



Profitability gain expectations for computed tomography of sawn logs

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Abstract

As the wood sawing industry in Central Europe is highly competitive, sawmills constantly try to increase their efficiency in the production process. The computed tomography (CT) technology is a promising way to increase the economic outcome of the sawing process. Nevertheless, the number of successful industry applications is still rare. In this study, the potential advantages of a roundwood scanning CT in a sawmill which uses bandsaw technology are analysed. A discrete event simulation model covering most of the sawmill's activities was developed and six output-altering CT-factors were implemented to identify the effects of the CT on sawing strategies. The CT-factors are applied to all assortments and affect the output of the sawing process. Since the CT scanner presumably affects the selection of logs for the sawing process, each CT-factor scenario was applied to different log selection strategies. By testing several scenarios, the prospective economic impact of a CT scanner could be revealed and an investment appraisal was conducted. Under different assumptions, an internal rate of return of 5% up to 42% was calculated.

1 Introduction

The wood sawing industry supplies the downstream value chain of many industries such as the building, furniture and paper industry with their valuable products. As the sawing industry is highly competitive, sawmills have to constantly try to increase their efficiency in the production process. Raw material costs represent a major part of the costs in sawmills. Therefore, the maximisation of the volume and value yield from the sawing process is pursued and many different approaches to reach this aim have been developed. However, applying these approaches is often not easy in real sawmills and the applicability also depends on the regarded sawing technology. In particular the bandsaw technology, which is often used for large log diameters, is strongly

dependent on qualified employees who have to decide within seconds where to set the next cut. In contrast to other sawing technologies this decision is mainly based on the outer characteristics of a log, respectively the cut surfaces, and the experience of the employee. Therefore, great benefit could be gained by using a computed tomography (CT) scanner to scan large-diameter logs and gain insight into their inner characteristics. Other sawing technologies are usually more limited in terms of cutting pattern flexibility. This enables identifying hidden material defects or knots and therefore potentially allows to increase the production yield. Several studies already proofed the benefit of using CT data. Wei et al. (2011) gave an overview of the numerous studies on scanning wood with a CT. The existing literature can be organised in studies on the technological capabilities of CT scanners, studies on the possible contribution of CT data to an increased yield of the sawing process, and studies dealing with assessing the economic effects of a CT scanner. The use of a CT scanner in an existing bandsawing process, which is the issue of this study, has not been targeted yet. Rinnhofer et al. (2003) used the information gained by a CT for manual optimisation of the log breakdown and concluded that the automation of that optimisation based on CT data would be very promising. Lundahl and Grönlund (2010) simulated the sawing process of CT scanned logs and showed the possibility of increasing the volume yield. They further stated that maximising the volume yield does not automatically

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lead to an increased value yield and vice versa. A primary breakdown of logs using the data of a CT was simulated by Berglund et al. (2013). An increase in volume yield and an even higher increase in value yield compared to the conventional sawing practice, the so-called horns down position, a commonly used log positioning method, was investigated. Fredriksson et al. (2014) showed the possibility to increase the value recovery of boards by up to 2.2% by only taking into account the internal knot distribution of logs at the sawing process. The possibility of automatically detecting knots in logs even with an industrial high speed CT was shown by Johansson et al. (2013). Berglund et al. (2014) used a CT to find the optimal sawing position and observed an increase in products value of up to 11%. Fredriksson (2014) showed the possibility to increase the value yield by 13% (with a volume yield increase of 0.5%) compared to the best position obtained by only using information about the outer shape of the logs. The horns-down position of the logs was outperformed by 21% in value yield with an increase of the volume yield by 8%. Fredriksson et al. (2015) simulated the sawing and crosscutting process of Scots pine logs based on the data of a CT scanner. Their simulation model predicted the outcome of the process very well, and the simulation generated results comparable to the results of the real industrial process. In further investigations, Fredriksson (2015) stated an increased volume yield compared to the conventional sawing practice.

Another approach was chosen by Breinig et al. (2015) who used the data of CT scanning to simulate a sawing process with the target of optimising the visual impression of the produced boards. The total volume yield of acceptable boards as well as the yield of individual target qualities could be increased. Rais et al. (2017) simulated the value increase of a sawing process comparing the horns-up positioning and the optimal sawing position calculated based on CT data of an industrial CT scanner. Different product price scenarios were also taken into account. The results of the simulation showed an increase of value between 4 and 20%. As differently graded products are sawn from one log, it is difficult to predict the different grades of those products. Petutschnigg and Katz (2004) showed the relations between log grades and the grades of lumber sawn from it. Oja et al. (2004) stated the crucial impact of reliable log grading and showed the possible contribution of a CT to a more precise log classification. The advantages and disadvantages of variously detailed log classification strategies were shown by Gil and Frayret (2016). Possible effects of CT data were not taken into account in that study. Petutschnigg et al. (2005) simulated the effects of a CT on the production, the development of the stock of lumber and the sales of a sawmill. Therefore, the optimal breakdown variants, slightly changed through the use of a CT, were chosen by a simulation model with respect to yields, net revenues, demands and stock levels.

Although CT scanning has some obvious merits, the potential productivity increase should be evaluated prior to investing in this technology. One of the main contributions of this paper is to show how this can be done and further define some application scenarios for a CT. Besides the use of a CT scanner, there are other approaches to optimise the output of the sawing process. The information gained by scanning the logs can be used to rise the efficiency of the other methods through minimising the uncertainty about the inner structure of the logs. One of these approaches is to increase the efficiency of the sawing process through maximising the volume and value yield by optimising the sawing pattern and the breakdown of individual logs. A mathematical model, which generates a maximum return through optimising the sawing pattern was already developed by Geerts (1984). Todoroki (1994) simulated a sawing process and applied two heuristics, which maximise the recovery. In the simulated sawing process of real logs, Todoroki and Rönqvist (1997) optimised the secondary breakdown. Afterwards, Todoroki and Rönqvist (1999) stated that according to a simulation model significant value increases can be achieved through combining the optimisation of primary and secondary log breakdown. Later, Todoroki and Rönqvist (2001, 2002) developed an optimisation model which takes market demands into account.

In contrast to optimising the cutting patterns for individual logs, another approach to increase the efficiency of a sawmill is to optimise the production plan and cut the right logs with the right cutting pattern at the right time as presented by Yáñez et al. (2009), Maturana et al. (2010) and Zanjani et al. (2013). If the CT scanner was used to support and further combine these methods, the efficiency of the sawing process could be increased greatly. Section 2 shows the crucial role of the use of a CT scanner in the combination of those approaches and deals with the importance of the right placement of the CT with respect to subsequent operations.

As it is still difficult to assess the real impact of a CT scanner on the production process of a bandsaw cutting large-diameter logs, a simulation model including the material flow and output distribution of the sawmill was built and different scenarios were tested in the present study. The simulation model allows for assessing the various sawing outcomes under different assumptions of the capabilities of a CT scanner. It covers the actual sawing process of a sawmill using bandsaw technology as well as the raw material and the product movements. A valuable contribution of this research is to evaluate potential effects of a CT log scanner on an existing bandsaw production process and to assess the economic impact of such an investment.

All approaches to increase a sawmill's yield are highly dependent on the properties of the sawn logs. Without knowing the internal characteristics of a log, there

is always a certain factor of randomness between the input and the output of a sawing process. Thus, if a log is wrongly classified, optimisations of value or volume yield as well as production planning cannot be applied efficiently since the sawn lumber does not meet the expected quality. This is less likely when a CT is used for classification according to Oja et al. (2004).

Since a CT is capable of providing insight into a log, a reasonable combination of several optimisation approaches can be achieved. As the focus is on the potential profitability increase when using a CT, the issue where to place the CT first has to be addressed. This decision affects storing principles and the whole production planning process. The difference between placing the CT scanner directly in front of the sawing process or in a decoupled way before storing the logs is described in Figs. 1, 2 and 3. Those figures show a common sawing process and how a CT could possibly be integrated into that process in different ways.

Figure 1 depicts a common sawing process without the use of a CT, which produces a certain amount of products with usually estimated quality. Figure 2 shows a sawing process with a CT installed directly before the saw. This arrangement would be sufficient to perform a virtual processing of the logs and calculate the optimal sawing pattern for the current production program and therefore reduce the amount of products with unrequired qualities. Since there is not much time between the scanning and the sawing process, a condition to efficiently use the data in that case is high speed data processing. However, this approach does not necessarily lead to an optimal production planning. It

does not guarantee that the picked logs are the most suitable ones for producing the required lumber.

This problem can only be redressed when the logs are already sorted according to the CT data before they are picked for sawing (Fig. 3).

In that case it is crucial to store the CT data to calculate a production plan. The roundwood storage can now rather be seen as a storage of possible products, which can be produced from the different logs with different cutting patterns. Therefore, the appropriate logs can be chosen for the production with the optimal cutting pattern assigned. As a result, the overlap of expected and actually produced products can be maximised.

As an effect of the different perspective on the roundwood storage, the CT might influence the sorting process and the classification of the assortments.

To assess the data at the sawing process, it is obligatory to install a recognizing system right before the saw. This can be done through a recognizing CT (which is a light version of the actual log scanner) or other recognition systems like RFID, QR-codes or barcodes.

Choosing the right logs and the right cutting pattern is especially crucial when every log is sawn with its individual cutting pattern as is often the case with bandsaw technology. Despite the fact that a lot of studies have been carried out on this topic, it is still very difficult to predict the actual benefit of a CT log scanner for a bandsaw process. Therefore, the goal of this study is to assess the effects of using a CT for log sorting on the value yield of an actual softwood bandsawing process sawing large-diameter logs under different roundwood

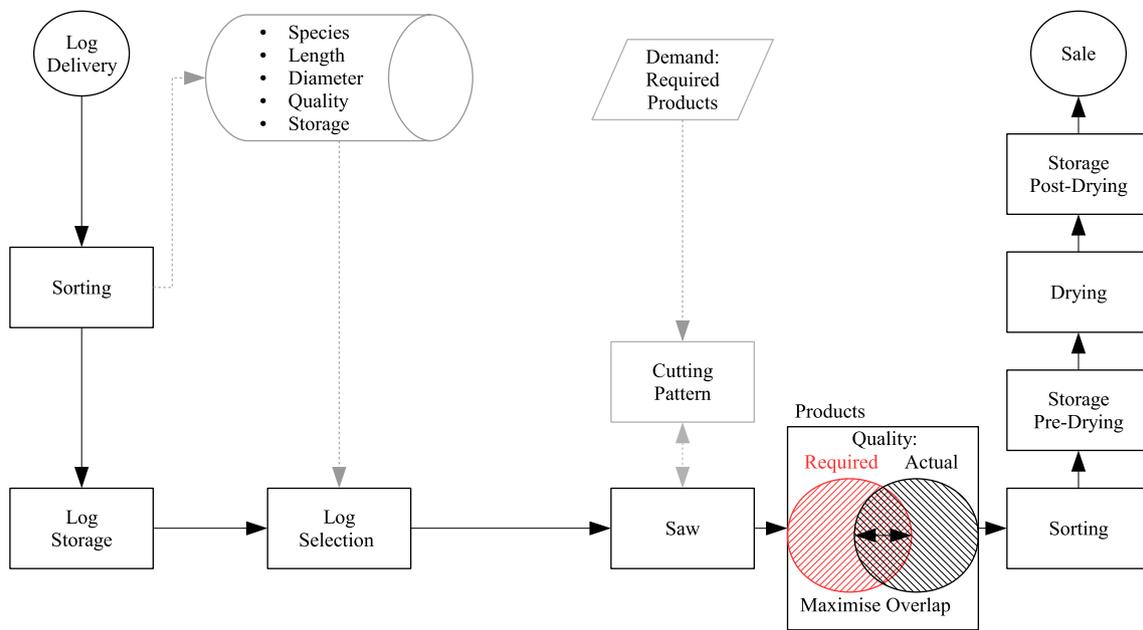


Fig. 1 A common sawing process

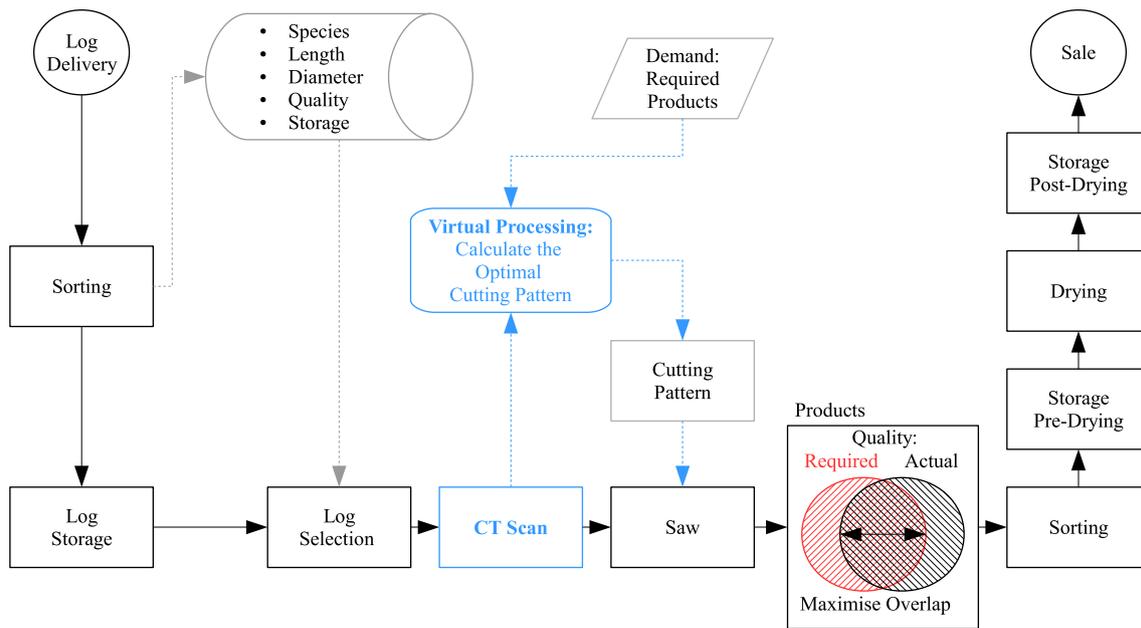


Fig. 2 Sawing process with a CT directly before the saw

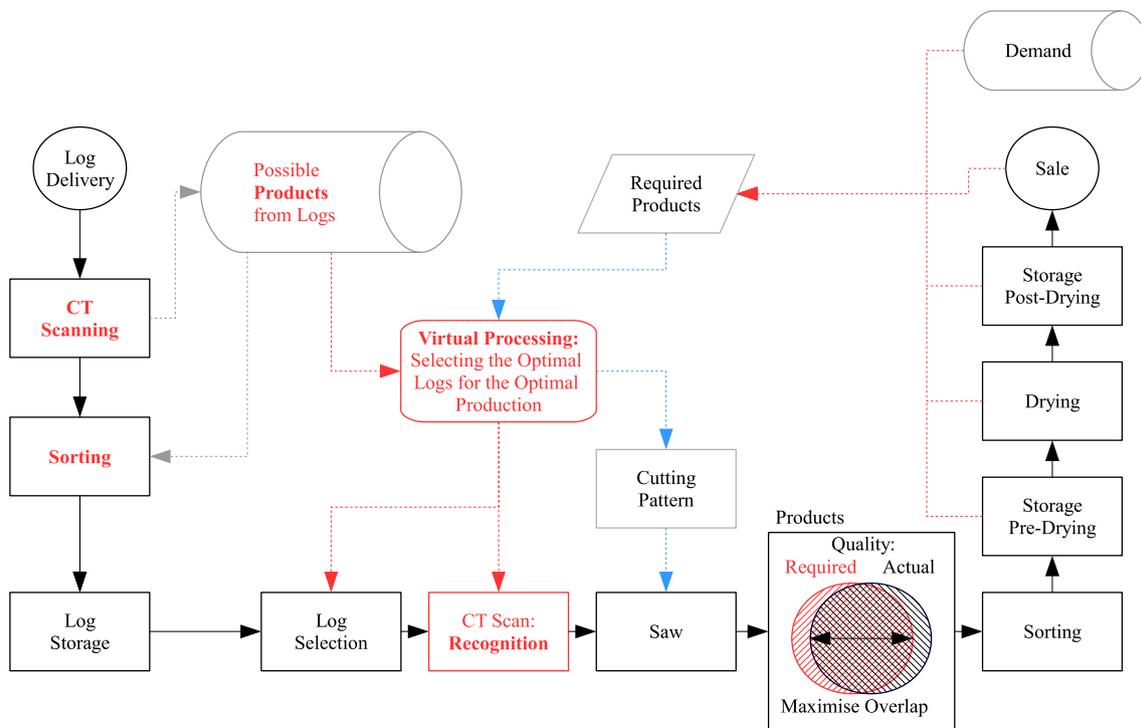


Fig. 3 Sawing process with a CT used for log sorting

selection strategies. Varying assumptions about the impact of a CT on the volume yields and distributions of the different products are made by specifically developed CT-factors.

Although a lot of studies have contributed to getting a better understanding of the potentials of a CT scanner, a study which assesses the effects of the CT on a bandsaw

production process with its different (mostly high-diameter log) assortments and characteristics is not available to the best of the authors' knowledge. This simulation study fills this gap through implementing the new concept of the CT-factor application. The concept is based on the use of CT-factors, which apply the potential shift in volume per product group of sawn timber when using a CT. The rest of the paper is organised as follows: in Sect. 2 the simulation model, its input data and its logic are described. Then, the scenarios for the simulation study are described. The last part of the paper consists of an investment calculation based on the results of the simulation model.

2 Materials and methods

The available data contains detailed information about the production process, its material input and its output of products. The discrete event simulation model depicts the actual production process and allows to deal with different assumptions about the CT and a changing roundwood supply over time. As it is not possible to directly infer from the assumptions about the CT to the changed process output, the simulation model is crucial to assess the benefit of the CT. This section presents the simulation model, the input data and the model parameters as well as the control logic of the simulation model. Important parts of the model, for instance the application of the CT-factors and the selection strategies for the raw material, are described in detail.

2.1 The simulation model

To assess the economic output and the changing effects on a bandsaw process due to the usage of CT information, a simulation model is required. To reach that aim, the model has to depict the whole sawing process and the volume and value yield of the bandsaw.

The simulated bandsaw process is part of a European softwood sawmill, which uses different sawing technologies: bandsaw, gangsaw and circular saw. It is a medium-sized sawmill with a total annual cutting volume of about 100,000 m³ of spruce and larch. To simulate the processes of this sawmill, a discrete event simulation model was created using the simulation software AnyLogic in the version 8.2.4. The focus of the simulation model is on the bandsaw process including the log storing and log selection for the sawing process and the actual bandsaw production process. The whole sawmill process from the roundwood delivery to the shipping of the sawn lumber was modelled to ensure that all other processes at the sawmill are capable of dealing with the changes caused by the integration of a CT scanner. The scope and the focus of the simulation model are shown in Fig. 4.

The validation of the simulation model was done through comparing the volume of processed sawn logs and the amount of produced lumber to real data on a yearly basis. The model further reacted plausibly to alterations of production parameters.

Using the raw material costs, production costs and revenues for the products calculated with the simulation models, it is possible to calculate the profit of the bandsawing process (as shown in Fig. 5). The profitability of the bandsaw (Eq. 1) and its alteration through the use of a CT (Eq. 2) can be calculated as follows:

$$\text{profitability} = \frac{\text{profit}}{\text{revenue}} \quad (1)$$

$$\Delta\text{profitability} = \frac{\text{profit}^{\text{CT}}}{\text{revenue}^{\text{CT}}} - \frac{\text{profit}}{\text{revenue}} \quad (2)$$

2.2 Input data and model parameters

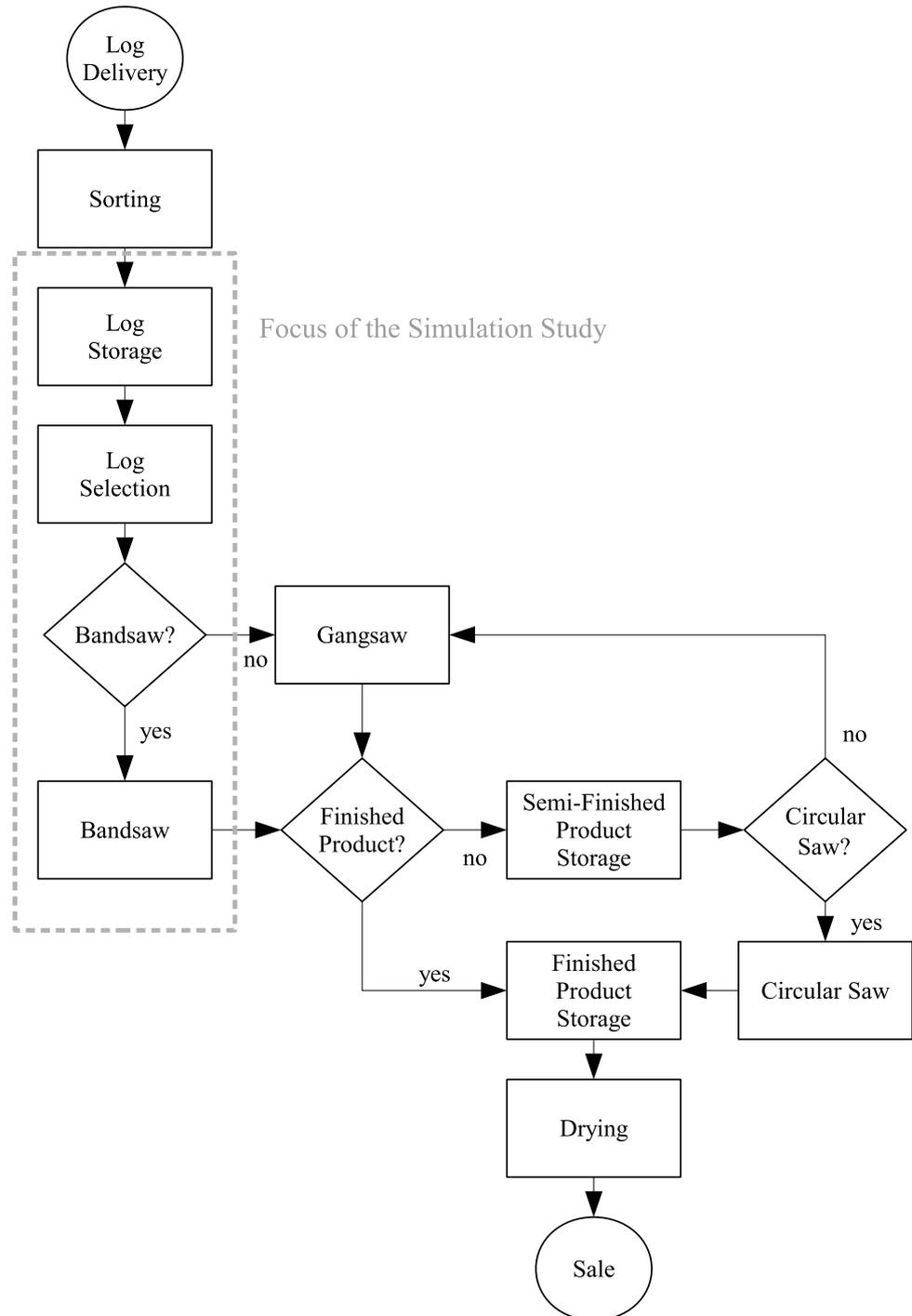
The basis for the raw material amounts and distributions in the simulation model is the sawmill's roundwood supply for 1 year. The logs were sorted into 56 different assortments from which 25 were actually sawn on the bandsaw and the remaining ones were processed with the gangsaw.

The parameters wood species, quality, length and diameter of the assortments, processed amount, material costs, processing costs, volume and value yield, profit per cubic meter and profit per processing hour per assortment are part of the available raw material data and are used in the model.

As detailed production data from every single shift during the regarded year was available, a production rate of the bandsaw depending on the processed raw material could be calculated. Since the sawing process on the bandsaw is very flexible and a lot of different products can be produced, the sawn lumber was clustered into 52 groups of similar bandsaw products. This clustering is necessary due to the high number of different products which can be sawn with a bandsaw cutting high-diameter logs. The classification also supports the possibility of substituting the roundwood input for the production of certain product groups. The underlying production data can be downloaded at https://www.wiso.boku.ac.at/fileadmin/data/H03000/H73000/H73400/BWL_der_Holzwirtschaft/Sawmill_Yield_Data.xlsx.

Even though a main part of the products are primary products and need further processing, the revenue, calculated from internal transfer prices, is used to calculate the value yield of the bandsaw. The profit is calculated through subtracting the raw material costs and the production costs from the revenue.

Fig. 4 Scope and focus of the simulation model



Since the primary products are further processed into different products, applying a demand pattern influencing the bandsaw production process was not suitable. Furthermore, the CT data is just altering the amounts of product groups which were actually produced but not creating any new products. Therefore, it is assumed that every product group processed on the bandsaw can be used for further processing

or sold as well, and specific demands were not taken into account.

Besides the parameters which are influencing the sawing process directly, the operational characteristics of the sawmill, such as wheel loader and forklift properties or storage capacities are also part of the model.

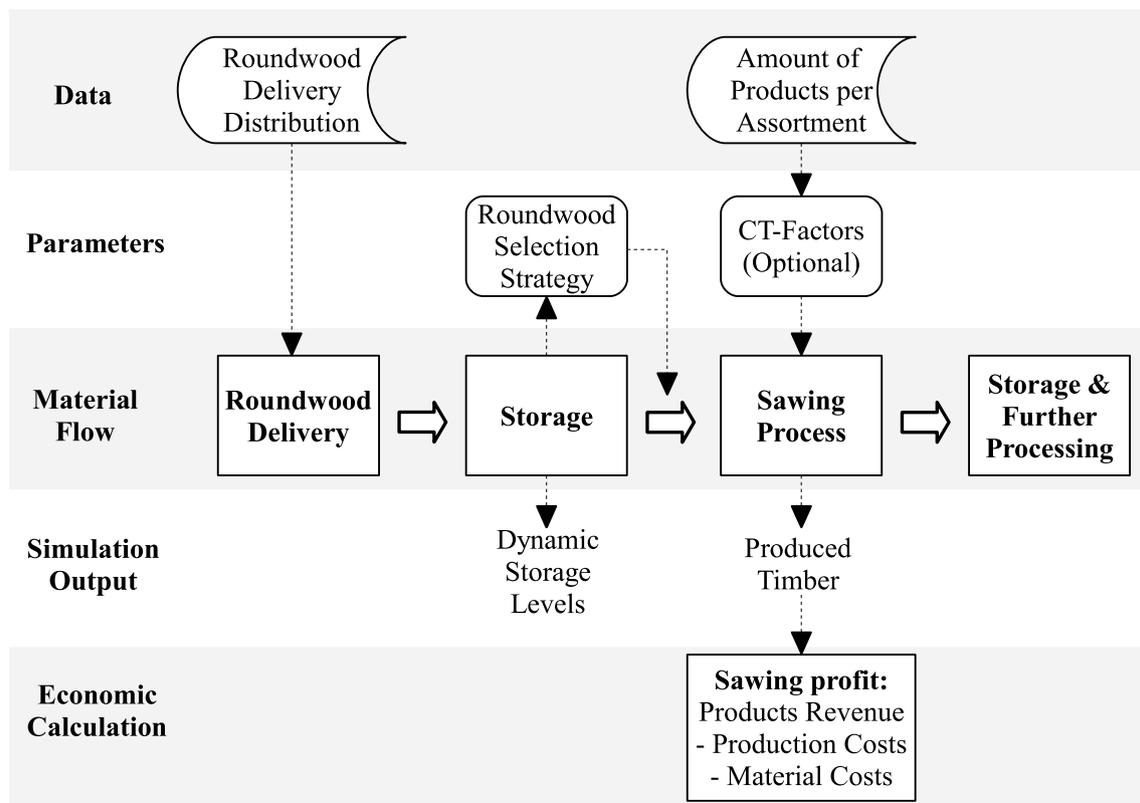


Fig. 5 Overall structure and input/output relations of the bandsaw simulation model

2.3 Changing the distribution of sawn lumber by CT-factors

To reliably predict the effects of implementing a CT on the yield of every roundwood assortment, a huge amount of sample scans or a database would be necessary. As this information was not available and a simplification of the effects through just changing the volume or value yield, seems not sufficient, a reasonable compromise was found by introducing six CT-factors (CTF). The intention behind the number of six CTFs is that six factors are still manageable and already allow a high flexibility in defining the effects of the CT-supported sawing process.

The aim of those CTFs is to increase the shares of products with a higher value at the expense of products with a lower value. As a result, a shift of the shares of products towards the ones with a higher value is achieved. Therefore, the increase in value yield is not necessarily equal to the increase in volume yield which was already stated by Berglund et al. (2014), Fredriksson (2014) and Rais et al. (2017).

Not every assortment is equally affected by the use of a CT. The idea of the CT-factors is that they can be applied to all assortments equally and yet have different impacts.

The logic of the bandsaw simulation model and how data and parameters such as the CTFs affect the simulation output is shown in Fig. 5. Roundwood (agents in the model) is delivered and later chosen according to the active selection strategy. The chosen logs are then transported from the storage to the appropriate saw by wheel loaders (resources in the model). The agent roundwood is then processed to products. At that point, products obtained from a certain roundwood are calculated. This calculation is influenced by the current CTF scenario. The products are further stacked and the product value is added to the total production revenue. When a certain amount of one product is produced, a new agent representing a product stack is created and it is further removed from the saw and moved through the subsequent processes.

The actual effect of the CTFs depends on n_r , which is the number of products sawn from one assortment and their corresponding values v_p . The CTFs affect the original shares of the products by just being added to the volume yields of the products. The products are sorted according to their values. CTF_1 affects the yield of the product with the highest value. As it is assumed that the share of the lowest-value-product cannot be reduced since sideboards cannot be avoided, CTF_6 affects the yield of the product with the second lowest value.

The explanation of the CTFs uses the following notation:

Table 1 Values of the *CTFs* for the illustrative example

<i>CTF</i> ₁	<i>CTF</i> ₂	<i>CTF</i> ₃	<i>CTF</i> ₄	<i>CTF</i> ₅	<i>CTF</i> ₆
2	2	2	-2	-2	-2

- R* Set of roundwood assortments with $r \in R$
- F* Set of CT-factors with $f \in F$ and $F = \{1, 2, 3, 4, 5, 6\}$
- P* Set of all products with $p \in P$
- P'* Subset of products gained from sawing a certain assortment r with $p' \in P' \subset P$ and $5 \leq |P'| \leq 12$, with $n_r = |P'|$
- n_r Number of product groups per assortment r
- $v_{p'}$ Value of product p'
- $a_{rp'}$ Share of product p' resulting from sawing assortment r
- $g_{rp'}$ Share of products p' resulting from sawing assortment r with a CT
- CTF*_{*f*} CT-factors.

As the number of products gained from one assortment can vary between 5 and 12, the subset *P'* can only contain between 5 and 12 products. If there are more, respectively less products than CT-factors, the CT-factors are apportioned, respectively combined. The following illustrative example shows how the CT-factors influence the shares of the products. Table 1S in Online Resource 1 shows the detailed calculation of the altered yields and in Fig. 5 the integration of the CT-factors into the simulation can be seen.

Table 1 shows the values of the six CT-factors for the illustrative example. In Table 2, the original shares of the products and the shares influenced by the CT-factors can be seen for a roundwood assortment processed to seven different product groups. The influence of the CT-factors on a roundwood assortment with eight products can be seen in Table 3. As every

Table 2 Original shares of the products $a_{rp'}$ and the shares of products after the application of the *CTFs* $g_{rp'}$ for a number of seven products ($n_r = 7$)

<i>p'</i>	1	2	3	4	5	6	7
$a_{rp'}$	15	15	15	15	15	15	10
$g_{rp'}$	17	17	17	13	13	13	10

Table 3 Original shares of the products $a_{rp'}$ and the shares of products after the application of the *CTFs* $g_{rp'}$ for a number of eight products ($n_r = 8$)

<i>p'</i>	1	2	3	4	5	6	7	8
$a_{rp'}$	12	13	13	13	13	13	13	10
$g_{rp'}$	13	14	15	15	11	11	11	10

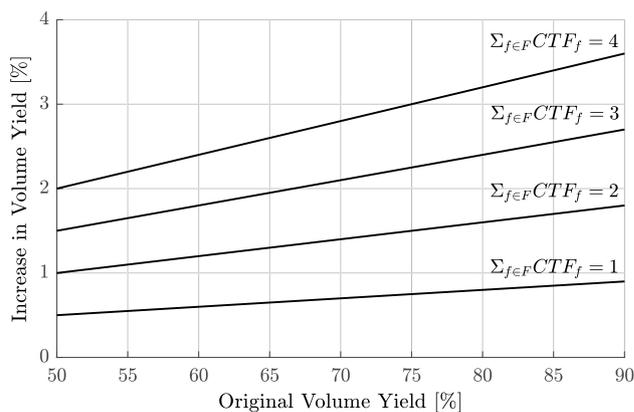


Fig. 6 Effects of the CT-factors on the volume yield

product group should be influenced, *CTF*₁ is split into the two products with the highest values.

To obtain g_{r1} , which is the share of product 1 when a CT scanner is used, it is necessary to determine the subset of products gained from sawing that assortment *P'*. This subset contains the number of products for the current roundwood assortment n_r . If n_r is 7, *CTF*₁ is simply added to the original share (Eq. 3), and if n_r is 8, *CTF*₁ is split and added to the normal share of the products a_{r1} and a_{r2} (Eq. 4):

$$\text{for } n_r = 7: \quad g_{r1} = a_{r1} + CTF_1 \tag{3}$$

$$\text{for } n_r = 8: \quad g_{r1} = a_{r1} + \frac{CTF_1 * a_{r1}}{a_{r1} + a_{r2}} \tag{4}$$

Each CT-factors can be either positive, negative or zero. If the six factors do not add up to zero, the total volume yield is either increased when the sum is positive or decreased in case of a negative sum. Figure 6 shows the effect of different sums of the CT-factors on the total volume yield of the sawing process in dependence of the original yield of a sawing log. The increase in volume yield of a log when a CT is

used is calculated through Eq. 5. This dependence results from the application of the CTFs on the shares of products. If the sum is two, for instance, the CT-supported process produces 102% of products compared to the conventional process. For an original yield of 50%, the increase in yield is therefore one percent:

$$\text{increase in volume yield} = \frac{\text{original yield}}{100} \sum_{f \in F} \text{CTF}_f \quad (5)$$

2.4 Strategies for roundwood selection

To test the effects of the CT-factors on the sawing process under different circumstances concerning roundwood supply, a series of simple roundwood selection strategies was introduced. For those six strategies, only data of the available assortments is taken into account. The six strategies are:

- * Selection of the assortment with the highest stock: The assortment with the highest current stock level is chosen for the bandsaw.
- * Random selection: This strategy is implemented as a comparison which is only based on randomness. Every assortment has the same probability to be chosen for production, as long as there is a minimal stock available that is necessary for production.
- * Selection of the roundwood with the highest costs: The raw material costs are the criterion for this strategy. The roundwood with the highest purchasing costs [€/m³] is sawn.
- * Selection of the roundwood with the lowest costs: This strategy chooses the assortment with the lowest raw material purchasing costs [€/m³].
- * Selection of the assortment with the highest profit: To take the earnings of an assortment into account as well, this strategy selects the roundwood with the highest profit [€/m³]. Scenario 5 and scenario 6 use the profit per assortment from the data provided from the sawmill.
- * Selection of the assortment with the lowest profit: As a contrast the assortment with the lowest profit [€/m³] is chosen.

According to the current roundwood selection strategy, a criterion is calculated for every assortment. The assortment with the highest criterion is then selected for production. Figure 5 shows how the simulation model is combining the input parameters and how the bandsaw process and its output are calculated.

2.5 Simulation experiments

In order to cover a certain range of possible effects, nine scenarios with altering CTFs were defined. In Table 4, the CTF combinations for all scenarios are listed. Each combination is tested for all roundwood selection strategies and compared to the results without the use of a CT. The scenarios cover a range of CTF combinations and are based on the expertise from the CT-scanner manufacturers, assumptions derived from feasibility tests about the CT-scanning of large-diameter logs, and the experience of sawmill staff who were involved in those tests. The tests showed that with the use of CT data more valuable cutting patterns for real life production can be generated. Although the number of logs used for the test was rather small, the sawmill staff gained a lot of experience of the capabilities of a CT-scanner and how reasonable CTF scenarios could be derived from those tests. The CTFs of some of the combinations add up to a positive value and therefore increase the total volume yield. While scenarios 1–4 affect the product groups with the highest respectively the lowest values most (all with a different intensity and increase of total volume yield), scenario 5 has a higher impact on the middle-value product groups. In scenario 6, the middle-value product groups do not change in total.

Scenario 7 depicts the possibility of pooling low-value parts of the logs in certain boards and therefore increases the share of those product groups. At the same time, the share of the highest-value product groups is increased to the expense of the second-highest-value products, which are decreased. In scenarios 8 and 9, the CTFs are more or less equally distributed with different intensities.

As the influences of stochastic elements in the model balance over longer simulation periods, the results of the simulation experiments become very robust for even a few weeks of simulated production. Since seasonality was not taken into account, the simulation of 1 month was considered sufficient. Therefore, the simulation was run for one simulated month for each scenario and roundwood selection strategy with the given raw material distribution. The values in the results section are average. The number of replications was considered suitable due to very small standard deviations.

3 Results and discussion

Although the simulation study generates data about the whole sawing and logistic process, the profitability and internal rate of return summarise the economic impact of the CT best.

Table 4 CT-factor combinations for the nine scenarios

Scenario	CTF_1	CTF_2	CTF_3	CTF_4	CTF_5	CTF_6	$\sum_{f=1}^6 CTF_f$	
1	3	2	1	-1	-3	-1	1	
2	3	2	1	-1	-2	-3	0	
3	3	2	1	0	-1	-2	3	
4	6	4	2	-2	-6	-2	2	
5	2	3	4	-3	-2	-1	3	
6	2	4	0	0	-4	-2	0	
7	3	-1	2	-2	-2	1	1	
8	2	2	2	-2	-2	-2	0	
9	5	5	4	-4	-4	-6	0	

3.1 The profitability of the sawing process

The increase in the profitability for every scenario and roundwood selection strategy is shown in Table 5. In general, the results do not vary widely within the scenarios. On the one hand this can be explained by the different availabilities of the roundwood assortments. There are some assortments with a very low impact on the total results over a certain period of time, because the available shares are very low. Assortments with a high availability are more likely to be chosen for the production in every strategy. On the other hand, the calculation of the profitability, which allows a better comparison of the results, could equalise some differences. That can be seen when only the revenues and profits are regarded. Those differences are originally caused by similar product value structures and product value to material cost ratios.

The analysis of the increase in profitability gives a first impression of the benefits of a CT scanner, but it is not sufficient to make a well-considered investment decision. Therefore, an investment calculation was done by regarding the internal rate of return of the CT scanner.

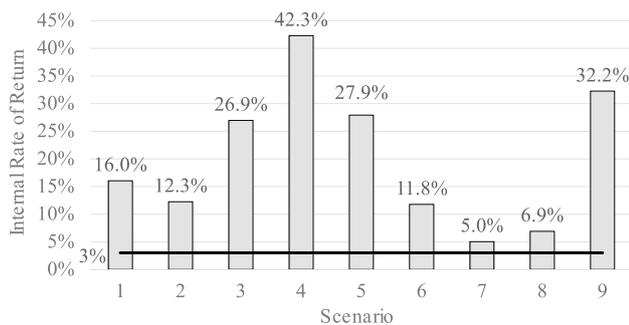
3.2 The economic appraisal of investing in a CT scanner

Every investment decision should be based on a reasonable investment calculation. Those calculations are a special field in corporate finance and are depending on several company-specific and even country-specific parameters. The following investment calculation can be considered as an approximation to real-life calculations with commonly used methods and parameters. In this case the method of the internal rate of return was chosen since the question whether to invest in a new technology or not can be supported profoundly with that method. The internal rate of return compares the investment costs and the running costs to the yearly additional income. The running costs include operation and maintenance costs. The yearly additional income through the use of a CT scanner is depending on the considered CT-factor scenario. As the results for different roundwood selection strategies within one scenario are similar, an average of the different strategies can be regarded for each scenario.

Figure 7 shows the internal rates of return for the different scenarios calculated for 10 years. The calculation period of

Table 5 Increase in profitability for the different scenarios and strategies

Scenario	Roundwood selection strategy							Ø
	1	2	3	4	5	6	Ø	
4	9.2%	9.4%	9.3%	9.2%	9.2%	9.4%	9.3%	
9	7.4%	7.8%	7.7%	7.4%	7.6%	7.5%	7.6%	
5	6.8%	6.9%	6.8%	6.8%	6.8%	6.8%	6.8%	
3	6.6%	6.7%	6.6%	6.6%	6.6%	6.6%	6.6%	
1	4.8%	4.9%	4.9%	4.8%	4.8%	4.9%	4.9%	
2	4.2%	4.4%	4.3%	4.2%	4.3%	4.3%	4.3%	
6	4.1%	4.3%	4.2%	4.2%	4.3%	4.1%	4.2%	
8	3.5%	3.6%	3.6%	3.5%	3.5%	3.5%	3.5%	
7	3.3%	3.2%	3.3%	3.2%	3.1%	3.4%	3.3%	

**Fig. 7** Internal rates of return for the different scenarios

10 years was chosen, because it is a commonly used depreciation period for industrial equipment. The figure further contains a mark at three percent which refers to the return on capital employed for the forest, paper and packaging industry in Europe calculated by PricewaterhouseCoopers (2016). This value enables the interpretation of the internal rate of return of the investment in the context of the regarded industry sector.

The results vary from 5.0% in scenario 7 to 42.3% in scenario 4. Scenarios 7 and 8, which show the lowest internal rate of return, can be considered as rather conservative

estimations of the possibilities of using a CT scanner. Both scenarios only have a slight impact on the sawing process and none or little impact on the volume yield. However, the value of comparison of 3% is already exceeded by those scenarios. Scenarios 1, 2 and 6 have similar internal rates of return ranging from 11.8 to 16%. The impact of the usage of a CT scanner on the volume yield is also considered quite low in those scenarios, but the shifts to the products with a higher value is more distinct. Scenarios 3, 5 and 9 form another group concerning the internal rate of return lying between 26.9 and 32.2%. This result is based on higher volume yields at scenarios 3 and 5 respectively quite high shifts towards high valued products at scenario 9. The best internal rate of return is achieved by scenario 4 with a value of 42.3%. The high value is a result of a combination of volume yield and quite high shifts towards high valued product groups.

As there is still a wide variety in the results, it is necessary to further collect data about the actual capabilities of a CT scanner to identify the most realistic scenarios. Since the regarded roundwood selection strategies are not taking customer demands into account, the consideration of demands to test the advanced planning possibilities arising through the use of a CT would be another interesting aspect.

The simulation depicts the positioning of the CT-scanner described in Fig. 2. It does not consider the use of the CT-scanner before sorting the logs (as seen in Fig. 3). The simulation of that case is not possible, because it requires information not only about the shifting of amounts between products, but also about the total substitution of products produced from one log. Without that information the full potential of optimizing the production plan using the information of a CT cannot be estimated.

4 Conclusion

Even though the CT technology is a promising way to gain insight into sawing large-diameter logs, the actual benefits on a real bandsaw process are difficult to assess. This study shows the theoretical potential of a CT and the importance of its positioning. The simulation study deals with the actual economic benefits on a bandsaw production process. Therefore, six output-altering CT-factors were implemented and a simulation study was carried out. The simulation model allowed to test different roundwood selection strategies and nine scenarios with varying CT-factors. The results of the simulation study are the determination of possible changes of profitability of the bandsawing process and the economical evaluation of the investment in a CT scanner under different circumstances. As extensive empirical data of the impact of a CT on the bandsawing process is not available, future studies should generate more CT data in order to build up a products database. With this an advanced prediction of the output will further improve production planning results and optimise the overall sawing process profitability. Production and demand data can be combined for future planning issues, and consequently a revenue model for log sorting and log procurement to analyse the benefits of a CT can be developed.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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