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Business Process Reengineering of a Large-Scale Public Forest Enterprise Through Harvester Data Integration

Eric R. Labelle, Julia Kemmerer

Abstract

Despite the extensive use of cut-to-length mechanized systems, harvester data remains largely underutilized by most stakeholders in Germany. Therefore, the goal of this study was to determine how business processes should be restructured to allow for a continuous use of forest machine data, with the main focus on harvester production data, along the German wood supply chain. We also wanted to identify possible benefits and challenges of the restructuring through a qualitative analysis of the newly designed business process. The Bavarian State Forest Enterprise was chosen for a case study approach. Based on expert interviews, the current and to-be processes were modeled. Results obtained from the qualitative data indicated that an integration of harvester data is achievable in Germany. Harvester data from forest operations can be provided to all subsequent activities along the supply chain. Core changes were the addition of a digital work order, the data exchange between harvester and forwarder, the pile order and the exchange of production data. Benefits for every stakeholder were determined. Through the reengineered process, harvesting and timber information are available and known at an earlier stage of the process, throughput information stations could be eliminated and working comfort could be improved. Ecological benefits could also be achieved through an anticipated reduction of CO_2 emissions and protection of sensitive nature areas. Negative consequences of harvester data integration could appear in the social sphere and were in line with the reduction of personal contact. Challenges for the implementation in reality, besides the legal situation, could be the availability of on-board computers in forwarders, cost for new IT applications, willingness of stakeholders to cooperate and availability of internet access. Further research should be focused on the combination of harvester data with other data types and the practical implementation of the TB process.

Keywords: StanForD, process improvement, wood supply chain, forest machine data, logistics, modeling, data exchange, digitalization information and communication technology, Industry 4.0

1. Introduction

Digitalization and other terms such as information and communication technology (ICT), are being increasingly used in many if not all manufacturing sectors and their importance in society and economy is paramount. In an industrial context, the political term »Industry 4.0« with its concepts and technologies strongly influences the digitalization of its processes (Beier et al. 2020). Continuous improvement is a main success factor of a business (Maarof and Mahmud 2016). In times of the fourth industrial revolution, the use of ICT can increase the competitive edge of businesses (Mihalic and Buhalis 2013, Crittenden et al. 2019) through cost savings, increased flexibility, improved customer orientation and opening up other market segments, which can in turn present new business opportunities (Mayer 2018).

Digitalization is also recognized as an improvement potential for forestry (Malmodin et al. 2014, Bayne et al. 2017). For the German agriculture and forest sector, an improvement potential of 15% of the gross value added is estimated through the application of Industry 4.0 (Bauer et al. 2014). For example, small wireless sensor networks can collect and relay data in real time to help better understand complex relationships within forest ecosystems and to further develop forest management (Bayne et al. 2017). Improvement potential in form of value-adds and changes due to the use of specific ICT applications in the fields of harvest planning, harvesting operations, harvest organization and control, transport and logistics, and timber sales were reported in Müller et al. (2019). Besides using a specific ICT tool for a special use case, a focus on using ICT applications for optimizing the wood supply chain and its information flow is given in Scholz et al. (2018). In an analysis of a German wood supply chain and its optimization potential (with regard to ICT), Baumann (2008) reported that using GPS for registration of wood pile coordinates could lower costs by about 0.10 €/m^3. Through restructuring measures and with the application of modern ICT, in particular by the use of a common data standard (e.g. ELDAT standard, Germany), lead time between harvesting start and final accounting could be shortened by an average of 25 days (28%) in German wood supply chains (Von Bodelschwingh 2006). Similar improvements of the wood supply chain were observed with the implementation of other data standards, such as FHPDAT (Austria), Efids (Great Britan), Papinet (Europe, North America) and Forestand (Sweden) (Kompetenzzentrum Wald und Holz 4.0 2020).

The wood supply chain process encompasses a vast amount of data such as log data, customer data, productivity data and geo-information, with a pivotal component stemming from forest machines (Müller et al. 2019). Nowadays, most harvesters and a considerable share of forwarders are equipped with an onboard computer (OBC) that monitors machine parameters, controls the harvesting head, and collects and stores data about machine performance, geo-information, and parameters from the processed wood (Nylén and Holmström 2011, Kemmerer and Labelle 2020). More specifically, log information of harvested timber, such as volume, length, diameter, assortment and species, as well as geo-information, are assessed and processed by the harvester OBC. There are optimal conditions for using this data, because they are generated as a by-product in the course of the timber harvesting process. In Germany, most of this harvester data remains as »idle data« since the majority of forest entrepreneurs are satisfied with using generic production reports from the OBC. Use of this idle data remains an essential part in reaching the potential of Industry 4.0 (Schmidt et al. 2015). One positive aspect is that, for most harvesters, the data collected is already in a standardized format. This global XML based standard StanForD 2010 (Standard for Forest machine Data and Communication) (Wodniok 2018) provides structured data and does not require conversions prior to further processing (Skogsforsk 2019). Production data concerning processed wood, its geo-information along with the geo-information of the machine could be used throughout the wood supply chain in Germany. In fact, they could be used in harvest organization, harvesting operations, harvesting control and sales processes (Müller et al. 2019). The position of processed wood logs would be of particular interest for the forwarder operator to allow for improved routing within the forest stand, while the forwarder is also providing information such as log pile geo-information, volume, assortment, and time ready for transportation automatically to logging trucks on the location of the roadside wood piles (Müller et al. 2019). Furthermore, harvester data can be used to improve work safety and decision making in thinning operations, to decrease soil rutting, to enhance the tracking of harvesting progress and quality control, to reduce the effort of post-harvest documentation as well as to foster a customer oriented wood supply. Real time communication between the forest owner, forest entrepreneur, decision makers and wood processing industry makes the data even more valuable (Müller et al. 2019).

In Scandinavia, data originating from harvesters is already used throughout the wood supply chain. In Sweden, for example, .prd files (production data files) of the harvester are sent to a central server at the end of each workday. The operations manager can then use these logging statistics to obtain an overview of the logged timber and its location (forest, forest road) to ensure that the amount of wood harvested corresponds to the amount of wood that should be delivered to customers (Nylén and Holmström 2011). In Finland, forest machine data is also widely used for planning and control of timber harvesting, wood sale, contracting payments, monitoring productivity, reporting performance and planning transport (Metsähallitus 2015, Anon 2017, Metsä Group 2020). Therefore, there exists a recommendation about the use, processing and ownership of harvester data, which regulates the handling for the different stakeholders of the wood supply chain (Anon 2017).

In contrast to Scandinavia, the extended use of forest machine data in Germany remains scarce and no general recommendations concerning the handling or property of harvester data exist. As a result, and also because of the different forest ownership structure, the data remains largely out of reach of interested stakeholders aside from forest entrepreneurs. Therefore, the objectives of this article are 1) to restructure business processes to allow for the continuous use of forest machine data, with the main focus on harvester data, along the German wood supply chain and 2) to identify possible benefits and challenges of the reengineered business process and improved information flow.

2. Materials and Methods

To achieve the above-mentioned objectives, a case study research approach was chosen with the focus on the roundwood supply chain of the Bavarian State Forest Enterprise (BaySF). To integrate forest machine data into the business processes of BaySF, a two-step approach was performed. First, the current business processes (business as usual: BAU process) were mapped based on results from expert interviews. Second, the to-be processes (TB process) were designed based on analysis of the BAU processes and expert interviews.

2.1 Study Material/Case Study

2.1.1 BaySF

The BaySF wood supply chain consists of the forest enterprise BaySF along with its forest entrepreneurs (machine owners/operators), logistic partners (recruited logging trucks) and customers (e.g. mills), which have long-term wood contracts. BaySF manages approx. 808,000 ha of state forest (BaySF AöR 2019a) and employs about 2700 people, (BaySF AöR 2019b) making it the largest forest company in Germany and one of the largest in Europe. It consists of 41 forest units divided in 370 territories (BaySF AöR 2019a). The average growing stock is 280 m^3/ha and the annual wood increment is 7.5 m^3/ha (6.1 million m^3/a in total) (BaySF AöR 2019b). The yearly harvested volume averages 4.3 million m^3 of which 3.9 million m^3 are sold (BaySF AöR 2019b) with the majority (75% of material sold) being sold »free factory« i.e. meaning that the coordination of the logging trucks is in the responsibility of the forest owner (BaySF) and the timber is their property until the mill gate (BaySF AöR 2019a). In 2019, the BaySF achieved a total turnover of 329.8 million Euro (BaySF AöR 2019b). The study was limited to the wood supply process, in which timber is harvested in Nordic Cut-to-Length operations and sold as roundwood »free factory«. At BaySF approximately 50% of the timber is harvested with fully mechanized systems (BaySF AöR 2020). Therefore, the business process reengineering discussed in this article could be applicable to approx. 2.3 million m^3.

A typical wood supply process of the BaySF starts with production planning and ends with the settlement (Fig. 1). Production planning is divided into three time horizons: forest management planning (target removal rate per stratum: 10-year horizon that is done at the BaySF level for all state forests), multiyear planning (spatialization of harvesting activities: 2 to 5 year horizon at the forest unit level) and annual planning (harvesting operation scheduling at block level: <1 year horizon at the forest unit level). The annual planning is further divided into four components: biological production, customer demand, silvicultural activity, and sales planning. To be able to react on unforeseeable events, the annual planning should be flexible and therefore, a monthly adaptive planning is required. This is necessary to ensure that the activities (operational, resources, delivery) are constantly revised for a continuous timber production. Once all planning activities are completed, the timber production ensues where trees are harvested, processed and transported to roadside landings. Timber production can either be done internally through BaySF workforce or via outsourced forest entrepreneurs. Once harvesting and forwarding activities are completed, the distribution of timber occurs where timber is commissioned and transported from the forest road to the customer (e.g. processing facility). During operations, forest entrepreneurs can ask for a prepayment, which is normally based on roadside pile measurements. Finally, there is the settlement consisting of credits for the forest units (where the wood was harvested) and transportation entrepreneurs. The final payment of the forest entrepreneur is based on measurements obtained at the processing facility. A control of processing facility measurements with BaySF internal measurements also occurs.

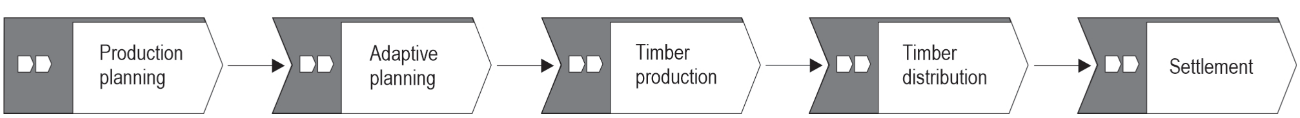

Fig. 1 General overview of the BaySF wood supply chain (created with ARIS® software from Software AG)

2.1.2 Implemented Machine Data

Forest machine data, which should be used for integration in the wood supply chain are the harvester and forwarder data in the StanForD format. More specifically, the volume, assortment, species, geo-informationn of the harvested timber (production data), route tracking, additional hints and geo-information points were selected for the harvester. Concerning the forwarder, data pertaining to the wood pile (assortment, volume, geo-information, species) and route tracking was used as integration information. It is also necessary to mention that, in this study, the measurements of the harvester were used in the context of a disposition/logistics measurement and not as an accounting measurement.

2.2 Expert Interviews

A semi-structured guideline (see A1) was used for the expert interviews with key actors of the Logistic, Technology, and Technical Production divisions of the BaySF. The guideline had a quadrinomial composition. After an introduction, the first part aimed at exploring the BAU processes, interfaces and information flow. The second part dealing with a reorganization process served as a transition to part three, which aimed to explore the TB processes when using harvester data. Part four focused on the opinions of the interviewees concerning harvester data. In the period from April 18, 2018 till February 13, 2019, 22 experts were voluntarily interviewed within 18 expert interviews. The interviewees were chosen based on their knowledge of the assessed topics and on the recommendation of employees of BaySF and the project steering committee. In total, ten interviewees were employees of BaySF, six were forest entrepreneurs (working for or having worked for BaySF) and six customers of BaySF, who have long-term contracts with them and buying wood »free factory« (Table 1).

All interviews were conducted in person following the guideline (Appendix A), and digital recordings were transcribed using the software f4transkript. Based on audio data, all transcripts were quality checked by the interviewer for any misunderstandings and not understandable segments. Finally, the after-interview-notes were added and transcripts were anonymized using the software MAXQDA 12 (version 12.3.5). The focus of the analysis was on the process steps, information flow and interfaces.

2.3 Modeling

The process boundaries included only softwood that was harvested cut-to-length and delivered »free factory«. Furthermore, the focus was directed at the wood supply process. Subprocesses concerning financial and technical aspects or inventory were not considered. For the process analysis, processes were first identified based on expert interviews, than structured and graphically depicted, as there could be deviations due to different working practices at each forest unit. For the modeling of this BAU wood supply process of the BaySF, the Architecture of Integrated Information Systems (ARIS) modeling technique was used, because of its intuitive use and suitability to address supply chain questions. The central element of this concept is the holistic description of business processes. The main model type used in this study was the event-driven process chain (EPC), which shows the logic-temporal procedure of a business process description (Software AG 2018). The software ARIS® Architect & Designer from Software AG was used to build the models since it is suited for modeling, analyzing and simulation of business processes. The developed process models were then validated through the project steering committee and the leader of the BaySF logistics department, and then adapted based on their feedback. Finally the BAU process was evaluated with regard to the information exchanged and the information needs of the stakeholder.

Table 2 General description of interviewees

Interviewees		Number of people
Organization	Role	
Forest management company		
BaySF	Supply control	2
	Forest unit leader	1
	Vice forest unit leader	1
	Service center leader	2
	Forest operation manager	1
	Customer service	2
	Forest technology leader	1
Forest entrepreneurs		
Forest company 2 and 5	Harvester operator, owner	2
Forest company 1, 3 and 4	Forwarder operator, owner	3
Forest company 6	Operation manager, employee	1
Customers		
Sawmill 1	Wood purchasing	4[a)]
Sawmill 2	Roundwood logistics leader	1
Chipboard plant	Wood purchasing	1
a) four interviewees asked in one interview		

Afterwards, the TB process, which means a process based on data from the harvester OBC, was designed according to results from the expert interviews and the designed BAU process. The aim was to create a TB process in which there is a continuous, bidirectional flow of digital machine production data. In the TB process, BaySF and the entrepreneurs have the ideal technical equipment for providing and using harvester data. For the modeling, the same method and software was used as for the BAU process. Results of a feedback discussion with the BaySF were again implemented in the TB process, which led to an improved process description and refinements.

3. Results

3.1 Description of Wood Supply Chain

3.1.1 BAU Process

Prior to harvester data integration, it was important to map the current BaySF wood supply chain, the so-called BAU process, while focusing on timber production. The current timber production starts when the operation is planned (Fig. 2). The service center of a forest unit, which consists of the service center leader and several operation managers, defines the work order based on forest unit data (see Table 2). This work order is either handed personally, sent via post as a hard copy, or electronically via e-mail to the forest enterprise. Afterwards, the operation manager performs a situational risk analysis with one person of the contracted forest enterprise, work instructions are finalized and the harvester operator begins felling and processing the trees according to the work order. Once sufficient wood is harvested, the forwarder operator begins extracting processed logs from the stand to roadside where logs are piled. During the operation, harvester and forwarder operators exchange information and questions about the operation personally or by telephone. When a log pile is created, the operation manager performs a pile inventory. This can be summerized as measuring the pile, defining quality, registering the location, assigning pile and batch numbers, and labeling the pile. This pile information will then be used by the operation manager to create a pile order in the BaySF SAP system. After the pile order is created, the next substantial process step of distributing the processed logs to the client starts. When harvesting and forwarding activites are completed, the operation manager performs a final approval of their work. If no harvested timber remains in the stand, the timber applies as processed and piled. Based on the recorded pile information, the service center creates an advance payment for the forest entrepreneurs. Once the final timber volume is measured in the mill, the finance department creates final payment for the forest.

3.1.2 TB Process

The TB process, based on harvester data integration, begins similarly to the BAU process with the difference of a digital work order: instuction files (.apt or .oin) according to the StanForD or StanForD2010 and shapefiles for maps instead of pdf files will be uploaded on the BaySF system, where the forest enterprises can download them (Fig. 3). The situational risk analysis will then occur as usual. Timber harvest and operational information is exchanged with the forwarder operator, but now mainly sending harvester data via e-mail to the forwarder operator (location, assortment and volume of concentrated logs along the machine operating trail, driven routes, alarm points and notes). At the end of the day, the harvester operator uploads a report with the daily harvester data to the BaySF system, where the data will be further processed. Every employee has only restricted access, to protect personal data. Parallel to the felling and processing process, the forwarder operator will extract the logs from the stand and transport them to roadside. Daily forwarder reports (forwarded area, timber assortments and amount) are also sent to the interface of the BaySF system for further processing. When a log pile is created at roadside, the forwarder operator generates a pile order based on the forwarder data (location of the log pile, estimated timber volume and assortment) in the BaySF system, where all pile information will be available. When the pile order is generated, the distribution can start based on the pile information. During harvesting and forwarding activities, the service center creates advance payments based on the harvester and forwarder datasets. When the work of the harvester and forwarder is complete, the operation manager does a final approval of the work. If no harvested timber is left on site, the timber applies as processed and piled. The finance department creates the final payment when the volume from the processing facilities is available. All the exchanged data and its information are listed in Table 2.

The BaySF system

In the following, an explanation is provided on how data transfer of the TB process at BaySF could technically take place. The focus is set on the interfaces, because the technological implementation of the data transferring process remains in the hands of BaySF.

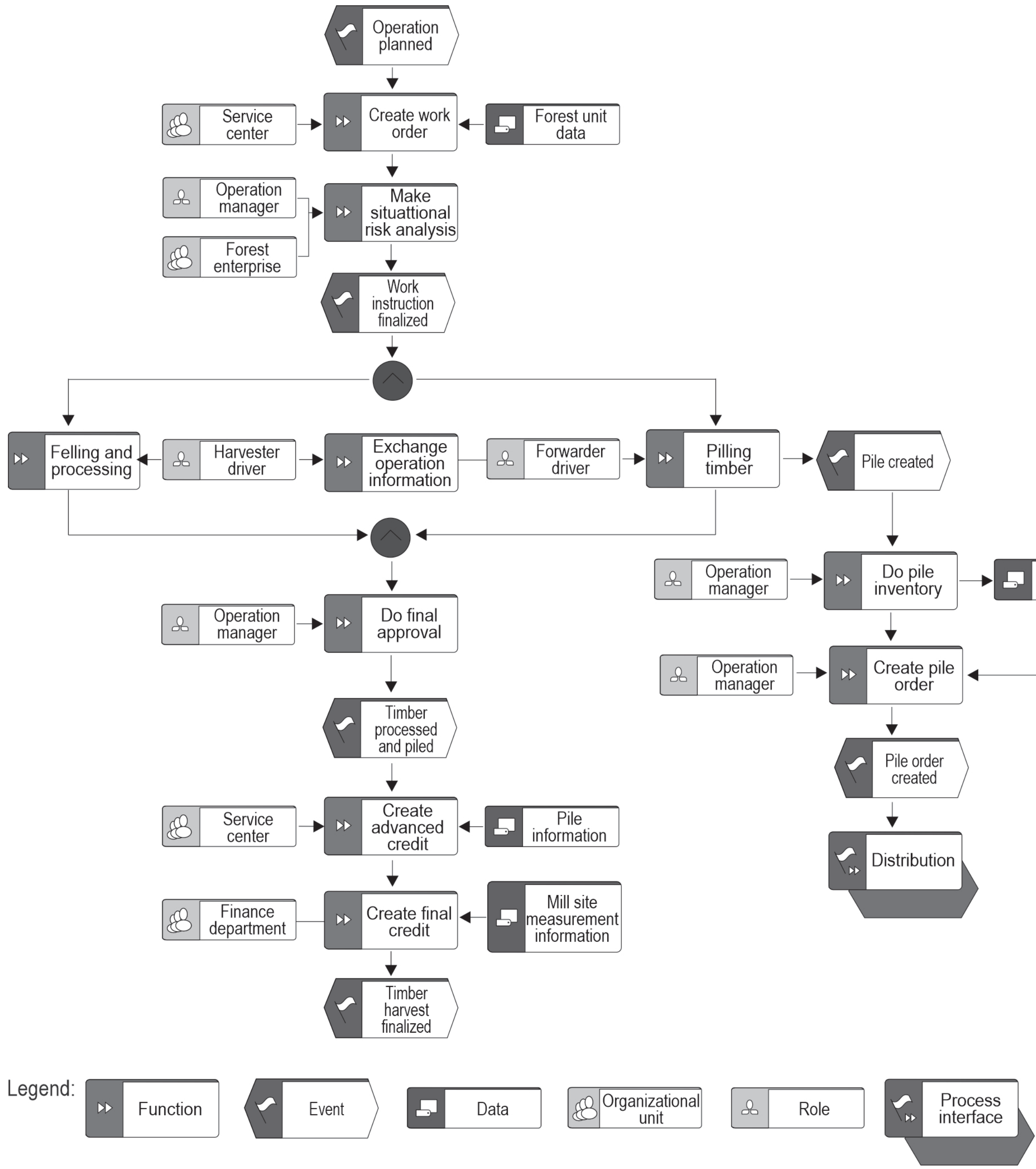

Fig. 2 Timber production of BAU process (created with ARIS® software from Software AG)

⇒the harvester operator signs into the interface of the BaySF system and can download key information provided by the service center data for the execution of his work

⇒this input information is then imported into the harvester on-board computer system

⇒through the interface, the harvester operator uploads his data (.prd/.thp,.hpr file, shape file) to the BaySF system and exchanges harvested timber, driven routes, wood pile locations, alarm points and notes with the forwarder operator via the on-board computer system (see Table 2)

⇒ the forwarder operator uploads his daily information on the interface of the BaySF system

⇒ the different divisions of BaySF (customer advisor, finance department, forest units with their service center, logistics department with supply control and disposition) also have direct access to this database in order to obtain information, such as operation progress control, amounts of timber ready for transportation to a processing facility, etc.

All interfaces should have defined access rights. Ideally, the database would be located in the SAP system of BaySF, because employees already use it for their daily work.

3.2 Changes and Anticipated Advantages

From the anticipated advantages through the application of the TB process, improved data quality and shortened throughput time for obtaining the data are the ones with the highest potential (Table 3). This is particularly the case for supply control, where the need for harvester data is stronger compared to the operation manager, who by design is much closer to the operations. Along with the changing climate conditions, a rise of calamities, such as windthrows and bark beetle infestation, is expected (Seidl et al. 2017), therefore improved data quality will also facilitate a more proactive planning approach, thus benefiting all levels of stakeholders. Concerning machine operators, it stands to reason that the forwarder operator will benefit greatly from the improved data quality, thus resulting in more independency, better route planning and time savings. This is particularly the case since a forwarder normally represents the highest risk of soil disturbance.

4. Discussion

4.1 Limitations of Exploration

The quality of the mapped processes largely depends on the knowledge of the expert interviewees and their experiences. Conducting expert interviews can be challenging in itself. In one case the interviewee felt very uncomfortable and in another case the interviewee was very unsure. The latter could be explained because the interviewee perceived the interviewer as a professional authority (Bogner et al. 2014). To overcome this manipulation, doorframe talks were done afterwards and notes were taken in order not to miss any pertinent information. Furthermore, a model only displays a part of the real world. At BaySF, the forest units interact differently and are somewhat flexible as there are no standards given from the headquarter. This often leads to flexible processes. Given this fact and the dependency of the experts' knowledge, the modeled processes were validated through the project steering committee. Another aspect is that advantages of the newly designed TB process could appear due to restructuring issues and not necessarily originate from harvester data. For example, there is no standard or work order for reporting harvesting progress in the BAU process.

4.2 Organizational, Ecological and Social Impacts

4.2.1 Organizational Impact

4.2.1.1 Earlier Availability of Information

The BaySF shows certain typical organizational issues commonly associated with large-scale enterprises: some employees in the headquarter, e.g. division of logistics, technology and technical production, reveal a lack of knowledge of day-to-day operations in the forest. In particular, information concerning harvested timber is only available in the computer system (SAP) of BaySF when a pile number is created. Therefore, the need for harvester data use is amplified as compared to those from the operation manager or the service center leader, both of whom are close to the operations. One major advantage of the TB process is that long waiting times for information can be greatly reduced because information is exchanged continuously. This is particulalry relevant when a stakeholder located near the end of the supply chain has a production related question. In this case, the question no longer needs to be asked backwards from the supply control over the forest unit leader and the service center leader to the operation manager. Long waiting times for information can also occur between forest machine operators or between the operators and the operation managers due to poor mobile connectivity in most German forests. This is one of the reasons why forest machine manufacturers have an OBC system, which makes it possible to upload files on a mobile phone and when the mobile phone has connectivity, which normally coincides to when the operator is at home from work, it automatically connects with the server and sends the data where needed.

The fast availability of information is crucial in critical situations such as wind storms and pest infestations. Obtaining earlier information facilitates planning and can increase flexibility. This is especially important for the supply control since they can, for example, reserve truck capacities when they know that considerable amounts of timber are harvested in a certain area and will likely be piled in the future. This could lead to a better reaction based on environmental conditions. Asmoarp et al. (2017) used historic harvester data to synchronize production and transport capacity by yield predictions for truck, mill planning and operations. An-

Table 3 Reengineered work tasks and anticipated advantages of the TB process for each stakeholder based on results of expert interviews

Stakeholder	Reengineered work tasks	Main anticipated advantages
Operation manager	Creates a digital work order Receives daily data from harvester and forwarder Has a system to verify the working progress	Obtaining a more comprehensive overview of harvesting process Reduction in number of visits required to harvest sites Reduction in number of phone calls to and from stakeholders Digital documentation of new and old machine operating trails as well as traffic pattern on trails Log pile measurements become obsolete
Harvester operator	Receives digital work order with detailed information (maps) of harvest sites Directly imports bucking instructions in the OBC Uploads harvester data	Improved orientation and higher sense of security within the working environment Less time required for machine settings Less error rates due to media breaks Easier communication with forwarder operator
Forwarder operator	Receives digital harvesting site map from harvester operator instead of only explanations or analogue maps Receives a proximity alarm warning of dangerous point Uploads forwarder data and creates pile order	Improved communications between harvester operator and operation manager Improved route planning: no exploratory drives, reduced risk of leaving timber on site, better knowledge of wet areas
Service center leader	Verifies harvesting progress in the computer system Obtains earlier knowledge about (small) timber amounts	Improved monitoring of forest operations Earlier detection of problems in the wood supply Reducing bark beetle infestations Allows accurate switching between assortments
Forest unit leader/ Vice forest unit leader	Verifies harvesting progress in the computer system No throughput position anymore	Fewer requests from supply control, customer service Better control of the harvesting/operational plan (as is-to be-comparison (adaptive planning)) Quicker problem detection Proof of volume verification
Supply control	Instead of obtaining amount of harvested timber when the pile order is done, volume information is known earlier through the BaySF system as harvesting activities occur Delivery prognosis not only based on estimated values of the forest units	Improved planning of logging trucks (e.g. reservation of trucks for a specific operation and time slot) More flexible planning of the wood supply of customer Faster transportation of the timber out of the forest: fresher timber, less risk of bark beetle infestation, less risk of blue rot and quality loss Better delivery prognosis due to a better data basis
Customer service	Verify the status of harvesting operations in the computer system	Fewer requests to the forest unit leader/vice forest unit leader, the service unit or the supply control Shorter information times for the customer (e.g. in the case of short-term timber orders) Better supply of the customer with the appropriate timber
Customer	Increased precision of delivery prognosis More information available about the ordered timber	Improved occupancy rate of the producing factory

other aspect concerns the payment of forest entrepreneurs. Instead of the current approach, where entrepreneurs are paid by conventional measurements obtained at the processing facility, harvester data could be used as a means of obtaining earlier payment. In general, forest entrepreneurs consider this option more equitable as compared to the payment from the processing facility measurement, since the latter only accounts for timber which is sold and does not include the timber which might remain in the forest, but still incurred operational costs (time and fuel). Baumann (2008) reported that the contracting authority often underestimates the agreed amounts. However, in order for this payment method to work, harvester measurements need to be accurate with proper quality control, an option that is already applied in Sweden through the use of Biometria (Wilhelmsson et al. 2019). In general, obtaining information earlier is better for planning, anticipating and reacting to problems/disturbances and can be an important competitive factor. The costs for fixing an error in later phases requires ten times more effort than in an earlier phase (Van Duyne et al. 2003).

4.2.1.2 Time Savings

Instructions of the forest entrepreneurs and the operation progress control by the operation manager is a time consuming process step. This is further exacerbated when involved parties are not local, which often happens due to the call for tender practice (Baumann 2008). A considerable advantage of the TB process is the digital work order, which facilitates the exchange of operator instructions (Müller et al. 2019). The interviewed machine operators explained that having a digital (interactive) map on their OBC lead to an improved orientation within the harvest site, thus reducing searching time in forest stands. An operation manager explained that these interactive maps along with the bucking instruction file could also be useful in the case of non-German speaking machine operators and when there is an operator change. These time saving possibilities would in turn trigger higher machine efficiency. Baumann (2008) also reported that timber harvesting machines and trucking lead to a higher control effort and additional time requirement in the absence of a digital network. Timber transportation is one of the most expensive components in the wood supply chain (Uusitalo 2010, Malladi and Sowlati 2017). Müller et al. (2019) suggested to improve timber transport by enhanced organization, scheduling and routing. As BaySF already optimizes their routing according to the findings of Smaltschinski et al. (2011), they could further improve the transportation by the integration of harvester data. Furthermore, Gurbaxani and Whang (1991) reported that a considerable share of harvester data costs is related to information acquisition and processing, which need time and can be reduced by the application of ICT.

Beyond the time saving opportunities mentioned above, individual stakeholders do not generally inherit any increase in time requirements, but some time relocations regarding specific tasks. For example, instead of the operation manager, it is the forwarder operator's responsibility to insert log pile information in the TB process.

4.2.1.3 Flexibility and Customer Orientation

Differences between expected and actual harvested volumes or assortments are best handled when discrepencies are known at an earilier stage since they offer more time to react accordingly. Through harvester data integration, customer service can verify the availability of the timber, and the supply control can adjust scheduling of the logging trucks. Moreover, log sorting at roadside can be improved or better tailored to customer demands since information on the harvested timber is updated continuously. Under even more volatile market conditions, the BaySF could send updated bucking instruction files to the harvester operator during an operation in order to better address changing customer demands and potentially achieve higher profits, similarly to what is being done in northern Europe (Kivinen 2004, Murphy et al. 2004, Kivinen 2006). Due to long-term contracts of BaySF with its customers, variations in weekly timber prices are not expected. However, as forest management changes from monoculture to mixed species stands, this aspect will become more important. This adaptation could now be handled in the TB process through the new digital work order. The harvester operator could simply upload the file (price and demand matrices) in a few seconds rather than manually entering the bucking instruction in the OBC, thus reducing the probability of transcription errors (Malinen et al. 2010). With the increased flexibility, BaySF could achieve a higher customer orientation and meet the demands of changing markets from a push to a pull situation (Kaiser 2005). Harvester data integration could also lead to fewer errors because of the expected reduction in media breaks. As Beimborn and Joachim (2011) reported, less frequent media discontinuity results in a performance increase in terms of cost, time and processing errors, while providing a more efficently controlled process.

4.2.2 Ecological Impact

With the improved data exchange between harvester and forwarder, avoidance of sensitive areas and improved route planning could be expected, thus ultimately contributing to a potential reduction in CO_2 emissions. Also, highly sensitive feaures such as biotope trees or areas with low soil bearing capacity, could be avoided through the warning function. If the harvester data could be coupled with data collected from a machine mounted LiDAR sensor, slippage and motor performance could help decrease soil rutting (Salmivaara et al. 2018). Lower fuel consumption should also be expected for i) the operation manager since the frequency of site visits could be reduced and

ii) the supply control because of the refined planning. Another aspect lies with the volume verification. Through appropriately calibrated harvesting heads, it is possible to obtain the exact harvested timber volume and to cross-reference this amount to the volume of the sales measurement, thus providing insight into volume that was left on the harvest site to increase resource efficiency.

4.2.3 Social Impact

From a social perspective, harvester data integration could lead to a reduction in the level of personal contact, which could prove difficult for certain stakeholders. This is particularly applicable for forest machine operators, who work alone all day, and often welcome the contact with the operation manager. However, an improved information situation and data exchange could also strengthen the cooperation between stakeholders and could facilitate working across organizational borders (Brettet et al. 2014). For example, if BaySF provides more detailed information in their call for tender and working order to the forest entrepreneurs, perhaps the entrepreneurs would be more willing to exchange their harvester data. Furthermore, job losses could be feared, because digitalization has a great rationalization potential (Ittermann et al. 2015). However, we believe that the continuous use and integration of harvester data would trigger task reorganizations rather than job losses.

4.3 Challenges for Implementation

One social prerequisite for a successful implementation of forest machine data is the quality and the trust in data (Hartsch et al. 2021). Therefore, it is a challenge to guarantee the accuracy and completeness of the data. The precision of the forwarded volume highly depends on the source of measurement. Besides estimations from the forwarder operator or measurements from a boom scale, which can be mounted on the grapple of the forwarder, the project FORWARDER 2020 has shown promising results by using the pressure curves of the crane cylinder to calculate the weight of the lifted timber (Sebulke 2020). Concerning the precision of the harvester data, regular calibrations, correct machine settings and control of the measurement with measurements obtained from processing facilities are necessary. When both conditions are met, harvester measurements are precise (Kuratorium für Waldarbeit und Forsttechnik e.V. 2010). Furthermore, the availability of OBCs in forwarders is a success factor for receiving data from the harvester and exchanging data to the BaySF system. Most of the forwarders currently in operation within Germany are not equipped with an OBC due to the high associated costs. As technology continues to progress and the need for continuous data exchange becomes stronger, we anticipate higher shares of forwarders equipped with OBCs. The availability of internet connection is in practice a success factor of the TB process, especially in the context of having real time information exchange. In German forests, with only a sporadic connectivity, the expansion of broadband internet connection is essential (Kagermann et al. 2013). Another aspect worthy of attention is the availability of data due to unclear data ownership and data protection in Germany (Hartsch et al. 2021, Roblek et al. 2016). Ethical considerations are, for example, that through .hpr files, calculation on productivity/performance of an operator can be made. This information could also be used to calculate the harvesting profit of a forest owner (Sellén 2016). Data security and trust in the technology is not only a technical but also a social challenge (Kagermann et al. 2013). The willingness to exchange information across company boundaries should not be understated (Brettel et al. 2014). Lastly, the costs for such an implementation of IT applications are another challenge (Baumann 2008, Scholz et al. 2018) along with the willingness to accept and the capability to apply these technologies (Hetemäki et al. 2010).

4.4 Areas of Improvement for Science and Practice

The advantages for the supply control/logistics could also be extended to other forest enterprises that are responsible for the transportation of forest products from the stand to the mill. Moreover, coupling machine data with data collected from additional sensors could be used to enhance forest inventory. On an operational level, post-harvest machine data could be used to estimate the expected productivity of harvesters operating under similar conditions. Further research can be done by combining the harvester production data with other types of data, such as weather data, wood quality (Sellén 2016), silvicultural treatments and soil data to analyze, for example, the impact of silvicultural treatments on tree growth or to determine the productivity of a specific site. Furthermore, it should be analyzed how private forest owners could benefit from machine data. Finally, benefits of the TB process should be quantified under practical applications.

5. Conclusions

The use of harvester data in the TB process has organizational, economic, ecological and social impacts. Benefits could be achieved for all stakeholders along the wood supply chain. By receiving harvesting information at an earlier stage, the ability of the BaySF to perform adaptive planning and remain flexible is increased. This advantage would be of even greater importance during calamities, where the importance of fast response and proactivity is paramount. Instead of a pull demand for information there is a shift in a push strategy for information. The findings from this study could be transferred to other companies, but as these results are only theoretical, further research is required to implement and quantitatively assess the performance of the TB process.

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Appendix A

A1 Guideline Expert Interviews

Introduction

(Introduction participants, thank you, time, PVDat, audio recording, anonymity, interview format, extensive answers, no wrong answers)

1. BAU Process

⇒ Opening question: What is your professional background?

⇒ How does your enterprise look like?

⇒ Could you please describe the BAU processes under considering the following aspects:

Process steps (Who does what, when, how, why?)

- ✓ Responsabilities
- ✓ Time needs (estimated)/ planning horizonts
- ✓ (Costs (wage, material, infrastructure))
- ✓ Interfaces (Which and where are those? How do they look like? analog/digital, Who is involved?

2. Transition Passage

⇒ Did your company went in the last years through a longer reorganization process? Or was a new software introduced? Could you please explaing, how this process has staken place? Which other opimization processes did you went through?

⇒ What were the sticking points/central challenges?

⇒ What has worsened? What has improved?

3. TB Process

⇒ If you think now about integrating harvester data into your workspace: Which difficulties could appear?

⇒ How could processes be downsized or accelerated through the use of harvester data?

⇒ Which information/data needs can be meet through harvester data?

⇒ How have the interfaces (analog/digital) have to be constructed between the stakeholders?

⇒ How do the data needs to be/needs to be prepared?

4. Opinion About Harvester Data

⇒ Do you trust the harvester data?

⇒ Who do you think owns the harvester data?

⇒ What do you think is the value of the harvester data?

Interview Closing

All in all, do you have the impression that we still forgot points that are relevant from your point of view for our investigation? Do you have anything to add?

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Author's address:

Assoc. prof. Eric R. Labelle, PhD
e-mail: eric-r.labelle.1@ulaval.ca
Department of Wood and Forest Sciences
Université Laval
2405 rue de la Terrasse
Québec City G1V 0A6
CANADA

Julia Kemmerer, MSc*
e-mail: julia.kemmerer@tum.de
Technical University of Munich
Hans-Carl-von-Carlowitz-Platz 2
85354 Freising
GERMANY
*Corresponding author

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