying companies (Lidén 1995; Ager 2014). Moreover, competitive forces among the service-providing contractors were considered to boost the development in harvesting operations. Nowadays, the competitive market forces in harvesting services are weak (Eriksson 2016). There are only a few, albeit large, customers of harvesting services on the market (Kronholm et al. 2019). Typically, contractors rely heavily on a business relationship with a single customer (Kronholm et al. 2021), which has immense influence on the contractor's business model (Benjaminsson et al. 2019).

Contractors providing harvesting operation services play an important role in handling the volatility and complexity of wood supply. Their work affects not only the cost and availability of raw material but also the environmental and social value of forests (Ollikainen 2014). Not surprisingly, customers of harvesting service providers place high demands on their performance (Eriksson et al. 2015; Erlandsson et al. 2017). Contractors' flexibility is highly appreciated in the harvesting service but is experienced by contractors to have negative effects on their own economic viability (Johansson et al. 2021). Flexibility in harvesting operation can mean different things (see, e.g., the work of Gautam et al. 2013; Erlandsson et al. 2017). In this study, contractors' flexibility is viewed according to the Johansson et al. (2021) description as a value attribute in harvesting service, meaning that the contractor adapts to variations and changes according to customer needs. That can, for instance, be customer needs to change the contractor's cutting plan, immediate adjustment of wood assortments and shortening or lengthening of time for harvesting. These needs can result in contractors' machines being utilized in uneven and unexpected levels during the year. Due to high investment costs, a consistent utilization of the machines is important for the contractors' profitability and their ability to provide competitive harvesting services to their customers (Mäkinen 1997; Erlandsson 2016; Erlandsson and Fjeld 2017).

How wood supply is managed by the customer affects the contractors. It is possible to collect detailed information from the machines about the trees, the machine work, and productivity during harvesting. Such information can be used to anticipate the wood flow and ensure that the demanded volumes are delivered on time to the industry despite the complexity of the wood supply chain (Eriksson and Lindroos 2014; Lindroos et al. 2015; Noordermeer et al. 2021). Delivering data to the customer that is produced by the machines during operations is normally a part of the contractors' harvesting services. However, some of this data is undoubtedly sensitive in that it relates to core business activities, and thus there are legitimate concerns about business partners' right to access it; for instance, work time data from machines could be counted as personal data. Legislation and agreements between the parties are some examples of measures

CONTACT Malin Johansson Malin.m.johansson@slu.se Stora Enso Skog, Åsgatan 22, Falun SE 791 80, Sweden

that regulate the access, right and usage of data. Issues about data protection and ownership of data processed and produced by harvesting machines currently lack clarity (Regulation EU 2016/679; Metsäteho Oy 2017; Kemmerer and Labelle 2020).

Aiming to keep the machines busy, but still with the ability to adjust the wood flow requires that the machines are used in working conditions that meet the desired output of wood quantity. Workflow can be managed in the customer's selection of stands for harvesting in the cutting plan by purposely using the differences in productivity when working in different conditions. For contractors to accept this type of management, the pricing of the work needs to be adjusted for the variations in work conditions. Payment per work time meets this requirement but might in many cases not be preferred by the customer. Payment per produced unit, on the other hand, is considered to promote work efficiency. For this pricing model to adequately compensate for work condition differences, there is a need to adequately predict the productivity of harvesting operations under various work conditions. Moreover, such business models also enable the matching of work conditions to desired wood quantities by selecting harvesting stands based on the predicted time it will take for the contractor to harvest the standing volume. With specialized machines, different conditions within thinning or final felling, respectively, can be chosen to manage the wood flow. Multipurpose machines can be used in both thinning and final felling. This gives opportunities to decrease relocation distances, as well as, rapidly increase or decrease delivered volume by changing between thinning and final felling (Andersson and Eliasson 2004; Erlandsson 2013).

Using productivity predictions to anticipate the wood supply requires accurate data about the forest to be harvested, the machines that will be used, and accurate productivity models. Data acquisition and methods to produce models are constantly being refined (Eriksson and Lindroos 2014; Liski et al. 2020). Even though the increased data quantities and improved qualities provide more reliable predictions, the outcome of a given operation may still deviate due to, for instance, large differences between machine operators (Purfürst and Erler 2011; Häggström and Lindroos 2016; Manner et al. 2016). The information about the forest that will be harvested can be insufficient (Gustafsson 2017) and the ability to handle variations in wood demand by adjusting the work conditions is also limited to the available harvestable stands during a given period (Guatam et al. 2013). Therefore, variations to the planned needs for harvesting services can be expected due to many different sources of uncertainties.

Customers can manage their varying need for harvesting services by hiring some of the contractors on short-term contracts or through spot purchases, but this increases the risk of lacking harvesting capacity when it is needed the most. Therefore, when there is a perceived lack of contractors on the market, it can be beneficial to secure the main, or even the full, share of the estimated annual capacity need on long-term contracts and then restructure the fleet of contractors to be tolerant to wood demand variations (Erlandsson 2016).

In general, profitability in the harvesting service sector is low, although it varies between different contractor groups (Kronholm et al. 2019, 2021). A study in Finland found that larger companies were more profitable in providing harvesting services. Profitability was attributed to their capacity to deliver large amounts of volume, versatile services, negotiation power and cost-effective operations (Jylhä et al. 2020). In comparison, contractors in Sweden are smaller (Häggström et al. 2013) and have, in general, weak negotiation power against their customers (Eriksson 2016; Kronholm et al. 2019). The service-buying companies also have leverage to affect the contractors' business models by influencing resource investments and their service delivery (Benjaminsson et al. 2019). Therefore, if there is a need for contractors' flexibility, then the customers should have an interest to enable it and at the same time promote contractors' profitability. Business management skills have also been cited as a reason behind contractors' profitability (Ollonqvist 2006; Jylhä et al. 2020), as well as good performance in harvesting services (Drolet and LeBel 2010). Thus, the need for flexibility in harvesting services is also a concern for the contractors themselves to handle. Success in this endeavor will lead to profitability and to the provision of competitive harvesting services to their customers.

How much flexibility different contractors actually need to manage has so far been barely investigated. Therefore, this study investigated contractors' workflow variation and identified differences between contractors. Specifically, this study measures the level of variation in contractors' workload between months in terms of wood volumes handled and time spent on the operation, and compared contractors' level of variation depending on their total workload, number of machines, and the type and size of the machines.

Materials and methods

This study was based on data from a forest company operating in central Sweden, with a large part of its harvesting work outsourced to contractors.

Data collection

Data on contractors' harvesting work during the calendar years of 2018 and 2019 were collected from the forest company's records stored in its IT system. To derive machines' monthly variation in harvesting volume, data about reported volumes were extracted per machine, stand, and date. The data was reported per day but aggregated per month in the data extraction. Moreover, information about type of operation, estimated productivity, reported time and compensation for other harvesting work, and hourly compensation rates were extracted to enable the derivation of machines' monthly variation in terms of work time. The information in the dataset also included machine size and type, and to what contractor the machine belonged (see Table 1). All data on log volumes were reported in solid cubic meters under bark (m^3).

The volumes were either automatically recorded from the machines or manually entered by the machine operator. In some cases, the reported volume was negative for a given stand in a month, which indicated a correction of previously reported volumes. All negative volumes were therefore transferred to the same machine and stand in the previous month, meaning that the reported volume for the machine and stand was reduced by the corresponding volume.

Estimated productivity was recorded for normal machine work in final felling and thinning and was used by the forest company to reimburse the contractors for the harvesting work. The productivity rate was defined as volume of logs produced per productive machine hour including downtime of a maximum 15 minutes per occasion (m^3/PMh_{15}). The estimated productivity rates used in the analysis were determined by the forest company as a mean value per stand and based on information about productivity-affecting factors, for instance mean stem size, based on data available after harvesting. Multiple productivity rate registrations for the same machine and stand occurred in 578 out of 40,546 cases. All duplicates were reduced by keeping only the latest updated value. Hours of normal work was calculated for each machine, stand and month by dividing the reported volume by the estimated productivity rate for the corresponding machine and stand.

The dataset also contained information defined as "other harvesting work," mainly about payments related to the machine-specific work of such a character that was not recorded or paid for as normal harvesting work in final felling or thinning. Such other harvesting work could be e.g. different actions for nature, cultural and social considerations, as well as salvage loggings after windstorms. This data was manually registered by the contractor either as a monetary sum or in number of work hours, and accepted by the production supervisor. Negative values in the monetary sum and number of hours were controlled with respect to associated notes. Most of the notes indicated repayments or resets for previous time reports. In such cases, the values for the stand and machine in question were reduced with the corresponding value. Normally, the time reporting for other harvesting work was done in connection with the summary for the month's invoicing, which was normally done on one of the first five workdays of the following month. Therefore, all time for other harvesting work and extra compensation reported on one of the first five workdays of a month were transferred to the previous month to represent the month in which the work had actually been carried out.

For cases in which contractors reported other harvesting work as a monetary sum, the corresponding work times were derived by dividing the sum by the hourly compensation rate unique for the specific machine, month and type of operation. Hours of other harvesting work was then derived for each machine on each stand and month. For the analysis, the reported volume and derived hours were aggregated and handled on a monthly basis.

The dataset also included information about machine sizes, classified by the service-buying forest company based on machine weight for harvesters and load capacity for forwarders. The machine weight for small, medium and large harvesters was <12 tonnes, 12–18.9 tonnes and >18.9 tonnes, respectively. The load capacity for small, medium and large forwarders was <12 tonnes, 12–16 tonnes and >16 tonnes, respectively.

Data reduction

The extracted data were, of course, initially entered into the company's systems for operational purposes and not for the purpose of this study. It was also a mix of data being manually entered into the system by different persons or automatically recorded from the machines. Thus, the occurrence of data errors was considerable, and this flaw had to be handled in order to get as reliable a reconstruction of the volume and time workflow as possible. To be able to investigate the workflow at machine level, it was important that the included machines had produced reliable data during the studied period. Therefore, the original data was refined by removing machines that did not meet the criteria of the three steps below. The aim being to minimize the effect of poor data quality on the results (Table 1).

Step 1: study time coverage

This step was to ensure that the included machines had operated for the main part of the studied period. Only machines for which volume had been reported for at least 22 of the studied 24 months were included in the analysis. Two months absence from operations was accepted due to the possibility that many machines that continuously operated for the customer could still be having long periods of inactivity. For instance, the risk of forest fires was exceptionally high during summer 2018, and machine operation in the forest was therefore not allowed at many locations. It was also taken into account that some contractors and their operators may have four continuous weeks of vacation per year, without hiring any substitute operators. Step 1 resulted in more than half of the machines, just about one-fifth of the total volume and one-fourth of the total time being removed from the dataset.

Table 1. Data quantities before and after data reduction.

Variable	Before reduction	After reduction	Description
Types of operations (n)	3	3	Final felling, Thinning, Other harvesting work.
Machine type (n)	2	2	Harvester, Forwarder
Machine size (n)	3	2	Small, Medium, Large
Months (n)	24	24	January 2018–December 2019
Forest stands (n)	9,700	4,300	Number of different stand identification numbers (rounded to hundreds).
Machines (n)	408	77	Number of different machine identification numbers.
Contractors (n)	130	39	Number of different contractors.
Volume (million m^3)	17.5	6.6	Cubic meters of solid wood under bark in total for all machines the whole study period.
Work time (million PMh_{15})	1.1	0.4	Estimated productive machine hours including downtime of maximum 15 minutes per occasion in total for all machines throughout the whole study period.

Step 2: completeness of work time estimations

The second step was to ensure that it was possible to determine the total number of worked hours. In some cases, the productivity rate and/or hours of other work was missing although volumes were reported. The reasons for the missing data could be, for instance, pure errors but also because of deliberate unconventional data recording for solving operational matters. The missing data meant that worked time by a machine would be either impossible to determine or seriously underestimated. Therefore, it was decided that the data completeness regarding estimated productivity rate and/or hours of other harvesting work on the reported volume for the machines should be high in order to keep them in the dataset.

Due to different productivities in the different types of operations (Table 1) it was considered to be insufficient to solely reduce machines based on the proportion of volume without an estimated productivity rate and/or hours of other harvesting work. Therefore, the time for the volumes with missing data was estimated in each month by dividing the volume, distributed on types of operations by the machine's mean volume weighted productivity during the total period for the corresponding types of operations (Table 1). If the total estimated missing time for a month corresponded to more than 10% of the reported estimated time for the month, the machine was excluded from the study. The estimated missing time was handled on a monthly basis because of the risk that a substantial amount of the unreliable time occurred during one or a few months, with a high impact on specific months. The level of 10% was set due to the observation that the main part of machines had been treated with a "special solution" resulting in the absence of some estimated productivity data and/or reported hours during the studied period. That can be explained by the long period, and the fact that all machines harvested many stands during this period. In normal operations, it is likely that situations which need "special solutions" will be encountered. Thus, tolerating up to 10% of unreliable time per month resulted in a set of machines with a relatively low and similar proportion of unreliable time. Step 2 resulted in almost half of the machines, volume and time remaining from step 1 removed from the dataset.

Step 3: quality of reported data

The third step of data reduction focused on ensuring good quality in terms of the reporting of data used to derive monthly volume and time for the machines. This reduction step consists of four parts.

Step 3, part 1, was set to ensure that the reported volume from the machines corresponded with the volume from the independent measurement organizations. That was done by comparing the reported volume for each machine with the volume recorded by industry or at a terminal by an independent wood measurement organization and registered for legal and payment purposes. Reported volumes were almost always lower than the volumes registered at the terminal or industry (see Figure 1). One possible reason for this may be that the contractors prefer to get an additional payment at a later stage, rather than incur a debt with the customer. Due to this frequent and systematic difference, up to 15% higher volume registered by industry than finally reported was accepted. All machines with 16% and higher differences were excluded. Step 3, part 1, resulted in 7% of the machines (Figure 1), and 4% of the volume and time remaining from step 2 removed from the dataset.

Step 3, part 2, was to ensure that the estimated time to harvest or extract the reported volume was realistic. Each machine's volume weighted mean productivity for the study period was calculated and compared to each other. This indicated the existence of some outliers. Hence, based on the observed clustering of mean productivities and comparison with documented long-term productivity levels (e.g. Eriksson and Lindroos 2014), machines with mean productivities of more than 40 m^3/PMh_{15} were excluded. Step 3, part 2, resulted in 6% of the machines (Figure 1), 6% of the volume and 5% of the time remaining from step 3, part 1, removed from the dataset.

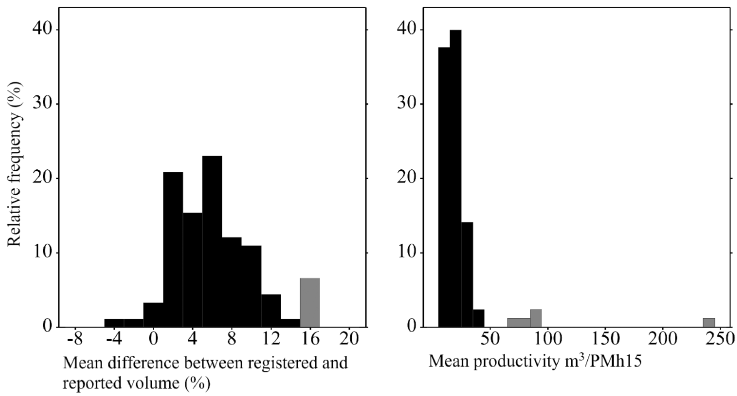

Figure 1. Data reduction of machines based on difference between volume registered by industry in relation to reported volume (N = 91 machines before outlier reduction) and mean productivity (N = 85 machines before outlier reduction, which also represent the number of machines after reduction based on mean correction). The gray bars illustrate the outliers of machines that were removed from the dataset.

Step 3, part 3, was conducted to ensure the reliability in the time report for the hours of other harvesting work. Two of the remaining machines from step 3, part 2, had unknown negative values in this time report and were therefore excluded from the dataset.

Step 3, part 4, was performed so that the time variation was realistic for the remaining machines from step 3, part 3. One machine deviated with an unusually high work time for one month (661 PMh_{15}) compared to the machine's mean monthly work time (170 PMh_{15}). That machine was not close to that amount of time during any other month. Moreover, the high work time would basically require the machine to work continuously for the whole month, since 24 hours of work during 30 days gives 720 hours. Hence, the recording was considered unrealistic and the machine was excluded.

The remaining dataset

The 77 remaining machines accounted for 19% of the machines, 38% of the total harvested volume and 36% of the total time in the original dataset (Table 1). In the original dataset, 3.4% of the machines were of small size, 67.4% of medium size and 29.2% of large size. All small size machines had been reduced in the first data reduction step because none of them operated continuously for the customer, and, thus, the remaining machines were of medium and large sizes. Medium machines operated mainly in thinning, but some were also put to final felling, while large size machines worked mainly in final felling. The volume in different types of operations (Table 1) also differed between machines. The analysis had to account for the machines' different workflows in volume and time in order to make their variations comparable.

Data analysis

The analysis was done with two main variation focuses (Performance variation and Workflow variation) and on two main aggregation levels (individual machines and contractor). For analysis at the contractor level, the volume and time on the machines owned by the same contractor were aggregated per month for the corresponding contractor. The statistical analysis was carried out in Minitab 18, with the significance level set to 5%.

Performance variation

Relative monthly performance variation for a machine was calculated by comparing monthly values with the mean value for the studied period, for both volume and time as well as for individual machines and for contractors. This created monthly performance variation values that were normalized to the performance of individual machines or contractors and were therefore comparable between machines or contractors.

Seasonal differences in relative performance variation in volume and in time were analyzed by one-way Analysis of Variance (ANOVA) with Tukey pairwise comparisons, with months as fixed main effect (with 24 levels). Relationships between relative volume and time variation were analyzed by use of Pearson correlations.

Workflow variation

The coefficient of variation (CV) was used to establish a single value per machine or contractor for the workflow variation during the studied period. CV is a relative measure of variation, in which the standard deviation is put in relation to the mean value. This created workflow variation values that were normalized to the workflow of the individual machine or contractor and were therefore comparable between machines or contractors. The workflow variation in volume will from hereon be expressed as CV_{volume} and workflow variation in time as CV_{time}.

A Pearson correlation was used to analyze relationships between CV_{volume} and CV_{time}, for all machines, as well as within groups based on machine size and type. Similarly, relationships between CV_{volume} and CV_{time} were also analyzed for all contractors, as well as within groups based on how many and what type of machines the contractor owned. Moreover, a Pearson correlation was used to analyze relationships between CV_{volume} and total work time and total volume, respectively, for the whole studied period. One-way ANOVA with Tukey pairwise comparisons were used to analyze differences in CV_{volume} and CV_{time}, respectively, between contractors having one, two or more than two machines (i.e. contractor size as fixed effect, with three levels).

Results

Performance variation

When analyzing the performance variation between months within the 77 machines, there was a large dispersion in both worked time and volume produced. It ranged from the lowest possible relative variation value of −100%, indicating that the machine had not been used or produced any volume at all, to more than 100% – which indicated a value more than double the machine's mean performance during the observed 24 months (Table 2). For all of the studied 24 months, there were many machines that substantially deviated from their mean values. Nevertheless, there were seasonal patterns during which most of the machines

Table 2. Distribution of relative monthly variation within individual machines or for all machines a contractor owned. Since the variation is reported relative to the mean value, the relative mean value is zero for all aggregation levels and variables. The lowest possible relative variation value −100% indicates that the machine had not been used or produced any volume at all that month. N = number of observations, where one observation represents one machine or contractor and one month.

Aggregation level	Variable	N	SD	Min.	Quartile 1	Median	Quartile 3	Max.
Machine	Volume	1,848	37.9	−100	−23.9	0.7	22.4	182.4
	Time	1,848	34.3	−100	−18.9	2.0	21.1	149.2
Contractor	Volume	936	35.4	−100	−21.2	1.9	21.8	152.0
	Time	936	32.5	−100	−16.7	3.4	19.7	130.7

performed above or below their mean volume and time values, with the most notable being the lower relative performances during the spring and summer months (May–July) (Figure 2). The observed significant differences between months (Tukey test, $p < 0.001$) were mainly observed for months in different seasons. However, the largest difference between all 24 months was observed between July and August 2018. For only two months, the machine performances were significantly different between years; performance in both time and volume were significantly higher in May 2018 compared to May 2019, whereas time performance was significantly higher in August 2018 compared to August 2019.

The relative variation of time and volume within months for all of the 77 machines pooled was positively correlated ($r(1848) = 0.78$, $p < 0.001$). The correlation was significant ($p < 0.001$) for all four combinations of machine types and sizes, but with the lowest correlation coefficient value for medium size harvesters and the highest value for large forwarders. Large harvesters and medium size forwarders had both correlation coefficient values similar to the large forwarders. It should be noted that the range of dispersion was considerably smaller for negative values compared to positive values of relative variation (Figure 3).

The dispersion of relative variation decreased when aggregating the machines on the 39 contractors that owned them. The dispersion was highest for the relative volume values, for both machine and contractor levels. The widest dispersion was observed for volume variation on machine level, in terms of standard deviation values, range between minimum and maximum values as well as in terms of range between the first and third quartile values. The lowest dispersion was found for the relative time variation on the contractor level (Table 2).

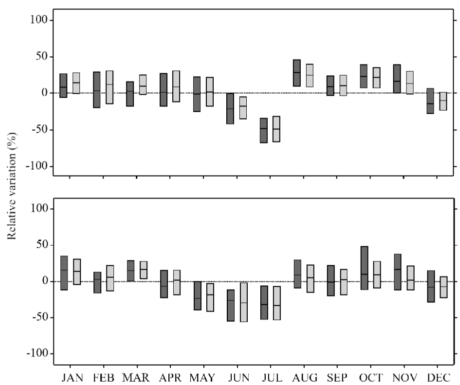

Figure 2. Relative variation in the machines' volume produced (dark gray) and worked time (light gray) over months for 2018 (upper panel) and 2019 (lower panel). Boxes indicate median and quartile values. A relative variation value of 0% indicates that the value for that month was the same as the mean value for the machine's performance during the observed 24 months. The lowest possible relative variation value −100% indicates that the machine had not been used or produced any volume at all that month. N = 77 machines per month.

Workflow variation

Machines' and contractors' workflow variation was indicated by their CV of volume produced and worked time over the studied 24 months. When analyzing and comparing workflow variation in volume (CV_{volume}) and time (CV_{time}) within and between aggregation levels, a range of differences were observed (see Table 3). There was a wide dispersion between the 77 machines' CV_{volume} and CV_{time}, which indicated differences between machines in their workflow variation in both volume and time.

The mean CV_{volume} was higher than CV_{time} at both aggregation levels. The standard deviation on CV_{volume} and CV_{time} was higher, and mean CV_{volume} and CV_{time} lower, for contractors than for machines, indicating bigger differences between contractors than between machines (Table 3). The distribution of CV_{volume} differed from the distribution of CV_{time}. CV_{time} had a more concentrated distribution for both machines and contractors compared to CV_{volume}. When aggregating to contractors, the CV_{time} was shifted to lower values, with a similar but less distinct effect on the $CV_{volume.}$ (Figure 4).

In general, there was a strong positive correlation between CV_{volume} and CV_{time} at both machine (Figure 5) and contractor (Figure 6) levels. However, there were also examples of substantial deviations between CV_{volume} and CV_{time} at both levels. The examples were especially common for medium size harvesters and forwarders (Figure 5) and contractors with medium size machines (Figure 6). Consequently, the correlation was low and not significant for medium harvesters ($r(20) = 0.39$, $p = 0.093$). For medium forwarders, there was a significant correlation, but less strong ($r(16) = 0.66$, $p < 0.001$) compared to big harvesters ($r(17) = 0.94$, $p < 0.001$) and big forwarders ($r(24) = 0.97$, $p < 0.001$).

It should be noted that most of the large correlation deviations were below the line that represents a perfect correlation (Figure 5 and 6). This indicates that in general there was a higher CV_{volume} than CV_{time}. Contractors with two medium size machines had the weakest correlation between CV_{volume} and CV_{time}. However, CV_{volume} and CV_{time} did not seem to only depend on machine size, since all machine sizes showed both low and high CV values (Figure 5 and 6). In contrast, number of machines seemed to matter, since contractors with more than two machines all had relatively low values in both CV_{volume} and CV_{time} (Figure 6).

Both CV_{volume} and CV_{time} were negatively correlated to the machine's total work time and total volume produced for the 24 month study period (Table 4). Thus, CV_{volume} and CV_{time} decreased with increased amount of work time and increased amount of volume produced. These observed correlations were not strong, and there were also differences between the machine types and sizes. For instance, CV_{volume} and total work time was correlated for all machines except for medium size harvesters. CV_{volume} and total volume was correlated for the large but not for the medium machines. CV_{time} and total work time was correlated for all machine sizes and types, so also with CV_{time} and total volume, with the strongest correlation for the forwarders.

Total time and total volume at contractor level depended both on the number of machines and total time, respectively, on the machines. The mean value for CV_{volume} and CV_{time}

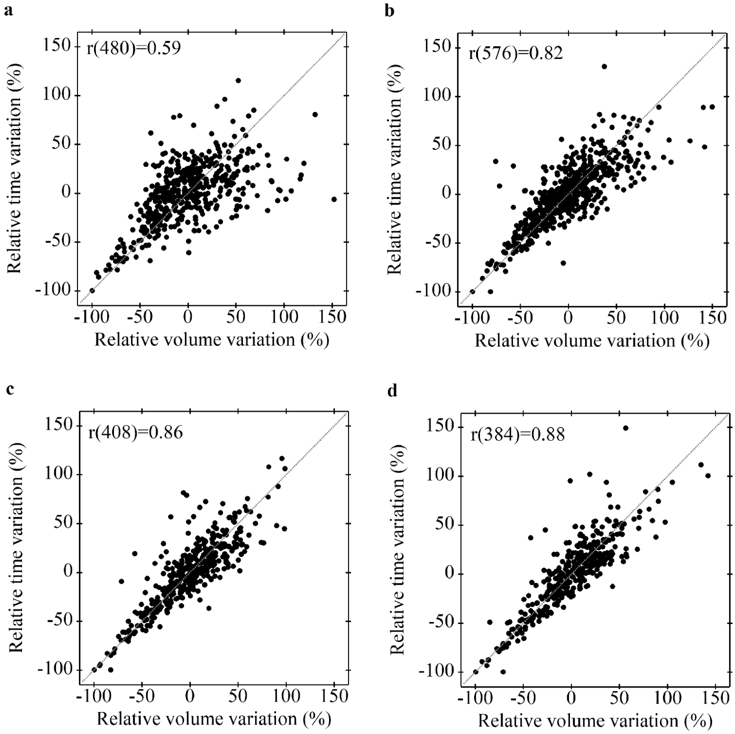

Figure 3. Relative monthly volume variation plotted against relative monthly time variation for the four combinations of machine sizes and types (a. = medium harvester, b. = medium forwarder, c. = large harvester, and d. = large forwarder). A relative variation value of 0% indicates that the value for that month was the same as the mean value for the machine's performance during the observed 24 months. The lowest possible relative variation value −100% indicates that the machine had not been used or produced any volume at all that month. The gray line indicates a perfect correlation between time and volume variation. r = Pearson correlation coefficient. The numbers in parentheses represent the number of observations, with an observation representing one machine and one month.

Table 3. Distribution of CV (%) for machines and contractors on their performance in terms of monthly volume and work time. N = number of observations, where one observation represents one machine on machine level or one contractor on contractor level. For each observation, the mean and SD values were based on the 24 values of volume produced or worked time within each machine or contractor.

Aggregation level	Variable	N	Mean	SD	Min.	Quartile 1	Median	Quartile 3	Max.
Machine	CV_{volume}	77	37.4	10.3	19.7	29.6	35.1	44.0	73.9
	CV_{time}	77	33.8	9.4	14.5	27.7	31.1	36.4	69.8
Contractor	CV_{volume}	39	34.4	11.2	17.1	26.4	31.7	40.3	73.9
	CV_{time}	39	31.5	10.4	18.5	25.4	29.4	36.3	69.8

decreased the more machines a contractor owned (Table 5). Contractors with three or more machines had significantly lower CV_{volume} and CV_{time} compared to contractors with one machine (Tukey test, p-value = 0.032 (volume) and 0.018 (time). The dispersion in both CV_{volume} and CV_{time} between contractors owning a certain number of machines decreased with the number of machines owned (Figure 7). From one, two to three or more machines, the standard deviation decreased (Table 5).

The near-lack of observations above the perfect correlation line in Figure 8 indicates both CV_{volume} and CV_{time} were in general lower at the contractor level than at the machine level. For the few exceptions, the difference was small (i.e. observations close to the perfect correlation line). The exceptions were eight forwarders of both medium and large sizes for which the CV_{volume} was lower at the machine level than when aggregated at the contractor level. For $CV_{time,}$ three harvesters that had a lower CV_{time} than the contractor owning them.

Discussion

The need for flexibility

The results showed a seasonal variation in harvesting activity (Figure 2), which is in line with other studies (Carlsson and Rönnqvist 2005; Uusitalo 2005; Audy et al. 2012; Erlandsson 2013, 2016). Typically, in Sweden demand and harvested volumes decrease during the spring and summer months,

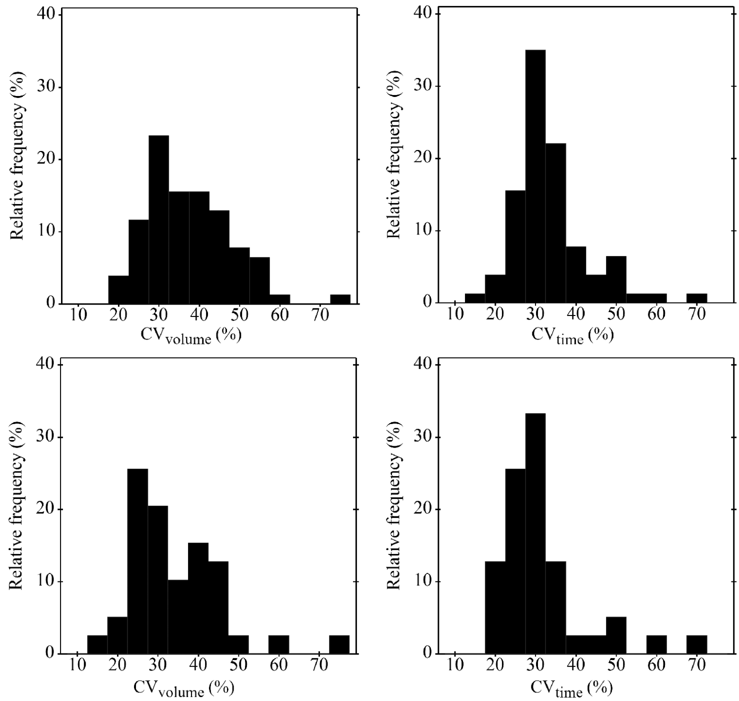

Figure 4. Relative distribution of volume and time coefficient of variation for the machines (upper panels, N = 77) and contractors (lower panels, N = 39).

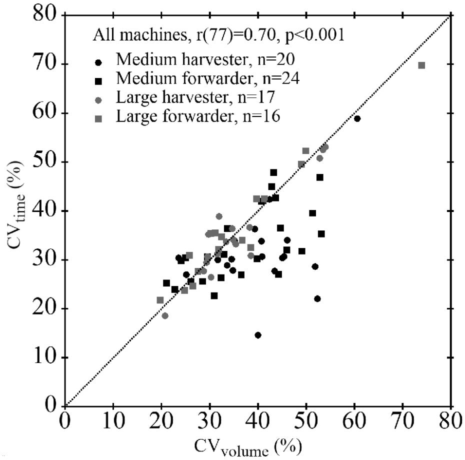

Figure 5. Relationship between the machines' CV_{volume} and CV_{time}, distributed over machine type and size. The closer to the line, the more equal CV_{volume} and CV_{time}. Machines under (to the right of) the line have a lower CV_{time} than CV_{volume}. r = Pearson correlation coefficient. The number in parenthesis represents the total number of machines. n = number of machines in each combination of machine size and type.

only to increase again in autumn. Even if the pattern of seasonal variations is well known, the study showed that there can still be differences between months in different years. For instance, differences were found between May 2018 and 2019 and between August 2018 and 2019. These are the months when the amount of harvesting operations typically starts to decrease and increase, respectively, and this is often related to the current levels of market demand, weather conditions and stock levels in the industry as a whole (Carlsson and Rönnqvist 2005; Uusitalo 2005). There were notably weather differences between the two years, with considerably more rainfall in May 2019 compared to 2018 and a drought during the summer of 2018. This drought resulted in decreased and halted operations due to the risk for starting fires during June and July. To compensate for the production loss, it is possible that many machines operated on extra time during August 2018. More extreme and unexpected weather contiditons are likely to influence the need for flexibility in workflow. Such changes should motivate further research into the relationships between harvesting operations efficiencies and the impact of the changing environmental conditions and climate.

This study investigated actual volumes delivered by contractors, and not the actual or predicted wood demand from the customer. As shown by Erlandsson (2016), the outcome can differ significantly from the prediction of delivered volume. Thus, there is an uncertainty and a need for flexibility due to changes in and from predicted production plans, as well as due to the fact that delivered volume may differ from the volume demanded. Wood demand also varies and thus managers at the

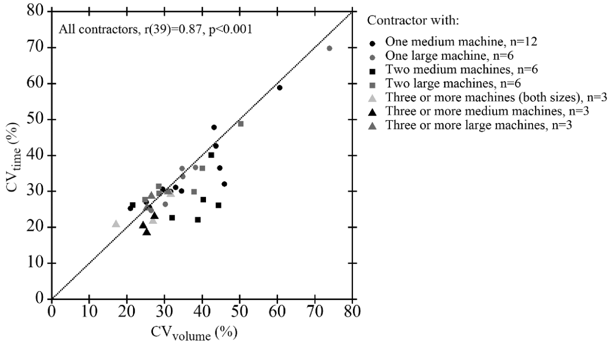

Figure 6. The contractors' machines' CV_{volume} and CV_{time} with information about machine size and number of their machines. The closer to the line, the more equal CV_{volume} and CV_{time}. Contractors under (to the right of) the line have a lower CV_{time} than CV_{volume}. r = Pearson correlation coefficient. The number in parenthesis represents the total number of contractors. n = number of contractors in each combination of number and sizes of machines.

Table 4. The relationship between CV_{volume} and CV_{time}, respectively, with total work time and total volume distributed over machine sizes and types. r = Pearson correlation coefficient. n = number of machines.

	Medium sized				Large sized					
	Harvester (n = 20)		Forwarder (n = 24)		Harvester (n = 17)		Forwarder (n = 16)		All machines (n = 77)	
Variable	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value
Correlation between CV_{volume} and;										
Total work time	−0.22	0.355	−0.50	0.012	−0.67	0.004	−0.73	0.001	−0.55	<0.001
Total volume	0.02	0.930	−0.38	0.065	−0.64	0.005	−0.73	0.001	−0.44	<0.001
Correlation between CV_{time} and;										
Total work time	−0.48	0.032	−0.68	<0.001	−0.61	0.009	−0.77	<0.001	−0.66	<0.001
Total volume	−0.50	0.024	−0.63	0.001	−0.63	0.007	−0.78	<0.001	−0.28	0.012

Table 5. Mean coefficient of variation (CV) on volume and time for contractors depending on number of machines the contractors have in the dataset. N = number of contractors with the number of machines.

		CV_{volume}		CV_{time}	
Number of machines	N	Mean	SD	Mean	SD
1	18	37.6	13.1	35.8	12.2
2	12	35.8	8.6	30.7	7.7
≥3	9	26.1	4.2	24.1	4.3
–All pooled	*39*	*34.4*	*11.1*	*31.5*	*10.4*

customer companies steer production to correspond to actual demanded wood volume, which can affect utilization of contractor resources (Erlandsson 2013).

In the case of the present study, the customer used productivity prediction models to direct the wood flow toward satisfying demand, while at same time trying to enable the contractors to utilize their resources at a high and consistent level through the year. Indeed, if the customer is able to achieve

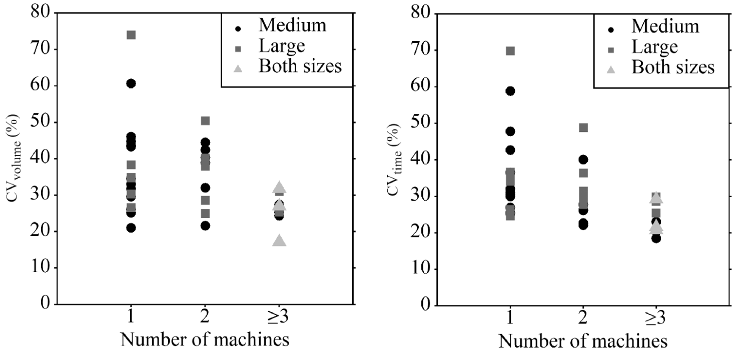

Figure 7. CV_{volume} and respective CV_{time} in relation to the contractors' number of machines in the dataset.

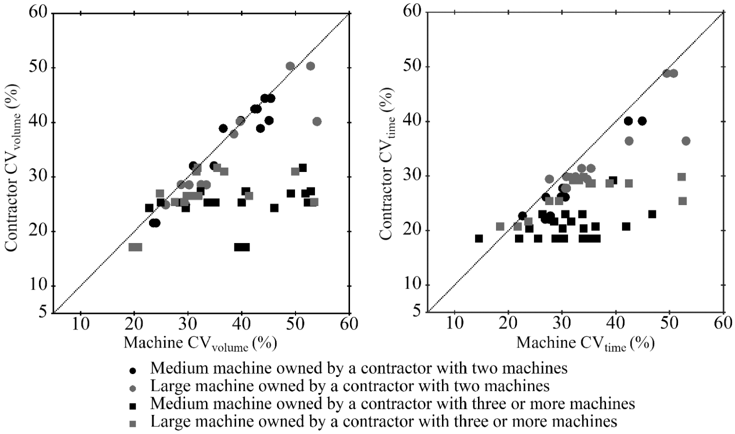

Figure 8. CV_{volume} and CV_{time} on the machines in relation to when machines are aggregated on the contractor that owns them. The closer to the line, the more equal the CV on the machine and contractor level. Machines under (to the right of) the line have a higher CV than they have aggregated on the contractor.

that goal, it has positive effects on contractor profitability and satisfaction (Erlandsson and Fjeld 2017). It will also reduce the cost of unused machines and manpower for which the customer may have to compensate contractors according to the common standard for agreements between customers and forest contractors (Skogforsk 2020). The assumption was therefore that the time would vary less than the volume. However, this study shows a significant correlation between volume and time-relative performance variation (see Figure 3). Therefore, the need for contractors' flexibility probably means variations for contractors in both delivered volume and their work time. Since the range of dispersion was considerably smaller for negative values compared to positive values of relative variation (Figure 3), the result indicates that flexibility to increase volume produced would be desirable, without the same need of flexibility in work time. If the need is for contractors' flexibility to decrease volume produced it would probably mean a need of contractors' flexibility in decreasing work time to manage as well.

Customer's opportunities to manage the need for flexibility

The findings of the CV_{volume} and CV_{time} for machines and contractors in the present study indicate that it is challenging to maintain an even workflow throughout the year, and the results also indicate that all contractors have demonstrated flexibility over the study time frame. In other words, their machines are utilized to a different extent each month, which can be caused by varying wood demands and weather conditions (Uusitalo 2005). Another factor that may influence the contractors' need to be flexible is the customer's management of their contractor crew: for example, the type of contract agreements they apply, the harvesting stands that are assigned, the quality of the information about stands to be harvested, how far in advance the information about stands is provided to the contractor, distances between harvesting sites and so on (Erlandsson et al. 2017; Gustavsson 2017). This study found differences between contractors in both CV_{volume} and CV_{time}, as well as the correlation between CV_{volume} and CV_{time}, which could be attributable to the size of their machines, the amount of total work time and total volume produced on the machines and how many machines the contractor had.

Many of the medium machines had a relatively high CV_{volume} while still having relatively low CV_{time} (Figure 5). It is possible to use those machines in both thinning and final felling, which gives the opportunity to rapidly increase or decrease volume production (Erlandsson 2013) without the need to increase or decrease the time on the machines (Eriksson and Lindroos 2014). Since it is the customer that provides stands for harvesting to the contractors, the contractors with medium size machines may need to be flexible in changing between types of operations (Table 1). As can be noted from Figure 3, the difference between relative variation in volume and time is smaller in negative values compared to positive values of relative variation. An explanation for this may be that the medium size machines are normally used in thinning, but when wood demand increases some of the medium machines are instead used in final felling to increase delivered volume. Increasing the woodflow in this way can be an effective way to rapidly handle a temporary increase in wood demand without requiring more work time.

It can also be effective to increase work time on the machines to meet increased wood demand and use the machines in the most suitable type of operation (Table 1). That may mean more variation in work time on the machines. Thus, it should be taken into account that large machines have higher productivity in final felling, even if the difference in productivity between the machine sizes decreases with smaller stem sizes and shorter extraction distances (Eriksson and Lindroos 2014). Final felling stands with small stem sizes can thus be used to either increase or decrease productivity in a short time depending on what machine size is used.

The hours that a machine can be used per day are limited, and with a high utilization rate there is consequently less time left to use for meeting temporary increases of volume production. This can be a part of the explanation as to why CV_{time} was correlated with both total work time and total volume produced (Table 4). A possibility to increase the production is, then, to provide stands in which the machines are expected to have high productivity. The results indicate just such success for some of the medium machines is due to high CV_{volume} with low CV_{time}, especially for the harvesters (Figure 5).

As discussed, medium size machines can be used in both thinning and final felling, which enables rapid adaption to variations in volume demand. Due to the machines' different suitability for thinning and final felling, and differences in productivity depending on stand characteristics (Eriksson and Lindroos 2014), it may be possible to reach a more cost-effective flexibility by improving stand selection in final felling for large machines and in thinning for medium machines. That possibility may be limited to available stands to be thinned or harvested (Gautam et al. 2013), and the study does not investigate how much of the potential to manage variations in volume demand with stand selection was achieved in this case. Therefore, more research is needed on the potential to manage the needs for flexibility from the customer's side by improving stand information and selection based on the attempt to maintain even workflow in time for the machines, even when external factors such as wood demand and weather conditions vary.

Contractors' opportunities to manage the need for flexibility

As indicated by the results, contractors' flexibility can have negative effects on their profitability and their ability to provide competitive harvesting services (Mäkinen 1997; Erlandsson 2016; Erlandsson and Fjeld 2017). As highlighted in Johansson et al. (2021), adaptability, including flexibility, is highly appreciated in harvesting services. Given the observed CV_{volume} and CV_{time}, this is not surprising since there is obviously a need for contractors' flexibility. Contractors seem to take different opportunities to manage the need for their flexibility (Figure 6).

It seems as though contractors can level their workflow between their machines (Figure 8), and that this possibility increases with more machines (Figure 7). The need to prioritize the use of the harvester or forwarder may differ over time due to, for instance, the difference between harvester and forwarder productivity varying between stand conditions and machine operators (Eriksson and Lindroos 2014; Liski et al. 2020). With more machines, the contractor also has increased opportunities to use them to compensate for each other when needed, for instance when a machine is unavailable due to repairs or being serviced.

That contractors may try to utilize their operators more evenly than their machines could explain why aggregation on contractor level had lower CV_{volume} and CV_{time} than the individual machines (Figure 8). Lack of machine operators is the main obstacle for high harvesting performance and business expansion (Kronholm et al. 2019), and it is also due to this that it can be expected that contractors will steer their operators to use the machine which is most needed at a given moment. Having many machines and employed operators also provides more possibilities for the operators to compensate for each other if needed. That requires good management skills by the contractor as well as skilled operators who are able to manage different types of machines and types of operations (Table 1).

Contractors with less work may take opportunities to increase the time on the machine when needed, and thus temporarily contribute with additional volumes in short-term agreements, as discussed by Erlandsson (2016). Also, contractors with only one or two machines may increase their chances of effectively managing the need for flexibility by cooperating with other contractors, and by that means maintaining a more cost-effective utilization of the machines and machine operators.

It is proposed that more research is needed on how machine operators and machines can be utilized to effectively manage flexibility. In this analysis, it seems the more medium-sized machines a contractor has, the more opportunities to effectively adapt the resources to varying wood demand. Most contractors in Sweden own just one, or a few, machines. Therefore, more research is needed about how cooperation models between contractors can be used to increase their opportunities to effectively respond to varying demands on their services. Contractors are competing for contracts and it should also be considered how such contractor-to-contractor relationships may affect the competitive forces to respond to varying demands.

Strengths and weaknesses

This study focused on contractor-owned machines that operated continuously for the same customer during the whole study period. The study did not represent the whole spectrum of the customer's need for contractors' flexibility. Instead, the study provided details in how contractors' workflow can vary, as indications of how much flexibility contractors operating continuously for the same customer need to manage. The first data reduction step was to remove machines without continuous work for the customer. Thus, all small machines, and also a large component of the medium and large size machines were removed from the original dataset. In this case, there were only a few small size machines in the original dataset and their potential to capture flexibility in volume production was therefore considered to be low. It is possible, but not investigated in this study, that the few small machines were used in special services requested by the customer.

The high share of machines being removed from the dataset due to not operating continuously during the whole study period is worth notice, since they probably account for some part of the flexibility in harvesting service. It is likely, but not shown in the study, that some of the customer's management of varying need of harvesting capacity lies in the temporary contracting of some of the machines that were removed in that step. Even if the contractors often receive the majority of their income from one customer (Benjaminsson et al. 2019; Kronholm et al. 2021), it is still possible that some contractors in this dataset also provided harvesting services to other customers. The study does not show if contractors level out the work between different customers, which can be a possible way to manage varying demands for their services.

What the result show is the variation for a part of the harvesting service, both in terms of the work of single machines and for machines owned by the same contractor that continuously operate for the same customer. When comparing the delivered volume and worked time on the contractor level the result only represents the work from the machines in the dataset. Some of the contractors had additional machines operating for the customer during the two-year period which were excluded during the data reduction process. Even though the results do not represent the complete extent of harvesting services at the contractor level, it still indicates what can happen with the workflow when the work is compiled over more than one task. The results in this study are built on the same 77 machines with relatively reliable information about their operations each month over the two-year study period. That made it possible to investigate and compare how the workload of individual machines differed over time on a monthly scale.

The estimated time in this study was calculated based on a productivity model used by the customer, taking different productivity-affecting factors into account at each stand. That is not the same as actual productivity, and it is likely that it is down to individual differences between machine operators to account for the difference between actual productivity and the estimated productivity (Purfürst and Erler 2011; Häggström and Lindroos 2016; Manner et al. 2016) – which affects the reliability of the estimated time result in relation to the real time. Therefore, it would also be beneficial to investigate CV_{time} for machines and contractors derived from operational monitoring data (e.g. drf files) as, for instance Purfürst and Erler (2011) and Eriksson and Lindroos et al. (2014) did for productivity modeling. In this study, the results represent the time that the contractor got paid for and the customer's expectation of how much time the contractors need to deliver the volumes. Therefore, the estimations could be expected to be reliable in the sense that they are approved by both parties as part of their business relationship.

In this kind of business relationship, the reliability of the productivity model and the accuracy of the included data is important for both the contractors' profitability and the customer's estimation of the required harvesting resources. Data collection and quality can be improved by use of modern data collection methods from forest operations. The utilization and availability of such real big data is limited due to regulations of data protection and data ownership (Regulation EU 2016/679). It should be considered how big data can be utilized in aiming to improve management of the customer's need for contractors' flexibility in a way that favors both parties in the business relationship.

Conclusions

Contractors' workflow vary in both volume and time. The level of unevenness in workflow differs between contractors, which can be attributed to the number of machines, machine sizes and total workload of harvesting services. It seems as if contractors with more machines can level out the workflow between their machines, resulting in a more even workflow at the company level than on the individual machines. In general, workflow variation in volume and time are correlated. An exception was found for medium size machines and especially harvesters, which in this study had a relatively high variation in volume while still having a relatively low variation in time. Contractors with a larger workload had, in general, lower workflow variation than contractors with a smaller workload. One explanation can be limited opportunities to lengthening time on the machines when demand increases. These findings are relevant for both parties in the business relationship when considering the need for flexibility to increase and decrease volume production and still promote contractor profitability.

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ORCID

Malin Johansson http://orcid.org/0000-0003-1156-4277
Ola Lindroos http://orcid.org/0000-0002-7112-4460

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Key drivers and obstacles for performance among forest harvesting service contractors – a qualitative case study from Sweden

Malin Johansson [a,b], Emanuel Erlandsson[a], Thomas Kronholm[a] and Ola Lindroos [a]

[a]Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, Umeå, Sweden; [b]Stora Enso Skog, Åsgatan, Falun, Sweden

ABSTRACT
The extensive outsourcing of forest harvesting operations means that the operational performance of contractors has an immense impact on the forest industry supply chain. This study describes perceived drivers and obstacles for strong performance in harvesting service based on semi-structured interviews with four production supervisors and eight contractors. The analysis of interview data revealed a wide array of factors considered to drive or hinder the performance. The factors were categorized into five types: Capability, Incentives, Commitment, Involvement and External factors. Factors concerning Capability, especially resources and competence, were most frequently considered by production supervisors as both drivers and hinders. The contractors considered most commonly Incentives to affect performance, especially motivation and strategy, as drivers and the economy as hinder. Both parties considered lack of resources as hinder to performance. For competence, relationship and collaboration interface, on the other hand, the two parties had different views on whether they acted as drivers or hinders. The knowledge presented in this paper is of interest to researchers or practitioners who wishes to understand the complexities underlying successful harvesting service performance. The insights can contribute to the reshaping of business practices to better target and leverage the mechanisms that most strongly affect performance.

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Introduction

In Swedish forestry, harvesting operations are mainly performed by contractors who are hired by forest companies or forest owner associations (Swedish Forest Agency 2018). That is the result of an extensive outsourcing process in the 1980–1990s during which forest companies offered to sell their machinery to machine operators who would continue as contractors instead of employees (Lidén 1995). Thereby, the previous employer became a customer.

Today, most contractors are small and medium-sized enterprises (SMEs), and forest companies often rely on contracts with several contractors to secure the required amount of harvesting operations (Häggström et al. 2013; Kronholm et al. 2019). Many of these forest service contractors engage in long-term business relationships in that they have one large forest company as their sole customer (Furness-Lindén 2008). It is not uncommon that considerable performance variations exist between different contractors. For instance, productivity and machine utilization rates can differ by more than 40% between two contractors (Eriksson and Lindroos 2014). This significantly affects both contractor profitability and customer satisfaction (Eriksson et al. 2015; Erlandsson et al. 2017).

Harvesting operation performance can be assessed from many perspectives. The definition of performance success is multidimensional since different stakeholders can have different opinions of how it should be measured (Erlandsson et al. 2017). From a contractor's point of view, success can be measured in terms of profitability (Mäkinen 1997; Penttinen et al. 2011; Erlandsson and Fjeld 2017), lifestyle objectives (Drolet and LeBel 2010), or satisfaction (Erlandsson and Fjeld 2017). Meeting these objectives is important for a contractor to stay in business, but another requirement for long-term business success is customer satisfaction. However, a contractor's profitability and/or satisfaction do not necessarily correlate with the degree of customer satisfaction (Erlandsson et al. 2017). Customer satisfaction can also be complicated to assess because customers often perceive several value attributes for each service, with each of these attributes affecting customer satisfaction in different ways (Kano 1984). These perceived value attributes have been identified and investigated in previous studies of customer satisfaction with harvesting performance (Eriksson et al. 2015; Erlandsson et al. 2017). The results revealed that customers (i.e. forest companies, forest owner associations, and non-industrial private forest owners) appreciate different

CONTACT Malin Johansson Malin.m.johansson@slu.se Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, Skogsmarksgränd, SE 901 83 Umeå, Sweden
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value attributes of the harvesting operations delivered by subcontractors. The value attributes a specific customer perceives as important are case-specific (Erlandsson et al. 2017), and thus, do not always influence the success of harvesting operation performance in the same way.

The current research base has only to a limited extent considered the complexity of contractors' harvesting performance and how the forest company – contractor business relationship can be improved. Eriksson et al. (2015) assessed four general strategies (active sourcing, adapted incentives, active use of power advantage, and tailored contractor development programs) for managing contractors according to contractor capabilities and performance alignment. Moreover, success factors for the customer–harvesting services provider relationship in terms of customer satisfaction (Erlandsson et al. 2017) and contractor profitability (Erlandsson and Fjeld 2017) have been identified. Other studies have specifically focused on the personal motivation factors of contractors (Drolet and LeBel 2010; St-Jean and LeBel 2014). However, the knowledge about interactions between factors that affect performance is limited. Moreover, there is limited knowledge about what reasons contractors and their business contacts at the service buying company perceive as being influential to performance. Such explorative studies could shed new light on the complex topic and would most likely benefit from a qualitative approach and in-depth analysis.

Using a case of one forest company as customer and associated contractors, this study aims to identify perceived drivers and hinders for performance considering that harvesting service consists of many value attributes. As performance is known to be affected by diverse factors, a theoretical framework was developed to handle a part of the complexity underlying performance.

Theoretical framework

Capability

To succeed as a harvesting operation provider, the contractor needs the abilities and qualities to deliver what has been requested by the customer. In a resource-based view (RBV) of a firm, resources are key for competitive performance (Wernerfelt 1984). The theory of RBV divides resources into tangible and intangible assets, with the underlying assumption that resources are heterogeneous and immobile between companies. That causes various case-specific successful strategies to achieve competitive advantage by using different bundles of resources unique for each company. In this way, each business case or project presents an opportunity for companies to bundle their unique assets in a way that will achieve a competitive advantage (Barney 1986). Tangible assets are physical resources such as land, buildings, machinery, equipment and financial capital, whereas intangible assets describe factors that are owned by the company but not physically present, for example, trademarks, patents, and knowledge. The main source of sustainable competitive advantage is intangible resources, since these assets cannot be freely purchased from the market and they are more difficult to copy than physical resources (Grant 1991).

Various organizational characteristics are often described in the forestry contractor performance literature. For instance, good leadership and processes are commonly mentioned in conjunction with high customer satisfaction (Norin and Thorsén 1998) and profitability (Norin and Karlsson 2010; Jylhä et al. 2020). Moreover, Cacot et al. (2010) argue that the profitability of large contractors is affected by knowledge, performance measurements and systematic improvement efforts.

Incentives

A contract is typically used to create a legally binding business agreement that includes set rewards and penalties. Various types of contracts can be used to state the agreements and terms between business parties. The drafting of a contract is a complex procedure that can vary widely for different situations and objectives (Van Weele 2009). Norin and Furness-Lindén (2008) highlight that the two most common approaches for purchasing harvesting services in Sweden are negotiation and invitations to tender. The pricing models for the purchasing of harvesting services can be used to align contractor activities with customer needs. For instance, with a gross, aggregated fee for operations or a piecework rate for the delivered volume. Norin and Furness-Lindén (2008) emphasize that piecework rate for delivered volume can be on different aggregations scales, for instance, site-specific and for all operations. On the other hand, a Canadian study found that many contractors are not primarily motivated by economic revenue, but rather driven by other factors such as independence (being one's own boss), life-style, or passion for the work (Drolet and LeBel 2010).

Commitment

Eriksson et al. (2017) have emphasized that contractors whose services are well aligned with customer needs are more likely to succeed. Misalignment between the parties can adversely affect contractor profitability as well as lead to conflicts and a lack of trust (either one-way or mutual). Both of these consequences will significantly increase the probability that the contractor will switch to another customer or liquidate the firm. Partnerships characterized by mutual trust rather than power imbalances and dynamics are more likely to be successful in the long run (Högnäs 2000; Eriksson et al. 2017). Moreover, the working environment provided by the customer is important for contractor satisfaction (Erlandsson and Fjeld 2017) and their motivation to stay in business (Ager 2014). An individual's commitment to an organization and working activities has been shown to correlate with performance, as committed individuals tend to be more likely to meet the organization's demands than less committed ones (Porter et al. 1974). This also applies to forestry contractors since the most successful contractors are often highly committed to their customers and tasks (Norin and Thorsén 1998). Commitment based on emotional attachment in the context of a business relationship has been described as "affective commitment". However, commitment also includes a calculative dimension, as the service provider's and client's behaviors can be affected by the evaluation of different alternatives (Gilliland and Bello 2002). For example, it is common that a forest company will assess alternative service providers, long-term benefits, and switching costs when deciding whether to engage in a business relationship (Morgan and Hunt 1994). In the Swedish context, contractors who offer harvesting services have high investment costs in machinery and rely on only a few large companies to make a living (Erlandsson 2016; Kronholm et al. 2019). Thus, these contractors understand that the cost for terminating a relationship will be rather high and will take this factor into account when deciding to enter a business relationship (Morgan and Hunt 1994; Gilliland and Bello 2002).

A contractor's commitment to the customer organization can be affected by certain promises or labor- and capital-specific efforts from the organization (Ghijisen et al. 2010). In contrast, low levels of trust between the contractor and customer, cases in which the customer is disrespectful towards the contractor, along with unprofessional and dishonest behavior are all attributes of conflictual relationships (Eriksson et al. 2017). These types of relationships can significantly harm commitment and hurt supply chain efficiency (Porter et al. 1974).

Involvement

A contractor can only deliver a requested service if the customer cooperates and provides them with the means to do so. For instance, the accuracy of the provided work order information will enable the contractor to plan and conduct the harvesting operation properly (Gustafsson 2017). In other words, reliable, up-to-date information from the customer will allow the contractor to plan the work well and avoid problematic issues. As such, this dynamic not only affects contractor profitability and satisfaction but customer satisfaction as well (Erlandsson et al. 2017).

Companies tend to cooperate with other members of the supply chain rather than do business on their own. As a result, companies depend on one another and prioritize developing long-lasting business relationships with existing partners rather than looking for new cooperations. This collaboration between companies has been important to achieving business goals (Grönroos 1997). In forestry, the customer has a large impact on how harvesting services are purchased (and paid for), as well as the business models that companies apply (Benjaminsson et al. 2019). As entrepreneurs should maintain a certain independence from their customers, this business relationship structure can hinder contractors' entrepreneurial behaviors, such as taking responsibility for the business and finding innovative solutions for further business development (St-Jean and LeBel 2012). Historically, improvement and development efforts in forestry have mainly been driven by the customers, for example, large forest companies, who hold significant power in dictating the business and operational practices of harvesting services (Ager 2014). On the other hand, entrepreneurial SMEs can be more exposed to supply chain risk since their actions do not always align with the rest of the supply chain members' needs (Falkner and Hiebl 2015). Because harvesting contractors have to invest heavily in machinery (Erlandsson 2016) and often experience small profit margins (Kronholm et al. 2019), they have relatively limited opportunities to develop their business on their own. SMEs are inherently constrained by limited available resources within the company. In this context, the social structure in which the SME is embedded contributes opportunities and resources that are external to the SME (Jack and Anderson 2002). For instance, Jack et al. (2004) emphasize that enterprise performance can be improved by effectively utilizing relationships with family members, business contacts, suppliers, competitors and customers.

Material and methods

Sample

Given the complexity in harvesting service performance, this study was carried out as a case study. This was done by focusing on a large Swedish forest company, representing as a customer for around 120 harvesting contractors. Most of these contractors were SMEs and had the forest company as their only customer. At the time of the data collection, the company organized its work into three geographical regions, with each region further divided into 4–5 districts. In each region, a production manager was responsible for a group of production supervisors, who, in turn, were responsible for being in contact with a group of contractors connected to each district. As a part of their regular work relationship, contractors and production supervisor had frequent contact with each other (most often several times per week), among other things, to discuss expectations and opinions on performance. In-depth interviews with four production supervisors and eight contractors were used to enable the collection of their reflections on factors perceived to affect performance

Snowball sampling was used to select the study participants and followed a specific structure, with the aim to find as much variation of perceptions about performance as possible within a limited sample. The sampling started with semi-structured focus group interviews, including all of the company's production managers, in October 2018. The production managers were considered as key persons because of their wide knowledge about the company and their subordinated local production supervisors and the associated contractors. The production managers were asked to reflect upon the tangible and intangible values that they perceived as most important in harvesting services. To help with this task, the managers were provided with a list of the harvesting service values identified by Eriksson et al. (2015) and Erlandsson et al. (2017). The values on this list have been divided into tangible and intangible value attributes. Examples of tangible values include timber quality, thinning quality, and environmental consideration, while delivery reliability, flexibility, management, collaboration, operates as a business driver, and communication are examples of intangible values. The production managers agreed that the list was suitable to use during the following individual interviews with production supervisors and contractors; however, one change was made as a result of the focus group interviews: delivery

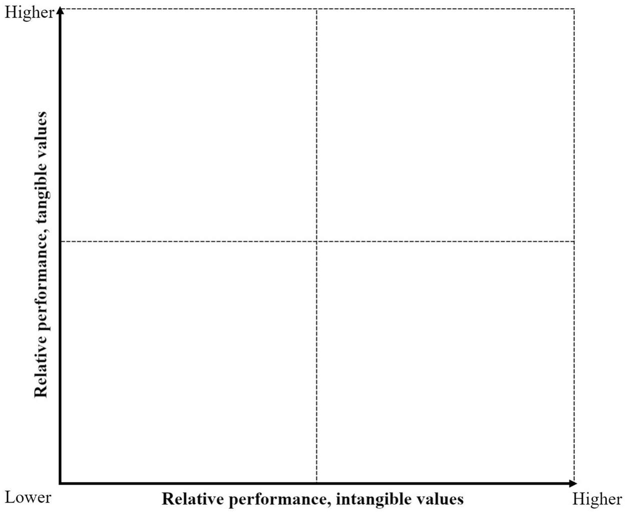

Figure 1. Combinations used to differentiate the performance of the districts and the contractors during the sampling process.

reliability was moved from intangible to tangible values (see Appendix 1). They were then asked to subjectively rank the districts in their respective region according to relative performance in the tangible and intangible values, respectively.

After the ranking exercise, each production manager was asked to explain the reasons for their ranking. They were also asked to reflect on the reasons for performance variations between districts. The purpose of using this approach was both to stimulate and to create a structured basis for discussions on what factors were actually being considered when comparing performances of different districts. A supporting matrix was used to differentiate the districts concerning their relative performance in tangible and intangible values (Figure 1). In order to capture as much variation in performance as possible within a limited sample, the managers were asked to together agree upon four districts to include in the interview sample, one from each of the four performance combinations resulting from sorting districts within the matrix. In their selection, the production managers were further guided in that the selected four districts should cover all of the company's three regions in order to also capture variation in geography.

Four production supervisors responsible for the selected districts with diverse performance were interviewed. In their turn, they contributed to the selection of contractors to interview by individually recommending two contractors with as relatively different performances in tangible and intangible values as possible. The production supervisors in the selected districts were responsible for 6–11 contractors each, which could have yielded a total of 32 contractors for performance assessments. Again, the same matrix used earlier was used as support during the interviews to differentiate contractors concerning their performance in tangible and intangible value attributes in order to select contractors with as diverse performance as possible (Figure 1). The production supervisors were quite free to choose which contractors they recommended for further interviews but were nevertheless guided to consider the positions in the matrix in order to ensure that they suggested contractors within diverse performance results (see Appendix 1). A total of eight contractors (two recommended by each production supervisor) were chosen and asked to participate in an interview for this study. Relative to others, four of them had higher performance in both intangible and tangible values, three had lower performance in both intangible and tangible values, and one had higher performance in intangible and lower in tangible values. The age of the selected contractors ranged from young individuals to contractors who were soon retiring, and the size of the companies varied. For some of the contractors, the investigated forestry company was their only customer, while other had several forestry companies as customers and/or offered additional services to harvesting.

Data collection

The individual semi-structured interviews with four production supervisors and eight contractors were conducted during the period October–December 2018. All interviews were conducted and analyzed by the same person. All the production supervisors and contractors were asked if they were willing to be interviewed for the aim of this study. Based on the participants' preference, the interviews were conducted at a restaurant during a lunch break or at the participant's office or home, with each interview lasting approximately 1.5–2 h. All of the interviews were recorded with the participants' permission, and the interviewing researcher ensured that the data would be handled in confidence throughout the research process. They were also informed about their right to withdraw their consent of participation and storage of their provided data material without any need to give reason for it. The participants were free to answer the questions as they liked and a questionnaire with open questions, a list of harvesting service values, and several exercises were used to stimulate the participants' reflections and thus provide rich data relevant to the research topic (see Appendix 1).

All participants were informed about the snowball sampling process. This implies that the participants were aware of the identity of the individuals they had recommended or been recommended by for the interview. However, no participant was given information about another participant's answers. Hence, those being recommended to participate did not know the reason for why they were recommended. Furthermore, when compiling and presenting the results, caution has been taken to not disclose information in such ways that it could be linked to specific participants.

During the interviews, all of the participants were asked to reflect upon tangible and intangible values of the harvesting service. The list with previously identified examples of harvesting service values, which was amended based on the focus group interview, was given to the participants to help stimulate them to reflect upon the values associated with harvesting services. All of the participants were also asked if they could think of other values.

Production supervisors performed a ranking exercise during their interviews to gain information on which value attributes are more important than others. In the ranking exercise, the production supervisors were asked to subjectively rank all the contractors they were responsible for based on the contractors' relative performance in tangible and intangible value attributes. The production supervisors were also asked to explain how contractors' performances in different value attributes had affected the ranking result.

Contractors were asked to assess tangible value performance, intangible value performance, and customer performance during their interviews. Each aspect of performance was symbolized as a line, stretching from poor to strong performance. During the tangible and intangible value performance assessments, the contractors were asked to mark their own performance result on the line according to how they perceived it. They were then asked to indicate where their customer would place them on the line. On the customer performance line, the contractors were asked to mark their perception of how the forestry company performed as a customer, as well as how they thought that the customer would assess themselves. To assess differences between the value attributes, the contractors were asked to explain how their performance in different value attributes affects their own perception, as well as that of the customer, of their intangible and tangible performances.

The participants were also asked to reflect on the reasons for their ratings of their tangible and intangible performance to gain insight into which factors drive and hinder contractor performance. For example, the production supervisors were asked to identify which factors supported and hindered the performance results of the identified contractors, and which of these factors explained the contractors' performance results. Similarly, the contractors were asked to identify factors that either supported or hindered their performance and how these factors explained their performance relative to other contractors.

Analysis

The recorded interviews were transcribed and analyzed by the same person who conducted the interviews. Each participant was given the opportunity to read through the transcript and to notify the interviewing researcher if they wanted to change or add anything. All of the transcripts were coded and subjected to content analysis.

The identified harvesting service values were categorized according to value attributes, which – in turn – were sorted into identified attribute groups. In the production supervisor transcripts, the harvesting value attributes were counted based on: (1) How many contractors the production supervisors related to a value attribute. (2) How many contractors the production supervisors related with a strength respectively weakness in performance in a value attribute. In the contractor transcripts, the value attributes were counted based on: (1) How many of the contractors considered a value attribute when discussing their tangible or intangible performance (services). (2) How many of the contractors considered their performance in a value attribute as a strength or weakness. The counting was made in order to reach information about what value attributes that the participants mostly mentioned in this study and the perceived performance in them.

According to the theoretical framework, identified factors were organized based on the themes of Capability, Incentives, Commitment and Involvement, along with External factors. In the production supervisor transcripts, the occurrence of each factor was counted in each attribute based on: (1) How many contractors that the production supervisors related the factor as the reason behind performance in the attribute. (2) How many of the contractors the production supervisor related the factor as a driver respectively an obstacle for the contractor's performance. In the contractor transcripts, the occurrence of each factor was counted in each attribute based on: (1) How many of the interviewed contractors mentioned the factor to affect their performance in the attribute. (2) How many of the contractors that had related the factor as a driver respectively an obstacle to their performance in the attribute. The frequency at which each identified factor had been considered was also quantified over all value attributes.

Results

Harvesting service performance

A total of 18 value attributes were found to influence harvesting service performance based on the production supervisors' ranking of contractors and the contractors' assessments of their own performance (Table 1). Almost all of the value attributes were mentioned by both production supervisor and contractors. Exceptions included safety work, which was only mentioned by contractors, as well as development potential and development cooperation, which were only mentioned by production supervisors. The value

Table 1. Harvesting service value attributes mentioned by production supervisors and contractors to affect the contractors' harvesting service performance.

Group	Value attribute	Description	Production supervisors		Contractors	
			n	%	*n*	%
Adaptability	Collaboration	Facilitates and supports the customer's work, provides suggestions and discusses how problems can be solved in a suitable way.	15	87	8	100
	Flexibility	Adapts to variations and changes according to customer needs.	13	100	7	86
	Operates as business driver	Adapts the work according to private forest owner needs and requests, enables wood procurement from forest owners and provides tips to the customer about possible wood purchasing opportunities from private forest owners.	5	100	6	100
Operational quality	Forest management	Performs harvesting services according to policy and instructions, the work does not cause soil damage, and only causes a low level of damage to the residual stand.	13	54	8	100
	Wood value	High and consistent bucking quality (length and diameter distribution), minimal damage to saw logs.	10	60	8	88
Delivery	Volume production	Describes the volume of harvested wood and the productivity of the operations.	12	58	5	60
	Deliver reliability	The agreed volume is accessible at the roadside at the agreed time.	10	80	7	71
Information	Data-gathering	The contractor can provide logs concerning machines, daily production, and sample trees, along with follow-up documentation about how the work was carried out.	10	40	4	100
	Communication	Informs the customer about problems on time. Provides relevant information regarding the performance ability of both parties.	5	100	6	100
Development	Development potential	Includes aspects related to current conditions, future ambitions, and company objectives.	13	46	–	–
	Continuous improvement	Works independently to improve – usually via gains in efficiency – different activities in the company.	4	50	3	100
	Development contribution	Educates the customer, helps the customer educate other contractors and machine operators. A step ahead in development. Shares information about potential areas for development.	2	100	–	–
	Educates new machine operators	Contributes to more competent machine operators in the forest sector, periodically employs and mentors trainees, runs or collaborates closely with educational institutions for machine operators, good ambassador for the forestry sector.	1	100	1	100
Independence	Professional business relationship	Well versed in negotiations, Skilled in professionally agreeing price and can demonstrate how the customer will benefit. Argues with facts and results.	12	33	2	100
	Administration	Documentation and control of different activities in the company, distribution of site maps and instructions to employees.	4	75	5	60
Stability	Employee management	Successful employer with healthy and motivated employees, low employee turnover, relatively successful in finding and keeping employees.	9	67	6	67
	Long-term reliable business relationship	Has provided harvesting services to the customer over a long time period, predictable and reliable, the customer knows what to expect.	3	33	1	100
Safety	Safety work	Makes sure to prioritize safety, evaluates and avoids possible risks according to health and safety guidelines before the work is started, low numbers of sick leave days.	–	–	3	100

Notes: The frequencies (n) of contractor examples for the identified value attributes are shown, as well as the proportion (%) of instances in which it was considered to have a positive effect on performance. The value attributes were divided into eight attribute groups, sorted in descending order according to the frequency of the total value attributes given by both production supervisors and contractors. The value attributes, in turn, are sorted in descending order according to frequency in the contractor examples given by all participants. Each value attribute is presented as the total number of contractor examples given by production supervisors and the total number of the interviewed contractors that mentioned the value attribute separately, along with the proportion of examples in which the value attribute was mentioned to positively affect the ranking result (production supervisors) or the performance assessment (contractors).

attributes were divided into eight attribute groups (Table 1). The production supervisors commonly mentioned both strengths and weaknesses of contractors' performance in different value attributes, with in total 66% of the examples mentioned as strengths of the contractor performance. Contractors also mentioned both strengths and weaknesses in their perceived performance in the value attributes, and in total, mentioned a higher share (88%) of examples perceived as strengths.

Overall, collaboration was most often mentioned by the participants in total. The production supervisors most commonly mentioned that they appreciate a contractor's collaboration ability. All of the interviewed contractors mentioned that they performed well in collaboration and forest management. The performance result in the wood value attribute was also discussed by all of the contractors, with one reporting this value attribute to be a weaknesses.

The weakness in contractors' performance, most commonly mentioned by the production supervisors, was a lack of professionalism in the business relationship. In contrast, there were only a few occasions when contractors mentioned weaknesses in their own performance results. These weaknesses were mainly related to volume production, volume reliability, administration and employee management.

The production supervisors provided many examples of contractors with both strong and weak performance in professional business relationship, development potential and data-gathering. In contrast, it was only a few or none of the contractors that mentioned their performance in these attributes. On the other hand, many of the contractors mentioned their performance in operating as a business driver (enable wood procurements from forest owners, etc.), communication, administration and safety, while the production supervisors seldom, or not at all, mentioned contractor performance in in those value attributes.

Key drivers and obstacles

Based on the participants' statements, 14 factors were identified to be affecting performance in one or more of the eight attributes (Table 2). When being categorized into the five themes, the factors were quite evenly distributed. Most of the affecting factors were observed to exert both a driving and hindering effect, which varied between contractors and value attributes (Tables 3 and 4). As visualized in Figure 2, the production supervisors most often mentioned factors connected to a contractor's Capability, especially *resources* and *competence*, when discussing drivers and obstacles to contractor performance. These two factors were among the most common drivers mentioned by the production supervisors, yet were also commonly described as obstacles for contractor performance. A similar observation was made for *personal characteristics* and *economy*, as both of these factors were often mentioned as drivers as well as obstacles.

The contractors mostly mentioned factors connected to Incentives when reflecting on what drove their performance, and factors connected to Capability when discussing obstacles to performance (Figure 2). The Capability theme showed the highest share of obstacles, although *competence* and *systems & processes* were mostly mentioned as drivers. This was because (lack of) *resources* was the factor most often perceived to hinder performance All four of the factors under the Incentive theme were commonly mentioned to drive performance, although the *economy* factor was also commonly identified as an obstacle to performance. The contractors mentioned various drivers at similar frequencies when discussing performance, yet the driving factor that was mentioned most often was *collaboration interface*. There were more differences in the occurrence of hindering factors. The contractors most often mentioned *resources*, *economy*, *collaboration interface* and *logging conditions* when discussing obstacles to performance.

Table 2. Factors that were identified to affect contractor performance in any of the studied value attributes, grouped into five themes. The themes are sorted according to the frequency at which the related factors were mentioned to affect performance (either drive or hinder) in the studied value attributes based on contractor and production supervisor interviews. The factors included in each theme are sorted according to the same logic, i.e. how often the factor was mentioned in conjunction with the studied value attributes by the participating contractor and production supervisors.

Theme	Affecting factor	Description and content
Capability	Resources	Human resources (quantity and competence), material equipment and machinery, financial resources.
	Competence	Contractor's knowledge, experience, skills and talent.
	Systems & processes	Common work routines and standards.
Incentives	Economy	Economic rewards and the estimated impact on profitability.
	Motivation	Lifestyle objectives, possibility to be one's own boss and set own schedule, personal acknowledgement that the work is important and appreciated.
	Strategy	Company goals, e.g. to be an attractive contractor to customers, private landowners and employees.
	Requirements	Abiding by laws and rules, entering into contract agreements
Commitment	Personal characteristics	Contractor's personal attitude, interest, engagement and feeling of responsibility in the work activities.
	Relationship	Contractor's attitude, interest, engagement and feeling of responsibility towards the customer (forestry organization), e.g. trust, loyalty and dependency to the customer, opportunities and possibilities to do other things or work for other customers.
Involvement	Collaboration interface	Customer's adherence to their part of the assignment, contractor accepts help and advice from the customer or other external parties, contractor uses contacts in their network.
	Supplier management	Customer's leadership style, treatment of the contractor, e.g. discussing the contractor's performance results, giving feedback, expressing expectations.
External	Logging conditions	Terrain, weather and wind.
	Competition & economic situation	Market conditions, availability of machine operators on the market, competition from other areas, demand for harvesting operations, other contractors in the area.
	Risk	Balance between potential benefits and losses.

Table 3. The factors mentioned by the production supervisors in specific value attribute groups.

		Value attribute group															
		Adaptability		Operational quality		Delivery		Information quality		Development		Independence		Stability		*All pooled*	
Theme	Factor	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Capability	Resources	3	100	3	33	9	56	1	0	5	40	–	–	5	40	*26*	*50*
	Competence	1	100	4	75	6	50	1	0	3	100	3	100	9	44	*27*	*63*
	Systems & Processes	–	–	3	67	2	50	–	–	2	100	3	100	–	–	*10*	*80*
Incentives	Economy	–	–	6	33	6	100	1	0	2	100	2	100	3	67	*20*	*70*
	Motivation	1	100	3	33	1	100	–	–	1	100	–	–	1	100	*7*	*71*
	Strategy	–	–	–	–	–	–	–	–	4	50	–	–	2	100	*6*	*67*
	Requirements	–	–	1	100	–	–	–	–	1	100	–	–	–	–	*2*	*100*
Commitment	Personal characteristics	2	50	8	88	1	100	4	0	5	60	3	67	2	0	*25*	*56*
	Relationship	6	100	1	100	–	–	–	–	1	100	–	–	–	–	*8*	*100*
Involvement	Collaboration interface	–	–	–	–	2	100	2	100	2	100	1	100	1	100	*8*	*100*
	Supplier management	–	–	1	100	1	100	2	100	1	100	–	–	–	–	*5*	*100*
External	Logging conditions	1	100	1	0	3	0	–	–	–	–	–	–	–	–	*5*	*20*
	Competition & economic situation	–	–	–	–	1	0	–	–	–	–	–	–	1	0	*2*	*0*
	Risk	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
All pooled		*14*	*93*	*31*	*61*	*32*	*63*	*11*	*36*	*27*	*74*	*12*	*92*	*24*	*50*	*151*	*66*

Notes: The frequencies (*n*) of contractor examples for the identified factors are shown, as well as the proportion (%) of instances in which it was mentioned as a driver of the contractors' performance. For the column and row "All pooled" the frequencies (*n*) represent the amount of mentioned examples and not the total number of contractors, as well as the proportion (%) of instances in which it was mentioned as a driver of contractor performance.

Table 4. The factors mentioned by the contractors in specific value attribute groups.

		Value attribute group																	
		Adaptability		Operational quality		Delivery		Information quality		Development		Independence		Stability		Safety		*All pooled*	
Theme	Affecting factor	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Capability	Resources	3	33	6	67	5	60	2	50	4	0	4	25	5	20	–	–	*29*	*38*
	Competence	3	100	4	75	2	100	2	100	4	100	–	–	7	71	3	100	*25*	*88*
	Systems & Processes	2	100	3	100	4	100	3	33	2	100	1	100	3	100	2	100	*20*	*90*
Incentives	Economy	5	0	6	17	5	80	1	100	3	33	5	80	2	50	1	100	*28*	*46*
	Motivation	3	100	2	100	2	100	3	100	6	83	1	100	4	100	2	100	*23*	*96*
	Strategy	5	100	3	100	1	100	2	100	4	100	3	67	4	100	–	–	*22*	*95*
	Requirements	5	100	5	100	2	100	3	100	-	-	2	100	–	–	–	–	*17*	*100*
Commitment	Personal characteristics	4	100	7	86	4	100	2	50	3	100	5	40	1	100	1	0	*27*	*78*
	Relationship	7	86	3	67	1	100	1	100	1	0	5	60	–	–	1	100	*19*	*74*
Involvement	Collaboration interface	7	86	5	60	5	40	2	50	3	100	6	67	3	100	1	100	*32*	*72*
	Supplier management	1	100	3	100	3	100	1	100	2	100	–	–	–	–	1	100	*11*	*100*
External	Logging conditions	1	0	4	0	4	0	–	–	–	–	–	–	–	–	–	–	*9*	*0*
	Competition & economic situation	–	–	1	0	–	–	–	–	–	–	–	–	4	0	–	–	*5*	*0*
	Risk	–	–	–	–	1	0	–	–	–	0	1	0	–	–	–	–	*5*	*0*
All pooled		*46*	*78*	*52*	*67*	*39*	*72*	*22*	*77*	*35*	*69*	*33*	*61*	*33*	*67*	*12*	*92*	*272*	*71*

Notes: The frequencies (*n*) of contractors mentioned the identified factors are shown, as well as the proportion (%) of instances in which it was mentioned as a driver of contractor performance. For the column and row "All pooled" the frequencies (*n*) represent the amount of mentioned examples and not the total number of contractors, as well as the proportion (%) of instances in which it was mentioned as a driver of contractor performance.

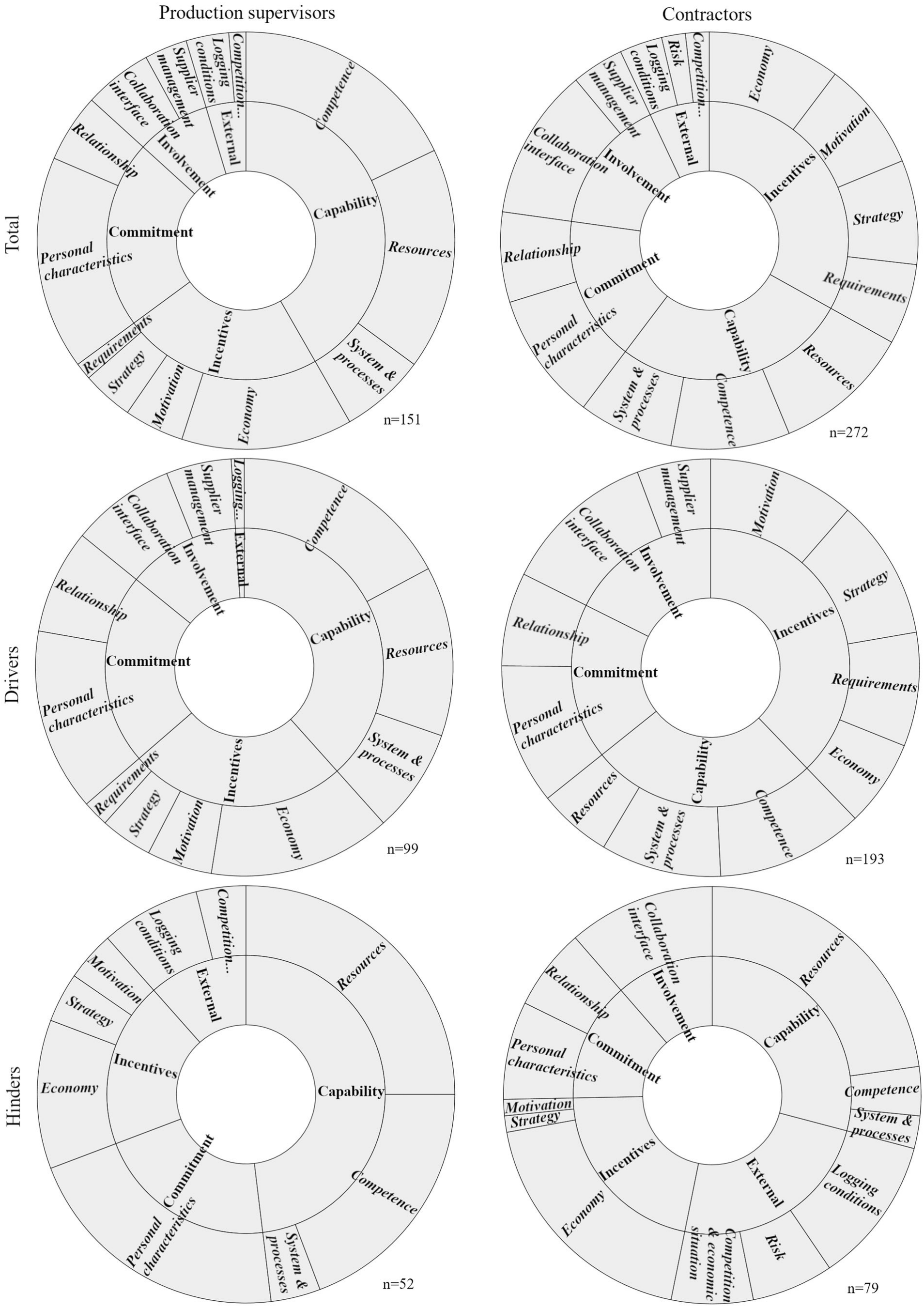

Figure 2. The proportions of the themes and factors within examples given (*n*) by the production supervisors and contractors, organized as total instances of cases in which the theme/affecting factor was mentioned as an obstacle or driver. The themes and factors are sorted according to frequency, with the theme that was mentioned most often at the top of each circle (frequency of mentions then progresses clockwise in descending order).

In general, the participants mentioned examples of how Capability, Incentives, Commitment and Involvement are drivers of performance more often than they provided examples of how these themes are obstacles to performance. The factors in the External theme were not mentioned very often, but both parties mainly considered these factors as obstacles to performance (Tables 3 and 4). Notably, *logging conditions*, that is, bad terrain and weather, were mentioned as a limitation to harvesting service performance. Both the production supervisors and contractors considered that *competition & economic situation* hindered contractor performance. The high demand for harvesting at the time of the study meant that the contractors did not need to compete heavily for harvesting contracts, yet they found difficulties finding employees from the small pool of skilled machine operators.

Resources, although often described as driver of strong performances, was the factor most often mentioned as an obstacle by both parties (Figure 2 and Tables 3 and 4). Both parties addressed the relative lack of machine operators as a concern, while contractors also mentioned the lack of financial capital as an obstacle. Contractor *competence* was another obstacle that was frequently mentioned by both production supervisors and contractors. Nevertheless, *competence* was mentioned both as a driver and an obstacle in these parties' explanations. This factor was the most common driver mentioned by the production supervisors, although this factor was also included in a relatively high share (37%) of examples concerning obstacles to contractor performance. The contractors, on the other hand, mostly mentioned c*ompetence* in a positive light. A similar pattern was noted for *collaboration interface*, which was the most common factor mentioned by the contractors during discussions of performance results. Although this factor represented the driver most frequently given by contractors, it was also mentioned in a relatively high share (28%) of the examples of obstacles to performance provided by contractors. The production supervisors only mentioned *collaboration interface* when providing examples of what drives contractor performance. Both production supervisors and contractors only mentioned *requirements* and *supplier management* as drivers of performance. The production supervisors only considered the *relationship* factor in examples of what drives contractor performance, while some of the contractors also considered this factor as an obstacle to performance.

Drivers and obstacles across the different harvesting service value attributes

The frequencies at which affecting factors – as both a driver and obstacle – were mentioned varied across the different value attributes. As shown in Tables 3 and 4, the production supervisors' and contractors' perceptions of contractor performance showed discrepancies in how the identified factors affected contractor performance across the various value attributes. Even if a factor was commonly mentioned as a driver or obstacle to strong performance, it could have variable effects on performance across the various harvesting service value attributes. The most commonly mentioned factor affecting contractor performance, *resources*, was perceived to influence many value attributes. For example, the production supervisors often mentioned that a contractor's *resources* affect the delivery performance result (Table 3), while most contractors considered that their *resources* affect their performance result in operational quality. However, many contractors also mentioned that *resources* had impacted on their delivery performance result (Table 4).

The factor most often mentioned by the production supervisors, *competence*, was related to contractors' performance results in most of the value attributes. Most of the production supervisors' examples of how contractor competence influences performance were linked to stability (Table 3), with the same result holding true for the contractors' responses (Table 4). Interestingly, the production supervisors gave almost the same number of examples for how a contractor's *competence* can drive and hinder stability performance (Table 3). In contrast, the contractors mostly perceived their *competence* to drive stability performance (Table 4).

The contractors most often perceived *collaboration interface* to affect adaptability performance, while the production supervisors mentioned how this factor was linked to delivery, information, and development performance. Nevertheless, a considerable number of the interviewed contractors felt that *collaboration interface* affected their delivery, information, and development performances.

The production supervisors gave a few examples of factors that influence contractors' performance in value attributes connected to adaptability, although these value attributes (especially collaboration and flexibility) were more commonly mentioned in their perceptions of contractors' performance (Table 1). As shown in Table 3, all of these examples except for one described drivers for contractors' adaptability performance. In these descriptions, *relationship* was the most common factor associated with a contractor's adaptability performance. The one obstacle that the production supervisors mentioned for adaptability performance was a contractor's *personal characteristics*. As shown in Table 4, the contractors linked various factors to their performance in the adaptability value attributes. Similar to the production supervisors (Table 3), the contractors commonly mentioned the *relationship* factor as a driver for adaptability performance (Table 4). However, one contractor felt that the *relationship* factor could hinder a contractor's adaptability performance. The most common perceived obstacle to adaptability performance was *economy*, and this was especially relevant in the short-term time scale.

Certain drivers and obstacles to performance were more commonly mentioned than others in conjunction with the value attributes that were generally identified as contractor weaknesses (Tables 1, 3 and 4). For instance, the production supervisors commonly mentioned that *competence* and *system & processes* positively influence independence, while *personal characteristics* were negatively linked to this value attribute. Some of the contractors considered that strong performance in the independence value attribute positively affected the *economy* factor, whereas *resources* and *personal characteristics* were mainly perceived to hinder independence.

The *economy* factor was commonly mentioned as both a driver and obstacle of many value attributes (Tables 3 and 4). Both parties most often mentioned that a contractor's delivery performance was driven by the *economy* factor, that is, by direct economic gains. Furthermore, the most common obstacle to operational quality performance – as identified by both parties – was the *economy* factor (i.e. lack of economic incentives).

Discussion

This study identified various drivers and obstacles to contractors' harvesting service performance and organized them in themes according to a theoretical framework. The results confirm that harvesting service performance is a complex, multifactorial metric. Harvesting services comprise many value attributes and – for this reason – it is difficult to compare the performances of different contractors since their performance across different value attributes can vary widely. Moreover, the results revealed that performance in these attributes is affected by many different factors. As multiple factors were commonly found to influence the performance in each value attribute, it is likely that interactions between factors exist, which will subsequently impact contractor performance in the different attributes.

Based on the production supervisor and contractor interviews, many of the factors could exert either a driving or hindering effect on performance, with the effect differing between value attributes. The production supervisors and contractors in this study generally had similar views about how various factors affect performance. Examples include the drivers behind operational quality, delivery, adaptability and stability, and obstacles to operational quality, development, and independence. There were, however, some notable differences in the parties' perspectives. The production supervisors and contractors had different perceptions about the drivers for development, independence and information quality, and obstacles to delivery, adaptability, stability and information quality. This shows that contractors and the customer can agree about what drives performance in a certain value attribute but can disagree about what hinders this performance and vice versa. Notable differences were observed for the parties' perceptions of contractor *competence*. The contractors mainly talked about the relationship between *competence* and certain value attributes in a positive light, while the production supervisors provided examples describing both positive and negative effects of contractor *competence* on performance. An opposite trend was observed for the *relationship* and *collaboration interface* factors. For both of these factors, the production supervisors provided examples about how their *relationship* and *collaboration interface* with the contractors positively influences performance. On the other hand, the contractors mentioned that these two factors are drivers of performance, yet also provided examples in which the *relationship* and *collaboration interface* with the customer had hindered their performance. Thus, the results indicate that it is easier for both parties to identify obstacles to performance in the other party than in themselves.

The categorizations of the factors revealed that harvesting service performance could be considered to be driven and hindered through a mixture of five themes. The theoretical framework including these themes, along with the factors that were identified to affect performance through its application, are discussed in more detail below.

Capability

The results indicate that a contractor's capability is crucial to harvesting service performance. The interviewed participants mentioned various factors when discussing Capability. The participants identified three main factors – *resources*, *competence,* and *systems & processes* – to influence Capability.

In line with RBV thinking (Wernerfelt 1984; Barney 1986; Grant 1991), the results of this study indicate that both production supervisors and contractors consider *resources* and *competence* to be key factors in harvesting service performance. In this study, the *resources* factor included both physical and non-physical resources, in line with the description by Grant (1991). *Competence*, on the other hand, is an example of a non-physical resource. This study separates the contractor's own competence from the competence of their employees. Thus, employee competence is included in the *resources* factor instead of the *competence* factor, which exclusively reflects the contractor's own competence. A lack of skilled machine operators was the most common obstacle that the participants mentioned when discussing the *resources* factor. Finding skilled machine operators has also been identified as a challenge for contractors in other European countries (Kronholm et al. 2019), especially for small contractors (Jylhä et al. 2020).

When considering *competence,* the contractor's leadership skills may improve the competence of the machine operator over time. Leadership skills were often identified by the production supervisors as a reason for the positive performance results of larger contractor companies, whereas an excessive focus on operational parts was provided as a reason for why some companies performed poorly. In contrast, the production supervisors' opinions changed when they discussed smaller contractors, as strong operational skills (e.g. handling of machines) were mentioned to positively influence performance but leadership skills were seldom mentioned. – To some extent, this may be explained by the nature of the work. Larger contractors have more employees operating the machines and, as such, will take on a clear management role (both internally and externally), with more time spent on managing the company rather than operating the machines (Jylhä et al. 2020). This does not mean that smaller contractors do not need leadership skills, but rather that the importance of leadership skills may increase successively with the size of the organization. Both contractors and customers should therefore benefit from assess the contractor's leadership and operational skills, as both of these factors are relevant to the sustainability of the business. However, the suggestion that required contractor skills depend on organization size should be investigated further. For example, future research could investigate how contractors develop and leverage different skills according to available business opportunities and how these decisions have consequences on their performance.

Incentives

The results indicated that pricing models affect contractor performance, especially since the *economy* factor was clearly mentioned to drive some value attributes and hinder others. On the other hand, contractors can be satisfied with low profitability (Erlandsson and Fjeld 2017) and may not be primarily motivated by economic incentives (Drolet and LeBel 2010). Accordingly, the contractors interviewed in this study more commonly mentioned the *motivation*, *strategy* and *requirement* factors to drive their performance, while economic incentives were more commonly mentioned to hinder performance. This was especially relevant for adaptability performance, as all respondents positively assessed the performance of most contractors in this theme. The most common obstacle that contractors mentioned when discussing their adaptability performance was the lack of economic incentives.

Commitment

In line with the theory that successful contractors are committed to their customer organizations (Porter et al. 1974; Norin and Thorsén 1998; Eriksson et al. 2017), the results of this study indicated that contractors' *personal characteristics* and *relationship* with the customer were perceive to affect harvesting service performance. Based on their discussions of *personal characteristics*, it seems as though the productions supervisors consider that contractor commitment mostly relies on the actions of the contractors. Notably, operational quality was mentioned to be driven by contractors' *personal characteristics*, that is, high enthusiasm and pride in performance. The contractors confirmed that *personal characteristics* drive operational quality performance, as they often described their own pride at performing well in these attributes. The *relationship* was also mentioned by both parties, but to a significantly higher degree by the contractors. The *relationship* factor seemed to be a common driver of the strong performance reported for adaptability. Many contractors were described to be adept at activities related to adaptability, which indicates a strong commitment to the *relationship*. Individuals tend to make more of an effort if they are committed to the task (Porter et al. 1974; Morgan and Hunt 1994; Gilliland and Bello 2002); hence, it can be expected that contractors will make more of an effort for customers they are committed to. In discussions linked to the relationship factor, many production supervisors and contractors mentioned a mutual trust between the parties as a driver of performance, with this characteristic especially mentioned for the adaptability value attribute. The contractors commonly experienced that their efforts in adaptability will improve the long-term *relationship* with the customer, which indicated a high level of trust in the customer. On the other hand, some contractors mentioned that their *relationship* with the customer could hinder their performance in development and independence. Since the development and independence performances of many contractors were identified as weaknesses by the production supervisors, it may be fruitful for both parties to reconsider the contractors' commitment to the customer's organization in order to improve development and independence.. Historically, the customers of harvesting service have taken the responsibility for development (Ager 2014). Hence, when customers start to require that contractors are responsible for improving their development and independence efforts, it may take time before contractors are committed to these activities in terms of *personal characteristics* and *relationship* with the customer.

Involvement

The results indicates that the performance of contractors is often perceived to be affected by the *collaboration interface* with the customer and other collaboration parties. The *collaboration interface* was perceived to drive adaptability because the *collaboration interface* was key to interacting with customers who were not acting and/or communicating as they should. For instance, work order information of insufficient quality or that was delivered just before harvesting execution was perceived to drive contractors' adaptability performance but hinder their delivery performance, which instead was driven by the *economy* factor. This provides more support to earlier studies' identification of timely and reliable work order information as important for contractor profitability and satisfaction as well as for customer satisfaction (Erlandsson et al. 2017; Gustafsson 2017).

On the other hand, many contractors witnessed the driving effects of *collaboration interface* because they received help and guidance from the customer and other parties when they asked for it. Both production supervisors and contractors expressed that a contractor's decision to use their contacts and business partners for help and advice supported their performance. This perceptions of the driving effects of collaboration interface indicates that contractors can improve their performance by effectively utilizing their network, which reflects what has previously been reported by Jack et al. (2004).

Both parties only discussed the supplier management factor as a driver of performance, and in numerous value attributes. This finding indicates that the production supervisor's leadership affects the contractor's performance and that both parties notice the driving effects of good leadership from the customer side.

External factors

Numerous factors that were mentioned as obstacles to contractor performance were neither connected to the contractor nor the customer. These factors included *logging conditions*, *competition & economic situation, and risk*. The external factors were predominantly perceived to hinder performance; however, one production supervisor considered that *logging conditions* were a driver for adaptability performance. This result indicates that the role of External factors is easier to notice when they are hindering performance. The results concerning External factors are also in line with previously mentioned indications that both production supervisors and contractors more readily identified weaknesses in others than in themselves. Following this train of thought, the participants may have preferred to mention external obstacles rather than obstacles related to one of the business partners.

Stakeholders should be aware of External factors when assessing a business relationship. As some of these External factors occur seasonally (Uusitalo 2005), they can be – to some degree – considered in advance. Moreover, knowledge about External factors can be used to predict productivity and to steer the wood flow (Eriksson and Lindroos 2014).

Interactions between affecting factors

It is important to consider all of the factors investigated in this study from a multidimensional perspective in that each factor can influence how the other factors affect performance. For example, a contractor's Capability can affect their possibility to react to different Incentives. Thus, aligning Incentives with customer requirements, as discussed by Eriksson et al. (2015), may not have the expected effect if the contractor does not have the Capability to react. Nevertheless, Incentives may affect how contractors build their Capability for service performance. For example, Benjaminsson et al. (2019) argue that customer demands, as well as how they pay for the service, affect a contractor's business model, and thus, Capability. On the other hand, this study indicates that certain contractors occupy unique niches on the market based on their decision – conscious or not – to specifically focus on certain value attributes. However, the identified perceptions still show that the customer affects the contractors business model. *Supplier management* efforts can also affect a contractor's Capability; for instance, the production supervisor may actively engage and give feedback to a contractor in order to improve their performance. Thus, Involvement from customers and other partners affects a contractor's Capability, which, in turn, affects service performance. The reverse can also be true, as existing Capability will influence the need for Involvement from customers and other partners to drive performance. In the context of Swedish forestry, the customers are often described to have a dominant position in the forest company–contractor relationship. For this reason, the customer is also interested in improving the contractor's Capability as this will influence the customer's ability to secure a long-term supply of wood (Benjaminsson et al. 2019). The intensity of these efforts may well be related to contractor Capability, as the company will need to invest more resources into contractors with poor Capability than contractors with a high level of Capability. In contrast, a high degree of customer involvement in the contractor business models has been argued to decrease innovation in contractor organizations (Mattila et al. 2013; Benjaminsson et al. 2019).

The degree of Commitment to service performance can be argued to be affected by Incentives and Involvement from other parties. For instance, different Incentives provided by the customer can affect the *Relationship* between the parties and the contractor's *Personal characteristics* in terms of willingness, care and interest in the performance of different value attributes. This is relevant because Swedish harvesting service contractors usually only have one or a few important customers. As such, the customer can leverage their dominant position in the business relationship to convince the contractor to act in a certain way (Eriksson et al. 2015). Since Commitment can be argued to influence how Involvement affects service performance, the customer must nevertheless be careful as to not disrupt the r*elationship* too much (Maloni and Benton 2000). For instance, a contractor with a high level of trust and loyalty to the customer may be more receptive to improvements suggested by the customer than a contractor with lower levels of trust and loyalty. Thus, Involvement efforts can both harm and encourage Commitment to service performance. How the customer fulfills their part of the assignment, and the consequences of these actions, may affect Commitment over time.

Value attributes

The presented results indicate that contractors are a blend of professionals characterized by unique focuses on different value attributes. Some contractors perform strongly across many value attributes, while others perform strongly in a few. Regardless of whether the decision to focus on certain value attributes is conscious or not, this result indicates the existence of different niches and business models among contractors. Furthermore, even if a customer has not considered a certain value attribute, it may still be important for both parties' interests. In general, service companies that are one step ahead and provide unexpected beneficial values can reach excellent customer satisfaction and a better market position (Kano 1984), which should be true also for harvesting contractors.

The results of this study indicate that production supervisors may be satisfied with contractors due to strong adaptability performance even if they perform poorly in other value attributes compared to their competition. As was shown in this study, the production supervisors appreciate contractors who perform strongly in adaptability because they can make changes in short time to the work order. This indicates that customers will be satisfied by contractors that demonstrate high adaptability, that is, rapid problem-solving ability, regardless if the problem was caused by the customer or the contractor. Based on those observations, it seems that adaptability is one of the most important attributes for a contractor maintaining customer satisfaction and harvesting service operations in the long-term. On the other hand, Erlandsson and Fjeld (2017) report that reliable, on-time work order information increases the contractors' satisfaction.

Customer demand for harvesting services can vary extensively between months (Erlandsson and Fjeld 2017), and it is reasonable to assume that this applies to the contractors in this study. According to the participating customers, most of the contractors performed strongly in collaboration and flexibility. These two attributes have previously been identified as important aspects of harvesting service provision

(Mäkinen 1997; Eriksson et al. 2015; Erlandsson et al. 2017). The main explanations for why these attributes are important for all contractors to address is that the industry is affected by seasonal variation in weather conditions and wood demand (Uusitalo 2005), as well as uncertainties in harvesting service demand (Erlandsson 2013). Managers at forest companies apply different methods to provide contractors with an even workflow and stable income throughout the year. This includes working with contractors who own a fleet of flexible machines that can operate in both thinning and harvesting (Erlandsson 2013) and providing harvesting sites based on how the stand conditions influence productivity (Norin and Furness-Lindén 2008; Eriksson and Lindroos 2014). These adaptations to fluctuating harvesting demand throughout the year prove the importance of collaboration and flexibility in harvesting service provision.

Study limitations

The sampling process aimed at finding a sample of maximum variation and diversity of performances in the harvesting service to reach multiple perspectives within a limited sample, a common approach in qualitative research (Creswell and Poth 2016). The study was conducted as a case of the real-life context with one large forest company as customer and associated contractors as providers of harvesting service. Thus, this does not represent all customers' and service providers' perceptions, neither all production supervisors' and contractors' perspectives. Nevertheless, the study succeeded to reach a broad spectrum of examples with different perspectives of factors affecting the value attributes in harvesting service. In contrast to other studies based on surveys (Drolet and LeBel 2010; Erlandsson et al. 2017), the result of this study is built on in-depth interviews within a case study. The strength is that new perspectives can be explored when the participants can reflect upon their experiences, and the interviewer can contribute with follow-up questions for gaining further details and understanding. Therefore, despite the relatively small sample, the results widen the insights about the complexity behind successful harvesting service provision. However, due to the intrinsic features of qualitative research, it is important to keep in mind that the results are a range of case-specific examples of different perspectives built on a sample of 12 persons and may not represent all contexts or cases. Therefore, these insights and case-specific examples can be used as indications, rather than conclusive results when researchers and practitioners consider performance in harvesting service in similar contexts.

The results do not consider the weight and importance of each value attribute or affecting factor. Previous studies have shown harvesting service provision to be a complex, multifactorial process (Eriksson et al. 2015; Erlandsson and Fjeld 2017), and the framework applied in this case study was designed based on previously identified customer service values. These examples of customer values that are relevant to harvesting service provision were shown to all of the participants at an early stage of every interview. This decision was made to simplify the interview process and leave more time for the participants to reflect on the drivers and obstacles that influenced the various value attributes. Therefore, the harvesting service values mentioned by the participants can be expected to have been highly influenced by the given examples. However, new value attributes were also identified in the analysis. These values were not mentioned as often as the previously identified values. This does not mean that these new values are any less important than previously identified values since expressed importance is not necessarily equivalent to perceived importance. Furthermore, it is natural that some values are not mentioned because they are taken for granted or are considered completely necessary to customer satisfaction (Kano 1984). In other words, even if a value is important, it may not come to a participant's mind during the interview situation. Moreover, it may be even more difficult for a participant to identify additional value attributes when they are provided with a list of specific values associated with harvesting service provision. With regards to the ranking exercise, it may be difficult for the customer to reliably compare contractor performance across all of the value attributes. The results from the ranking of a contractor's performance across tangible and intangible values in relation to other contractors depend on how each participant weights the importance of various value attributes. Furthermore, even if the production supervisors work for the same company, it is possible that they have different perceptions of the relative importance of various value attributes. During the interviews, participants were asked to provide examples of value attributes other than the cost of harvesting services. Although the cost of harvesting services is an important attribute, the presented research tried to describe the wide array of value attributes relevant to harvesting services rather than quantify them in monetary terms. The selection process for participants was designed to maximize – with the available time and monetary resources – the possibility of obtaining as many distinct perspectives as possible by gathering participants from different districts and performance groups. The frequency at which certain value attributes, as well as drivers and obstacles to performance, were mentioned reflect the participants' opinions during the interview situation. As such, it is impossible to know if their responses would have been different in a less formal environment, or if they had been given a longer time to reflect on their answers, yet the applied methodology increased the likelihood of obtaining a wide spectrum of opinions.

In this study, the production supervisors evaluated the contractors' performances, which was contrasted to the contractors' evaluations of their own performances. Frequent discussions about and evaluations of performance is an essential part of the production supervisor–contractor business relationship. Nevertheless, some individuals may have considered the study's questions to be sensitive, and that it potentially could harm the business relationship between parties if the information could be linked to any participant. Thus, there is a risk for bias in the participants' answers if they had any doubts on the researchers' ethics. To minimize such risks, all participants were clearly informed about how the information they shared would be used and handled. However, it is impossible to know if all participants fully trusted the researchers. Moreover, the methodology is intrinsically related to a certain risk of biased answers due to purposely or unpurposely dishonest participants. However, the consent process reduced that risk of bias and increased the probability that the participants shared their honest thoughts during the interviews.

Future research

Even though numerous approaches for handling variations in wood demand exist today, various parties of the timber supplier chain are still exposed to several risks and obstacles. For example, although forestry companies will try to provide contractors with an even work flow, there will be cases – due to myriad factors – in which contractors will have to change the scale of their operations temporarily to meet customer demand. Erlandsson and Fjeld (2017) argue that contractors have different sensitivities to workflow variations depending on expectations and company structure. This study identified that the *economy* factor can negatively affect Adaptability; therefore, the expectation that a contractor will show high Adaptability may adversely affect the contractor's profitability. For this reason, further investigation can be recommended on how contractors can develop their companies to be tolerant to a changing market environment. Moreover, further investigations are recommended on drivers and obstacles to these types of changes; for instance, what models customers use to purchase harvesting services and how adaptability can be promoted without jeopardizing contractor profitability and satisfaction.

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ORCID

Malin Johansson http://orcid.org/0000-0003-1156-4277
Ola Lindroos http://orcid.org/0000-0002-7112-4460

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This thesis provides new perspectives on the balancing of the flow of wood and use of machinery in harvesting operations to improve performance. The general conclusions are that the balance between the flow of wood and use of machinery could be improved by harvesting groups cooperating to share flexibility, and that a more holistic perspective on performance in harvesting operations would be beneficial for the wood supply chain.

Malin Johansson undertook her doctoral education at the Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, where she also received her Master of Science in Forestry.

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