An Activity-Based Costing Method for Sawmilling

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Abstract

The production cost of lumber is a key factor when determining the price of logs at a sawmill gate. Some of the production costs are also manageable elements in price setting. There is a lack of exact knowledge of how the costs really act when some factor of production varies. This study introduces an activity-based costing (ABC) method for a large-scale sawmill that produces approximately 200,000 m^3 of sawn lumber annually. Production processes were identified and their cost structures were analyzed in detail. The identified processes were log receiving, unloading and log sorting, log debarking, sawing and edging, green sorting and stickering, drying, quality sorting, and packing and storing with shipping. Resources, activities, and cost drivers were defined for each process. Sensitivity and applicability of the costing model were analyzed with two case studies in a virtual sawmill. Results indicate that the sawing pattern is an important variable in the production cost formation: a 16 percent decrement in the volume of sawn lumber led to a 4.5 percent cost reduction with the same log distribution. The findings of this study support the ABC method being a useful tool in controlling cost at a sawmill and a cost structure of a sawmill having an effect on the logistic chain of timber procurement.

Wood procurement management has traditionally been seen as a single business function that embraces a rather broad spectrum of activities aimed at providing the many mills and plants of the forest industry with the basic raw material, i.e., wood. For many years, the international scientific community has used the term ''supply chain management'' (SCM) in conjunction with wood procurement (Uusitalo 2005). SCM emphasizes the interactions that take place between marketing, logistics, and production. In general, the SCM concept includes raw material supply (so-called upstream), processing as well as delivery to the customer (downstream). The supply chain encompasses all activities associated with the flow and transformation of goods from raw material through to end user, as well as the associated information flows (Stadtler 2005). SCM is the integration of these activities, through improved supply chain relationships, to achieve a sustainable competitive advantage.

Forestry researchers have focused studies more on SCM research (Jungmeier et al. 2002; Nurminen et al. 2006, 2009; Satyaveer et al. 2009). They have also mainly focused on the logistic chain modeling for the raw material delivery to factories. These upstream models are useful, especially in raw material flow guidance; however, the upstream models need input data from the production and downstream flows for efficient resource planning (Hsu and Hsu 2008).

In Nordic countries, the development of the sawmilling industry has been closely connected to strategic decisions of the pulp and paper industry (Roos et al. 2001). Sawmills have acted as a source of favorable raw material for pulp and paper mills (Carlsson and Rönnqvist 2005, Virtanen 2005). Large-scale companies have had a chance to direct raw material to most profitable processing plants by the demands of markets. Since the sawing industry in Finland pays almost 70 percent of the gross stumpage earnings to forest owners (Peltola 2009), unbiased cost structures of sawmills form an important part of the total profitability calculations of different wood value chains.

Sawmill costing studies have mainly concentrated on end product prices, while paying little attention to the value of raw material at the mill gate. Hakala (1992) studied the effects of top diameter on financial results of sawing. Johansson (2007) focused on how the market prices of end

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product affect sawmill production planning. The predicted cost of processing the raw material is important information when defining the potential prices of timber assortments. In the cut to length–based wood procurement chains, the tree bucking decisions are dependent on the value of each timber assortment (Uusitalo 2005). The values or value relations used in tree bucking can be derived from the potential prices at the mill gate, thus the pricing and costing methods in industry are important in successfully managing the entire supply chain. Wessels and Vermaas (1998) applied an activity-based costing method for sawmill management. Howard (1993) introduced a method for sawmill processing cost calculation that features some basic principles of a time-driven activity-based cost calculation method (TDABC), which is presented by Kaplan and Anderson (2004).

In activity-based costing, the target, or ''cost object'' of the costing, product, or service, is first determined (Turney 2005). Second, the information flows of the production are recorded as accurately as possible. Total production of the cost object is divided into applicable processes for detailed analyses. Each process has one or more activities, which are the actions for refining the product or service forward. The activities consume resources of process, and thus cause the production costs. In activity-based costing, the division to variable and fixed costs is insignificant because all the costs are calculated as cost pools for each process and then appointed to the cost object (Turney 2005). The cost allocation to cost object is done with a cost driver. The cost driver determines the workload and effort required to perform an activity (Turney 2005). In the TDABC, the processing time of each product is the cost driver (Kaplan and Anderson 2004).

In traditional and most simple costing methods, the fixed and variable costs of production are allocated to products by their share of total production quantity (Young 2003), but these methods have been noted to be ineffective (Turney 2005). Costs are not necessarily distributed to processes, only total costs and end product volume distributions are known (Johnson and Kaplan 1987). If production is automated and some of the end products need special handling, the traditional method may skew the results of cost allocation and thus also the pricing (Nurminen et al. 2009). Activity-based costing is developed because of this dilemma (Turney 2005).

Recent publications on ABC case studies lead to the general idea that successful implementation and use of ABC are influenced by multiple factors. These can be summarized in four basic conditions, which have to be simultaneously met to a satisfactory degree. Any newly implemented ABC system should be technically sound, managerially useful, behaviorally acceptable, and economically feasible.

Technical soundness relates to the reliability of ABC data resulting from adequate definition of cost drivers and activities as well as from measurement of these factors (Player and Keys 1995b). Cobb et al. (1993) reported that many organizations have had trouble designing adequate ABC systems as well as getting reliable data because most overhead activities crossed departmental boundaries and individual areas of responsibilities. Managerial usefulness means the degree to which ABC information is helpful in designing and executing the organization's strategy. Although ABC was initially introduced as a system for reconsidering selling prices and product assortment (Cooper 1988, Cooper and Kaplan 1988), in most cases ABC is primarily used for managing overhead costs (Cobb et al. 1993, Groot 1993, Innes and Mitchell 1995, Selto 1995). At this stage, ABC information does not only seem helpful in controlling overhead activities and related costs, but also in redesigning business processes (Harr 1990, Malcolm 1991). ABC introduction should be behaviorally acceptable, meaning that its introduction should not lead to dysfunctional behavior of participants (Henning and Lindahl 1995). If the ABC system is used for the reduction of non–value-adding activities, some studies show that people are not willing to participate (Shanahan 1995) or are inclined to report more activities as value adding or to downplay the time devoted to non–value-adding activities (Robinson 1989, Player and Keys 1995a, Selto 1995). The final litmus test of the acceptability of ABC is its economic feasibility. Wessels and Vermaas (1998) indicated that developing and implementing ABC systems is an expensive undertaking. The benefits of improved decision-making using ABC information should therefore at least offset the costs of development, implementation, and operation of the ABC system (Horngren 1989, Staubus 1990).

In this article, we present a time-driven ABC-based methodology to calculate the cost of the sawing process. The principle of the ABC theory is used to define the cost of sawing of each individual log class at a sawmill. ''A Greenfield'' virtual sawmill is constructed to demonstrate and test the applicability and validity of the model. Provided the data behind the model are reliable, the model can be used as a tool to estimate the cost of the sawing process in general.

ABC Model for Sawmill

The model consists of seven sawn lumber production stages that are later referred to as processes: receiving, unloading, and sorting of logs; debarking; sawing and edging; green sorting and stickering; drying; quality sorting (grading) and packing; and storing and shipping of finalized lumber packs. Production of wood chips and sawdust is closely related to lumber production and considered part of the first three processes; after sawing and edging, it is a separate process. Administration is also considered a separate supporting process.

Logs are conveyed through the first three processes in a lengthwise direction, and after sawing and edging, the lumber pieces are conveyed in crosswise direction through the rest of the processes. This must be considered when determining the material flows and cost drivers in each process.

General cost factors

As the basic principle of ABC states, activities consume resources, and that consumption causes costs. All processes have some common cost factors: machinery, buildings, and constructed ground cause interest costs and their value decrease annually; these have to be taken into account as capital costs in relevant processes. The capital cost calculation is partly controlled by national legislation, so the following method is directional. In this article we use the capital recovery charge method (Liebster and Horner 1989), and the annual capital cost is calculated as follows:

$$\mathrm{AC}_{\mathrm{capital}\_t} = \mathrm{PP}_t \cdot \left[\frac{I \cdot (1+I)^{\mathrm{SL}_y}}{(1+I)^{\mathrm{SL}_y} - 1}\right] \tag{1}$$

where

$\mathrm{AC}_{\mathrm{capital}\_t}$ = annual capital cost for an object t (€/y),
PP_t = purchase price of object t (€),
SL_y = service life in years, and
I = interest rate, in decimal form.

All production processes need workers, which leads to labor costs. The labor costs are formed from direct hourly wages and indirect wage costs. Indirect wage costs consist of pension contributions and other social costs paid by an employer. Annual labor costs for a person are calculated with Equation 2.

$$\mathrm{AC}_{\mathrm{lab}\_p} = \mathrm{WH} \cdot \mathrm{WC} + \left(\mathrm{WH} \cdot \mathrm{WC} \cdot \frac{\mathrm{IWC}}{100}\right) \tag{2}$$

where

$\mathrm{AC}_{\mathrm{lab}\_p}$ = annual labor costs for person p (€/y),
WH = working hours (h/y),
WC = wage cost (€/h), and
IWC = indirect wage costs (%).

Ground construction and administrative costs are common for all processes and are handled as general cost factors and determined in Equations 3 and 4. The cost allocations of administrative and ground construction costs to processes are presented in Equations 5 and 6. Ground construction costs are first allocated to administration and production processes, and then the administration costs are allocated to production processes (Fig. 1). The production costs are allocated to refined products within each process. The general infrastructure, including ground construction, must be brought to a level at which commercial operation is possible. Ground construction costs ($\mathrm{AC}_{\mathrm{gr\_cost}}$), including interest cost, are calculated as follows:

$$\mathrm{AC}_{\mathrm{gr\_cost}} = A_{\mathrm{saw}} \cdot C_{\mathrm{gr\_const}} \cdot \left[\frac{I \cdot (1+I)^{\mathrm{SL}_y}}{(1+I)^{\mathrm{SL}_y} - 1}\right] \tag{3}$$

where

$\mathrm{AC}_{\mathrm{gr\_const}}$ = annual costs from ground construction (€/y),
A_{saw} = basal area of sawmill (ha), and
$C_{\mathrm{gr\_const}}$ = ground moving costs (€/ha).

Successful production requires operative mill level management, which includes general director and secretaries. Administrative costs also include the costs of office building and other general administrative costs.

$$\mathrm{AC}_{\mathrm{admin}} = \mathrm{AC}_{\mathrm{lab\_admin}} + \mathrm{AC}_{\mathrm{lab\_gd}} + \mathrm{AC}_{\mathrm{build}} + \mathrm{AC}_{\mathrm{admin\_gen}} \tag{4}$$

where

$\mathrm{AC}_{\mathrm{admin}}$ = annual administrative costs (€/y),
$\mathrm{AC}_{\mathrm{lab\_adm}}$ = annual administrative labor costs (€/y),
$\mathrm{AC}_{\mathrm{lab\_gd}}$ = annual general director labor costs (€/y),
$\mathrm{AC}_{\mathrm{build}}$ = annual costs from office building (€/y), and
$\mathrm{AC}_{\mathrm{admin\_gen}}$ = annual general administrative costs (€/y).

Ground construction and administrative costs are allocated to processes by Equation 5. Cost driver for ground construction is the basal area of each process proportioned with the total basal area.

$$\mathrm{AC}_{\mathrm{gr\_cost}\_a} = \mathrm{AC}_{\mathrm{gr\_cost}} \cdot \left(\frac{\mathrm{BA}_a}{\mathrm{BA}_{\mathrm{tot}}}\right) \tag{5}$$

where

$\mathrm{AC}_{\mathrm{gr\_cost}\_a}$ = annual ground construction cost for process a (€/y),
BA_a = basal area of process a (ha), and
$\mathrm{BA}_{\mathrm{tot}}$ = total basal area of sawmill (ha).

The administration costs ($\mathrm{AC}_{\mathrm{admin}\_a}$) are directed to production by the process worker count or according to direct benefit to process. The administrative cost driver is the number of employees (includes both process managers and workers) in each process proportioned to the total number of mill employees.

$$\mathrm{AC}_{\mathrm{admin}\_a} = \mathrm{AC}_{\mathrm{admin}} \cdot \left(\frac{\mathrm{EP}_a}{\mathrm{EP}_{\mathrm{tot}}}\right) \tag{6}$$

where

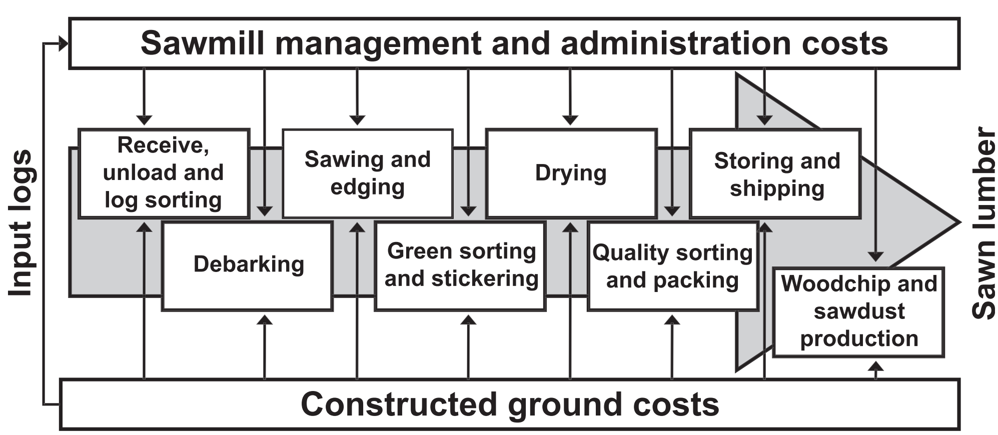

Figure 1.—Description of ground construction, mill management, and administration cost allocation to production processes.

$\mathrm{AC}_{\mathrm{admin\_}a}$ = annual administrative cost for process a (€/y),
EP_a = number of employees in process a, and
$\mathrm{EP}_{\mathrm{tot}}$ = total number of employees in processes.

A modern commercial sawmill has numerous electric motors and other hardware, which consume electricity. The technical capacity utilization rate affects the net load factor of electricity consumption, because stopping machinery also ends the consumption of electricity. It must be noted that all other costs continue to accumulate during a standstill. Annual electricity costs are calculated with following equation:

$$\mathrm{AC}_{\mathrm{electricity\_}a} = \mathrm{OH}_a \cdot \frac{(P_{\mathrm{electricity}} \cdot E_{\mathrm{nominal\_}a} \cdot E_{\mathrm{load\_factor\_}a})}{100} \tag{7}$$

where

$\mathrm{AC}_{\mathrm{electricity\_}a}$ = annual cost of electricity for process a (€/y),
OH_a = annual operating hours of process a (h),
$P_{\mathrm{electricity}}$ = price of electricity (€/kWh),
$E_{\mathrm{nominal\_a}}$ = electricity wattage in process a (kW), and
$E_{\mathrm{load\_factor\_}a}$ = net load factor of electricity consumption in process a (%).

Production processes need heavy machinery that transports products between some activities. In a sawmill these tasks are handled with a wheel loader or forklift, and their annual costs ($\mathrm{AC}_{\mathrm{loader}}$) are calculated with following equation:

$$\mathrm{AC}_{\mathrm{loader}} = \mathrm{WH} \cdot \mathrm{HC}_{\mathrm{loader}} \tag{8}$$

where

$\mathrm{AC}_{\mathrm{loader}}$ = annual costs of wheel loader or forklift (€/y) and
$\mathrm{HC}_{\mathrm{loader}}$ = hourly costs of wheel loader or forklift (€/h).

Detailed descriptions and cost driver definitions of the production processes for a log length and small end diameter class

Annual costs of all processes consist of capital costs, which are derived from buildings and machinery (Eq. 1), labor costs (Eq. 2), ground construction costs (Eq. 5), administrative costs (Eq. 6), electricity costs (Eq. 7), and wheel loader and forklift costs (Eq. 8). These costs are allocated to products or product groups within a process. The log is considered as a product group, which consists of bark, lumber, chips, and sawdust.

The appointed costs of product groups have to be allocated to individual product by the volume share of each product. Let l_{log} be the length, V_{bark} the volume of bark, V_{chips} the volume of chips, V_{dust} the volume of sawdust, and V_{boards} the volume of boards obtained from log L in a length and small end diameter class. Further, let l_i be the length, w_i the width, t_i the thickness, and v_i the volume of each board b_i (i = 1, 2, 3 . . . n) and n the number of lumber pieces cut from the log. In many cases, board sawn from the log does not fulfill the minimal requirements, but certain reduction of the nominal volume has to be done due to wane or imperfect quality. In sawing processes, the part of the board that does not fulfill the requirements is cut away and converted to chips. Let r_i be the average relationship between the nominal volume and actual volume of board. The volume of board b_i can then be defined as $v_i = l_i \cdot w_i \cdot t_i \cdot r_i$ and the volume of all boards in the log is then calculated as

$$V_{\mathrm{boards}} = \sum_{i=1}^{n} v_i \tag{9}$$

And the total volume of log as

$$V_{\mathrm{log}} = V_{\mathrm{boards}} + V_{\mathrm{chips}} + V_{\mathrm{dust}} + V_{\mathrm{bark}} \tag{10}$$

The debarking process subtracts the bark from the group and sawing separates the lumber, chips, and sawdust from each other. From green sorting on, the costs are appointed directly to the individual lumber piece.

Receiving, unloading, and sorting of logs.—The first production process starts when the log truck arrives to the mill yard and the grapple loader unloads the logs. In an ideal situation, the loader lifts logs straight to the log table. If the log table is not operating or does not have capacity, the logs are temporarily laid in the field before sorting. The costs of the log truck are not assigned to the sawmill.

In the sorting, every log is individually conveyed through dimensional and quality measurements. At this point, the log length, diameter, and taper are measured. In modern sawmills there are usually metal detectors and in some cases two- and three-dimensional x-ray scanners are an integral part of the log sorter. There usually has to be a gap between the logs because of the measurements. In principle, the gap lowers the capacity of the process. Debarking is sometimes carried out as a part of the sorting process. Logs are separated by their visual or scanned quality, small end diameter, species, and length. If the logs are not suitable for sawing (e.g., they contain metal or the taper is not appropriate), they are sorted to maximize their potential within agreed standards from the rest of the processes, mainly for pulping or energy production. Rejected wood can be credited to the sawmill as a net production to wood cost. The operative production planning determines when a certain log class proceeds to the next process.

The main resources are wheel loader, one administrative secretary, log sorter machinery with operators, and the log yard. The use of the resources leads to costs, which are described as $\mathrm{AC}_{\mathrm{sort}}$.

Let s_{sort} be the average speed of the log sorter (m/min), with the technical capacity utilization rate taken into account in the electricity costs of the process (Eq. 7); the speed in every calculation is the net speed of the sorter. Let the l_{log} be the total log length (m), $l_{\mathrm{gap\_sort}}$ the total length of gap between logs (m), and $\mathrm{PT}_{\mathrm{sort\_an}}$ the annual production time of log sorter (h) machinery. The production time cannot exceed the working time. The capacity of the log sorter (logs/min) is then calculated as

$$\mathrm{CA}_{\mathrm{sort\_min}} = \frac{s_{\mathrm{sort}}}{l_{\mathrm{log}} + l_{\mathrm{gap\_sort}}} \tag{11}$$

If the gap between the pieces in process a is measured in time units ($t_{\mathrm{gap\_}a}$) instead of distance and the speed of machine is known, the $l_{\mathrm{gap\_}a}$ is calculated as follows

$$l_{\mathrm{gap\_}a} = s_{\mathrm{sort\_}a} \cdot t_{\mathrm{gap\_}a} \tag{12}$$

And, the annual capacity of log sorter is

$$\mathrm{CA}_{\mathrm{sort\_an}} = \mathrm{CA}_{\mathrm{sort\_min}} \cdot \mathrm{PT}_{\mathrm{sort\_an}} \cdot 60 \tag{13}$$

The cost driver of log sorting can be defined as the share of the sorter's annual resources that one log utilizes. The cost to sort one log ($C_{\mathrm{sort\_log}}$) is then defined as

$$C_{\mathrm{sort\_log}} = \mathrm{AC}_{\mathrm{sort}} \cdot \frac{1}{\mathrm{CA}_{\mathrm{sort\_an}}} \tag{14}$$

Debarking.—Debarking starts when the logs are dropped on the feeder deck. Logs are dropped as a batch and with different lifts and rollers separated again and set to a single line before the debarker machine. Depending on technical installations, the debarker may require a gap between the logs. Logs are debarked individually, usually with a ring debarker. Bark is conveyed to separate stocks for further use. Bark may be burned at the sawmill or sold as a product to horticulture, and value could be attributed as a net return or an opportunity cost.

The main resources are machine operator, wheel loader, building, share of constructed ground, and debarking machinery, including log and bark conveyors. Let $\mathrm{AC}_{\mathrm{db}}$ be the annual costs originating from the resources of the debarking process.

Let s_{db} be the average net speed of log debarker (m/min), l_{log} the total log length (m), $l_{\mathrm{gap\_db}}$ the gap between the logs (m), and $\mathrm{PT}_{\mathrm{db\_an}}$ the annual production time of the debarker (h). The gap between the logs can be determined as presented in Equation 12. The capacity of the debarker in a minute is then calculated as

$$\mathrm{CA}_{\mathrm{db\_min}} = \frac{s_{\mathrm{db}}}{l_{\mathrm{log}} + l_{\mathrm{gap\_db}}} \tag{15}$$

And, the annual capacity of log sorter is

$$\mathrm{CA}_{\mathrm{db\_an}} = \mathrm{CA}_{\mathrm{db\_min}} \cdot \mathrm{PT}_{\mathrm{db\_an}} \cdot 60 \tag{16}$$

The cost driver of log debarking is defined as the share of the debarker's annual resources that one log utilizes. The cost to debark one log ($C_{\mathrm{db\_log}}$) is then defined as

$$C_{\mathrm{db\_log}} = \mathrm{AC}_{\mathrm{db}} \cdot \frac{1}{\mathrm{CA}_{\mathrm{db\_an}}} \tag{17}$$

Sawing and edging.—After debarking, the log is conveyed directly to the sawing line. Before sawing, the log undergoes either two- or three-dimensional scanning. Log quality assessment can also be made by x-ray or acoustic testing. Sawing pattern, which defines the thickness, width, and length combination of each sawn lumber piece with computer-aided software, is planned by the measurements. In full profiling saw line, the log is sawn with a single run using several adjustable shaper cutters and circular saw blades. If the sawing line is executed with other technology, for example band saw, separate re-sawing is usually needed, which has to be taken into account when defining the cost driver. Lumber pieces are separated and conveyed onward to green sorting. Wood chips and sawdust are transported to separate storage areas via belt conveyors, usually located in the sawmill subfloor area. If the machinery requires a gap between logs, for example for changing the sawing pattern, the gap can be taken into account as a reductive coefficient.

Sawing and edging resources are process workers, buildings, share of constructed ground, and machinery, including the processing machinery with automation: conveyors for debarked timber, lumber, chips, and sawdust. $\mathrm{AC}_{\mathrm{saw}}$ is the annual cost of the whole sawing and edging process.

Let s_{saw} be the average net speed of saw (m/min), l_{log} the total log length (m), $l_{\mathrm{gap\_saw}}$ (m) the gap between logs, and $\mathrm{PT}_{\mathrm{saw\_an}}$ the annual production time of saw (h). The gap between logs can be determined as presented in Equation 12. The capacity of the saw in a minute is then calculated as

$$\mathrm{CA}_{\mathrm{saw\_min}} = \frac{s_{\mathrm{saw}}}{l_{\mathrm{log}} + l_{\mathrm{gap\_saw}}} \tag{18}$$

And, the annual capacity of sawing is

$$\mathrm{CA}_{\mathrm{saw\_an}} = \mathrm{CA}_{\mathrm{saw\_min}} \cdot \mathrm{PT}_{\mathrm{saw\_an}} \cdot 60 \tag{19}$$

The cost driver of log sawing can be defined as the share of annual sawing and edging resources that one log utilizes. The cost to saw one log ($C_{\mathrm{saw\_log}}$) is then defined as

$$C_{\mathrm{saw\_log}} = \mathrm{AC}_{\mathrm{saw}} \cdot \frac{1}{\mathrm{CA}_{\mathrm{saw\_an}}} \tag{20}$$

Green sorting and stickering.—After sawing, the lumber pieces are turned in a crosswise direction, and the lumber pieces are graded and stacked. In the first grading, lumber is evaluated by the dimension and usually by the visual quality with fully automated sorters. If sawn pieces have wane at the top end, they are normally shortened with a trim saw in order to have full edges. Measured and finalized pieces are conveyed to storing pockets by dimension and quality.

When a predetermined amount of a certain dimension and quality class is sorted, the lumber pockets are emptied and pieces are conveyed for drying bundle stacking. Pockets are conveyed for dry bundle stacking or packed for unseasoned dispatch. Packs to be dried are then kiln pinned with sticks in order to get space between layers for an even drying process. These bundles are then packed in carts or packs for transport to kilns.

Green sorting and stickering requires workers, buildings, conveyors, automated sorters, cut of saws, stickering, and stacking machines. The sawn pieces are usually transported via pocket conveyors, in which the gap between pieces is implicitly calculated within the net speed of the sorter. $\mathrm{AC}_{\mathrm{green\_sort}}$ expresses the annual costs of the process.

Let the net speed of the green sorter be $s_{\mathrm{green\_sort}}$ (sawn lumber pieces/min) and $\mathrm{PT}_{\mathrm{green\_sort\_an}}$ the annual production time (h) of the green sorter and sticker. The cost driver is the production time of one sorted and stickered lumber piece with regard to annual production time. The cost to sort one sawn lumber piece b_i is calculated as follows:

$$C_{\mathrm{green\_sort\_}b_i} = \frac{\mathrm{AC}_{\mathrm{green\_sort}}}{\mathrm{PT}_{\mathrm{green\_sort\_an}} \cdot s_{\mathrm{green\_sort}} \cdot 60} \tag{21}$$

Since there is information about the number of sawn pieces i from a single log, the green sorting cost of the log ($C_{\mathrm{green\_sort\_log}}$) can be calculated with following equation:

$$C_{\mathrm{green\_sort\_log}} = \sum_{i=1}^{n} C_{\mathrm{green\_sort\_}b_i} \tag{22}$$

Drying.—Lumber carts are moved to drying kilns. In modern kiln drying processes, there are both chamber and channel dryers. Chamber dryers are filled with several bundles and dried with one entry. Channel drying is a continuous process, in which bundles are inserted as the drying process is concluded for earlier added carts. Chamber dryers are mainly used for drying pieces thicker than 63 mm or different special orders, and channel dryers are used for drying thin lumber.

Drying resources are process workers, wheel loader, chamber and channel constructions with buildings, ground construction, rails, carts, and heat transfer systems. The heating plant can be administered by the sawmill, or heat energy can be bought from outside provider. These resources cause annual costs (AC_{dry}) of the drying process.

The drying process is highly energy intensive, and electricity and heat energy costs have to be handled differently than in other processes. In annual costs of drying AC_{dry}, the cost of electricity and heat energy (C_{energy_dry}) is calculated as follows:

$$AC_{energy\_dry} = V_{boards} \cdot (E_{electricity} \cdot P_{electricity} + E_{heat} \cdot P_{heat}) \tag{23}$$

where

$E_{electricity}$ = electricity consumption (kWh/m^3),
E_{heat} = heat energy consumption (kWh/m^3), and
P_{heat} = price of heat energy (€/kWh).

The number of lumber pieces in a drying cart is dependent on the lumber dimensions. Let h_{bundle} be the height, w_{bundle} the width of the drying bundle, and h_{stick} the height of the kiln sticks used between each level of boards. Each board b_i is dried together with the boards having the same thickness. The number of boards in each bundle where b_i is dried can then be defined as

$$N_{b\_bundle} = \frac{h_{bundle}}{t_i + h_{stick}} \cdot \frac{w_{bundle}}{w_i} \tag{24}$$

Drying is carried out in two types of spaces, in chambers and channels. Let $N_{chamber}$ be the number of bundles that all chambers and $N_{channel}$ the number of bundles that all channels of the sawmill can take at each moment. Total drying capacity in bundles at each moment is then defined as

$$N_{bundle} = N_{chamber} + N_{channel} \tag{25}$$

Let PT_{dry_an} be the annual production time of drying chambers and channels (h) and PT_{dry_b} the dimensional drying time in hours for each board b_i. The cost driver of drying can then be defined as the share of what one board utilizes the process out of the annual capacity. The cost to dry one board ($C_{dry\_b_i}$) is then defined as

$$C_{dry\_b_i} = AC_{dry} \cdot \frac{PT_{dry\_b}}{PT_{dry\_an} \cdot N_{bundle} \cdot N_{b\_bundle}} \tag{26}$$

The drying cost of a log, C_{dry_log}, can be calculated with following equation:

$$C_{dry\_log} = \sum_{i=1}^{n} C_{dry\_b_i} \tag{27}$$

Quality sorting and packing.—When the drying is completed, bundles or packs are removed from the carts and lifted to the destacking conveyor. Lumber pieces are conveyed in crosswise direction to the end of the entire production via belt or pocket conveyors. The drying sticks are then recycled. Boards are evaluated visually and mechanically according to end customer demands. Lumber pieces are finalized with trimmers, if needed, and conveyed to storing pockets by dimension and quality. When the chosen amount of lumber pieces is finished, the pockets are emptied for packing. Packer systems are automated with pack stackers and belt binders. Packed and marked lumber bundles are then transported to terminals to wait for the delivery to customers.

Workers, buildings, wheel loader, and automated conveyors with storing pockets are key resources of the process. $AC_{quality\_sort}$ states the annual costs of the process. Let the net speed of the quality sorter be $s_{quality\_sort}$ (sawn lumber pieces/min) and $PT_{quality\_sort\_an}$ the annual production time (h) of the quality sorter and packer. The cost driver is the production time of one sorted and packed lumber piece proportioned to annual production time. The cost to sort one sawn lumber piece b_i is calculated as follows:

$$C_{quality\_sort\_b_i} = \frac{AC_{quality\_sort}}{PT_{quality\_sort\_an} \cdot s_{quality\_sort} \cdot 60} \tag{28}$$

The green sorting cost of the log $C_{quality\_sort\_log}$ can be calculated with following equation where i is the number of sawn lumber pieces in a log.

$$C_{quality\_sort\_log} = \sum_{i=1}^{n} C_{quality\_sort\_b_i} \tag{29}$$

Storing and shipping.—Packed lumber bundles are stored in warehouses. Production management updates the storage information and supervises the fulfillment of agreed contracts. The lumber is loaded to tractor trailers or railroad cars and transported to customers.

Storage buildings, fork lifter, and process workers, including one secretary from administration, are the main resources of the process. The storing and shipping process does not have any production machinery, thus there are not any feasible cost drivers available. Annual costs of the process $AC_{storing}$ are allocated to different products b_i by the share of quantity (m^3). The cost to store a single lumber piece ($C_{storing\_b_i}$) is calculated as follows:

$$C_{storing\_b_i} = AC_{storing} \cdot \left(\frac{V_{b_i}}{V_{boards}}\right) \tag{30}$$

Storing and shipping costs per log $C_{storing\_log}$ are calculated as follows:

$$C_{storing\_log} = \sum_{i=1}^{n} C_{storing\_b_i} \tag{31}$$

Wood chips and sawdust.—Besides the lumber, sawing and edging produces chips and sawdust. After the sawing process, chips and sawdust are conveyed to separate storage areas for sale or dispatch. Screening can be carried out as part of this process to add value through separation of different fractions. Different fractions can be separated for additional refinements, and applicable fractions can be transported for example pulp mills or wood pellet industry.

Belt conveyor, chipper, screen, worker, wheel loader, and buildings form the resources of the process and comprise the annual costs (AC_{chips_dust}) of the process.

Sawdust and woodchips are separated in sawing and edging from the main production line, and part of the production costs are accumulating in the sideline process. The cost driver of the process is closely related to sawing and edging because the raw material flow is created there. $C_{\text{chips\_dust}}$ describes the price of processing the chips and sawdust from one log and is calculated as follows:

$$C_{\text{chips\_dust}} = \text{AC}_{\text{chips\_dust}} \cdot \left(\frac{V_c + V_d}{V_{\text{log}}}\right) \cdot \left(\frac{1}{\frac{s_{\text{saw}}}{l_{\text{log}}} \cdot \text{PT}_{\text{saw}} \cdot 60}\right) \quad (32)$$

From total processing costs to log, end product, and log distribution costs

When each process cost are calculated and allocated to log in the log class, all processing costs are summed for a total cost analysis. The total processing cost of the log ($C_{\text{tot\_log}}$) is calculated as follows:

$$C_{\text{tot\_log}} = C_{\text{sort\_log}} + C_{\text{db\_log}} + C_{\text{saw\_log}} + C_{\text{g\_sort\_log}} + C_{\text{dry\_log}} + C_{\text{q\_sort\_log}} + C_{\text{stor\_log}} + C_{\text{chips\_dust}} \quad (33)$$

Total processing cost can be transformed to log processing unit costs $\text{UC}_{\text{tot\_log}}$ (€/m^3) with the following equation:

$$\text{UC}_{\text{tot\_log}} = \frac{C_{\text{tot\_log}}}{V_{\text{log}}} \quad (34)$$

The cost of the log is assigned to boards ($C_{\text{tot\_boards}}$), chips ($C_{\text{tot\_chips}}$), sawdust ($C_{\text{tot\_dust}}$), and bark ($C_{\text{tot\_bark}}$) as follows:

$$C_{\text{tot\_boards}} = \frac{V_{\text{boards}}}{V_{\text{log}}} \cdot C_{\text{tot\_log}} \quad (35)$$

$$C_{\text{tot\_chips}} = \frac{V_{\text{chips}}}{V_{\text{log}}} \cdot C_{\text{tot\_log}} \quad (36)$$

$$C_{\text{tot\_dust}} = \frac{V_{\text{dust}}}{V_{\text{log}}} \cdot C_{\text{tot\_log}} \quad (37)$$

$$C_{\text{tot\_bark}} = \frac{V_{\text{bark}}}{V_{\text{log}}} \cdot C_{\text{tot\_log}} \quad (38)$$

And the processing cost of the boards can be assigned to individual board b_i as

$$C_{\text{tot\_}b_i} = \frac{v_i}{V_{\text{board}}} \cdot C_{\text{tot\_boards}} \quad (39)$$

Alternatively, cost formation can be approached from the end product point of view. The processing costs of each product and each process are summed up, and the total cost of processing one lumber piece $C_{\text{tot\_}b_i}$ is calculated as follows:

$$C_{\text{tot\_}b_i} = \frac{\text{AC}_{\text{sort\_log}} \cdot v_{b_i}}{V_{\text{log}}} + \frac{\text{AC}_{\text{db\_log}} \cdot v_{b_i}}{V_{\text{log}}} + \frac{\text{AC}_{\text{saw\_log}} \cdot v_{b_i}}{V_{\text{log}}} + C_{\text{g\_sort\_}b_i} + C_{\text{dry\_}b_i} + C_{\text{q\_sort}} + C_{\text{stor\_}b_i} \quad (40)$$

The unit cost of processing the lumber b_i is calculated in Equation 41:

$$\text{UC}_{\text{tot\_}b_i} = \frac{C_{\text{tot\_}b_i}}{v_i} \quad (41)$$

The production unit costs can be presented as costs per running meters.

The costs of processing bark ($C_{\text{tot\_bark}}$) and woodchips and sawdust ($C_{\text{tot\_chips\_dust}}$) are summed up from relevant processes.

$$C_{\text{tot\_bark}} = \frac{\text{AC}_{\text{sort\_log}} \cdot v_{\text{chips\_dust}}}{V_{\text{log}}} + \frac{\text{AC}_{\text{db\_log}} \cdot v_{\text{chips\_dust}}}{V_{\text{log}}} \quad (42)$$

The unit costs of processing bark $\text{UC}_{\text{tot\_bark}}$ is calculated as follows:

$$\text{UC}_{\text{tot\_bark}} = \frac{C_{\text{tot\_bark}}}{V_{\text{bark}}} \quad (43)$$

The total costs of processing chips and sawdust from end product viewpoint is calculated with Equation 44.

$$C_{\text{tot\_chips\_dust}} = \frac{\text{AC}_{\text{sort\_log}} \cdot v_{\text{chips\_dust}}}{V_{\text{log}}} + \frac{\text{AC}_{\text{db\_log}} \cdot v_{\text{chips\_dust}}}{V_{\text{log}}} + \frac{\text{AC}_{\text{saw\_log}} \cdot v_{\text{chips\_dust}}}{V_{\text{log}}} + C_{\text{chips\_dust}} \quad (44)$$

The unit cost of the chips and sawdust ($\text{UC}_{\text{chips\_dust}}$) production is calculated with following equation:

$$\text{UC}_{\text{chips\_dust}} = \frac{C_{\text{tot\_chips\_dust}}}{V_{\text{chips\_dust}}} \quad (45)$$

The presented cost calculation method of single log length and small end diameter class can be applied to a log distribution. When calculating the processing costs of the distribution, the cost drivers are determined with total sums of the log pieces, log lengths, gaps between logs, total log volumes, total number of lumber pieces, total lumber volumes, total bark volume, and chips and sawdust volume over all log length and small end diameter classes.

Example Calculation of an ABC Model in a Sawmill

The example calculation combines the ABC cost calculation and costs structure of a Scots pine sawmill in southwestern Finland that produces approximately 190,000 m^3 of sawn lumber. All volume units are presented as solid cubic meters. The key resources were determined by interviewing sawmill managers, machinery manufacturers, and other professionals from the fields of sawmilling and industrial constructing. Detailed information combining company identities and technical information are confidential and therefore not presented in this study.

Activity-based cost calculation

With the presented model, we tested two different scenarios of production cost: later referred to as Case 1 and Case 2. In Case 2 we diminished the amount of sideboards in comparison to Case 1 sawing pattern from all log small end diameter class. The input log distribution and key cost factors were same for both cases. The sawing patterns (Table 1 for Case 1, and Table 2 for Case 2) were determined by adapting the material from Uusitalo (1995).

Table 1.—Sawing pattern of Case 1 for each small end diameter class over the studied length classes.[a]

Small end diameter class (cm)	Centerpieces				Boards							
	Thickness (mm)	Width (mm)	Length (%)	Pieces	Thickness (mm)	Width (mm)	Length (%)	Pieces	Thickness (mm)	Width (mm)	Length (%)	Pieces
17	50	100	100	2	19	100	90	4				
19	50	125	100	2	19	100	95	4				
21	50	150	95	2	19	100	90	6				
23	50	150	100	2	19	125	95	2	19	100	95	4

[a] Length (%) expresses the length of the trimmed lumber piece relative to the length of the log.

Table 2.—Sawing pattern of Case 2 with reduced number of sideboards.[a]

Small end diameter class (cm)	Centerpieces				Boards							
	Thickness (mm)	Width (mm)	Length (%)	Pieces	Thickness (mm)	Width (mm)	Length (%)	Pieces	Thickness (mm)	Width (mm)	Length (%)	Pieces
17	50	100	100	2	19	100	90	2				
19	50	125	100	2	19	100	95	2				
21	50	150	95	2	19	100	90	4				
23	50	150	100	2	19	125	95	2	19	100	95	2

[a] Length (%) expresses the length of the trimmed lumber piece relative to the length of the log.

The tested log distribution is described in Table 3. The log volumes were calculated by the instructions of the Ministry of Agriculture and Forestry of Finland (2002). Lumber volumes were defined with the sawing patterns (Tables 1 and 2) for both cases, and bark volumes were calculated by formulas presented by Heiskanen and Rikkonen (1976). Chips and sawdust volumes were calculated by subtracting the lumber and bark volumes from the total log volumes.

The administrative cost factors in the sawmill are presented in Table 4 and cost factors of each process in Table 5. The material of the study was gathered mainly during year 2009. The machinery price information and technical solutions were based on information received from machinery manufacturer interviews. Value-added tax is not included in prices.

Ground construction cost factors were derived from industrial earth moving enterprises (Table 4). The cost of ground construction comprised gravel, tarmac, sewerage systems, and the assembly costs. The cost of office building was nominal and did not include the cost of basement. Labor, indirect wage cost, and the hourly costs of forklifter and wheel loader were received from mill managers. The price of electricity was from 2006 and included the cost of electricity and the transportation tariffs (EMA Finland 2010), and the price of heat energy is based on mill manager interviews.

Results of the ABC modeling

By using cost calculation and allocation functions (Eq. 1 through 45), cost factors, sawing patterns, and log distribution (Tables 1 through 5), we get the processing costs for Cases 1 and 2. The costs were calculated for individual log in small end diameter and length class (Table 6) or for the end products (Table 7).

Table 3.—The log distribution over four log length classes and four small end diameter classes for Cases 1 and 2.

Log length class (m)	Small end diameter class (cm)	Logs	Log volume (m^3)	Lumber volume (m^3)		Chips and sawdust volume (m^3)		Bark volume (m^3)
				Case 1	Case 2	Case 1	Case 2	
4.0	17	120,000	14,304	8,083	6,442	3,761	5,402	2,460
	19	120,000	17,520	9,466	7,733	5,146	6,879	2,908
	21	120,000	21,024	11,765	10,123	5,643	7,285	3,616
	23	120,000	24,960	12,832	11,099	8,035	9,768	4,093
4.3	17	120,000	15,377	8,689	6,925	4,043	5,807	2,645
	19	120,000	18,834	10,176	8,313	5,532	7,395	3,126
	21	120,000	22,601	12,647	10,882	6,066	7,831	3,887
	23	120,000	26,832	13,794	11,931	8,638	10,500	4,400
4.6	17	120,000	16,450	9,296	7,408	4,325	6,212	2,829
	19	120,000	20,148	10,885	8,893	5,918	7,911	3,345
	21	120,000	24,178	13,530	11,642	6,490	8,377	4,159
	23	120,000	28,704	14,756	12,764	9,240	11,233	4,707
4.9	17	120,000	17,522	9,902	7,891	4,607	6,618	3,014
	19	120,000	21,462	11,595	9,473	6,304	8,427	3,563
	21	120,000	25,754	14,412	12,401	6,913	8,924	4,430
	23	120,000	30,576	15,719	13,596	9,843	11,966	5,014

Table 4.—Ground construction, general, administrative, and cost factors.

Factor	Value	Unit
Cost of the ground construction	352,000	€/ha
Purchase price of the office building	100,000	€
Administrative working hours in a day	8	h
General director labor cost	30	€/h
Process manager labor cost	20	€/h
Secretary labor cost	17	€/h
Process worker labor cost	15	€/h
Indirect wage costs	70	%
Annual general administrative costs	10,000	€/y
Depreciation time for ground construction and building costs	30	y
Depreciation time for machinery	10	y
Basal area of administration process	0.03	ha
Administrative working days annually	238	days
Interest rate	5	%
Electricity	0.0722	€/kWh
Heat energy	0.03	€/kWh
Forklifter	45	€/h
Wheel loader	38	€/h

The activity-based production costs of chips and sawdust in Case 1 were €8.12/m^3 and for bark were €2.79/m^3. The same costs in Case 2 were €7.67/m^3 and €2.79/m^3, respectively.

Total production costs of Case 1 were €7,489,766 and for Case 2 were €7,162,146. The cost distributions of the two cases are presented in Figure 2.

Traditional cost calculation

If the production costs were allocated to raw material with the traditional, volume-based method, the cost differences disappear from between the log length and diameter classes. If the same cost equations, raw material, and cost factors were used but the costs were allocated by the volume share of each end product group (also described in Tables 1 through 3) instead of cost drivers, the cost of processing in Case 1 was €21.63/m^3 and in Case 2 was €20.69/m^3 for logs. The processing cost of lumber in cubic meters in Case 1 was €34.21 and in Case 2 was €37.41; chips and sawdust in Case 1 was €8.67/m^3 and in Case 2 was €8.18/m^3. The cost of processing bark in Case 1 and Case 2 was the same, €3.47/m^3.

Discussion

Virtual sawmill cost calculation model is at its best at assessing the cost structure of a planned sawmill, when there are no substantial reference points to compare the blueprints: the management can estimate the most cost-efficient technical solutions for the sawmill by comparing the costs with different input variables. The presented model was designed mainly for large-scale automated sawmills that use modern sawing techniques. If the technical solutions differ, for example there is a band saw line instead of a full profiling line, the cost structure and the cost drivers would be determined in a different way.

Since the model is for a production cost calculation, working capital costs are ignored. If working capital costs are taken into account, this extra cost may be incurred through extended storage of round and sawn wood as a requirement of operational service.

The model does not incorporate the heat energy production. The required heat is bought from an outside provider. Outsourced heat energy production is not the most common strategic decision for a Nordic sawmiller, but it simplifies the cost modeling. Usually the bark is burned for energy at the sawmill, but the bark also has an opportunity cost, which can be calculated within the model. It is also possible to adapt the presented model to have a heating plant as a separate process or as a subprocess of the drying. Figure 2 indicates that drying is the most expensive process; controlling this cost is essential and the strategic decisions of energy production procedures are important.

Repair and maintenance costs for sawmills were ignored because of the lack of useful information. The ABC theory states that all costs must be allocated to end products with appropriate cost drivers (Turney 2005), and because realistic, process-based information is not available, the repair and maintenance costs were disregarded in the model.

The technical limitations of the model require attention. The processes within the model are links in the chain. The capacities of machines within the processes have to be scaled to an equal order of magnitude. If limitations in capacities are not included, the production chain can bottleneck at some of the processes. This can be prevented by comparing the annual capacities of each process by the produced amount. In Cases 1 and 2, the receiving, unloading, and log sorting was the limiting process, with over 99 percent utilization rate.

The results of the case studies (Table 7) showed that diminishing the amount of sideboards decreases the production costs in lumber, chips, and sawdust productions. This was mainly due to heat energy saving in the drying process but also the enhancement of efficiency in chips and sawdust production. In both cases, the larger logs had lower unit costs. The speed of sawing may decrease as the log small end diameter increases. This may affect the unit costs, but the feeder speeds were fixed in the example and as noted, the speed of the saw was not the bottleneck of the production. The notable difference of cost development between small end diameter classes 19 and 21 cm are due to increments of lumber pieces (from six to eight in Case 1 and from four to six in Case 2, respectively), which increases lumber handling costs. Since the amount of bark was the same in Cases 1 and 2, and the costs of debarking were not dependent on the changes in the sawing pattern, the absolute costs were the same. A discussion with sawmilling professionals indicated that the cost levels seemed to be realistic; however, strategic decisions on the technical structure of the mill have a strong effect on costing. Generally, the costing levels in both case studies acted as Hakala (1992) demonstrated; as the log size increased, the unit costs of sawing decreased.

If the Case 1 and Case 2 costs were calculated with the traditional costing method, the results were parallel to the ones with the ABC method. The average processing costs for logs decreased, when the yield decreased. Traditional cost calculation allocates more costs to marginal sawmill end products as Rappold's (2006) study indicated. The unit costs of bark processing were 20 percent higher with traditional cost calculation than with the ABC method. The production costs of the lumber were equalized over all dimensions with the traditional cost calculation. The ABC method revealed that the production costs of larger lumber dimensions (50 by 150 mm) were significantly lower when

Table 5.—The key cost factors of each production process.

Cost factor	Value	Unit
Receive, unload and log sorting		
Price of machinery	1,700,000	€
Speed of log sorter	84	m/min
Gap between logs	0.5	m
Working hours in a day	8	h
Working days in a year	238	d
Process manager	1	person
Process worker	4	persons
Share of the use of wheel loader	50	%
Cost of buildings	30,000	€
Basal area of process	1	ha
Electricity wattage	167	kW
Electricity load factor	80	%
Debarking		
Price of machinery	600,000	€
Speed of debarker	84	m/min
Gap between logs	0	m
Working hours in a day	8	h
Working days in a year	238	d
Process manager	0.5	person
Process worker	1	person
Share of the use of wheel loader	50	%
Cost of buildings	30,000	€
Basal area of process	0.05	ha
Electricity wattage	800	kW
Electricity load factor	80	%
Sawing and edging		
Price of machinery	3,800,000	€
Speed of the saw feeder	84	m/min
Gap between logs	0	m
Working hours in a day	8	h
Working days in a year	238	d
Process manager	0.5	person
Process worker	2	persons
Cost of buildings	300,000	€
Basal area of process	0.2	ha
Electricity wattage	2 500	kW
Electricity load factor	70	%
Green sorting and stickering		
Price of machinery	3,700,000	€
Speed of sorter	150	pieces/min
Working hours in a day	8	h
Working days in a year	238	d
Process manager	1	person
Process worker	3	persons
Cost of buildings	300,000	€
Basal area of process	0.2	ha
Electricity wattage	300	kW
Electricity load factor	80	%
Drying		
Price of machinery	11,000,000	€
Height of the drying bundle	4,300	mm
Width of the drying bundle	2,000	mm
Height of the kiln stick	25	mm
Drying chambers	4	
Lumber bundles in a chamber	5	
Drying channels	7	
Lumber bundles in a channel	12	
Drying time of the bundle,	44	h
by lumber thickness	90	h
Drying days in a year	330	d
Working hours in a day	16	h
Process manager	1	person

Table 5.—Continued.

Cost factor	Value	Unit
Process worker	1	person
Share of the use of wheel loader	50	%
Basal area of process	0.4	ha
Heat energy consumption	255	kWh/m^3
Electricity consumption	34	kWh/m^3
Quality sorting and packing		
Price of machinery	4,850,000	€
Speed of sorter	150	pieces/min
Working hours in a day	8	h
Working days in a year	238	d
Process manager	1	person
Process worker	3	persons
Cost of buildings	300,000	€
Basal area of process	0.2	ha
Electricity wattage	680	kW
Electricity load factor	80	%
Storing and shipping		
Working hours in a day	8	h
Working days in a year	238	d
Process manager	1	person
Process worker	2	persons
Share of the use of forklifter	100	%
Cost of buildings	300,000	€
Basal area of process	0.2	ha
Chips and sawdust process		
Price of machinery	800 000	€
Working hours in a day	8	h
Working days in a year	238	d
Process worker	1	person
Share of the use of wheel loader	50	%
Cost of buildings	120,000	€
Basal area of process	0.1	ha
Electricity wattage	200	kW
Electricity load factor	70	%

compared with smaller (19 by 100 mm) ones, when scrutinizing the unit costs (€/m^3). The unit cost in euros per running meter acted in opposite ways when comparing the lumber dimensions because of inherent contradiction of the volume and length distributions with the dimensions.

The process definition is the primary decision on the path to selecting the right cost drivers. Most of the large-scale industrial sawmills have equivalent processes, which help the selection and enable the comparison of results between mills. The ABC model provides an efficient tool for sensitivity analysis for mill managers. There is a chance to assess the effect of changes at a strategic level. The model can also be applied to existing sawmills instead of virtual Greenfield models with applicable cost factors. When the mill management has selected the ABC as the cost calculation method, the introduction phase is important. As Shanahan (1995) reported, there is prejudice among employees against changes in cost follow-ups. The mill management has to be able to manage the changes in a way that employees are ready to accept them. The results of the example calculations demonstrated the accuracy and applicability of the activity-based costing method. Time-driven ABC is easy to execute and the amount of input information is quite moderate. As Norris (1994) suggests, the economical feasibility is one key of a successful cost

Table 6.—Activity-based cost per roundwood cubic meter for Cases 1 and 2 (€/m^3).

Small end diameter class (cm)	Log length class (m)							
	4.0		4.3		4.6		4.9	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
17	25.11	23.65	24.64	23.21	24.23	22.83	23.87	22.50
19	22.37	21.12	21.99	20.76	21.65	20.45	21.36	20.18
21	22.11	21.67	21.69	21.23	21.32	20.85	21.00	20.52
23	20.53	19.64	20.18	19.28	19.87	18.96	19.60	18.67

Table 7.—Activity-based costs per lumber piece classes, over all log length classes for Cases 1 and 2.

Small end diameter class (cm)	Centerpieces				Boards							
	Thickness (mm)	Width (mm)	€/running meter	€/m^3	Thickness (mm)	Width (mm)	€/running meter	€/m^3	Thickness (mm)	Width (mm)	€/running meter	€/m^3
Case 1												
17	50	100	0.178	35.59	19	100	0.076	40.01				
19	50	125	0.206	32.93	19	100	0.071	37.52				
21	50	150	0.240	31.96	19	100	0.070	36.83				
23	50	150	0.228	30.41	19	125	0.081	34.04	19	100	0.077	40.59
Case 2												
17	50	100	0.194	38.78	19	100	0.093	48.96				
19	50	125	0.223	35.68	19	100	0.087	46.03				
21	50	150	0.259	34.53	19	100	0.085	44.52				
23	50	150	0.247	32.88	19	125	0.094	39.66	19	100	0.090	47.58

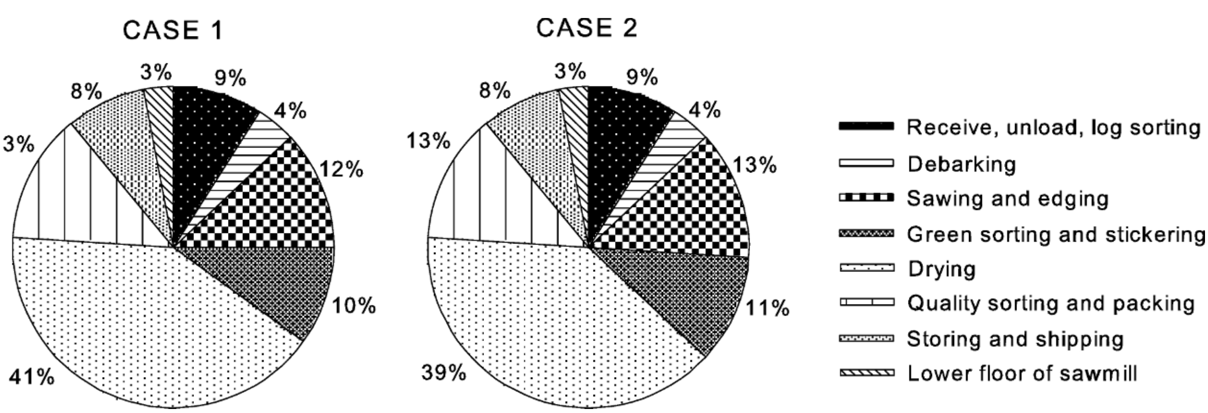

Figure 2.—Processing cost distribution of Cases 1 and 2.

calculation method, and as the costing structures and formulas are determined, needed updates to the model are easily made.

The results of this study indicate that activity-based costing is a promising method to assist sawmill management in strategic decision making. Revenues of the production will be handled in future research, after which the entire profitability gestalt of a sawmill will be completed. The costing model proved to be a relevant tool for assessing the production costs in a sawmill and it enables a sensitivity analysis of production. The model is a new and significant tool for supply chain management in forestry since the tree bucking control requires more accurate information of prices and demands of each timber class. Accuracy, applicability, and effectiveness are strong reasons to consider the ABC method in sawmilling.

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Literature Cited

Carlsson, D. and M. Rönnqvist. 2005. Supply chain management in forestry—Case studies at Södra Cell AB. *Eur. J. Oper. Res*. 163: 589–616.

Cobb, I., J. Innes, and F. Mitchell. 1993. Activity-Based Costing Problems: The British Experience, Advances in Management Accounting. Vol. 2. JAI Press, Greenwich, London. pp. 63–83.

Cooper, R. 1988. The rise of activity-based costing—Part two: When do I need an activity-based cost system? *J. Cost Manag*. 2(3):41–48.

Cooper, R. and R. S. Kaplan. 1988. How cost accounting distorts product costs. *Manag. Account*. 69:20–27.
EMA Finland, The Energy Market Authority of Finland. 2010. The statistics of the price of electricity. (In Finnish.) http://www.energiamarkkinavirasto.fi/files/Kehitys0912.pdf. Accessed February 4, 2010.
Groot, T. L. C. M. 1993. When activity-based management leads to the abolition of activity-based costing, a case study in the use of ABC for cost control purposes. Research Memorandum MARC-RM93-0 13, Rijksuniversiteit Limburg. Presented at the European Accounting Association Conference, April 22–24, 1992, Madrid.
Hakala, H. 1992. Financial result of sawing pine logs as influenced by top diameter and other associated factors. *Acta For. Fenn*. 226. 74 pp. (In Finnish with English summary.)
Harr, D. J. 1990. How activity accounting works in government. *Manag. Account*. 72:36–40.
Heiskanen, V. and P. Rikkonen. 1976. Bark amount in coniferous sawlogs and factors affecting it. *Folia For.* 250. 67 pp. (In Finnish with English summary.)
Henning, K. L. and F. W. Lindahl. 1995. Implementing activity based costing: the link between individual motivation and system design. *Adv. Manag. Account*. 4:45–62.
Horngren, C. T. 1989. Cost and management accounting: Yesterday and today. *In:* Research and Current Issues in Management Accounting. A. Hopwood and M. Bromwich (Eds.). Pitman Publishing, London. pp. 31–43.
Howard, A. F. 1993. A method for determining the cost of manufacturing individual logs into lumber. *Forest Prod. J*. 43(1):67–71.
Hsu, H.-P. and H.-M. Hsu. 2008. Systematic modeling and implementation of a resource planning system for virtual enterprise by Predicate/Transition net. *Expert Syst. Appl*. 35:1841–1857.
Innes, J. and F. Mitchell. 1995. A survey of activity-based costing in the U.K.'s largest companies. *Manag. Account. Res*. 6(2):137–153.
Johansson, M. 2007. Product costing for sawmill business management. Doctoral thesis. Växjö University, Sweden. 84 pp.
Johnson, H. T. and R. S. Kaplan. 1987. Relevance Lost: The Rise and Fall of Management Accounting. Harvard Business School Press, Boston. 269 pp.
Jungmeier, G., F. Werner, A. Jarnehammar, C. Hohenthal, and K. Richter. 2002. Allocation in lca of wood-based products experiences of cost action E9 part II examples. *Int. J. Life Cycle Assess*. 7(6): 369–375.
Kaplan, R. and S. R. Anderson. 2004. Time-driven activity-based costing. *Harvard Business Review* November:1–9.
Liebster, L. and C. Horner. 1989. The Hamlyn Dictionary of Business Terms. The Hamlyn Publishing Group Limited, London. 276 pp.
Malcolm, R. E. 1991. Overhead control implications of activity costing. *Accounting Horizons* December:69–78.
Ministry of Agriculture and Forestry of Finland. 2002. Maa- ja metsätalousministeriön asetus puutavarapölkkyjen kappaleittaisten mittausmenetelmien vahvistamisesta. *Puutavaranmittauslaki (Legislation of timber measurement)* 364/1991 17§:n 1 mom.
Norris, G. 1994. User perceptions of an application of activity-based costing. *In:* Advances in Management Accounting. Vol. 3. K. M. Poston and M. J. Epstein (Eds.). JAI Press, Greenwich, London. pp. 139–177.
Nurminen, T., H. Korpunen, and J. Uusitalo. 2006. Time consumption analysis of the mechanized cut-to-length harvesting system. *Silva Fenn*. 40(2):335–363.
Nurminen, T., H. Korpunen, and J. Uusitalo. 2009. Applying the activity-based costing to cut-to-length timber harvesting and trucking. *Silva Fenn*. 43(5):847–870.
Peltola, A. (Ed.). 2009. Finnish statistical yearbook of forestry. Finnish Forest Research Institute, Vammalan kirjapaino Oy, Vammala. 452 pp.
Player, R. S. and D. E. Keys. 1995a. Lessons from the ABM Battlefield: Getting off to the right start. *J. Cost Manag*. Summer:26–38.
Player, R. S. and D. E. Keys. 1995b. Lessons from the ABM Battlefield: Developing the pilot. *J. Cost Manag*. Summer:20–35.
Rappold, P. M. 2006. Activity-based product costing in a hardwood sawmill through the use of discrete event simulation. Doctoral dissertation. Virginia Polytechnic Institute and State University, Blacksburg. 249 pp.
Robinson, M. A. 1989. Stanadyne diesel systems (B). *In:* Cases from Management Accounting Practice. Vol. 5. M. A. Robinson (Ed.). National Association of Accountants, Montvale, New Jersey. pp. 27–31.
Roos, A., M. Flinkman, A. Jäppinen, G. Lönner, and M. Warensjö. 2001. Production strategies in Swedish softwood sawmilling industry. *Forest Policy Econ*. 3. 9 pp.
Satyaveer, S. C., J.-M. Frayret, and L. LeBel. 2009. Multi-commodity supply network planning in the forest supply chain. *Eur. J. Oper. Res*. 196:688–696.
Selto, F. H. 1995. Implementing activity-based management. *J. Cost Manag*. Summer:36–49.
Shanahan, Y. P. 1995. Implementing an activity-based costing system—Lessons from the Australian Post. *J. Cost Manag*. Summer:60–64.
Stadtler, H. 2005. Supply chain management and advanced planning—Basics, overview and challenges. *Eur. J. Oper. Res*. 163:575–588.
Staubus, G. J. 1990. Activity costing: Twenty years on. *Manag. Account. Res*. 1(4):249–264.
Turney, P. B. B. 2005. Common Cents. How to Succeed with Activity-Based Costing and Activity-Based Management. McGraw-Hill, New York. 315 pp.
Uusitalo, J. 1995. Pre-harvest measurement of pine stands for sawing production planning. *Acta For. Fenn*. 259. 56 pp.
Uusitalo, J. 2005. A framework for CTL method-based wood procurement logistics. *Int. J. Forest Engineer*. 16(2):37–46.
Virtanen, J. 2005. Analysing sawnwood supply distribution in Finnish sawmilling industry with database approach. Doctoral dissertation. Helsinki University of Technology, Department of Forest Products Technology, Laboratory of Wood Technology, Finland. 182 pp.
Wessels, C. B. and H. F. Vermaas. 1998. A management accounting system in sawmilling using activity based costing techniques. *S. Afr. Forestry J*. 183:31–35.
Young, D. W. 2003. Techniques of Management Accounting: An Essential Guide for Managers and Financial Professionals. McGraw-Hill Professional, New York. 275 pp.