DOCTORAL THESIS

Total Quality Management in Sawmills

Carl Gustav Lundahl

LULEÅ UNIVERSITY OF TECHNOLOGY

DOCTORAL THESIS

Total Quality Management in Sawmills

Carl Gustav Lundahl

Luleå University of Technology
Division of Wood Science and Technology
LTU Skellefteå
931 87 Skellefteå
2009

Printed by Universitetstryckeriet, Luleå 2009

ISSN: 1402-1544
ISBN 978-91-86233-71-6

Luleå 2009

www.ltu.se

Abstract

This work was initiated in order to show the potential for Swedish sawmills to achieve higher productivity by implementation of improved process control tools in breakdown and production flows. An effective and profitable sawmill must utilize its raw material and the skill of its staff effectively. Sawmill production could usefully adopt appropriate areas of process thinking and optimizing methods from the mechanical process industry.

Breakdown simulations performed during this study show a potential to improve volume yield by treating logs as single individuals during the breakdown procedure rather than treating logs as parts in a batch. Increased volume yield can be achieved from every log by applying optimal sawing pattern, log rotation and lateral offsets in first and second saw. Results achieved during surveys and simulations reveal a large potential to improve equipment availability and effectiveness on the sawline.

Appropriate methods, tools and a higher awareness are required in order to achieve improvements. A toolbox containing methods, process-monitoring or decision-support tools such as Total Quality Management (TQM), process measurements, visualization and benchmarking methods, analysis tools and simulation software creates a solid base for implementation of process control, knowledge and improved productivity.

Overall Equipment Effectiveness (OEE) is a benchmarking method addressing product quality and equipment availability and performance issues. These factors can be monitored over a period of time. Achieved metrics can be compared to earlier performed measurement and furthermore preferably be used in order to visualize improvement for the staff.

A successful deployment of the TQM concept would gain from deployment of fact-based decisions, cross-functional teamwork and a clearly defined focal point, actively supported by management and resources. OEE can serve this purpose, if properly adapted to sawmill prerequisites.

Accessible and reliable production data are crucial to providing information concerning the area of process control. Flexible diagnostic systems can, besides providing a sawmill with diagnosis and process knowledge, provide process data required for simulation models. These tools enable decisions to be based on facts.

Simulation software provides tools with which log-breakdown or production scenarios can be evaluated repeatedly without causing disturbances in the sawmill. The resulting model shows that Discrete Event Simulation models can be credible and quite exact if correct stoppage data are available. The final model is, however, only valid under the prerequisites included in the model. The dynamics of independently occurring events occurring on a sawmill log yard serves an excellent example where Discrete Event simulation is adequate. A logging module added to a GPS support system simplified activity monitoring and data acquisition and serves as an example of invaluable modern technology implemented in sawmills.

Key Terms: Yield, Optimization, Process Control, Total Quality Management Overall Equipment Effectiveness, Discrete Event Simulation, Breakdown Simulation, Process Monitoring.

Preface

Dear reader!
This thesis is not a thriller or nail-biter!
It is probably not even a block buster!
So, my dear reader, in order to help you to endure a long story about my research journey, I have included some small features in the thesis. When you find these features, stop reading for a while, contemplate about what you see and when spirit and curiosity once again returns, proceed to the next chapter. Keep in mind, there may be more to find.

I would like to thank all my colleagues in Skellefteå, who once again, are more or less “responsible” for this thesis. You have all contributed in some way to my work during discussions, coffee breaks or just by being there.

Some of you, however, have a very special place in my heart and mind—thanks for all the support and inspiration you have given me during these years. The team-building week in Cabannes, France, will never be forgotten.
Margot, thanks for being the one “lacking a vestibule”. Karl, there has been many well spent hours of breakfast meetings, Ph.d.-courses and travelling in the Mazda, well let´s just say…travelling.

Don´t part with your illusions.
When they are gone you may still exist, but you have ceased to live.

—Mark Twain

I must admit that I have always pondered curiously what the members of the grading committee discuss during the their closed meeting. Nostalgic memories of days past, military service, grand children or maybe this time, the imminent moose hunt.

Nevertheless, as long as they keep me out of the discussion….

About the front page picture:

The left sign: Kaizen
The japanese word ”kaizen” consists of the symbol “kai” meaning to “change” and “zen” which means “good”. Together this represents “changing for the better”. The term Kaizen in the quality context was first used by Maaski Imai (Imai 1986)

The right sign: Quality
The japanese sign for the concept of quality. The first sign is pronounced “hin” and roughly means “product”. The second sign is pronounced “shitsu” and roughly means “quality”. Originally this second sign illustrated two axes on top of a mussel and could be interpreted as “a promise of money or the value of money”. Nowadays, the combination of the signs denotes the concept of Quality.

Source: Bergman *et al. 2003.*

Acknowledgements

The work presented in this Doctoral thesis was carried out at the Division of Wood Science and Technology, Luleå University of Technology, Skellefteå Campus, and supervised by Professor Anders Grönlund. The work was financially supported by the SkeWood program, through the Kempe Foundation, the Swedish Agency for Innovation Systems (Vinnova) and Tillväxtverket, the Swedish Agency for Economic and Regional Growth.

A special thanks to:
Professor Anders Grönlund for his support and supervision during the study.

Professor Olle Hagman, LTU and TräCentrum Norr for invaluable cooperation and support.

Staffan Nilsson, LTU Skellefteå, Anders Marklund, Peter Andersson and Robert Westman at Datapolarna AB and, of course, the students at LTU Skellefteå for their contributions during the development of the process monitoring system.

Eva-Stina, Kersti and Marianne LTU Skellefteå, our LADOC managers.

Brian Reedy for revising my English writing.

The staff at the Kåge Sawmill and Martinsons Sawmill for all your support during surveys and equipment testing.

Docent Johan Oja and Doctor Karin Sandberg for cooperation during projects and scientific writing.

Urban Nordmark, Sveaskog, for your simulation support.

ProModel Corp. for the loan of the simulation software.

Skellefteå, July 2009
C G Lundahl

List of publications

Lundahl, Carl Gustav and Grönlund, Anders 2005.
*Process Control in Sawmill*s. Proceedings of International Wood Machining Seminar. IWMS 17. 2005.
(Poster on next page)

Hagman, Olle and Lundahl, Carl Gustav 2006.
Developing OEE tools for monitoring the sawmill process: A Triple Helix experience? Wood resources and panel properties. Cost Action E44 - E 49. Conference in Valencia on Wood Resources and Panel Properties. Conference proceedings. Valencia, AIDMA, 2006.

Lundahl, Carl Gustav.2007.
Optimized processes in Sawmills.
Licentiate thesis Luleå University of Technology; 2007:02.

Broman, Olof; Grönlund, Anders; Nordvik, Enar and Lundahl, Carl Gustav. 2008.
Estetiska kvaliteter och skillnader i preferenser för limfog: en jämförelse mellan två intervjumetoder. Technical report Luleå University of Technology; 2008:05.

Lundahl C. G. and Grönlund A. 2009
Increased Yield in Sawmills by Applying Alternate Rotation and Lateral Positioning.
Submitted to Forest Products Journal

Lundahl C. G., Sandberg K. and Grönlund A. 2009
Production of Heartwood Products – Effects on Volume Yield.
Submitted to Forest Products.Journal

Lycken, A., J. Oja and C. G. Lundahl. 2009. *Kundanpassad optimering i såglinjen – Virkeskvalitet On-line.* SP Rapport 2009:05 (in Swedish).

Process Control in Sawmills

Carl G Lundahl, Anders Grönlund

International Wood Machining Seminar 17
Rosenheim, Germany 2005

Background

Process control in modern sawmills and optimization tools have not followed the rapid development of production speed and automation and is rarely up to date with its counterparts in the pulp industry.

Few sawmills continuously monitor process variables such as sawing accuracy, long and short stoppages and their causes, feeder speeds, gap between logs or chip quality.

In order to optimize the production, a sawmill need know:
- the optimal log gap and feeder speed
- optimal saw blade thickness
- how the feed speed affect the measurement- and positioning accuracy
- how the feed speed affect the share of downtime
- the causes of downtimes

The Project

The aim of this project is to show how improved process control can increase yield and productivity in sawmills

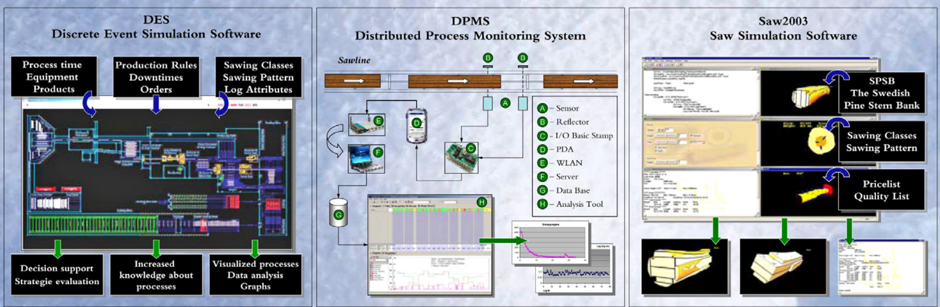
Saw simulation softwares, Discrete Event Simulation models and Process Monitoring Systems are efficient tools for monitoring, analysis and optimization of the sawmill process.

In this study, the production flow in a Swedish sawmill is modelled. The model is validated and verified against real production data.

A comprehensive benchmarking and analysis method, OEE - Overall Equipment Effectiveness is used to measure the impact of improvements

Toolbox

OEE = Availability x Performance x Quality



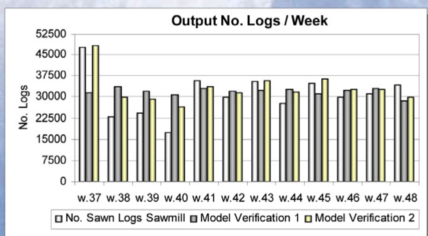
Results and Conclusions

The experiences from this work show that the success of a Discrete Event Simulation project is highly depending of the process data quality.

The study clearly depicted the need for better automatic monitoring systems for diagnostics, simulation, benchmarking tools and for continuous use at sawmills

The lack of data made the model verification complicated and is considered as an process determined by ongoing measurements made by the DPMS.

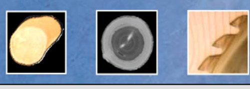
The model was created with the influence, participation and commitment of the sawmill staff, thus increasing knowledge about processes and downtimes.



The graph shows the output from the real sawmill compared to the output from the model. The model and the input data was modified before verification 2.

In order to verify the model, output from the real sawmill and the model was compared on two levels, the total output during 3 months and the output per week during the same months.

LULEÅ UNIVERSITY OF TECHNOLOGY
Division of Wood Science and Technology
Skellefteå Campus, Sweden www.ltu.se
Carl G. Lundahl



LULEÅ UNIVERSITY OF TECHNOLOGY

Poster presented at the International Wood Machining Seminar. IWMS 17. 2005.

Glossary:

Benchmarking:
Comparisons over a period of time of, for example, the effectiveness of a process or the performance of a machine.

Centre boards
Boards with a width larger than 32 - 38 mm.

Customer
A customer is generally defined as the buyer of products or services, but the relationship with the customer is not to be driven by a requirement of money being involved.
A common definition is that a customer is the one we want to create a value for.

Effectiveness:
Effectiveness of a system means the output of the system and the degree to which the output serves the needs of its intended users.

GPS
Global Positioning System. 24 orbiting satellites used for navigation

Posting list:
A set of sawing classes and the corresponding sawing patterns are usually combined in a post list stating lower and upper limit for every class.

Performance:
The degree to which intended functions of equipment are accomplished.

Process:
A series of dependent operations conducted with the aim to achieve clearly stated results.

Sawing Pattern:
A sawing pattern is a set of usually 2–4 centre boards and from 2 to 6 side boards combined in order to achieve an optimal volume yield from logs in the corresponding sawing class. Different sawing patterns with similar diagonal measurement of the centre board cross section can be assigned to the same sawing class. Also called “Postings”.

Sawing Class:
Logs are sorted into predefined groups called sawing classes according to the top diameter and/or quality. These groups contain logs with a smallest top diameter within the stated limits, normally in intervals from 10 to 20 mm in width.

Side boards
Boards with a width less than 32 mm.

Volume Yield:
The share of achieved valuable board volume in relation to the purchased true log volume.

Quality
A products or service ability to satisfy, or preferably exceed, the needs and expectations of the customer


Bonnstan
Skellefteå

Table of content

1 Introduction

1.1 A brief historical review

The sawmill industry has for centuries played a significant role in the Swedish economy and processed log volumes have almost constantly increased over the last hundred years. Since 1979, the produced volume has increased from close to 11 million m^3 per year (Figure 1.1) and 2007 became a top year when the Swedish sawmills produced 18.6 million m^3 of sawn wood products. More than 60 percent of the volume, 11 million m^3 was exported to other countries as bulk or refined products (Swedish Forest Industries Federation 2009) to a value of 27.5 billion SEK, showing a trading surplus exceeding 25.4 billon SEK. The total Swedish trading surplus the same year was close to 110 billion SEK (SCB 2009).

Swedish sawmills purchased 38.2 million m^3 (solid volume under bark) of logs during the same year. More than 97 percent of the total volume was purchased and harvested within the Swedish borders (VMR 2007). Nevertheless, the total available growing forest stock is still higher than ever even though harvested volumes have increased. This achievement is the result of a foresightful and successful forest replanting programme (Staland *et al.* 2002).

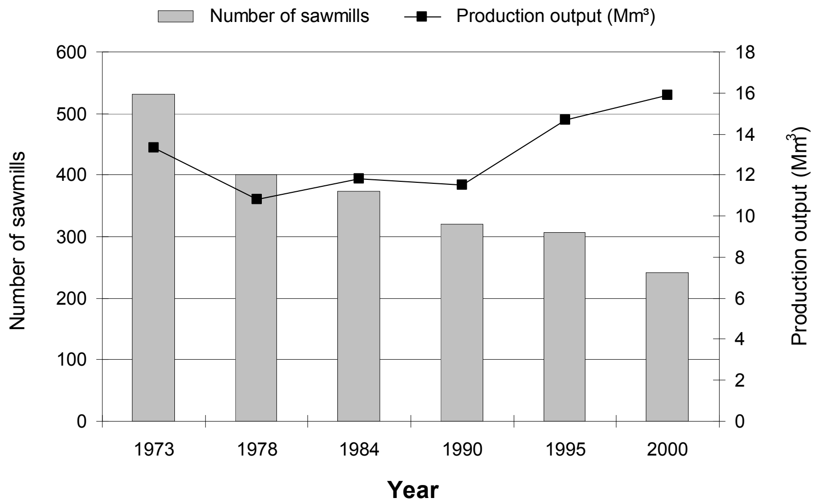


Figure 1.1 Number of sawmills producing more than 5,000 m^3 of sawn products in reference to total production volume per year in Sweden (Staland et al. 2002).

The sawmill industry has experienced a rather dramatic restructuring over the last decades. The total number of sawmills in Sweden has constantly decreased and there are now fewer sawmills with higher capacity and productivity, run by fewer employees. Units producing over 100,000 m^3 have increased, while the number of sawmills with an annual production of less than 50,000 m^3 has decreased dramatically Figure 1.1. The number of employees has been cut to almost a fifth during the last 40 years. Between 1995 and 2000 alone, employee numbers decreased by 30 percent to 9,200 people Figure 1.2 (Staland *et al.* 2002).

However, during the economic boom of recent years, sawmills have hired more people. In 2007 close to 13,700 people were working in Swedish sawmill enterprises. The Swedish paper, pulp and wood mechanical trade organization, The Swedish Forest Industries Confederation (Skogsindustrierna) estimates the number employed by forest contractors to be almost at the same level.

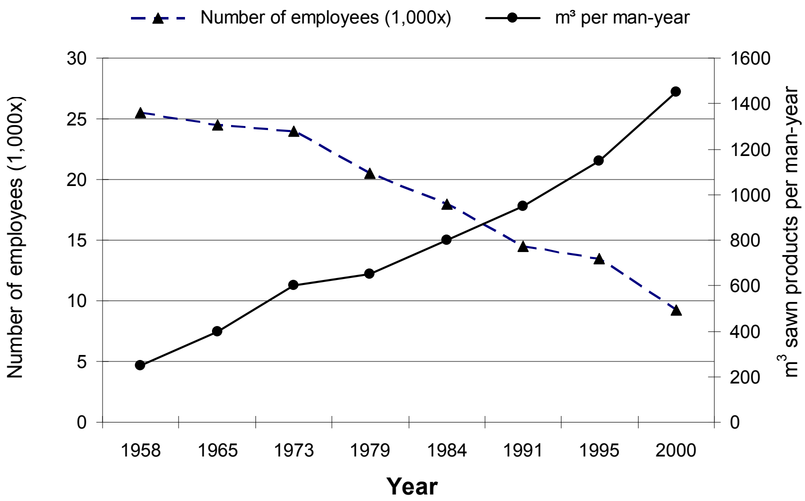


Figure 1.2 Number of employed staff at Swedish sawmills and productivity expressed in m^3 of produced boards per man-year (Staland et al. 2002).

During the year 2000, the ten largest sawmill enterprises produced 44 percent of the total production. Productivity expressed as m^3 (produced boards) per man-year has on average increased by more than 15 percent from 1995 to 2000 (Staland *et al.* 2002).

This concentration of production capacity, carried out at the expense of small mills may primary be caused by expected benefits in the large-scale operation concept and an increasing international competition in the sales market in combination with limited supplies of raw material .

A vital generic key performance indicator in the sawmill industry is volume yield, that is the share of the purchased log volume that becomes saleable boards. The contradiction in this case is that the volume yield has constantly decreased over the same period of time that sawmill enterprises experienced a concentration of production capacity and maximized production volumes Figure 1.3 (Staland *et al.* 2002).

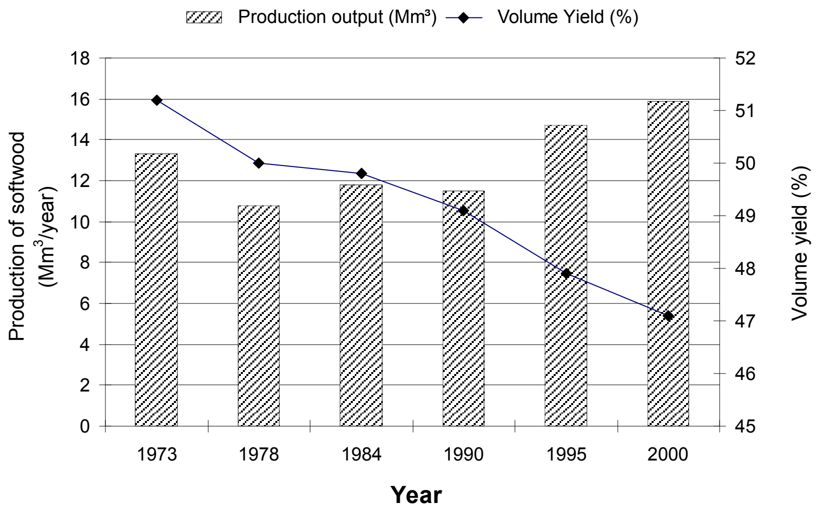


Figure 1.3 Changes in average volume yield from 1973 to 2000 in reference to total annual production volume of sawn softwood in Sweden (Staland et al. 2002).

The decrease in average volume yield can be explained by an increased share of small-dimension logs, extraction of fewer side boards on the sawline, increased use of profile reducing equipment and a higher degree of conversion (Staland *et al.* 2002). An additional factor may be found in the fact that feed speed on sawlines has in general increased over the years. Performed research shows that higher feed speed is causing variations in the sawing process, thus less volume yield (Grönlund 1981).

Skellefteå Church town – “Bonnstan”

1.2 Background

Modern sawmills are becoming increasingly like process industries. This type of industry is often characterized by a production process continuously running at all hours with very large values flowing through the process every single second. This fact makes it vital for every company to utilize its expensive equipment and raw material as effectively as possible, thus achieving high value yield and productivity. Additionally, sawmills must constantly struggle to optimize value yield and reduce the effects of the “sawmill paradox” (Grönlund 1992). This refers to the fact that close to half of the sawn board volume will be turned into chips or sawdust, and half of the produced boards will become low priced products because of low demand.

In sawmills in general, the main income is from sales of lumber and of byproducts such as chips, sawdust and bark. The cost of raw material is known to be the single largest budget item for sawmills, followed by labour, capital, and operations costs. However, prices for raw material as well as for sawn products are governed and controlled by competition in the sales market.

The sawmills’ sales conditions in the market are also more complicated than those of mechanical industries where production and sales are known to be more focused on customer demand. The international competition in the wood sales market has increased, and demand and prices for sawn wood products are known to fluctuate beyond the control of the sawmills.

The sale of standard wood products generally takes place within a special market situation wherein the competitors are aware of prices both for sellers and buyers (Grönlund 1992). This means that price reductions often result in price wars, and the actors are well aware of the phenomenon. Furthermore, standard wood products are stock commodities, which means that suppliers can easily be replaced.

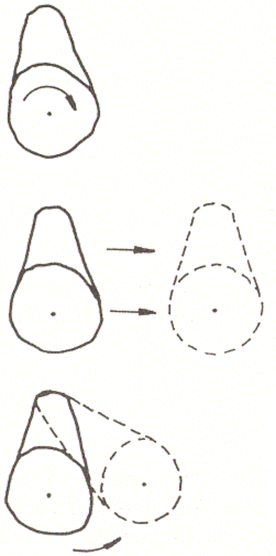
This fact makes it crucial for Swedish sawmills to produce boards and refined wood products efficiently in order to keep their share of the total market. Nevertheless, a sawmill can still independently control its production costs and volume yield, *i.e.*, the ratio between the total log volume and the volume of produced boards. A high volume yield is known to be a significant factor in obtaining good sawmill economy as well as in optimizing the whole conversion chain (Usenius 1996, 1999).

For example, a sawmill purchases 400,000 m^3 sub of logs per year and achieves an average volume recovery of 45.0%. A 0.5 percent point increase in volume yield can reduce the necessary purchase volume by almost 4,400 m^3 sub.

Modern sawmills have a tendency to prioritize speed and production volume of log sawing instead of volume and value yield recovery. Even though the breakdown process in sawmills is difficult to control and optimize fully, it is important to ceaselessly seek to reduce the detrimental effects of variations in sawing accuracy (Stern *et al.* 1979). As production speed is raised, variations caused by inadequacies in the sawing process must be compensated for with an increased sawing allowance and larger saw-kerf width, with a consequent reduction in volume yield.

Studies and simulations (Grönlund 1981) have shown that a reduction by 0.5 mm of variations in board dimensions makes it possible to reduce the value for sawing allowances by 0.8 mm. The same study also indicates that a reduction by 0.8 mm in the sawing allowance increases volume yield by up to 1.3 percentage points. Additional factors that influence the achieved yield are positioning accuracy in sawing machines and usage of curve or straight sawing technique.

Optimal positioning can be defined in basic terms as the means of placing and handling a log during the sawing process in order to maximize the volume yield. In a typical Swedish sawmill, this procedure involves log rotation, centring the log face to the saw blades and, when curve sawing is applied, calculating and controlling the log through the second sawing machine according to a predicted optimal kerf line. (Maness *et al.* 1994; Selin 2001). Figure 1.4 shows the definition of positioning parameters.



A – Rotation of the log around its long axis with positive rotation to the right.

B – Parallel dislocation or offset of the log, positive to the right and measured in mm/m.

C – Twist or angle dislocation of the log. Shift at the root end while the top end is still, positive to the right and measured in mm/m.

Figure 1.4 Definition of positioning parameters for logs (Drake et al. 1986).

As simple as they might appear, in reality some of these actions must be performed in a split second to fulfil the demand for speed and productivity on the production line. When the performance of the equipment is pushed towards or beyond its upper limit, sawing accuracy can suffer due to inaccuracies and wear and tear on the mechanical equipment. The true level of sawing and positioning accuracy can therefore vary over time due to the status of the actual equipment in use.

A process according to Bergman and Klefsjö (2003), *is "a network of activities that are repeated in time, whose objective is to create value to external or internal customers"*. The authors emphasize that this is not merely a machine related issue but processes and management of processes are also very much about teamwork and coordination between people rather than technical issues and assembly lines.

In order to perform an optimal breakdown process, detailed knowledge about the outer shape and inner structure of each individual log is required. A development of the CT-scanning technique (Grundberg *et al.* 1999) called X-ray LOG-scanner is at present in use in some Swedish sawmills.

The X-ray LOG-scanner is capable of scanning logs online at full translation speed, and automatic algorithms have been developed to make decisions on how each log should optimally be split. Still, in most curve-sawing mills, a known and reliable technique is used in which the log is centred and rotated with its crook upward (“horns down”) in the first saw and the subsequent breakdown in the second saw is done by saw kerfs following the midline of the cant. Curve sawing technique has been used for more then a century in Scandinavian sawmills due to its ability to follow the natural form of a cant and to the relatively high volume yield it produces. This technique will produce straight lumber after drying even from highly curved logs. Nevertheless, straight sawing is still used in many sawmills.

The production flow must also perform as intended and designed in order to be able to efficiently produce the desired volume of sawn boards. The sawmill process is in many ways similar to the mechanical industry even though the raw material delivered to the sawmill is very special.

This means that the properties of the wood must be taken into account in every step of the process, Nevertheless, in a mission to optimize production flow and machinery in a sawmill, many methods can be adapted from mechanical enterprises with long experience of working with continuous improvement.

In summary, there are numerous parameters that must be taken into account in order to achieve an optimal sawmill process.

2 Objectives and Limitations

This work was initiated in order to show the potential for Swedish sawmills to achieve higher productivity by implementation of improved quality management and process control in breakdown and production flows. The objective in this study was to create a "toolbox" providing the quality management and optimization tools needed for this work and to describe how these tools could be used as decision support for the staff in order to improve productivity and profit.

A potential to improve productivity was identified and classified into three main improvement areas:

- Process control, monitoring systems and analysis tools.
- Volume and value recovery in the breakdown process.
- Equipment utilization, availability and performance of the production process.

The project was carried out independently, but in association with TCN, TräCentrum Norr (WoodCentre North) and local sawmills in order to achieve a close industrial influence and for experimental purposes. The focus of this work is limited to include log handling, sorting and breakdown, green sorting and board stacking processes, represented by blocks 2, 3 and 4 in Figure 2.1.

The tools used in this work and in the proposed toolbox were selected because they were considered adequate for the purpose. No complete benchmarking was done during the selection phase.

Knot definitions were deactivated in the saw simulation software in order to achieve an explicit volume yield optimization without knot-related influences.

Figure 2.1 shows the structure for an entire sawmill process involving the whole conversion chain.

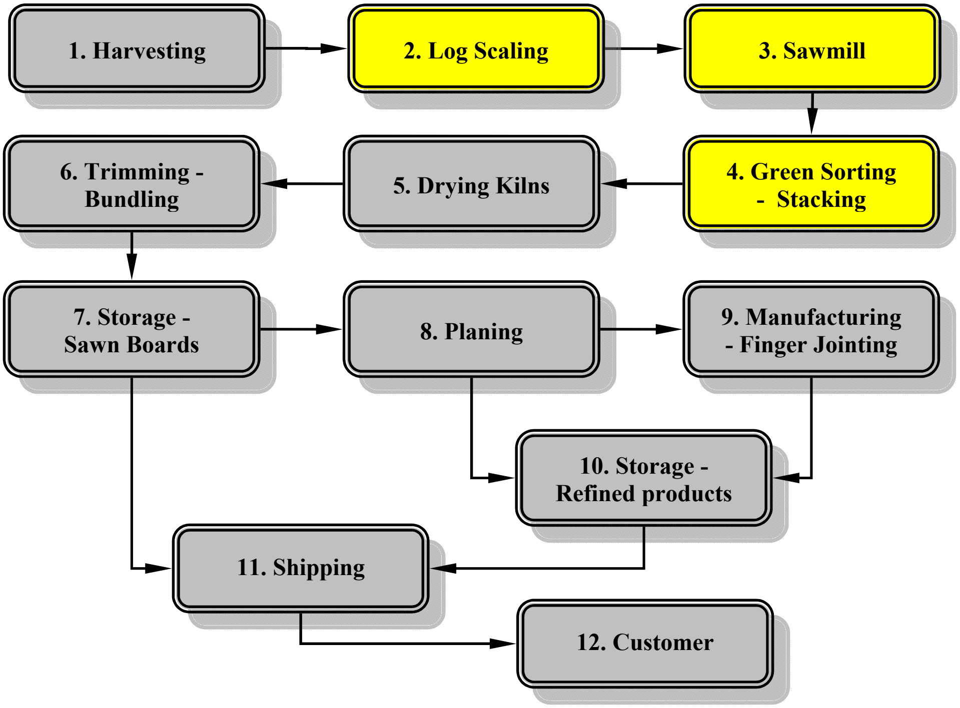


Figure 2.1 Sawmill Process – from forest to customer.

3 Materials and Methods

3.1 Research approach

The main motivation for a research activity is an existing phenomenon or problem that needs to be explained, understood or solved. This particular research activity started out as a task focused on a single objective, how to improve process control in Swedish sawmills and more specifically processes connected to the saw line and the green sorting area —a practical "down to earth" problem closely related to the sawmill industry. This type of pragmatic research is defined by Patel and Davidsson (2003) as applied research. The present study also included an element of fundamental research with the aim to gain and widen knowledge for future use. This task was soon found to be more complex than expected mainly due to lack of available and reliable process data, monitoring equipment and suitable DES software.

First impressions of the sawmill industry were rather confusing in the view of the lack of process thinking and generic quality management approaches. This was a major contrast to the more structured mining and mechanical industries in which I have garnered most of my work experience. The contrast to the highly structured automotive industry is especially stark. This cognition initiated a quality management approach in order to depict similarities between the wood industry and the mechanical industry and applicable quality management tools. The research task was thus set to depict and evaluate if and how generic tools used in the mechanical industry could be adapted to sawmill prerequisites and requirements.

The comprehensive research approach in this study can be defined as quantitative, positivistic and inductive. In other words, results can in most cases be presented as unambiguous values and conclusions are to be based on facts and experiences. Facts and process data always exist in some shape, consequently observable and it is up to the scientist to correctly collect and objectively systematize the information as a foundation for analysis and conclusions (Alvesson & Sköldberg 1994).

Developed tools and quality management framework were evaluated in a general case study approach. This case study was performed as a parallel two-lane research approach on breakdown procedure in one lane and production flow issues in the other. Parts of the case study such as improved breakdown procedures addressed fictive, but still highly applicable, sawmill issues. The main part of the case study involved development of tools and analysis of actual production- and quality-management-related issues at the sawmill.

Whenever research is conducted, two fundamental requirements must be met. First, all experiments and studies must be possible to recreate and results and conclusions possible to evaluate. Second, collected data for research need to be reliable and valid (Carmines *et. al.* 1979).

High reliability is achieved if a phenomenon is independently measured under similar circumstances at different times and the results after data processing are similar or close to similar. Reliability is, however, not directly related to the validity of the data to since the validity explains how well the phenomenon is measured (Holme and Solvang 1997).

Empirical survey data such as production rules, stoppage distributions, stoppage causes and sawing accuracy collected and used in this work were acquired at a local sawmill. These surveys were performed over a period of four years. Process data collection served two main purposes. Data were needed in order to build and verify the discrete event model. At the same time, these process measurements established metrics on availability and effectiveness used in the benchmarking concept.

The initial process data sets were secondary data, *i.e.*, the data were retrieved from the sawmill´s existing process-monitoring systems. The research approach requires that all kinds of collected data sets and the methods used for collection need verification and analysis in order to be valid. The received secondary data was found to be of bad quality and sometimes also corrupt. This lead on to an altered research strategy and a very time-consuming step in the project applying an approach of developing a flexible and reliable process-monitoring system in order to collect, process and visualize primary data.

Two major quality management and process-analysis tools, a Discrete Event Simulation model and a Diagnostic Process monitoring system were developed parallel to the thesis work. The need for reliable data-collection and error-report systems adapted to the sawmill industry has also given me the opportunity to act as an initiator and project manager/participant of two triple helix projects in cooperation with local sawmills, a software company, students at Luleå University of Technology, Skellefteå Campus and TCN, TräCentrum Norr (WoodCentre North).

The TCN-constellation is a centre formed within Luleå University of Technology for the purpose of cooperation between researchers and the wood industry in northern Sweden. The developed Distributed Process Monitoring System offers data acquisition and an interactive stoppage-cause reporting system. Furthermore, this system has been commercialized and has been purchased by five companies.

Other tools such as previously developed breakdown simulation software (Nordmark 2005), have also been used in a number of studies.

Manual surveys on sawing accuracy were performed with calibrated tools and according to current standards. This inductive approach contributed highly to a broader process knowledge and a focus on problem areas in need of attention. The Discrete Event Model was validated and verified in close collaboration with the sawmill staff. This work included a detailed control of the model´s functions and performance.

The reliability of the monitoring systems was verified in terms of ability and consistency to replicate measurements to an acceptable level. The validity of the collected data, *i.e.,* if the measurements are correct and reflects what is supposed to be measure was also verified by manual survey performed during a sufficient period of time in order to register seasonal and short-term fluctuations.

The validity of the collected empirical data was furthermore verified in close cooperation with the sawmill´s staff and by comparing true sawmill throughput and the achieved throughput from developed Discrete Event simulation models containing the collected data. Data were examined and transformed into appropriate formats such as generic statistical distributions, probability levels and/or graphs using a quantitative approach.

Secondary empirical data on logs´ inner and outer properties from the Swedish Pine Stem Bank (Grundberg et al. 1995) and the Spruce Stem Bank (Anon 2000) were used. These data has been previously verified and have been used in numerous research tasks over a period of 10 years.

The initial objective stated that this work should focus on processes starting from the sawmill´s log intake and end at the stacking area. This was also the case during work performed up until the licentiate thesis was presented. The work and focus area during the final years of this work has enlarged further to include log handling procedures. This is at present day (July 2009) an ongoing project focused on evaluating the potential to improve log handling, log stacker activities and sorting and stacking strategies and by utilizing GPS technology for data collection and by using Discrete Event Simulation modelling. This log-yard related project is also governed by TCN, with participation of stakeholders from four sawmill constellations attached to the TCN-network. I am presently (June 2009) serving as project manager and representative for the university parallel to the scientific thesis work.

This research project was a part of the SkeWood research programme and has annually given opportunities to present results and development of tools during workshops attended by members of the Swedish research council and the Skewood steering committee. These workshops have given valuable feed back and a number of opportunities to practice the noble art of presentation technique. The on-going work has also been presented to involved sawmill staffs, during local seminars and workshops and also during public popular scientific arrangements. The research was presented in a poster session during the 17th International Wood Machining seminar in Rosenheim, Germany 2005.

A flowchart on project events is presented in figure 3.1.

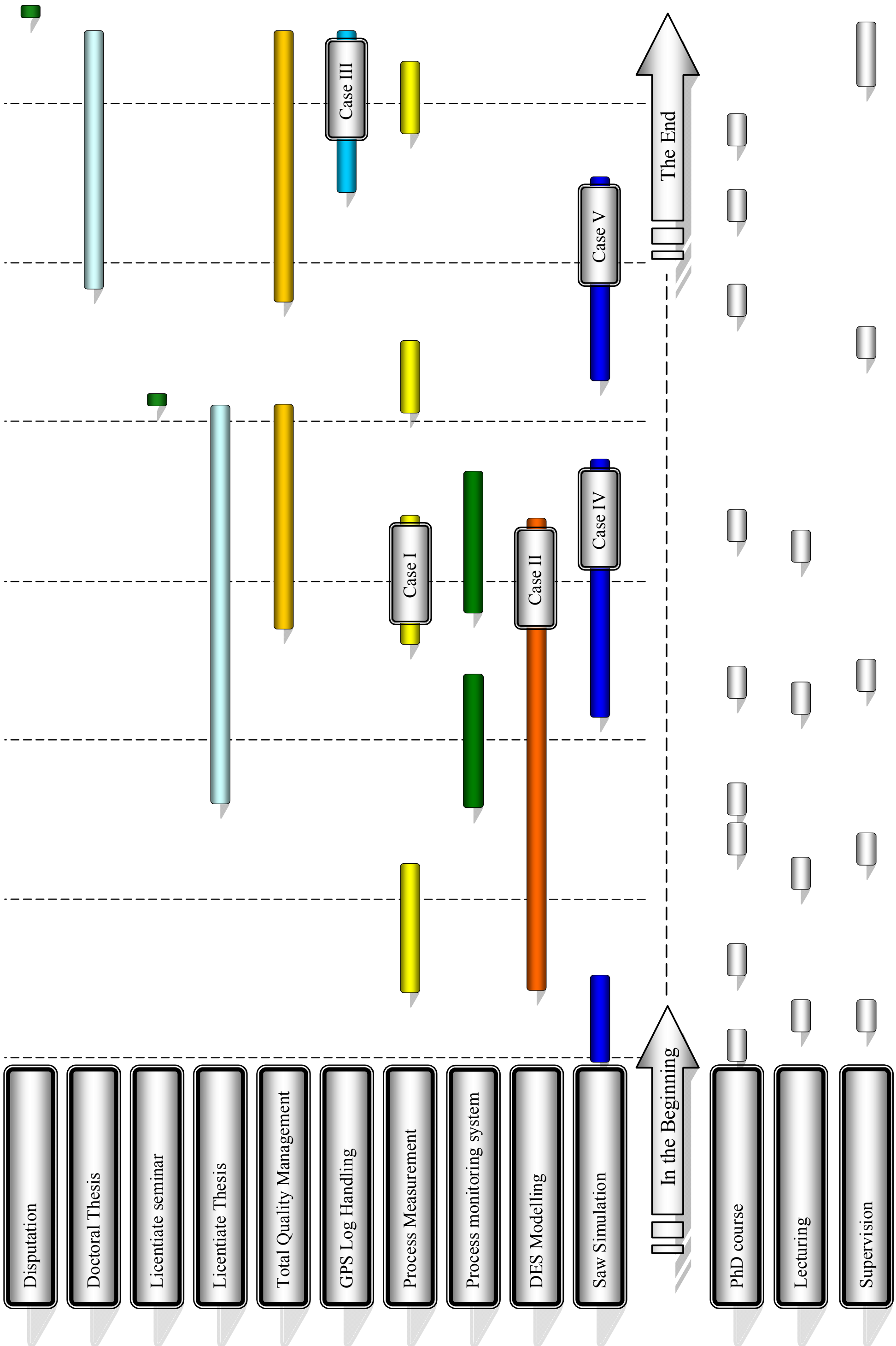


Figure 3.1 Project flowchart.

3.2 The Swedish Pine Stem Bank (SPSB)

The Swedish Pine Stem Bank (SPSB) is a database containing detailed information about 200 Scots pine trees (Grundberg *et al.* 1995). These trees were chosen from 33 plots all over Sweden and were carefully documented through their growth. The database includes log geometry, silvicultural and stand data as well as information achieved from CT-scanning of the logs. Six trees were chosen from each plot, two small, two medium-sized and two large trees. After harvesting, all trees were cut according to common Swedish bucking rules, resulting in 2 to 4 logs per stem. The achieved log length varied between 3.1 and 5.5 meters, and the top diameter varied from 92 mm up to 371 mm.

After harvesting and cross cutting, the logs were measured and graded by two independent log graders from the Swedish Measurement Society (VMF). A medical CT scanner (Siemens SOMATOM AR.T) was then used to scan the logs. The CT-scanning process measures the density difference between sapwood, heartwood, knots (sound and dead) and the pith. The CT images were saved as 8-bit greyscale images with a resolution of 256 x 256 pixels. The heartwood border and surface geometry of the log are depicted by one radius per degree at every 10-mm offset along the log. The pictures were automatically analyzed using automatic image-analysis methods.

The resulting images from CT-scanning of a log are detailed descriptions of outer shape, heartwood border, location of the pith and a parameter description of the knots. Each knot is depicted by nine parameters that describe the knot geometry, position and direction in the log (Oja 1999). Once the CT-scanning procedure was performed, all logs were cant sawn with a standard sawing pattern, and all boards were dried to a moisture content (MC) of 18%.

All the centre boards were then scanned with a CCD (Charged Coupled Device) line camera on all sides. Subsequently, all boards were graded by skilled personnel according to the commonly used grading system Nordic Timber Grading Rules (Anon. 1999). All data connected to each log were stored in the SPSB using a unique ID tag that gives users the ability to match every log to the corresponding yield and board output. The data stored in the SPSB makes it possible to recreate the outer shape and inner structure of every log using dedicated saw-simulation software.

3.3 The European Spruce Stem Bank (ESSB)

The European Spruce Stem Bank is a database containing detailed information about 750 logs from Norway spruce trees harvested from 31 different sites in France, Finland and Sweden (Anon 2000). A medical CT scanner (Siemens SOMATOM AR.T) was used to scan the logs. The resulting images from CT-scanning of a log are detailed descriptions of outer shape, heartwood border, location of the pith and a nine-parameter description of the knots (Figure 3.2). The detailed data stored in the Spruce Stem Bank makes it possible to recreate the outer shape and inner structure of every log using dedicated saw-simulation software.

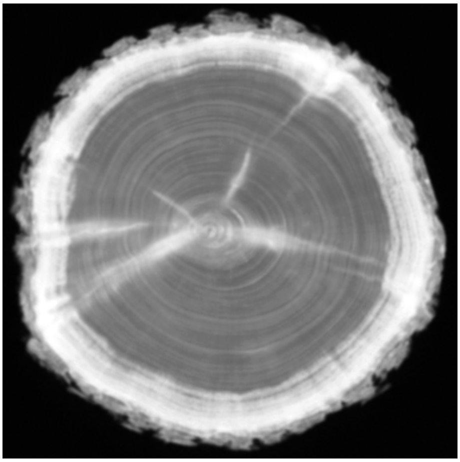


Figure 3.2 CT image of Norway spruce.

3.4 Breakdown Simulation

Detailed log data containing information about log shape and inner structure make it possible to regenerate logs in PC-based software with which logs can be evaluated over and over again while applying any number of different breakdown scenarios. Saw simulation technique is an efficient method to study the impact on volume yield caused by log properties or different sawing strategies. Several studies and research projects have been performed in order to create and utilize software imitating a sawmill breakdown process. This technique has been verified and used, for example, by Lundahl (2007), Nordmark (2005), Pinto *et al.* (2002, 2005), Chiorescu *et al.* (2000), Grundberg *et al.* (1999), Todoroki *et al.* (1999), Usenius (1999) and Johansson (1978).

3.4.1 Cant Sawing (Square sawing)

Cant sawing is by far the most-used sawing method in Sweden. Figure 3.3 show a simplified description of the cant sawing procedure. Initially, the log is rotated with the crook up, horns down (A), and the log face is centred to the first sawing machine. The log is then cut into a cant and 2 to 4 side boards (B). Pictures B and D show the side boards after processing in the edger. The cant is rotated 90 degrees (C), centred, and the second saw machine cuts the cant into 1 to 6 centre boards and 2 to 6 side boards (D). It is possible to apply curve or straight sawing technique during the second breakdown procedure.

The cant sawing method is used and preferred because of its ability to produce a relatively high volume yield as well as it being possible to use in an effective, low-cost sawing process.

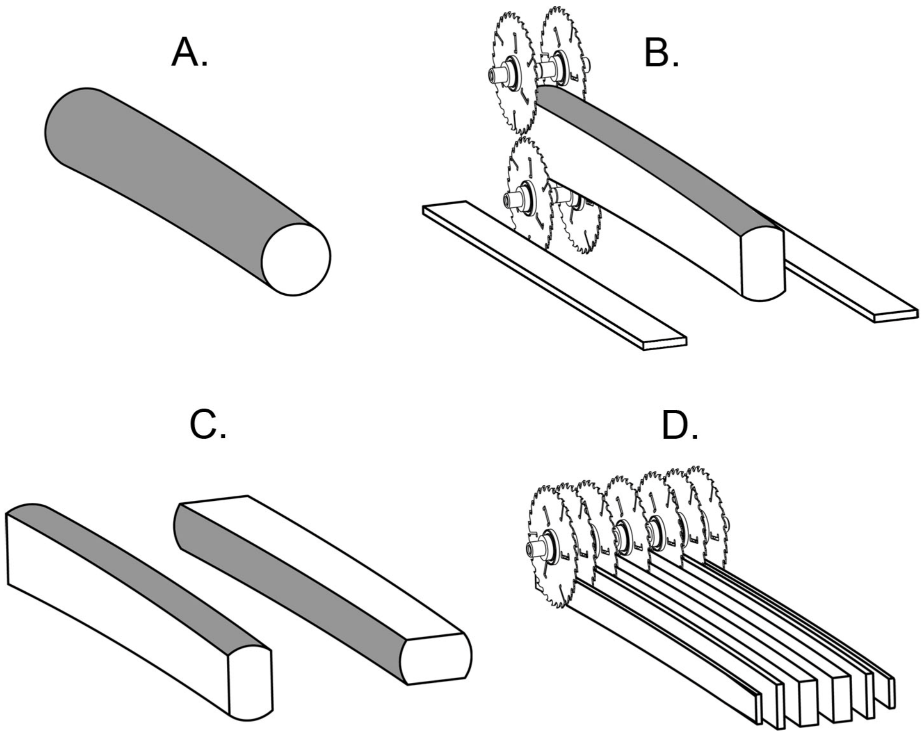


Figure 3.3 The cant sawing concept

3.4.2 Sawing Patterns

A sawing pattern is a set of usually 2 to 4 centre boards and from 2 to 6 side boards combined in order to achieve an optimal volume yield from logs in the corresponding sawing class (Figure 3.4). Different sawing patterns with similar diagonal measurement can be assigned to the same sawing class.

3.4.3 Diagonal Measure of the Sawing Pattern (DMSP)

Figure 3.4 shows the definition of the diagonal measure of the Sawing Pattern. The height, H, of the cant is calculated by adding 4% for shrinkage and sawing allowance. To calculate width, W, the width of the saw kerf plus 4% is commonly added to the nominal value of each centre-board crosscut dimension.

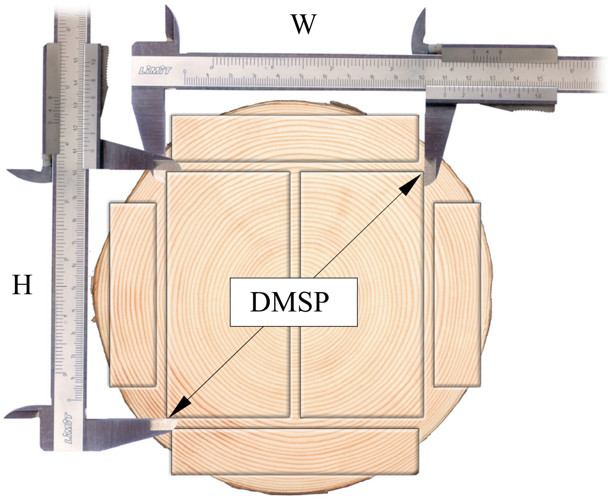


Figure 3.4 The Diagonal Measure of the Sawing Pattern, DMSP.

3.4.4 Sawing allowance - Trimming

The market generally demands centre boards with limited or no presence of wane or defects along the edges. The allowed presence of wane in order to achieve the highest quality classification is stated in Nordic Wood – grading rules for pine and spruce sawn timber (Anon. 1999).

In order to produce centre boards with sharp edges along the whole log length, the diagonal measure of the sawing pattern should be less than the lower limit of the actual sawing class. For sawing allowance, *i.e.*, sawing procedure deviations and shrinkage, 4% was added to the nominal value for each board dimension in this study.

The shortest allowed board length was set to 1800 mm, and boards were trimmed to a length module of 300 mm. Boards graded as D are not generated, because they have no commercial value and are thus sent to the chipper. The default software settings trim 20 mm from the butt and top of every board. The board value is then maximized during a final trimming procedure.

3.4.5 Volume Yield

The volume yield is defined as:

$$Yield\,(\%) = \left(\frac{\text{Nominal volume of trimmed Boards}}{\text{True Log volume}} \; x \; 100 \right)$$

Nominal volume of trimmed board is the final board volume after drying to 18% moisture content and trimming. True log volume is the green log volume under bark.

The volume of each board was calculated by the software based on the nominal trimmed and dried volume (18% MC). The volume yield of centre and side boards is dependent on the quality grading parameters, *i.e.*, trimming caused by presence of wane and knots.

The achieved gross volume yield prior to grading and trimming is mainly dependent on such factors as sawing method and log geometry, while the final net volume and value yields are governed by quality factors and defects such as wane, knots, rot and cracks.

3.4.6 Average yield vs. True yield calculations

The volume yield for a batch of logs can be calculated in two different ways—as the arithmetical average yield or as the true yield. The true yield is the calculated quotient of true board volume divided by the true log volume. The arithmetically calculated yield often presents a different value than the true yield value

Example 1:
The added true log volume for the logs used in the SPSB is 116.3 m^3, and the total of the simulated true board volume achieved from the log batch is 59.2 m^3. All logs consistently showing low yield due to corrupt log data were removed before the calculation.

Method 1: The average yield for the batch is 59.2 / 116.3 m^3 = 50.9%
Method 2: The true arithmetical average yield: 47.2%
The calculated difference between the results is 3.7 percent points.

Example 2:
Annual demand: 100,000 m^3 of boards.
Demand log volume Method 1: 100,000 / 0.509 = 196,500 m^3 sub.
Demand log volume Method 2: 100,000 / 0.472 = 211,900 m^3 sub.
Difference between calculation methods: 15,400 m^3 sub.

Thus, the true arithmetical yield (true yield) concept is used in the results presented in this study. The average yield for a batch can still be used as a value for comprehensive comparisons between simulations. However, the average method causes differences when it is used for log-demand calculations.

3.5 Saw2003 Simulation software

The Saw2003 simulation software (Nordmark 2005) is a PC-based C++ application developed to utilize the digitized data information contained in the Swedish Stem Bank (SPSB) and is used to simulate the breakdown process according to the common rules used in Swedish sawmills, the Nordic Timber Grading Rules (Anon. 1999). Figure 3.5 shows the Saw2003 breakdown simulation software interface.

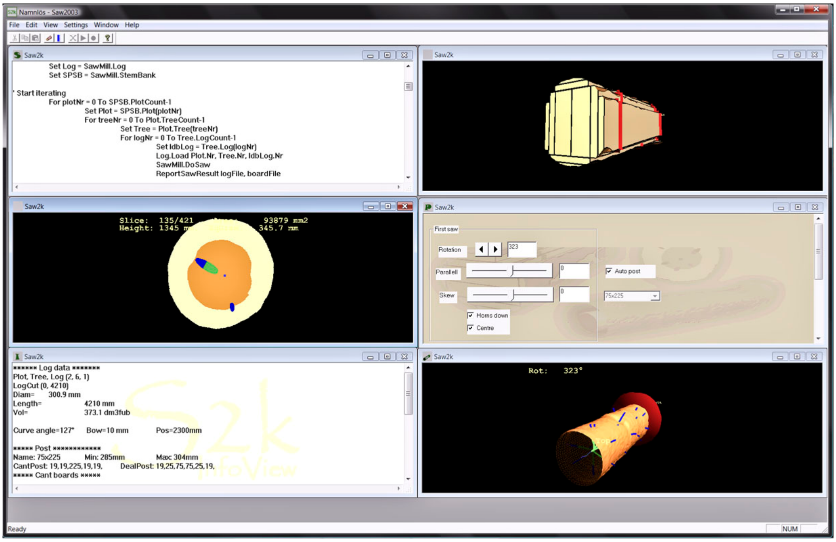


Figure 3.5 The Saw2003 breakdown simulation software interface (Nordmark 2005).

The software is capable of regenerating and displaying the log in a 3-D representation of the outer shape as well as the internal structure, *i.e.*, sound and dead knots, knot position and knot geometry. Each generated board can be viewed and checked on the screen as well as in a detailed printable report. The default report shows achieved board dimensions, volume yield, board value, total value, *etc.*

The software is capable of doing the following:

- Utilize the Stem Bank log-parameter files as input data
- Apply cant-sawing and generate boards by using predefined sawing classes, quality definitions, sawing patterns and price lists
- Use Nordic Timber Grading Rules in board edging, trimming and grading procedures
- Apply straight or curve sawing
- Apply automatic or manual positioning of the log face to the saw blades in the first and second saw
- Use automatic or manual "Horns Down" positioning in the first sawing machine
- Use flexible settings for sawing setup with user-defined scripts, e.g., for batch simulations
- Optimize value yield
- Calculate and export the total board volume and value yield to a printable file

The grading rules define allowed wane on boards and state limits and allowed sum of sound- and dead-knot diameter. Boards are graded A, B or C where Grade A has the strictest allowances and grade C has the widest allowances. Every board is graded and trimmed, and the value is set according to quality, achieved product, length and price per m^3. Once the sawing procedure is completed, a detailed report is generated.

3.5.1 Sawing Classes - Posting list

The basic concept for the breakdown process is that the volume and value yields realized from every single log should be optimized by utilizing the most appropriate sawing pattern and applying optimal positioning and rotation in the sawing machines. Therefore, it is an essential aspect of the optimization of the breakdown process to define the sawing classes and their related sawing patterns, *i.e.*, the posting list. The posting list also defines the position and width of the sawing classes, and the logs are initially sorted into these predefined classes when they arrive at the sawmill.

Swedish sawmills commonly use predefined sawing patterns based on customer demands, *i.e.*, dimensions required by the market. The logs are initially scaled and sorted into groups when they arrive at the sawmill. These groups contain logs with a smallest top diameter within the stated limits, normally in intervals from 10 to 20 mm in width. The sawing-class limits are individual for every sawmill and are for this reason often classified as confidential information. The different sawing classes and the corresponding sawing patterns are combined in a post list covering groups with top diameters from approximately 100 mm to 400 mm. Each sawing class/pattern can be optimized with regard to class width and distance from the lower class limit to the diagonal measure of the sawing pattern. However, the combined post list must consider and maximize the value and volume yield for the entire sawmill production.

3.5.2 Quality definitions

The Saw2003 simulation software was set to utilize the Nordic Timber Grading Rules for grading and trimming. The different products are normally defined and reported as qualities A, B and C. In this study, the centre boards were always graded as A quality because of demand for least allowed wane presence on centre boards and because knot definition was turned off during the simulations performed in this study. The strict wane limitations on the centre boards allow a maximum of 1 mm of wane on the edge. However, the allowed wane on the side boards was governed by the common rules stated in Nordic Wood (Anon. 1999).

3.5.3 Price list

The boards were priced according to Table 3.1 Boards classified as D are chipped. The chip price was set to 200 SEK per m^3.

Table 3.1 Price list used during simulations. B and C qualities are not applied on centre boards because of allowed wane presence and turned-off knot definition.

Grade	Centre Board (SEK/m^3)	Side Board (SEK/m^3)
A	1850	3000
B	(1600)	1400
C	(1000)	1100

3.6 Discrete Event Simulation (DES)

When a process becomes complex, whether it is production related or some complicated economical transaction, its behaviour and output also become difficult or impossible to comprehend, predict or take in. This is particularly the case when the occurrences of events vary over time or when input values are random, for example, in a typical dynamic production process. In this case, it is appropriate to use simulation techniques, assuming the process can be described in logical and mathematical terms.

3.6.1 ProModel v6.0 Discrete Event Simulation Software

In this study, ProModel v6 software was used (ProModel Corp, USA). The ProModel software is a 2-D discrete event simulation program. The software is able to design and import icons as well as background layouts from CAD software in order to visualize products, machines or facilities. This level of visualization makes it possible to build a scale model in which it is easy to understand the process flow, products and resources included. The modelling process in the ProModel software is adapted to focus on the production setup rather than on programming. If needed, however, a complete simulation language is available for use in more complex programming. Machines, products, events, *etc.*, are inserted into the model as predefined-but-adaptable elements.

Figure 3.6 shows the simulation software interface and the developed sawmill model.

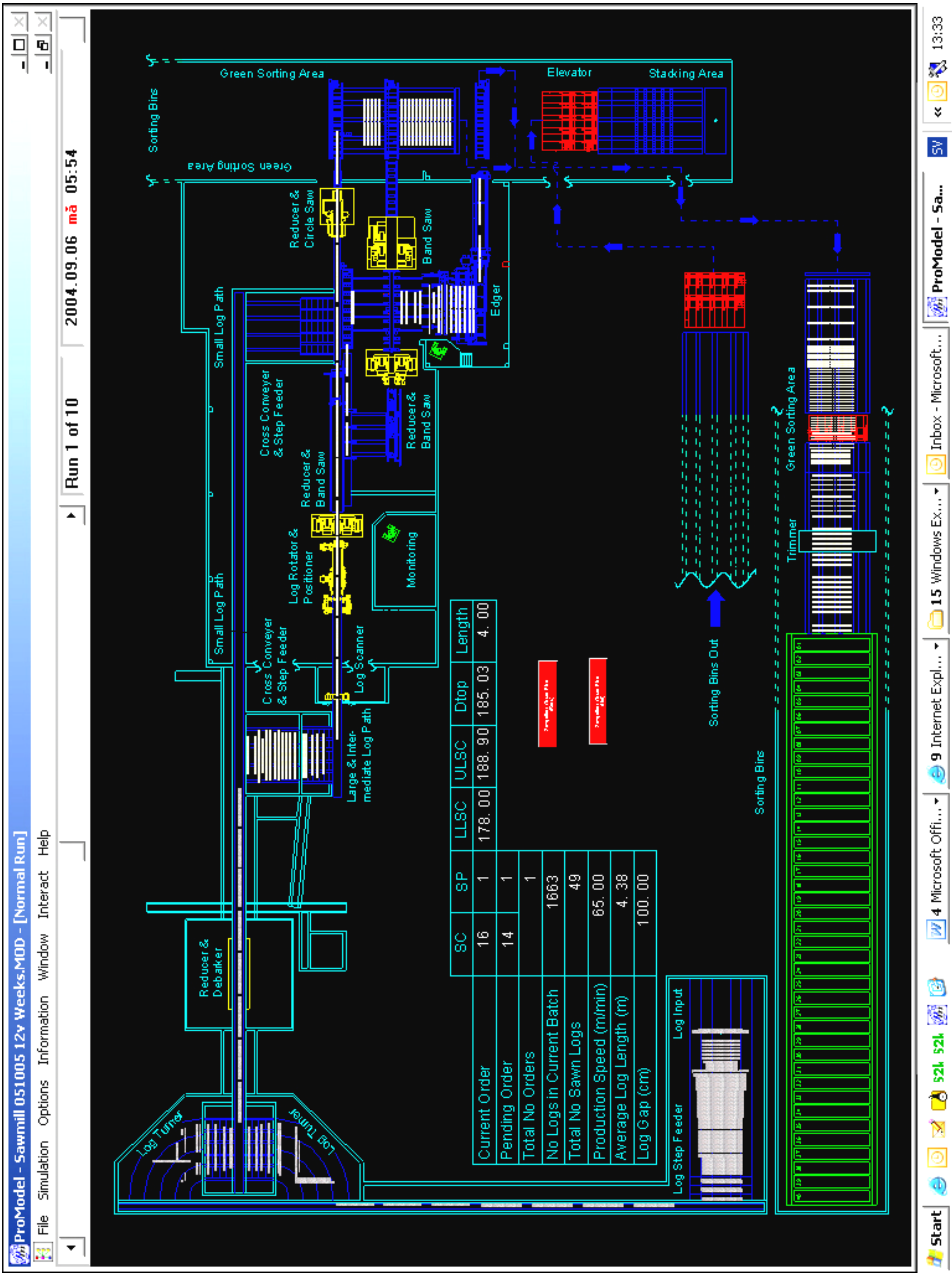


Figure 3.6 ProModel Discrete Event Simulation Model.

3.6.2 DES Fundamentals

Discrete Event Simulation (DES) is a powerful and flexible tool for handling and analyzing complex processes and dynamic events. DES can be used to analyze the impact of proposed changes in production or of alternate strategies. Making a digital model of a real process with a performance and output close to a real or suggested process permits the user to perform advanced experiments in order to create decision support and help determine measures for improvement.

A principal benefit of a discrete event model is that it makes it possible to evaluate and test ideas or strategies before implementing them in the real system. Interference with the actual production system is thus minimized.

DES modelling and simulation techniques have been used for analysis and development of production systems for more than 40 years. Initially, the technique was only available to a limited number of specialists skilled in unique simulation languages, and was thus not available for use by industrial engineers and production staff. As a result of the rapid development of cheaper and more powerful personal computers during the late 1980s, cheaper and user-friendlier simulation software was developed. This made the technique available to production staff, and the improved software also provided a tool that could be used to visualize, for example, a planned production line.

DES has been used more frequently for the last two decades in manufacturing industries as an optimization tool applied during planning for new plants or for minor changes. At present, large companies such as Volvo and GM have stated that all major changes in their production lines should be evaluated through simulation techniques before they are implemented. This tool is still not commonly used in the wood manufacturing industries, though knowledge and usage of DES is on the increase even here. The technique has been used for planning new plants for, for example, flooring manufacture (Johansson 2002). Johansson emphasizes the importance of using the DES tool for decision support.

Some work has also been done in sawmill simulation concerning the effects of machine replacements and for defining scenarios for improving grade recovery (Dogan *et al.* 1997). That study describes the benefits of simulations used as a decision support, as well as the help they provide during the entire project, *i.e.*, as an aid for the staff to learn and understand the processes involved. However, there are pitfalls to be aware of. Lack of reliable data or excessive detail in the modelling phase can easily overrun both time and budget.

A Discrete Event Simulation model can be described as a logical description of how a system works and performs. The system can be, for example, a production line, an emergency reception at a hospital or a description of how bank transactions work. In general, there are no limits to the types of systems or processes that can be modelled. Dedicated simulation software is commonly used in order to create a digital model of an existing or planned system, thus visualizing the system at the same time. There are many programs available on the market at different prices and user levels.

A DES model is also capable of representing complex and dynamic events caused by random occurrences. Simulation is thus used as a decision support in order to:

- Predict results of actions
- Evaluate effects of modifications
- Identify bottlenecks and problem areas
- Increase system knowledge
- Visualize and communicate planned changes to the staff

Modelling requires detailed knowledge about the system and is therefore never a one-man job, and it is important to execute the work as a structured project. The team selected must always consist of personnel from all areas of the simulated system.

A DES model should contain enough details to provide a proper representation of the system without containing unnecessary information. If the modelled system in not completely defined, it is still possible to make a rough model by beginning with an approximation and gradually refining the model as knowledge and understanding improve.

As the model is refined, it also becomes more accurate. This “step-by-step” method also makes it possible to create and handle models of large and complex systems. A principal benefit of a discrete event model is that it makes it possible to evaluate and test ideas or strategies before implementing them in the real system. Interference with the actual production system is thus minimized.

Many companies have explored benefits beyond just providing a look into the future (Banks 2004). These advantages are mentioned by many authors (Banks *et al*. 2000; Law et al. 2000; Schreiber 1991) and include the following areas:

- Making correct choices and wise investments
- Compressing and expanding time
- Understanding "Why?"
- Exploring possibilities
- Diagnosing problems
- Identifying constraints
- Visualizing the plan
- Achieving commitment and consensus
- Preparing for change
- Specifying requirements
- Training the team

However, there are disadvantages to simulation, such as:

- Simulation results might be difficult to interpret
- Model building requires special training
- Simulation modelling and analysis can be time consuming and expensive
- Simulation might be used inappropriately

The listed areas of advantage and disadvantage are further discussed below.

1. Making correct choices and wise investments

Using simulation gives the user the ability to test every aspect of a major proposed change or modification without committing large resources at an early stage of the project. This is crucial, because once the contracts have been signed or material-handling systems have been installed, changes and corrections can be very expensive. Simulation allows the operator to test designs without heavy investment. The typical cost of a simulation study is substantially less than one percent of the total amount expended for the implementation of a design or redesign. Because the cost of a change or modification to a system after installation is so great, simulation is a wise investment.

2. Compressing and expanding time

By compressing or expanding time, simulation allows the user to speed up or slow down events so that they can be thoroughly investigated. If desired, it is possible to examine an entire shift in a matter of minutes or to examine all the events that occurred during one minute of simulated activity.

3. Understanding "Why?"

Managers want to know why certain phenomena occur in a real system. Simulation can determine the answer to the "why" questions by reconstructing the scene and conducting a detailed examination of the system. It is not possible accomplish this with a real system because it is too complicated or complex to survey or control it in its entirety.

4. Exploring possibilities

One of the greatest advantages of using simulation is that once a valid simulation model has been developed, it is possible to explore new policies, operating procedures and methods without the expense and disruption of experimenting with the real system. Modifications are incorporated into the model, and the user observes the effects of those changes on the computer simulation rather than on the real system.

5. Diagnosing problems

The flow of activity in a modern factory or service organization is very complex. It is often so complex that it is impossible to consider all the interactions taking place at a given moment. Simulation enables better understanding of the interactions among the variables that make up such complex systems. Diagnosing problems and gaining insight into the importance of these variables increases a staff's understanding of their effects on the performance of the overall system.

6. Identifying constraints

Production bottlenecks give manufacturers headaches. It is easy to forget that bottlenecks are an effect rather than a cause. However, by using simulation to perform bottleneck analysis, the user can discover the cause of delays in work in process, information, materials or other processes.

7. Visualizing the plan

A simulation model can take design beyond CAD layouts using the animation features offered in many simulation packages. A 2-D or 3-D animation allows the project team as well as the staff involved to see the facility or organization running from various levels of magnification. This visualization also enables detection of design flaws within systems that appear credible when seen on paper or in a 2-D CAD drawing.

8. Achieve commitment and consensus

Simulation provides an increased objective basis for decision-making. It is easier to approve or disapprove designs, because it is possible to simply select the designs and modifications that provided the most desirable results, whether it be increasing production or reducing the waiting time for service.

If the model and the data it is based on are reliable and accepted by the personnel involved, the simulation results will also be accepted. In order to maintain commitment, it is also very important to consider suggestions and ideas conveyed by the staff.

9. Preparing for change

Answering "what-if" questions is important for both designing new systems and modifying existing systems. During the problem-formulation stage of a simulation study, different scenarios should be discussed with everyone involved in the project so that the model will be built correctly and perform adequately in order to answer the correct questions. What if? The options are unlimited.

10. Training the team

Simulation models can provide excellent training when designed for that purpose. When a model is used in this manner, the team provides decision inputs to the simulation model as it progresses. The team, and individual members of the team, can learn from their mistakes and learn to operate better. This is much less expensive and less disruptive than on-the-job learning.

11. Specifying requirements

Simulation can be used to specify requirements for a system design, for example, the required specifications for a particular type of machine to achieve a desired goal in a complex system. By simulating different capabilities for the machine, it is possible to establish the requirements.

The disadvantages of using simulation technique can include areas such as:

1. Model building requires special training

Model building is an art that is learned over time and through experience. Furthermore, if two models of the same system are constructed by two competent individuals, they might have similarities, but it is highly unlikely that they will be identical. The results will also differ, but not by much.

2. Simulation results might be difficult to interpret

Because most simulation outputs are essentially random variables (they are usually based on random inputs), it might be hard to determine whether an observation is a result of system interrelationships or randomness.

3. Simulation modelling and analysis can be time consuming and expensive

Limited financial resources for modelling and analysis might result in a simulation model or analysis that is not sufficient to the task.

4. Simulation might be used inappropriately

Simulation is used in some cases when an analytical solution is possible, or even preferable. This is particularly true in the case of small queuing systems and some probabilistic inventory systems, for which closed-form models (equations) are available

However, these disadvantages can be countered as follows:

1. Simulators make model building easier

General simulation packages have been developed that contain models that only need input data for their operation. Such models have the generic tag "simulators," templates or run-time models.

2. Statistical analysis tools make analyzing output easier

Discrete Event Simulation software includes statistical analysis software that has the capability to perform very extensive analyses. The use of these programs reduces data-handling time on the part of the user, although the user must still understand the analysis procedure.

3. Simulation is getting faster and faster

Simulation can be performed faster today than yesterday and will be even faster tomorrow. Some speed improvements come from advances in hardware that permit rapid running of scenarios. Other speed improvements come from simulation packages becoming easier to use. For example, the software includes templates for modelling material handling systems such as conveyors, path movers, overhead cranes, power-and-free systems, kinematics, tanks and pipes. The less work the simulation engineer must do, the faster the project can be completed.

4. Limitations of static models

Although static models are useful for small queuing and inventory problems, most real-world problems are too complex to be solved with these approaches. Simulation is necessary when there are a large number of random events and interactions in a system, which is true of most manufacturing problems.

3.6.3 Steps in a simulation study

The flow chart in Figure 3.7 shows a set of steps to guide a model builder in a thorough and sound simulation study (Banks *et al*. 2000).

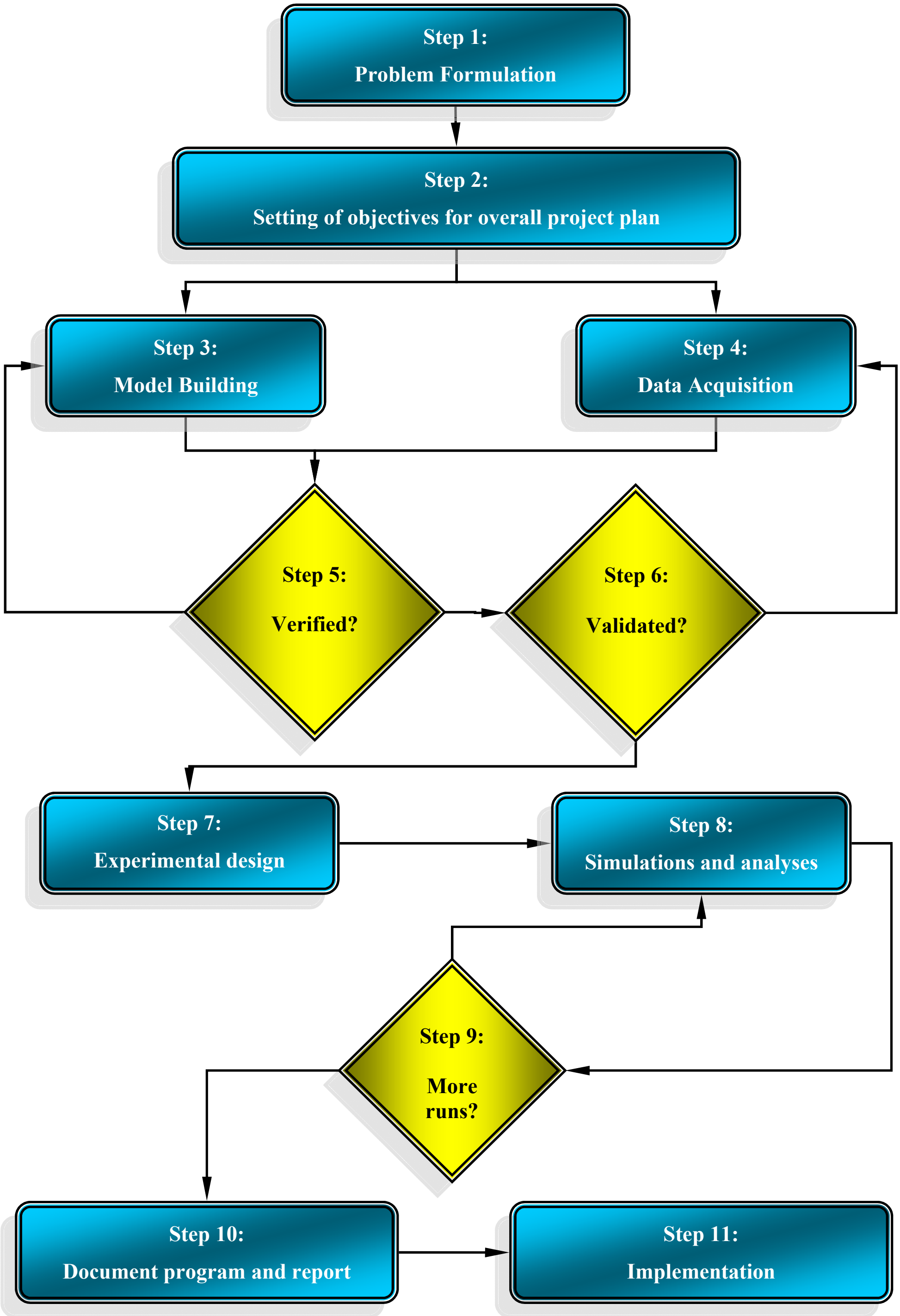


Figure 3.7 Discrete Event Simulation project flowchart.

Step 1: Problem formulation
Every simulation study should begin with a clearly formulated statement of the problem and a detailed description of which questions should be answered, what results are expected and why discrete event simulation is needed.

Step 2: Setting of objectives and overall project plan
The objectives, *i.e.,* questions to be answered and an overall plan for a simulation study must be determined. The project plan should include a preliminary statement of the various scenarios that will be investigated, level of detail in the model and of course, a time and cost schedule.

Step 3: Model building
It is recommended that modelling begin simply and that the model grow until a model of appropriate complexity has been developed. A common pitfall in this stage is to create a model that is unnecessarily complex or complicated, adding cost- and time-consumption.

Experience from previously done work shows that it is easier to achieve commitment and interest from the involved staff if they can recognize "their own place of work". Building of the model is therefore preferably started by inserting a scaled CAD drawing as a background representing, for example, the physical layout of a proposed line in a production unit.

The next step is adding products, routings for the products and all rules governing the production flow. This is also the part where the staff's detailed flow knowledge is essential and is furthermore known to increase. All vital rules that govern products and the production must be defined and implemented in the model. It is often possible to use entity attributes, a label or a number of labels, as a method for routing products or for detailed control of processing time in different machines. When a product arrives in a module, the attributes are read and the defined process rules decide which action to take governed by the attribute values.

Step 4: Data Acquisition.
When it comes to creating a model as close as possible to reality, breaks, stoppages and breakdowns must be added to the model. Model building and data collection are shown as parallel processes in the flow chart Figure 3.5, since the model can be created while data collection is progressing.

The acquisition of these data can potentially become the most time-consuming part of the entire project. It is common that 60% of the total time is spent on collecting and analyzing process data. Nevertheless, this is also the most critical part of a simulation project, because the outcome of this stage will set the standard of the model and the simulated results. Individual values are usually needed, not summary measurements. Lack of reliable data is usually the cause when a simulation project exceeds its time limit. One major problem is that even though each and every company monitors its production at some level, the monitoring systems are rarely adapted to produce data sets suitable for simulation models. A manual analysis is always needed, and the analysis requires the trained eye of a skilled operator to detect errors in the data.

Step 5: Model verification
Verification refers to the process of determining and ensuring that the model is working properly according to the defined rules. Verification of the model is extremely important, because a faulty model will not perform as expected, thus producing bad simulation results. This part is preferably done in close cooperation with all the staff involved. Verification of the model is extremely important, because a faulty model will not perform as expected, thus producing bad simulation results. There are many common-sense ways to perform verification. Balci (1998) presents more detailed information on the topic.

Step 6: Model validation
Validation is the determination of whether the model is an accurate and credible representation of the real system. If there is an existing system (called the base system), then an ideal way to validate the model is to compare the model's output to that of the base system. When designing a new system, there is rarely a base system available; hence, the validation is more complicated. In this case, the project team must decide when the model should be approved.

Step 7: Experimental design.
For each scenario that is to be simulated, decisions need to be made concerning the length of the simulation run, the number of runs necessary and the manner of initialization.

Step 8: Simulations and analyses.
Production runs and the subsequent analyses are used to estimate measures of performance for the scenarios that are being simulated. Multiple simulations with the same settings must be carried out in order to calculate an average value and observe trends. The number of simulations needed is dependent on the number of random variables included in the model.

Step 9: More runs?
Based on the analysis of runs that have been completed, the simulation analyst determines whether additional runs are needed and whether additional scenarios need to be simulated.

Step 10: Document program and report results
Documentation is necessary for numerous reasons. If the simulation model is going to be used again in the future, and perhaps by other users, it is imperative to understand how the simulation model operates. The results of all the analyses should be reported clearly and concisely and presented to the staff involved. This will enable the project group to review the final formulation, the alternatives that were addressed, the criteria by which the alternative systems were compared, the results of the experiments and recommendations.

This will also create confidence in the performance of the simulation model so that the client can make confident decisions based on the analysis. Additionally, modifying a model is much easier with adequate documentation.

Step 11: Implementation
The report prepared in step 10 stands on its own merits and is provided as additional information that the client can use to make a decision. If the client has been involved throughout the study, and the simulation analyst has followed all of the steps rigorously, it is likely that the implementation will be successful.

3.7 Distributed Process Monitoring System (DPMS)

In order to be able to continuously monitor and register data from different sawmill processes, a Distributed Process Monitoring System (DPMS) was developed based on distributed modules with sensors connected via WLAN to a main PC server. Figure 3.8 shows the principal structure of the mobile diagnostic tool.

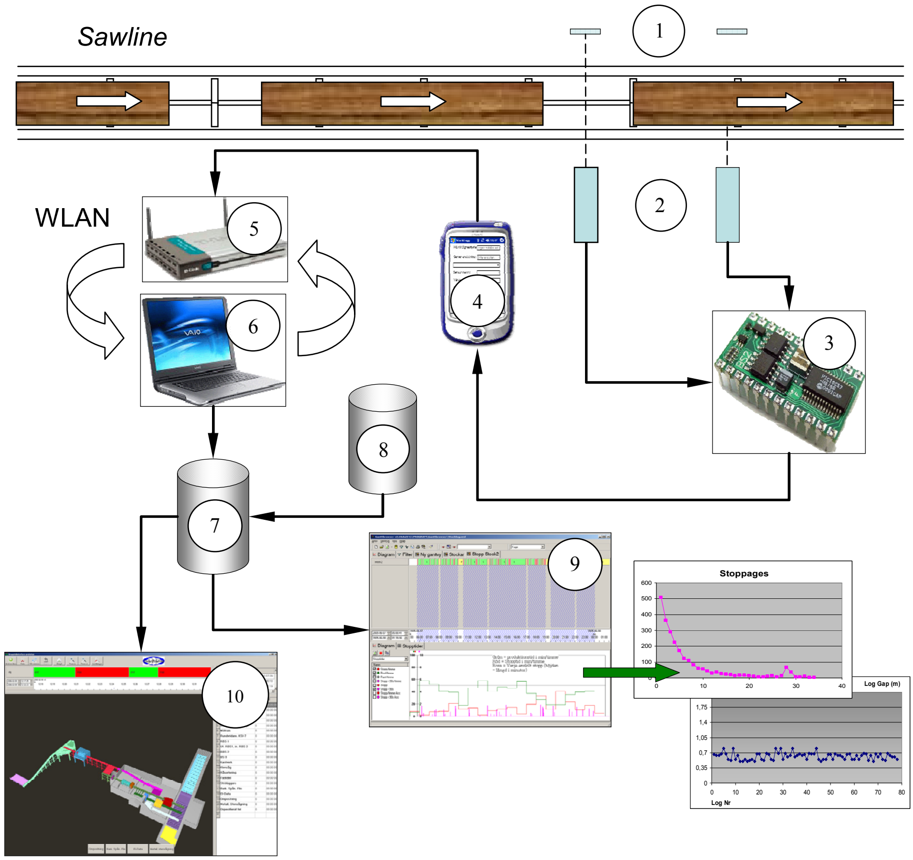


Figure 3.8 Basic structure of the Distributed Process Monitoring System, DPMS.

1. Reflectors
2. Sensors
3. I/O Basic Stamp 2
4. PDA
5. WLAN Access Node
6. Server
7. Database
8. Auxiliary Database
9. Analysis Tool – GanttBrowser
10. Graphical Error-report System

3.7.1 Basic Concept

The system consists of a PC server hosting a database (6 and 7, Figure 3.8). The server is preferably located in the monitoring room, and a number of sensor units are bidirectionally connected via WLAN Access Nodes and a WLAN network (5). The number of units is limited to 254, and every unit can handle and transmit signals from four individually addressed sensors (1 and 2). The function and performance of the system can be monitored remotely via the Internet. The system is mobile and flexible and is capable of simultaneously monitoring and registering data from scattered locations at a sawmill, thus collecting information for making a comprehensive diagnosis.

The system is also capable of collecting data from other databases (8). This could include information about current sawing class, sawing pattern, log length and top diameter, feed speed, *etc*.

The system is built from easily replaceable standard parts and products. The system is adapted to use digital reflective, diffuse, through-beam (transmitter/receiver) or inductive sensors, but the chosen system architecture also enables data from, for example, image-processing cameras and other equipment to be transmitted. The PDA unit (4) is a standard Pocket PC and contains the most complex software in the system. The PDA handles sensor id settings and signal configuration from the I/O unit (3).

Before the data are ready to be transmitted via wireless WLAN, they are time-stamped and packed. This procedure is controlled by a Session Message Handler (SMH) in order to ensure proper transmission in case the network is temporarily down. If this is the case, the SMH will queue the data packages and send them to the server when the network is available.

The software in the PC Server, the Personal Digital Assistant (PDA) and the I/O-unit can be configured individually. In this way, optimal signal processing can be achieved. The I/O unit receives signals from the sensors and forwards them to the PDA via a dedicated transfer protocol. The Basic Stamp 2 I/O unit utilizes a built-in software language. If analogue sensors are used, the unit can handle these signals if an A/D converter is added. The transmitted data are received by the PC server and stored in a database. The server also acts a master unit to the distributed PDAs by sending synchronized time signals to all monitoring units. This ensures that the clock time in all units is synchronized and constantly updated. In order to analyze and visualize the data on a time line, the GanttBrowser software (9) developed by DataPolarna AB was used.

3.7.2 Error-Cause Reports

In systems in use today, incorrect or missing stoppage reports are mainly a consequence of complicated user interfaces and/or unmotivated operators. In some cases, the complicated data systems even constrain production, because errors must be reported before the sawing line can be restarted. Sawmill operators quite naturally prioritize the production of boards, and it can therefore be difficult to motivate them to continuously report errors if reporting is complicated by the provided system. Furthermore, this problem will increase if errors are frequent. A new graphical error-report system and interface were therefore developed and adapted to the DPMS in order to simplify and improve the error-report procedure (Figure 3.9).

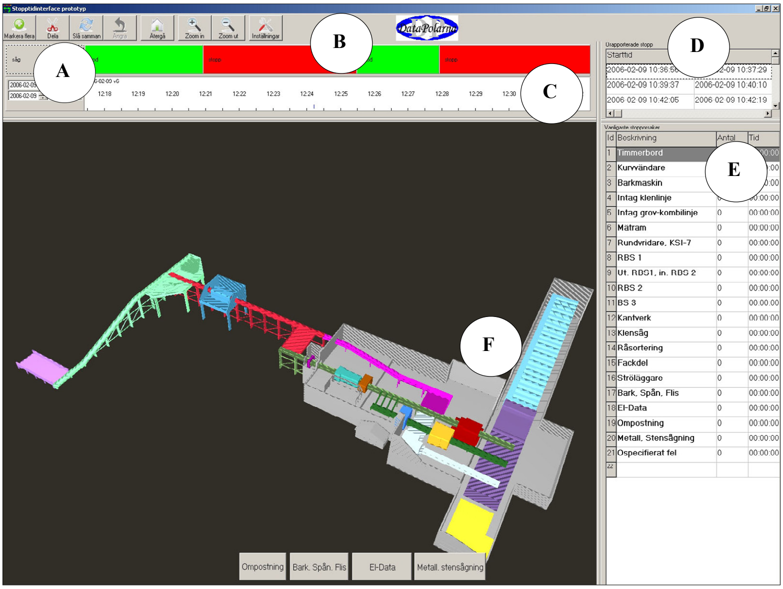


Figure 3.9 Graphical Error-report Interface.

A. Graphical Interface on touch screen.
B. Events.
C. Time scale.
D. Stoppage and time of event.
E. Error Cause List.
F. Graphic 3-D layout.

The concept is based on a graphical process view of the sawmill and includes the following features: A touch screen (A) is used for a graphic presentation of stops (D), sawmill layout (F), Time scale (C) and events (B). When the operator wants to report an error, he or she selects the appropriate machine or area by pointing on the screen. The choice is confirmed on the screen by a blinking machine or area.

If a detailed report level is desired, a pop-up menu with proposed errors is showed on the screen. The error can then be reported by picking the correct predefined error cause. If preferred, the graphical interface will zoom in closer on the chosen area, enabling a more detailed choice at the next level.

All work stops and errors are registered and queued in the system and displayed visually on the screen. The reported stoppage and cause of error are then stored in the DPMS database. This feature enables reporting of stops and identification of causes while production continues to run normally.

The level of detail for reported errors and causes can be configured. At the basic reporting level, errors are referred to an area, for example the debarker. At the highest level of detail, errors in, for example, the debarker's sensors, motors or power supplies can be reported.

3.7.3 GanttBrowser analysis software

Appropriate tools for data analysis and presentation are important to use in order to enable an effective workflow and efficient presentations of results. This becomes even more crucial when large amounts of data from related processes are processed and analyzed. It is often appropriate in such cases to present data from parallel processes as time-related graphs.

The registered activities and events are visualized on a timescale in the Gantt-Browser (Figure 3.10) as colour-coded blocks or plotted curves. Various combinations of functions and graphs can be created by establishing and calculating new responses from mathematical formulas. The GanttBrowser can also utilize shift schedules in order to distinguish stoppages from regular breaks.

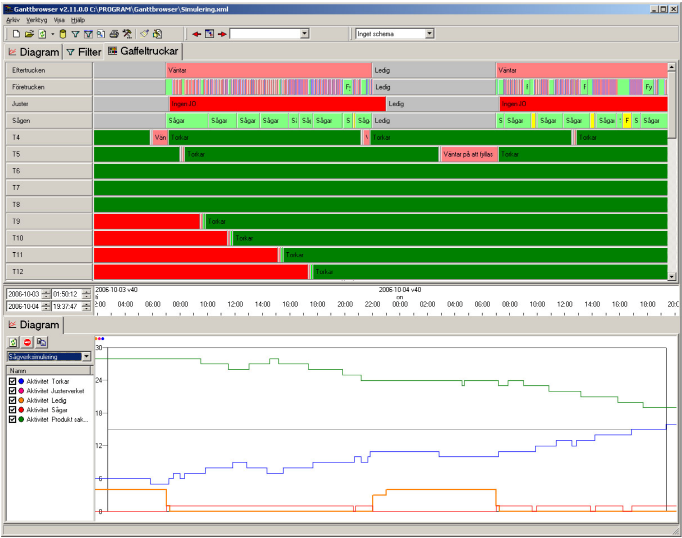


Figure 3.10 The GanttBrowser developed for analysis and visualization of time-related production data (DataPolarna AB 2006).

GanttBrowser (DataPolarna AB 2006) is software developed for visualization and analysis of time-based data. The software is capable of reading data from optional ODBC (Open Data Base Connectivity) sources, and options are available for data filtering, calculations, presentations and data export to Excel worksheets.

Skellefteå Church town – “Bonnstan”

4 Total Quality Management approaches

"Better to ask what can be improved rather than why we fail".

—*Unknown thinker*

4.1 Sawmill prerequisites

The comprehensive objective of every company and its management is to maximize profit and to continuously improve productivity; *i.e.*, the calculated difference between revenues and costs is expected to be positive and maximized. This goal can be achieved by improving process quality and utilizing methods to minimize equipment and material losses. However, a vital part of this work is to create involvement and commitment from the entire staff—they are the ones that do the work.

The import of optimizing production processes in order to increase productivity is twofold because low costs will improve prerequisites to outlast low conjunctures and furthermore enable maximized profit during economic boom.

The productivity concept is an often and widely used expression, but as yet, no unambiguous definition exists. "Productivity is the ratio of output to input where input consists of labour, material, capital and services and outputs are measurements of results in products or services" (Juran *et al*. 1988). Commonly used definitions are "the number of produced parts per time unit" or "the number of produced and approved parts per time unit". However, this definition has flaws, because it does not consider whether production is profitable or not.

Helling (1991) presents a list of productivity definitions clearly indicating a close and positive connection between productivity and quality. For example: *"It is the certainty of being able to do better today than yesterday, and less well than tomorrow."*

However, these definitions should still be handled with care and common sense, because in the sawmill industry, raw material prices as well as customer prices are very much outside the control of the individual sawmill. Even when a sawmill is able to increase its equipment performance to some degree, profit can still be diminished by increased raw material costs. Fair effectiveness and productivity rates should therefore be compared under similar conditions.

In the comprehensive view, improvements in the sawmill process will also place demands on the planning process for raw-material supply. The sawmill must be supplied with adequate raw material at the right moment to be able to efficiently produce the demanded products. This also underscores the importance of viewing the total sawmill process as an integrated process including raw material acquisition, planning, production and sales.

The main purposes of creating a planning model for the sawmill (Johansson 1978) are thus:

- To decide and predict the quantity of demanded products during a period
- To decide when the appropriate logs should be purchased and delivered at the sawmill
- To decide how the wood products should be most efficiently produced

Sawmill production is sometimes regarded as a special case requiring special and different production rules. However, the main difference between mechanical industries and sawmills concerns the raw material, *i.e.*, the logs. The staff at an assembly plant can state its demands on parts, raw material and quality in advance, thus always knowing what material they will use in production and what qualities the expected final product will have.

The sawmill staff, on the other hand, only know which products they require, but not the internal structure and properties of the actual log that will produce the demanded boards. Furthermore, the sawmill production flow is divergent and properties of every single log and board are different. The properties of the refined product, that is the boards, must therefore be evaluated prior to every further step in the conversion chain. Another area that differs from many other branches of industry is the varying production conditions during the seasons, as frozen logs exhibit different properties from nonfrozen logs.

An essential and continuous task for the sawmill production staff is therefore to monitor and control the incoming raw material. The aim is to always split “each and every log into adequate products” with a minimum of low-priced byproducts or waste, *i.e.*, chips and sawdust. Thus every log should be broken down to produce boards with an optimized value yield.

Even though the volume yield is commonly considered a vital productivity parameter, it is still the value yield and the production costs that govern and affect the total sawmill economy most.

Considerable experience and knowledge are needed to choose and classify the appropriate logs. However, advanced research during the 80s and 90s has produced a variety of methods, for example, log-scanning technology, to aid and support these decisions (Grundberg *et al*. 1999).

The sawmill logistics with regard to the production-flow logistics including feeders and saw machinery cannot, however, be regarded as special or complicated compared to comparable sectors of the mechanical industry. Nevertheless, the traditional serial production-line setup makes sawmill production sensitive to small disturbances.

4.2 Generic Total Quality Management Tools and Methods

"Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs".

—W. Edwards Deming, Point 5 in: Out of the Crisis (1982)

4.2.1 Introduction

Sawmill production could usefully adopt appropriate areas of process thinking and optimizing methods from the mechanical process industry. Increased productivity in mechanical assembly and production plants is achieved in the main by controlling processes and minimizing all kinds of losses in the conversion chain. Statistical Process Control (SPC) (Shewhart 1931), Total Productive Maintenance (TPM) and Overall Equipment Effectiveness (OEE) (Bergman *et al.* 2003; Nord 1997) are known Total Quality Management tools and methods especially developed to focus on process control as well as on minimizing losses and optimizing equipment performance.

Process control and optimization tools in sawmills have, however, not followed the rapid development of automation and raised production speed. At a modern sawmill, great amounts of data are generated that can be utilized for process control, but a lot of the data needed are also lacking. For instance, few sawmills know if it is running with an optimal feed speed or log gap, what the optimal saw blade thickness is or how the feed speed affects measurement accuracy, positioning accuracy and share of downtime.

4.2.2 Total Quality Management

Total Quality Management (TQM) is a comprehensive management concept that is focused on customer needs and expectations as well as product quality. The main TQM focus core values are (Bergman *et al*. 2003):

- Management and leadership commitment
- Focus on customers needs and expectations
- Base decisions on facts
- Focus on processes
- Staff involvement
- Improve continuously

These core values are the basis for the culture of the organization. The concept can also be seen as a management system encompassing values, methodologies and tools Figure 4.1 (Hellsten *et al.* 2000). Methodologies and tools listed in the figure are just examples, supplemented, however with areas of specific interest in this study such as OEE, simulation techniques, process monitoring systems and visualization tools. Suitable tools and methodologies exemplified in the management system are expected to support the core values and are needed in order to achieve an effective improvement process (Bergman *et al.* 2003).

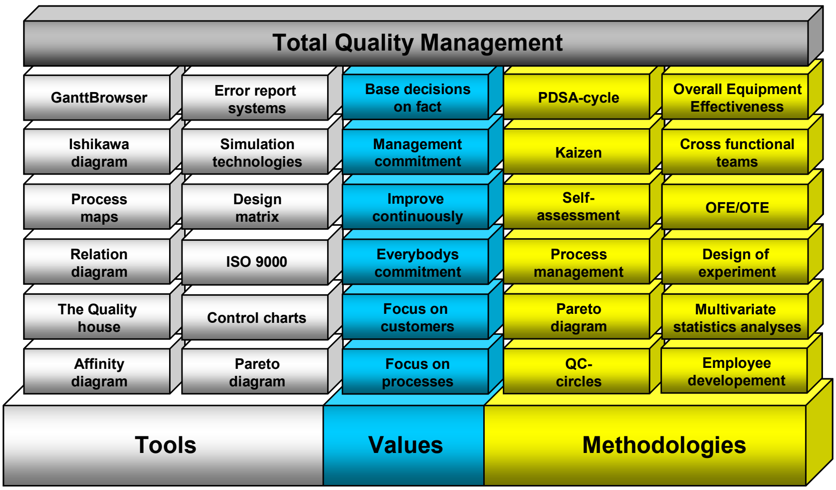


Figure 4.1 The Total Quality Management concept described as a management system based on three main areas; tools, values and methodologies.
Source Hellsten et al. 2000.

The methodologies will not work effectively without the use of specific and suitably chosen tools according to Klefsjö et al. (1999). The basic message is simple and easy to understand: make the staff aware of how their behaviour, skills, commitment and involvement affect quality and customer relations. The "ultimate" goal can be achieved when and if the staff accepts this as an "at-work lifestyle". On the other hand, the staff must always know that management values the efforts they make.

A number of quality awards have been instituted all over the world in order to stimulate and reward successful work on quality management and improvement. The awards are given to companies that have shown great success in increasing productivity and decreasing losses. The common factor among these award winners is the focus on quality management, education and preventive activities to reduce quality losses.

The Japanese "Deming Prize" was instituted in 1951 to honour W. Edwards Deming and his contribution and pioneering work for quality development in Japan (Bergman *et al*. 2003). In 1987, the American Malcolm Baldridge National Quality Award was instituted and confirmed in law by President Ronald Reagan. The Malcolm Baldridge National Quality Award Criteria for Performance Excellence are based on a foundation of core values and concepts for integrating business requirements within a result-oriented framework in order to implement TQM in companies and organizations and for individuals. (Vokurka 2001).

The stated core values and concepts are (Vokurka 2001):

- Visionary leadership
- Customer-driven organization
- Management by fact
- Valuing employees and partners
- Agility
- Organizational and personal learning
- Focus on the future
- Managing for innovation
- Public responsibility and citizenship
- Focus on creating value
- System perspective

The Swedish successor, The Swedish Quality Award, instituted in 1992 by the Swedish Institute for Quality (SIQ), is essentially based on the same core values. The major difference is that environmental protection aspects have been added to the Swedish version (Bergman *et al*. 2003).

The core values clearly state the importance of a committed leadership setting distinct directions and a customer-driven organization. Hopefully, however, all individuals will establish their own values and expectations according to the goals established by the leadership.

Customer-driven quality is a concept focused on customer satisfaction and the gaining of market shares and growth on that basis. The main issue to be addressed is that quality and performance are judged by customers. Focus is commonly placed only on external customers, but this principle applies regardless of whether they are considered internal or external customers.

A successful organization depends on information derived from measurement and analysis of performance. In order to achieve this, reliable and relevant information is vital to creating a confidence that changes are indeed implemented based on facts, not merely on assumptions or prior experiences. Successful companies challenged by global competition are also forced to create a base of knowledge and a capacity for flexibility and rapid change (Vokurka 2001).

The demand for flexibility can, however, easily be offset by the staff's desire for stability and security. Nowadays, secure life-long employment also requires a commitment to life-long learning. Creating a satisfying work environment where the staff expresses an urge to learn and practice new skills can thus become a considerable challenge for management.

It is possible to identify seven main tools or resources to use for potential improvements in the sawmill production process:

TPM – Total Productive Maintenance (comprehensive)
OEE – Benchmarking methods (comprehensive)
Staff involvement and commitment (comprehensive)
Saw Simulation (breakdown process)
DES – Discrete Event Simulation (logistic process)
Process monitoring (logistic and breakdown process)
SPC – Statistical Process Control (comprehensive)

The value of working with continuous improvements is a vital part of the TQM concept and is often visualized with the Plan-Do-Study-Act cycle (Figure 4.2).

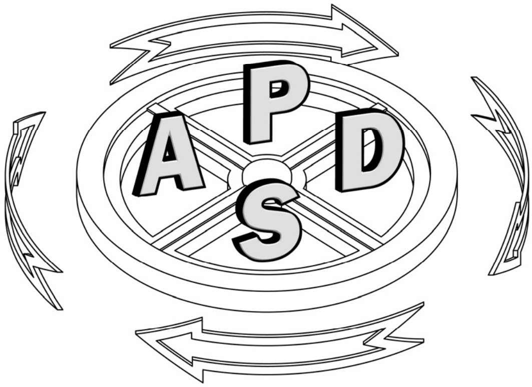


Figure 4.2 The PDSA-cycle describing a continuous improvement work approach.

An increased and optimized usage of a suitable "tool package" including benchmarking methods, simulation software, process monitoring and analysis tools forms a solid base from which to achieve increased productivity. However, it is crucial to avoid suboptimizations without considering a perspective on the whole. Furthermore, when these tools are in full and continuous use, they enable the implementation of Multivariate Statistical Process Control (MSPC) as a further step to accomplish a comprehensive and systematic process control.

4.2.3 Total Productive Maintenance (TPM)

In order to control and optimize the production process, the availability and performance of all the equipment and machinery must be monitored and controlled. Japan's industrial success during the last decades was founded when it imported and adapted the concept of preventive maintenance (PM) from the United States more than 40 years ago. The adapted version, Total Productive Maintenance, was defined in 1971 by the Japan Institute of Plant Engineers and includes five goals (Nakajima 1988):

- Maximize equipment performance – improve overall effectiveness
- Develop a system of productive maintenance for the life of the equipment.
- Involve all departments that plan, design, use or maintain equipment
- Actively involve the entire staff, from top management to operators
- Promote TPM through motivation management involving autonomous small-group activities

The goal of TPM is to increase equipment performance so each piece of equipment can be operated to its full potential and maintained at that level. The main goal can be separated into two parts: zero breakdowns and zero quality defects. To approach 100 percent quality yie1d is very difficult, but a strong belief that zero defects can be achieved is regarded as a vital concept.

The TPM method focuses on eliminating the Six Big Losses in order to achieve the five goals (Nakajima 1989):

- Breakdowns due to equipment failure
- Setup and adjustment
- Idling and minor stoppage losses
- Speed losses when equipment runs slower than design speed
- Quality defect losses
- Start-up losses

The design speed is the speed interval a machine or conveyer is designed to run within. If used below design speed, the equipment and the money invested are not utilized optimally. On the other hand, if the equipment is run at considerably higher than design speed, it will not perform as expected. For example, measurement accuracy is known to be directly affected by excessively increased speed (Grönlund 1981).

Table 4.1 shows the Six Big Losses, targets to achieve and examples from the mechanical industry (Nakajima 1989). The specific losses are further explained below.

Table 4.1 Improvement targets for losses (Nakajima 1989).

Type of Loss	Target to achieve	Examples from the mechanical industry
1.Breakdown losses	0	Reduce to zero for all equipment.
2. Setup and adjustment losses	minimize	Reduce setups to less than 10 minutes.
3. Speed losses	0	Bring actual operation speed up to design speed; then explore possibilities to make improvements in order to exceed design speed by 15 percent.
4. Idling and minor stoppage losses	0	Reduce to zero for all equipment.
5. Quality defect and rework losses	0	Extremely slight occurrences acceptable.
6. Start-up yield losses	minimize	

1. Breakdown losses

Breakdowns due to equipment failure—sporadic and unexpected breakdowns are usually obvious and easy to correct, but often account for a large percentage of the total losses in time. TPM focuses on the fact that breakdowns can and must be eliminated by planned maintenance.

2. Setup and adjustment losses

Setup times can be reduced considerably by making a clear distinction between internal and external setup time. Internal setups must be performed while the machine is down, thus causing loss of production time. External setups are completely or mainly performed while the production is running, thus minimizing losses. For example, a new set of circular saws can be prepared ahead of time so the actual change setup time that entails a production stop can be minimized.

3. Idling and Minor Stoppage Losses

Machine idling occurs when a running machine lacks parts to process or the gap between delivered parts is larger than the designed time. Idling in the sawmill production can be referred to as the fraction of the total production time the saw blades are not cutting wood, even though the machinery is running. Log gaps and lack of logs are the main causes of equipment idling.

Still, in most cases a limited fraction of idling must be accepted because of physical limitations in the equipment. For example, one log has to leave a specific feeder before the next one can arrive.

Minor stoppages are caused by temporary malfunctions and differ clearly from breakdowns. Normal production can be restored by removing the cause and restarting the machine. However, seemingly small problems such as short stoppages often have a dramatic impact on equipment performance, because the accumulated time can be surprisingly large. Short stoppages are also easy to overlook because they can be difficult to measure. If minor stoppages are to be reduced, production processes must be closely and continuously monitored (Nakajima 1989). Sawmill production is particularly sensitive to disturbances, because of the commonly used line-production setup and lack of parallel redundancy. Large, bulky logs produce more boards, and the green sorting area can easily become a bottleneck. If there are small or no buffers at all between the sawing line and the green sorting area, a stop in the latter area will cause the whole chain to stop.

4. Reduced Speed Losses

Reduced speed losses refer to the difference between the design speed and actual operating speed of equipment. The goal is to eliminate the gap between the design speed and actual speed in order to obtain correct yield from invested money. In some cases, the operating speed must be lower than the design speed for quality reasons. For example, sawing accuracy in a sawmill is directly affected if the feed speed is pushed above the optimal speed. Equipment is often run at lower than ideal or design speed because of mechanical problems or variations in the raw material, but often the optimal speed is simply not known.

5. Quality Defect and Rework Losses

Quality defects in process and the resulting rework time are losses in quality caused by failing or malfunctioning equipment. In reality, reworking of sawn lumber rarely occurs. If the final board dimension deviates too much from the target size, the boards can in the best case be planed to a reduced dimension or sold at a lower price than expected, thus decreasing profit. Normally, the boards will be chipped. Quality defects can also occur if logs or boards are not handled with care through the whole conversion chain.

6. Start-up Losses

Start-up losses are yield losses that occur during the early stages of production, from machine start-up until production is considered stable. In some cases, a small part of the new batch is run and the results are then checked. The rest of the batch can then be finished after process calibrations.

4.2.4 Benchmarking

Benchmarking can be defined as the search for best practices that will lead to superior performance (Camp 1998). In a more detailed definition, it is called "a process for measuring a company method, process, procedure, product, and service performance against those companies that constantly distinguish themselves in the same category of performance" (Watson 1992).

Simply stated, benchmarking can be defined as a systematic project aimed at providing information to compare processes, solve problems or optimize a process. Hence a benchmarking study can also be defined as a research project (Watson 1992; Emory 2002).

However, benchmarking methods are also commonly used and adapted to compare the performance of a production process. The investigated process is monitored and measured before and after changes are made. The new capability value is then compared to the earlier, thus giving a rate of improvement.

4.2.5 Staff involvement and commitment

"If you want to find out what's wrong and how to fix it, ask those who do the work."

This simple principle was used by Dr. C. C. Crawford in the 1920s, Walter Shewhart in the 1930s and Edward Deming and Joseph Juran in the 1940s; the Japanese industry integrated it into their design and production in the 1960s and 1970s. Methods to capture employee know-how and encourage employees to influence the decision making system began with Dr. Crawford's 1926 invention of his "Crawford Slip Method" to simultaneously capture written opinions, problem statements, concerns, ideas and recommendations of a group.

In his book *Using the Crawford Slip Method*, H. William Dettmer (2003) explains step by step how to focus on the creativity and expertise of people with knowledge of a subject on the problems and challenges associated with solving them.

W. Edwards Deming has also stated in two of his 14 points (Deming 1988) the importance of committing the entire staff in the continuous work of improvement.

“Break down barriers between departments. People in research, design, sales, and production must work as a team, to foresee problems of production and in use that may be encountered with the product or service”. And further, “Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job”.

The frontline process operator of today, as well as management, plays a vital role in improving quality and productivity in the sawmill industry. This fact is sometimes easy for smaller industries to ignore, but it is nevertheless still vital to success.

A structured and predetermined management method is also needed if the improvement process is to be long lasting. Bamber *et al.* (2003) promotes cross functional team working in order to address effectively all the six big losses and hence improve overall equipment effectiveness (OEE). Cross-functional teams can possess the combined necessary skills and knowledge of an entire production system. Clifford and Sohal (1998) reports that one of the benefits of team working that companies recognize is increased productivity through improved machine efficiency, improvements in uptime and improved preventive maintenance.

4.2.6 Process-Monitoring systems and Process-Control thinking

One structural problem area is the common way of viewing each machine, monitoring system or data system as a detached system rather than as part of a greater process. This fact makes it difficult to access and survey the sawmill’s performance. Hence there is an identified need to introduce and use effective methods of collecting and connecting information, analysis and evaluation, as well as methods for rapid linking of results and adopted measures back to the production line.

A golden rule is that decisions and measures for change should always be based on facts (Deming 1988; Bergman *et al.* 2003). In order to be able to make such important decisions concerning improvements in production processes, reliable facts and data are a crucial necessity. Thus automatic and reliable systems for collecting process data must be implemented.

An adequate monitoring system must provide:
- Reliable and detailed process data
- Easily accessible data and process information
- Communication with other systems and databases
- Visualized process data and events
- Improved statistical data analysis capabilities
- A user-friendly graphical interface for continuous error reporting and monitoring

It is common in Swedish sawmills that short stoppages of up to 90 seconds are not registered and are therefore excluded from the stoppage data. This way of excluding parts will skew the process data, thus affecting analysis results and future decisions.

The reliability of present systems is also dependent on active operators, as the cause for the stoppage must be noted manually. The collected data is also often difficult to access and thus to analyze. Under these conditions, process control will be complicated and time consuming. Furthermore, when deviations and problems occur in the process, detection and corrective measures are delayed, with value loss as a result.

4.2.7 Statistical Process Analysis and Control

Statistical thinking involves examining the process, finding sources of variation and designing and executing experiments to identify and quantify their contribution to inefficiency.

The first principles of statistical process control (SPC) were outlined by Walter A. Shewhart in the early 1930s (Shewhart 1931). The use of SPC concepts and methods has since increased rapidly and become very important in most industrial sectors. The objective of these methods is to monitor the performance of a process in order to understand whether the process behaves as expected.
If the process deviates from the established limits, an SPC analysis should provide a suggestion to solve and correct the problem.

The basic assumption of SPC is that a process always functions within a state of statistically controlled limits unless special events occur.
A state of statistical control exists when certain critical process variables and/or product attributes stay close to their target values and do not change perceptibly. Only unavoidable and marginal fluctuations are accepted.

However, the SPC method was established when few process measurements were made, and production processes revealed few signals about the actual process status. This fact made it possible to apply control-charting methods to a limited number of variables and examine the charts one by one. Nevertheless, common control charts can give the false impression that process and quality variables are independent of each other.

Furthermore, conventional SPC and univariate control charts are not applicable to complex processes, because they ignore the correlations among process variables. Improved methods for creating, monitoring and controlling processes were established more than 50 years ago explicitly in process industries such as chemistry and pulp & paper. This work also enabled the development of Multivariate Statistical Process Control (MSPC) (Martens *et al.* 1989; MacGregor *et al.* 1995; Kourti *et al.* 1996; Kano *et al.* 1999).

Multivariate Process modelling is a multifaceted discipline. The method can be used for control and improvement of existing processes or for development of new processes (Umetrics 2001).

Improved monitoring systems and multivariate control of a process give the process operator advanced warning when the process is changing conditions and suggest the probable cause. Furthermore, an automatic feedback control system can be applied to take corrective actions and reduce variability in product and process variables.

Supervision of an existing process is accomplished by monitoring process data and comparing these to models based on historical data. By diagnosing causes for the events and removing them, the process can be improved (MacGregor et al. 1995). The model is examined to reveal the most influential process parameters. These parameters are then used to design experiments that may assist in the detection of better process conditions.

Regardless of whether an existing process or a new one is to be modelled, the objective and the performance of the data analysis are the same:

- Monitoring the state of the process.
- Understanding the relation between factors (X) and responses (Y).
- Optimization to achieve optimal process behaviour.

Chemical processes are often monitored at frequent time intervals, creating data sets with many variables and observations. This has increased the focus on multivariate statistical methods for the analysis, monitoring and diagnosis of process operating performance. Principal Component Analysis (PCA) and Partial Least Square (PLS) have often been used successfully and have proven to work efficiently with process data (MacGregor *et al.* 1995; Kourti *et al.* 1995).

The multivariate approach is appropriate for a number of reasons:

- Process deviations are often difficult to detect by looking at the variables one at a time. A deviation in a process is often expressed by a group of correlated variables rather than in the individual variables.
- Outliers, variables that break the general correlation, are easily detected.

The multivariate approach based on PCA and PLS offers a number of useful and informative tools that help the user to understand how and why a particular process event occurs. This information makes it possible to take corrective action in order to prevent similar occurrences in the future.

Knowledge about these factors makes it possible to optimize complex processes by introducing appropriate modifications to the most important factors (Umetrics 2001). Further, if a data set contains both factors and responses, they can be analyzed together by using PLS. A PLS model facilitates understanding of:

- Which X variables are influential for a particular Y variable
- Which X variables provide similar and unique information about the state of the current process
- How the Y variables are associated with each other

Recent approaches to multivariate statistical process control are based on multivariate statistical projection methods, PCA, PLS, multiblock PLS and multiway PCA. These methods not only utilize response data (Y), but also all of the available process-variable data (X). The conventional MSPC method has been further developed, and the present advanced methods outperform the earlier ones. Every operator or technician in the sawmill needs a toolbox containing the means to execute assignments. Such suitable tools have been developed and put into use in the mechanical industry and can easily be adapted to fit different production setups in sawmills.

4.3 Overall Equipment Effectiveness (OEE)

OEE is a measure of total equipment performance used to track and trend, the degree to which the asset is doing what it is expected to do (Williamson 2006). Nakajima (1988) introduced the original concept but the exact definition of OEE can differ over time, between applications and authors.

4.3.1 "Effectiveness" vs. "Efficiency"

The concepts of Effectiveness and Efficiency are two terms, frequently used in production or process-related discussions. The two terms are also applicable to quality management and leadership issues. It is however not so easy to understand the difference in implications between these two words since dictionaries often return the same translation. The definition also differs between areas of use.

A somewhat technically influenced definition is given by Farell (1957) declares that when one talks about the efficiency of a firm one usually means its success in producing as large as possible an output from a given set of inputs. This usage is generally accepted. A more easily conceivable explanation is that efficiency is how well you do something, and effectiveness is how useful it is.

For example, if a company is not doing well and they decide to train their workforce on a new technology. The training goes really well - they train all their employees in record time and tests show they have absorbed the training well. But overall productivity doesn't improve. In this case the company's strategy was efficient but not effective.

4.3.2 The OEE-concept

OEE is used as a comprehensive benchmarking tool for detailed analysis of production processes. The method is used to depict and focus on the areas of enhancement that provide the greatest improvement and return on asset. OEE also makes it possible to present a value of the current level of effectiveness, and the impact of continuous improvements can be measured, visualized and communicated back to the staff.

The use of OEE is also intended to develop and improve collaboration between asset operations, maintenance, purchasing and equipment engineering to jointly identify and eliminate/reduce major causes of poor performance since maintenance alone cannot improve OEE (Williamson 2006).

Overall Equipment Effectiveness was recognized as a fundamental method for measuring equipment performance beginning in the late 1980s and early 1990s (Gouvêa da Costa *et al.* 2002). Now it is accepted as a primary performance metric (Hansen 2001).

The OEE value is the calculated value derived from three OEE factors:

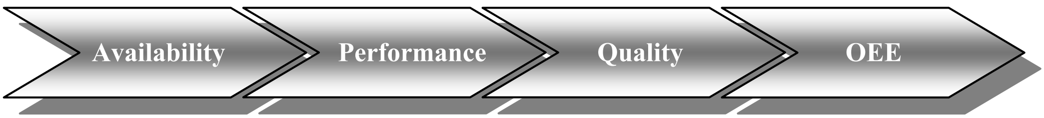
- Availability (A)
- Performance (P)
- Quality (Q)

Availability (%) x Performance rate (%) x Quality rate (%) = OEE (%)

The definition and use of OEE is not univocal and has been widely debated over the years. The differences are often subtle, but differences in definitions made by recognized OEE experts and between applications has led to considerable confusion for the users. (Bamber *et al.* 2003, Williamson 2006). OEE is a benchmarking concept suitable for comparing changes over a period of time. One fundamental mistake made by users has been to use OEE for comparing performances for machine-to-machine, plant-to-plant, or company-to-company.

OEE was designed to make comparisons on a specific machine or production line over a period of time rather than comparisons between, for example, two similar machines situated in different production units (Williamson 2006). This is also consistent with Ljungbergs conclusion that the use of OEE measurement is an effective way of analysing the efficiency of a single machine or an integrated machinery system (Ljungberg 1998).

No exactly defined OEE-formula exist but this is not to be regarded as a problem, but rather as an asset because the concept is supposed to be adapted to the topical process in order to utilize its potential. It is furthermore suggested by OEE-experts that whatever formula is used, the key to improving OEE is still constantly in the approach of both data collection and component calculation (A, P, Q) (Bamber *et al.* 2003).



4.3.3 The Purpose of OEE

Managers in general, want to have one simplified and clear metric that show how a process or the company performs. Managers appreciate such an aggregated metric instead of many detailed metrics (de Ron *et al.* 2005). What "performance" really means is according to Lebas somewhat contradictive since performance measures are poorly defined and few people agree on what performance really means (Lebas 1995). The most important objective of OEE is not to get an exact or optimum measure, but to create an incentive and framework for improvement related work (Ljungberg 1998, Jonsson *et al.* 1999).

Optimal performance rate is a matter for each firm and organization to define by different parameters such as available production capacity, sales market and staff. Performance is never objective, it is only a way of defining the expected achievements and where one wants to go (Lebas 1995).

This means that performance rates are difficult or even impossible to compare between production units or companies since circumstances are rarely identical (Leachman 1997). Lebas emphasizes that "understanding the process of performance generation not only facilitates the identification of measures and therefore of corrective actions, it allows for a clear deployment of strategy at all levels of responsibility". If we understand which of the steps in the process is defective, appropriate corrective actions can be identified (Lebas 1995).

For a long time it was considered adequate to measure the average productivity and use this as a measure of how well the process or company performed (Farrel 1957). Process analysis has furthermore over the years also to a high degree focused on availability and quality issues. These traditional metrics for measuring productivity, throughput and utilization are insufficient for identifying the problems and improvements needed to improve performance (Huang *et al.* 2003).

The OEE tool is an appropriate concept since it takes into consideration the changes and impact of three different factors. In assessing the performance of equipment in relation to the ideal production output, the ultimate goal is equipment that performs as follows (McKellen 2005):

- Operates 100% of the available time (availability 100%)
- Produces at 100% of the specified output (performance 100%)
- Produces 100% approved products (quality 100%)

However, things are never perfect in reality—OEE quantifies current effectiveness as percentages of the ideal state.

OEE is not intended as a monitoring or control tool. The main objective of OEE is not to create a metric; it is to identify the losses and supports a systematic work for process improvement initiatives (Bamber *et al.* 2000). Measurement tools are, however, a very vital part of the concept. OEE integrates practical management tools and techniques in order to achieve a balanced view of process availability, performance rate and quality and could provide topical information for daily decision. (Dal *et al.* 2000).

4.3.4 OEE-fundamentals

In his book Business Research Methods, C. William Emory presents a list of characteristics of good OEE benchmarking studies and research criteria:

- The purpose of the research should be clearly defined
- The research method should be repeatable
- The research should be planned to provide objective results
- Conclusions should be justified by the data
- The researchers should report any flaws in their research process and estimate the effect these may have on the results
- The analysis should identify the significance of the results, and the methods used should be appropriate

The author also states that it is important that the research staff performing a study should be known and should have a reputation for integrity. Nevertheless, the listed criteria are not useful just in benchmarking projects—they should be significant factors in all studies performed (Emory 2002).

Performance benchmarking methods are also highly suitable for achieving and improving knowledge about the actual processes as well as the result of the work done. When measures have been decided upon and implemented, the next vital step is to verify and show the impact of changes made. Availability and Quality are areas that are commonly focused on, but more variables are needed if a process is evaluated.

Figure 4.3 shows the main definition of the OEE concept (Nord et al. 1997). Initially, the available production time is calculated as the planned stoppages are separated from the unplanned, thus showing the remaining time available for production.

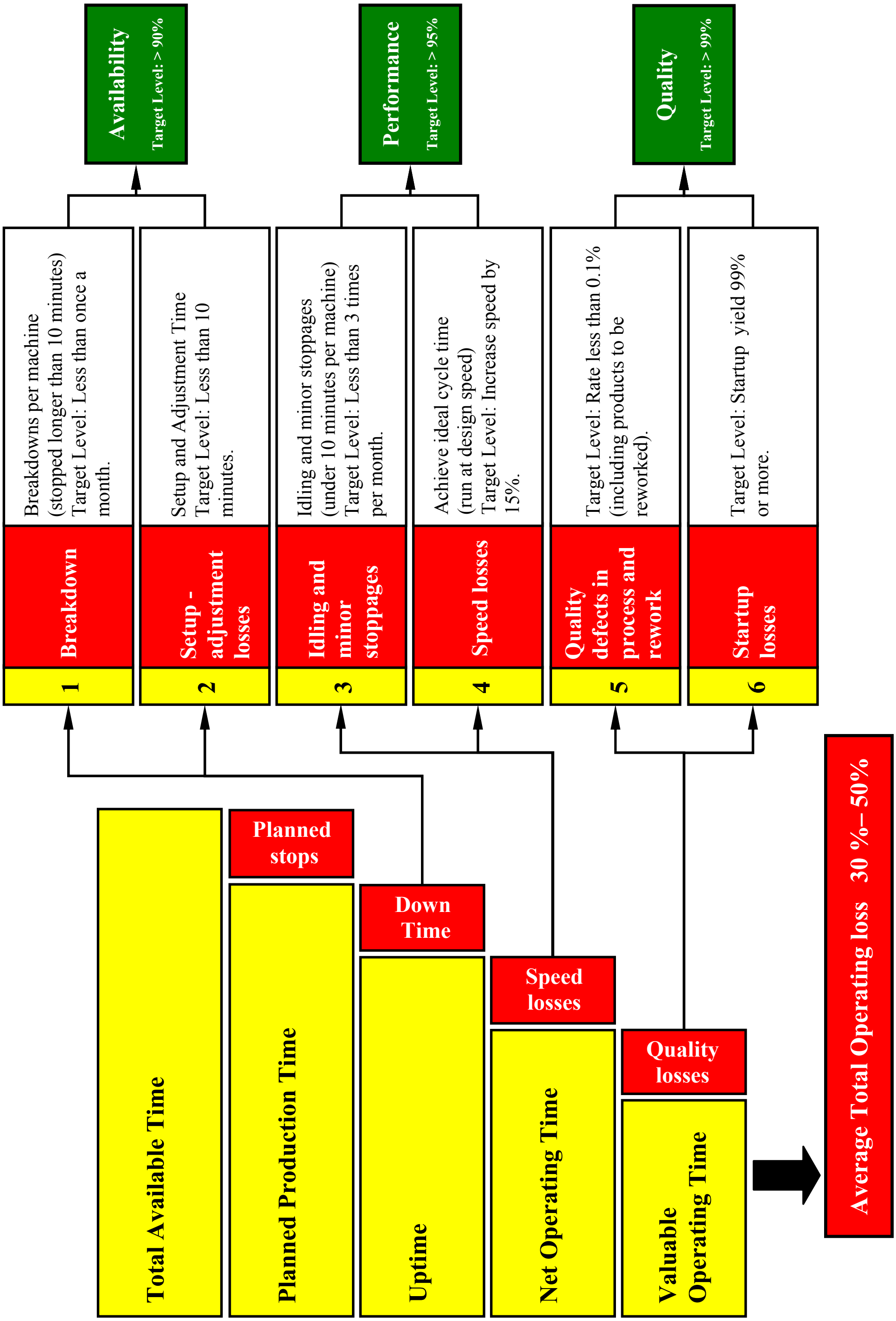


Figure 4.3 The OEE concept with examples of target levels from the mechanical industry (Nord et al. 1997).

4.3.5 OEE-factor A - Availability

The concept of Availability shows the fraction of the total time a machine is in full function. The availability rate is calculated as below:

$$Availability\,(\%) = \frac{Actual\ operating\ time}{Planned\ operating\ time} * 100$$

Planned operating time is calculated as the total available production time minus planned stoppages. The actual operating time is planned operating time minus the accumulated time for unplanned stoppages and breakdowns. An important factor within the availability element is loading time. Dal *et al.* define the total available production time after deductions for planned downtime as “Loading time” (Dal *et al.* 2000).

There is a lack of agreement on the definition of how the availability rate should be calculated (Williamson 2006). Common definitions of planned production time include time reduction from the total available production time caused by planned activities such as maintenance, breaks and meeting. Planned preventative maintenance is not regarded as a loss in this respect. A high degree of planned maintenance would in most cases increase the probability of a high availability while the production is running. However, excessive use of planned maintenance hours will nevertheless also reduce maximal production capacity since less production hours are available (Dal *et al.* 2000).

A paradox all industries, including sawmills, have to handle is that planned stops such as weekly maintenance will decrease available production time. However, this can become a major pitfall, because lack of maintenance will cause more stoppages and fatal breakdowns. Therefore, planned stops are always to be preferred over breakdowns.

Effective efforts during a planned stop are easier to organize, and severe damage to the equipment can be minimized (Nord *et al.* 1997) This is one flaw if the availability concept. A second flaw is that availability can be 100%, but the machine is still not producing any parts because of lack of material. To describe the effects of this phenomenon, it is suitable to add the Performance variable (Ljungberg 1998). The availability metric is still very dominating and many companies only measure time losses. The availability rate is also often used as a measure of how efficient the maintenance department is operating (Ljungberg 1998).

4.3.5.1 Planned Maintenance and stops – Accepted loss or not?

One common approach is to increase working hours as an alternative to reducing losses. This approach is however defensive, costly and does not focus on or solve the real problems.

Another more offensive approach could be to consider an approach where the equipment is expected to work 24-7 (8760 hours/year) at full cycle time without any losses. Ljungberg is doubtful if time losses such as meetings, education and planned maintenance should be left out from loading time. If those activities are carried out during normal production hours they should be regarded as losses equal to other losses. This indicates that a substantial part of losses are ignored and never seen due to the method of calculating the availability rate (Ljungberg 1998).

Kotze claims that defined time base should be the time period that the equipment is accessible and enabled to perform its intended function without being limited by circumstances from outside. This time base is the effective time. This theoretical time base concept must however be governed by legal aspect such as summer vacations, public holidays and permitted working hours. Economical reasons such as expensive night shift can also be considered (Kotze 1993).

Presented availability rates are often incorrect since minor stoppages are ignored. Furthermore, if planned downtime is included in the production time, the availability would be significantly lower, but the true availability would be shown (Jonsson *et al.* 1999). Stoppages shorter than 60-90 seconds are commonly not registered in Swedish sawmills. This means that presented availability metrics is to be regarded as uncertain and optimistic.

4.3.6 OEE-factor P - Performance

As mentioned earlier, the performance ratio (P) is intended to reflect how well a process is doing what it is supposed to do in comparison to the expected rate (Williamson 2006). The performance rate takes thus into account speed-losses, idling machinery and lack of raw material. For example, if the actual feed speed on a sawline is lower than the ideal speed, so called design speed, the performance rate becomes lower than the stated ideal level (Dal et al. 2000). Lack of material or excessive gaps between parts will also cause losses in shape of idling machinery. This is not reflected in the availability ratio since mentioned losses not always are caused by a stoppage or breakdown. However, effects caused by bottlenecks or malfunctioning equipment outside the measured process will not automatically be registered.

Ljungberg has also found cases of positive cycle time losses, which means that the process is run at a shorter cycle time (or higher speed) than nominal. This can be caused by incorrect calculation of nominal speed or unexpected changes in raw material properties (Ljungberg 1998).

These kinds of losses are common in sawmills since log gaps and deviations in feed speed are common. Optimized feed speed is governed by individual log properties, season and machinery. Actual measured cycle time for a log include sawing time and log gap. Optimal cycle time is achieved when feed speed is optimized and log gap is close to zero. Logs gaps can be caused by imprecise feeders, machinery prerequisites or be induced by operators in order to lower production capacity. The sawmill process is also affected by seasonal effect since frozen logs requires lower feeder speed in order to preserve machinery from increased wear and tear.

4.3.7 OEE-factor Q - Quality

In mechanical manufacturing industries, the Quality factor is commonly defined as the degree of which products characteristics agree with the requirements specified for the product or output (Williamson 2006, Gouvêa da Costa *et al*. 2002). The monitored characteristics are often measures governed by specific tolerance limits or acceptable finish on visible surfaces.

However, this is not an adequate approach in a sawmill. The OEE Quality aspect applied to production in sawmills must therefore mainly focus on the level of sawing accuracy or the achieved value yield in reference to the optimal yield. To define and set the optimal yield requires breakdown simulations in which different sawing patterns can be evaluated in terms of width, position and strategies.

The achieved quality factor depends on process- and log breakdown quality on the sawline but is not immediately measurable or visible like stoppages or speed losses. The final product quality becomes evident after drying and trimming. This is commonly a time lag of at least one week after log breakdown. This phenomenon where raw material can be consumed as a part of the process but do not appear in the finished product which also have an impact on material yield is mentioned by Eldridge *et al.* 2005.

Reworking of faulty or scrapped products occurs in the mechanical industry but it is rarely economically possible to rework the sawn boards. Boards with incorrect dimensions will in the worst case risk defect claims or will be sold at a lower price, rendering the sawmill less income than expected. This lack of product quality has, however consumed irreversible raw material (Eldridge *et al.* 2005). The author accentuates that this is an example when specific characteristics of a process must be taken into account in the quality measurement. Simulation performed by Eldridge *et al.* (2005) indicates that in some processes, the scrap rate is unimportant compared with the time lost due to down time or slow running. This can be explained by the fact that scrapped parts does not consume available processing time and cost. This is a specific challenge in the sawmill industry to find the optimal levelling between optimized sawing accuracy and production output.

4.3.8 "Best of the Best"

An initial OEE benchmarking process is easy to implement just by measuring the three OEE factors over a couple of weeks. When the factors have been registered, it will be possible to define a new benchmarking value called "the Best of the Best".

Table 4.2 Example "Best of the Best" (Nord et al. 1997).

	w.1	**w.2**	**w.3**	**w.4**	**w.5**
Availability	0.80	0.82	0.80	0.81	0.84
Performance	0.90	0.92	0.95	0.93	0.91
Quality	0.97	0.98	0.96	0.97	0.95
OEE	0.70	0.74	0.73	0.73	0.73

Table 4.2 shows an example of how the "Best of the Best" value is defined. The OEE value for each week is calculated by multiplying the corresponding three OEE factors together. The "Best of the Best" OEE value in this example is calculated by multiplying the three best values for the OEE factors. Thus the calculated "Best of the Best" factor for this example is (0.84 x 0.95 x 0.98) x 100 = 78%.

The difference between "Best of the Best" and the achieved value calculated for every week, i.e., 70%–74%, shows the initial potential for improvement in a pedagogical manner. The highest value for each OEE factor establishes the initial and total OEE rate, thus creating a reachable target level for the improvement work.

If the measures are to be taken as some sort of yardstick for judging the success of individual plants, firms or industries, this is likely to have unfortunate psychological effects; it is far better to compare performance with the best actually achieved level than with some unattainable ideal.

This "Best of the Best" value can easily be accepted by the staff because each and every OEE value has been achieved during the monitored period, even though not during the same week (Nord *et al.* 1997). However, the tool should be used with some caution and common sense, because there can be limitations or priorities to consider.

The target level must always be defined so it can be reachable. For example, the gaps between logs should always be kept to a minimum, but in reality is it not possible to achieve zero log gap due to requirements or limitations in the equipment.

A common sawmill production setup also often entails a number of feeders and sawing machines connected to a single serial line with or without buffers. This is a setup known to complicate possibilities for achieving high effectiveness. When one machine performs less well than expected, it will directly affect the performance of the others.

4.4 Monitoring and Measuring processes

"*If you cannot measure it, it does not exist*"

--Lord Kelvin

What has not been properly measured can hardly be improved.

4.4.1 Why and what do we want to measure?

Measurements are a vital contribution in the work aimed to solve problems in a production process. The Kaizen concept, which implies continuous changes for the better, was introduced 1986 by Maasaki Imai (Imai 1986). Kaizen is directly linked to TQM activities and minimizing losses. A vital part is the fundamental cornerstone "to go out and observe in order to improve". To measure is to observe.

It is important to know why and what we should measure. Five distinct reasons was defined by Lebas (1995):

- Where have we been?
- Where are we now?
- Where do we want to go?
- How are we going to get there?
- How will we know we got there?

The measurements of processes makes it possibile to transform an often highly complex reality into metrics suitable for analysis, benchmarking and, most important, results and figures that can be communicated to the staff.

However, according to Ishikawa (1982), the incentive for process measurements and collecting data should not be to present impressive figures, but to create a base for actions and development of processes.

Increased process knowledge is also a basis for cross-functional discussions and can create a sense of belonging for all actors in the organization (Lebas 1995). A complete an detailed recording of numerous process parameters is more precise but also more time consuming. (Dal *et al.* 2000). Furthermore, the authors emphasizes that process data from the past data is accumulated knowledge and can hence be used to understand which parts in the process that need improvement.

De Ron *et al.* (2005) state that is clear that performance measures should be created on a well-defined basis, in order to get the right improvement activities (Means based on facts). Results from process measurements should be correct, simple, easy to understand, calculate and use. If the performance measure is incorrect, the set point of benchmark value may be wrong, thus making improvement work difficult (Huang *et al.* 2003)

Data collection should be at such detailed level that it fulfils its objectives without being unnecessarily demanding of resources. A too detailed data collection may however result in unmotivated personnel and reaction against the measurement (Jonsson *et al.* 1999).

Accurate process performance data must be available in order to utilize the OEE concept correctly and effectively. Ljungberg (1998), Dal *et. al.* (2000) and Jeong *et al.* (2001) emphasize the need for accurate measures in the determination of OEE. The quality of the stated OEE is hence related to the industry´s capability in data collection. Incorrect data will lead to lack of credibility in the measuring system and will be liable to discredit the person who presents the results. Incorrect data will also create problem if it is fed into Discrete Event simulation models. It is therefore essential to invest time (and in reliable monitoring systems) in the improvement of the source data collection and recording methods. (Dal *et al.* 2000)

Ljungberg (1998) suggest a method for collecting process data such as stoppages and idling time, where computerised systems are combined with manual recording of stoppage causes. Computerised systems for collecting data on OEE can be very precise, but it can be hard to assess the underlying reasons for failure. Further, computerised systems can be expensive and sometimes difficult to use.

Skellefteå Church town – “Bonnstan”

5 Sawmill case studies

These case studies were performed in order evaluate and demonstrate how quality-management tools and simulation techniques can be used to improve sawline processes in a sawmill.

5.1 Scenario introduction

The management of a Swedish sawmill is determined to increase its ability to compete in the market. In order to achieve this, the management has adopted an improvement plan for the sawline production. The management's goal is to evaluate the potential for improvements, make decisions about changes and achieve goals by utilizing adequate benchmarking methods, simulation techniques and quality-management tools.

A comprehensive plan for improved process monitoring and control is established in order to facilitate the making of decisions regarding required changes and investments. These decisions must be based on facts, and the initial work is focused on gathering facts for decision support.

The plan is focused on reducing losses and costs in the breakdown and logistic processes and contains goals such as:

- Increased yield and raw material utilization by an optimized breakdown process
- Increased availability and performance on the sawing line, including processes in between the log scaling and stacking area
- Improved process monitoring and control
  This includes further training of the operators
- Increased staff commitment and education

Log geometry data from the Swedish Pine Stem Bank provided data for the saw simulation software in this study. By default, the saw simulation software uses the SPSB data containing full information about knots and defects.

However, this initial comprehensive case study is mainly focused on increasing the volume yield, and in order to eliminate indeterminable effects from knots and defects, the knot function was turned off in the simulation software. The breakdown simulations thus evaluate the effects of log geometry such as diameter, taper, surface unevenness, ovality, *etc*.

The Lejonström bridge Skellefteå

5.2 Case study I: Availability and Performance status on a sawline

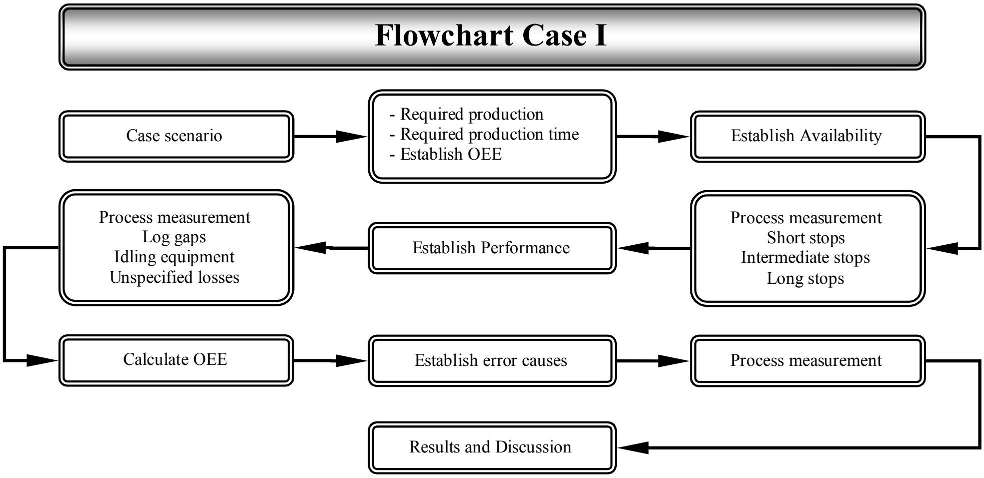


Figure 5.1 Case study flowchart.

5.2.1 Case scenario

The specified production goal is not achievable at present because of low process availability and performance. The present production target is achieved by a short-range solution in which two supplementary and expensive shifts are inserted during weekends.

In order to improve the sawmill´s effectiveness, the management initially wanted to find the true level of sawline availability and performance. The production was therefore monitored over a period of four weeks utilizing the Distributed Process Monitoring System. The main task during the monitoring phase was to register all stops longer than 10 seconds and to establish the current OEE values for availability and performance. The registered actual production time for all sawing classes during the five weeks was analyzed and compared to the teorethically required net production time.

5.2.2 Required production time

The required net production time to saw the required volumes was calculated based on historic information on sawn postings over a period of time, an average log length, log gap and the stated feed speed for the respective sawing classes. Table 5.1, column A, shows the required net time in reference to an average log gap. This gap is induced by equipment requirements or is, in some cases, enlarged by operator behaviour. Nevertheless, and most importantly, log gaps can be reduced by modern material-handling equipment. Log gaps close to zero are desirable in order to achieve the highest production effectiveness.

Table 5.1 columns C–E also show the required process availability in reference to altered feed speed. The calculated values in the table also show that the required production time is increased by 130 hours if the average log gap is increased from 0.4 metres to 0.8 metres. This is the equivalent of 16 shifts per year.

Table 5.1 Required net time to saw 150,000 m^3 of centre boards and required equipment availability in percentage of the annual available time and with reference to specified feed speed and average log gaps. Annual gross production time is calculated to be 3,416 hours, 2 shifts per day.

A. Log Gap (m)	**B. Required net time to saw (h/year)**	**C. Sawline feed speed: 90%**	**D. Sawline feed speed: 100%**	**E. Sawline feed speed: 110%**
0.0	2,744	89.8%	80.4%	73.4%
0.2	2,838	92.9%	83.1%	76.7%
0.4	2,903	95.0 %	85.0%	80.0%
0.6	2,968	97.1%	86.9%	83.3%
0.8	3,033	99.2%	88.8%	86.6%
1.0	3,097	101.4%	90.7%	89.9%

In many sawmills, equipment-induced log gaps are governed by the minimum time a cross-step feeder requires to make its stroke and by the performance and consistency of the cross feeders. This implies that the stroke and log gap are expected to be constant in time and size during the processing of a sawing class. However, the log gap can still vary substancially in size, depending on intermittent feeder performance, malfunctions, sawing speed or operator preferences.

Given a feeder speed of 100% of the design speed, the required availability is increased by 3.8 percent points when the log gap is increased from 0.4 metres to 0.8 metres (Table 5.1, column D). The sensitivity to the impact of performance variations in a cross-step feeder is even more obvious when the actual time delay causing these extended log gaps is calculated. A gap increase of 0.4 metres can be caused by a 0.32-second time delay at the step feeder, given a sawline feeder speed of 75 m/min. The process is also sensitive to speed losses, as Table 5.1 shows.

A 10.0% overall decrease in feed speed on the sawing line increases availability requirements by 10%, given a 0.4-metre log gap. This equals a loss of close to one shift of production time per week.

These facts accentuate the importance of improved log handling systems.

5.2.3 Process data and Process knowledge

Detailed knowledge about process variables such as stoppages, idling equipment or error causes is vital within the OEE concept. The real sawline was therefore monitored over four weeks (two separate two-week periods) in order to collect time-related production data and to establish the current OEE values for availability and effectiveness. This monitoring phase was performed on the intermediate log line with the aid of the Distributed Process Monitoring System, and the main task was to register all stoppages longer than 10 seconds as well as the log gap size.

The registered stoppages and their causes were sorted into three main category groups:

- A. Short stoppages — stops of between 10 and 89.9 seconds
- B. Intermediate Stoppages — stops of between 90 and 599.9 seconds
- C. Long Stoppages — stops longer than 600 seconds

Stoppages shorter than 90 seconds are commonly not registered in sawmills. Therefore, information about their frequency and the accumulated time is unavailable. This limitation on registered data is commonly made in order to reduce the amount of process data. However, this also limits the possibilities for a detailed analysis of the process. The monitoring equipment and sensors were placed ahead of the first sawing machine, and the performed monitoring phase produced data for four production weeks. Apart from the fundamental availability data, sawline capacity was also measured.

The capacity measure is often presented as the number of sawn logs per hour. However, this measure is highly sensitive to the influence of log length, actual log gap and the predefined and sawing-class related feeder speed. A more adequate measure is therefore to define the effectiveness index by measuring the accumulated sawn log length in comparison to the measured and accumulated sawline feeder translation during the same period. This index is independent of the posting used and is only affected by stoppages, missing logs and/or the actual log gap.

5.2.4 Availability

The stoppages classified into the A group represent in the main, stops registered when the sawline is momentarily halted by the operator and requires no further action before it can be restarted. These stops are in most cases induced by the operators in order to reduce the effects of bottlenecks in the edger or green sorting area. This fact is supported by a survey showing that few of the occurring problems on the sawline, that require an operators attention are solvable within the 90-second limit. The shortest possible time for the operator to leave the monitoring room in order to solve a problem is at least 45 seconds, and this type of problem rarely occurs.

Stoppages classified into the B category represent stops that require efforts and fast action from an operator. Examples of this are logs stuck in the debarker or a log that needs to be pushed back onto the feeder. Because of the limited number of operators, the sawline is always halted while an operator attends to the problem. Category C represents serious breakdowns or malfunctions that require more time-consuming efforts from an operator or from mechanical or electrical support functions. The results from the process-monitoring period show an average 32.0% loss of valuable production time. However, the total loss exceeds 36% during w3 as shown in Figure 5.2. This equals a total of 27.2 hours for the week in question, or 3.4 hours per shift.

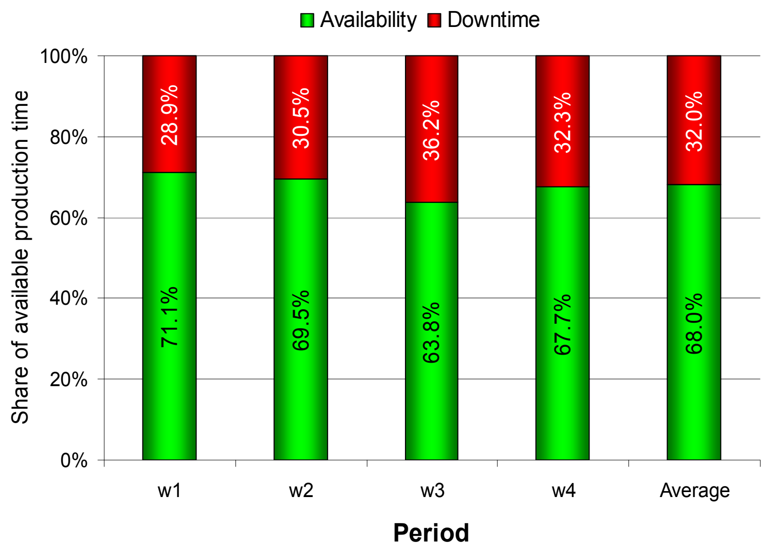


Figure 5.2 Accumulated availability and downtime on the sawline.

Furthermore, when availability information is presented or used for capacity calculations, category-A stoppages are usually excluded, mainly because knowledge about the frequency and accumulated amount simply does not exist. The average availability index for the period would in this case have been presented as 72.6% in comparison to the true 68.0% when category-A stops are included. The average annual discrepancy between the performed measurement and the common method exceeds 150 hours, or more than two entire 2-shift workweeks.

These results depict the level of the “suspected-but-still-ignored” factor concerning frequency and accumulated amount of short stoppages. This fact also confirms the importance of monitoring the entire process without excluding large areas of crucial data, as well as the importance of using adequate monitoring equipment.

A more detailed analysis of the grouped data shows that the share of short stoppages below 90 seconds averages 4.5% of the production time for the monitored period. This is equivalent to 3.4 hours per week (Figures 5.3 and 5.4).

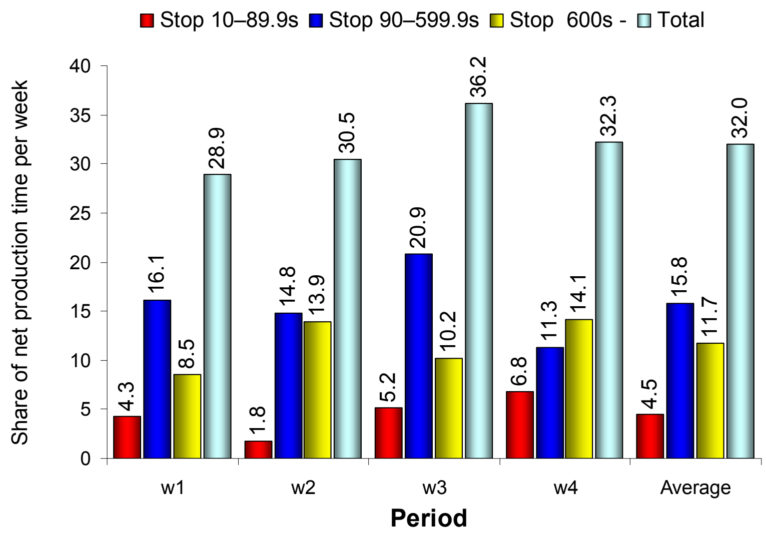


Figure 5.3 Short and long stoppages expressed as percent of the net operating time. Nominal operating time is 74.5 hours per week.

For example, given sawing class no. 9 (“50 x 200 mm”), the specified nominal feeder speed and a 0.4-metre log gap entail an annual board-production loss of 210 m^3. Simulation results show that expressed in income this equals a loss of 357,000 SEK. Short stoppages during one particular week, w4, totalled 834, *i.e.*, an average of 11 short stoppages per hour, and the accumulated time was 5.1 hours Figure 5.4 and 5.5.

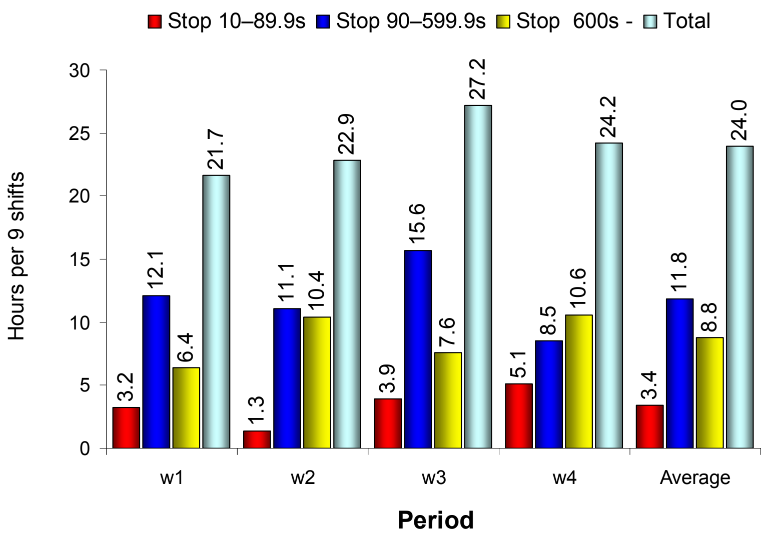


Figure 5.4 Short and long stoppages expressed as total time per week. Nominal operating time is 74.5 hours per week.

The B- and C-category stoppages are in most cases fewer than the A-category stoppages, but expressed in accumulated time, they are constantly larger than the accumulated time for the A-category stoppages in this study. Figures 5.4 and 5.5 show that the accumulated B-category time and stoppage frequency are higher during w1 and w3 than during w2 and w4.

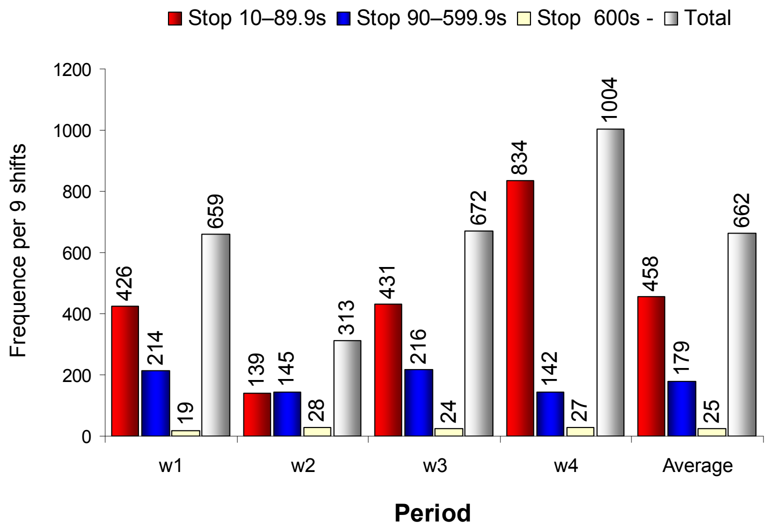


Figure 5.5 Short and long stoppages expressed as total frequency per week. Nominal operating time is 74.5 hours per week.

A review of the postings sawn during these weeks shows that logs from the lower sawing classes were sawn during w2 and w4, while during w1 and w3, mainly intermediate sawing classes were processed. The intermediate sawing classes generally contain more products than the lower sawing classes. This fact could explain to some degree the higher level of B-category stoppages during these particular weeks.

Given that the design feed speed and an average log gap of 0.4 metres are applied for all postings, an availability of 85% is required in order to achieve the specified production target (Table 5.1). The lowest availability, 63.8%, was found during w3, and in order to achieve the production target, almost 16 hours of valuable production time must be reclaimed. Calculated on the average availability for the weeks in question, results show that the downtime must be decreased by almost 50%, or 11.25 hours per week. Thus, all types of stoppages must be reduced in order to achieve the valuable production time needed.

5.2.5 Performance – Unspecified losses

The theoretical effective sawing time needed to execute individual postings can be calculated from available sawmill information. This was done by applying nominal sawing speed to the logs sawn during the four monitored weeks. Information about the exact log lengths and actual log gaps was not available, and the calculations were made by assuming an average log length of 4.3 metres and an average log gap of 0.4 metres. Figure 5.6 shows the net available production time separated into theoretical sawing time, registered downtimes and share of unspecified losses.

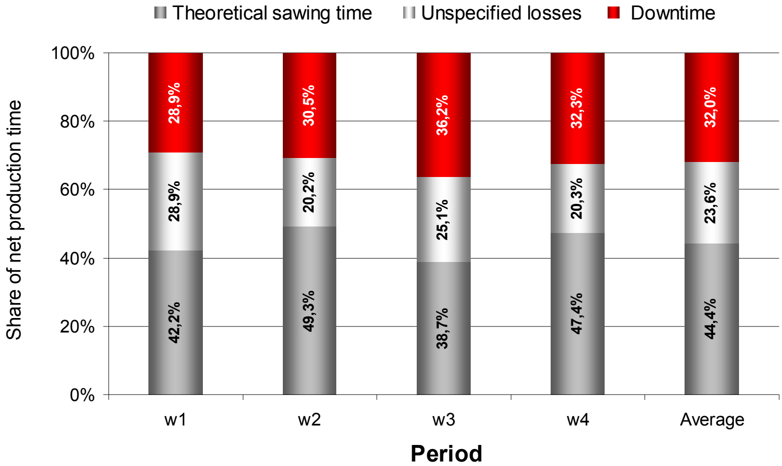


Figure 5.6 Total available production time separated into valuable time and losses. Theoretical sawing time calculated at an average log length of 4.3 metres and average log gap 0.4 metres.

The results show that there is a large amount of unspecified loss of valuable production time per week, equal to two hours per shift. Possible causes are larger log gaps than assumed in combination with a high degree of idling equipment.

The sawline performance was also monitored during the survey. Due to some malfunctions, data from some weeks were not regarded as reliable and were therefore excluded from the material. The registered performance data in Table 5.2 imply a large share of log gaps or idling equipment.

Table 5.2 Calculated OEE index excluding Quality losses based on measurements performed at the real sawmill with the aid of the Process Monitoring System. N/A = Data not available.

Period	Availability	Performance	OEE (excl. Quality)	Note
w1	0.711	N/A	N/A	
w2	0.695	0.782	0.543	Large share of reduced log line utilization
w3	0.638	0.591	0.378	
w4	0.677	0.632	0.428	Large share of greater log line utilization
Average	0.680	0.668	0.450	OEE index 0.45 calc. on 3 weeks' data

The registered weekly true performance rate (Table 5.2) measured during the sawmill survey was utilized in order to calculate the true average log gap during individual weeks. Performance rates for single logs can be calculated as in the example below by dividing the log length by the total space it occupies on the sawline, *i.e.*, log length plus log gap.

For example, the measured performance rate during w3 is 59.1% (Table 5.2).
Example Performance calculation:
x = log gap (metres)

$$\frac{4.3}{(4.3+x)} \approx 0.591 \Rightarrow x \approx 2.97\,metres.$$

The total performance rate for the sawline during individual weeks was measured in the same manner by the diagnostic monitoring equipment and calculated by dividing the total length of sawn logs by the total sawline feeder translation during the same period (Table 5.2).

The calculated true average log gap in this case is 2.97 metres rather than the assumed 0.4 metres. The actual average log gaps during test weeks 2, 3, and 4 were calculated to be 1.20, 2.97 and 2.45 metres respectively (Figure 5.7).

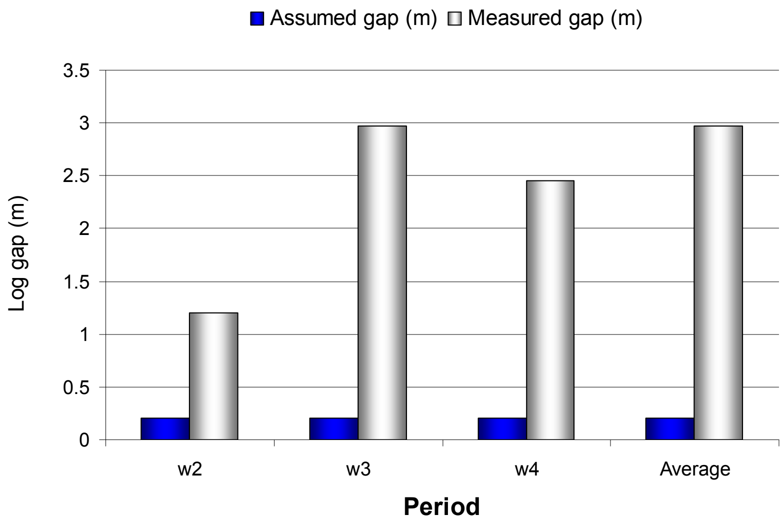


Figure 5.7 True measured average log gaps in comparison to assumed.

5.2.6 Error causes

Stoppages such as category A and B in this case are mainly caused by bottlenecks, operator behaviour and inadequately designed equipment and are thus easier to predict and rectify than the more unpredictable category-C breakdowns.

In a study performed over 56 shifts, the error cause reporting system developed for the study was used to register all stoppages and their causes. The results in Table 5.3 show that 30.3% of all reported stops were reported as problems arising in the green sorting area. The accumulated time for this category of stops equals an average of 3.8% of the total production time, or 2.8 hours per week. The arithmetical average stoppage time for this category is short, 145.2 seconds, and the detailed data show that most stoppages, expressed in frequency as well as in total time, are actually caused by problems in the green sorting area.

Table 5.3 Reported error causes during 56 shifts (466 hours).

Error Cause	Total Time (hours)	Share of measured production time (%)	Loss of valuable time (hours/week)	Freq. No.	Freq. (%)
Green Sorting Area	17.5	3.8	2.8	434	30.3
Unspecified	16.1	3.5	2.6	475	33.2
Log Turner	6.5	1.4	1.0	112	7.8
Debarker	6.4	1.4	1.0	40	2.8
2nd sawing machine	4.3	0.9	0.7	47	3.3
Edger	3.0	0.7	0.5	54	1.6

The second largest accumulated stoppage topic is regrettably, still referred to as "unspecified stops". The error cause report system was developed in order to minimize general handling to two taps with a fingertip on the touchscreen, with the intention of eliminating the number of stops defined as unspecified. The amount of stoppages registered as "unspecified stops" causes problems not only because of decreased availability—the unspecified errors also result in difficulties in addressing the real causes.

The results from this survey is not complete thus maybe ideal since reported errors mainly refers to production in the small log line during the main part of the time. No stops were registered during the time the intermediate sawline was operational. This means that the true number of stops is likely to be much higher.

Furthermore, the actual problems in the green sorting area could actually be even larger, as these errors could be contained and hidden in the group of unspecified stoppages. The errors that are reported as "unspecified" could likely have been specified in detail and reported into more specific error causes. To some extent, this lack can be excused, because it can be difficult to remember all the causes when many short stops occur over a short period.

Nevertheless, this phenomenon is familiar and can probably be referred to as “a matter of operator convenience“, and the problem could be solved by a more sophisticated error reporting system. In any event, this category represents 23.5% of the accumulated stoppage time, equal to 2.6 hours per labor week. This makes it crucial to refine the system and motivate the operators in order to improve the reliability of error reporting.

A survey shows that one main problem in the green sorting area is related to low capacity, thus causing most category-A stops. The sawline is often halted by the operators in order to temporarily reduce the effects of a bottleneck. The problem is in this case not to be defined as an availability issue, but merely a matter of low capacity or performance. Because of the characteristics of the category-A downtimes, this could be solved by increasing performance and/or capacity in the green sorting area and edger.

The effects of short stops in the green sorting area could also be minimized by optimizing the utilization of the feeder located between the sawline and the green sorting area. This feeder is meant to simultaneously serve as a buffer, but too low capacity in the green sorting area may cause this buffer to overflow. This is one main reason why operators choose to halt the sawline early, even though the buffer is not completely filled.

These category-A related causes reveal an obvious potential to increase average availability from 68% to 72.5% by attending to and removing the causes of most of the short stoppages. This potential and the effects of proposed improvements and better buffer utilization can most appropriately be analyzed and verified using the DES sawmill model.

The B-category stops are, as previously noted, often caused by stuck or misaligned logs and boards on feeders or sawline. Table 5.3 shows that frequent stops are caused by the log turner and debarker. The survey shows that the average time to attend to the 40 registered stoppages in the debarker is close to 10 minutes per occurence. Errors and downtime caused by material-handling systems such as feeders and by malfunctions in the debarker, sawing machines or edger represent a total of 3.2 hours per week. An improved material-handling system in which the logs and boards are controlled and moved securely will greatly decrease the occurrence of problems in which the operator is forced to stop the sawline in order to solve the problem.

5.2.7 Case study I - Discussion and Conclusions

The results depict a large loss of valuable production time due to stoppages and idling time. The actual frequency and impact of short stoppages and excessive log gaps were revealed by a simple and short but focused survey. The conclusion is that money invested in expensive equipment is not efficiently used since the sawline is not producing any valuable products during a large portion of a week. Even though the earlier unknown level of short stoppages was surprisingly high, focus must be on attending to category-B and –C stops, since these cause the largest accumulated loss in production capacity. The aim must furthermore be to reduce log gaps to a minimum since this becomes a vital production booster without increasing feeder speed or wear and tear. This is a commonly neglected potential. Furthermore, losses in performance in combination with availability furthermore have a cronic detrimental effect on the total output.

Feeder speed, stoppages and idling were measured on a limited part of the sawline. This means that causes of excessive log gaps, or as is frequently the case, missing logs can to some extent be hidden in malfunctioning equipment upstreams in the sawline. This kind of problem is generally not solved by the sawline operator. The sawline is therefore not always stopped while the error is fixed, and the error is thus not registered as a stoppage. Nevertheless, the event causes losses in valuable production time.

The “un-specified” category shows the same levels as specific problems in the green sorting. This serves as an example of a less appropriate choice of available error causes in the monitoring system since the real causes are still hidden and therefore difficult to address.

The particular weeks monitored may not be fully representative of the sawmill’s annual effectiveness in general, since these weeks were situated close to the summer break. Nevertheless, is this a potential area where valuable production time can be reclaimed. The need for a diagnostic monitoring tool was clearly revealed during the acquisition of process-related data. The Distributed Process Monitoring system enabled an invaluable supply of both stoppage data and their registered causes and furthermore revealed the true and unexpected high level of valuable production time losses. Modern sawmills are generally equipped with improved monitoring systems.

However, a diagnostic system serves a genuine purpose when it comes to performing detailed surveys and to diagnosing the true level of losses in older sawmills and modern sawmills.

This tool also makes it possible to handle and vizualize time-related data without large and time-consuming efforts from the staff. This should not be seen as the final destination of this tool, because it can be further developed in order to become an integrated part of a comprehensive process-control system connecting equipment for online measurement surveillance or log traceability to the existing data base.

5.3 Case study II: Discrete Event Simulation modelling

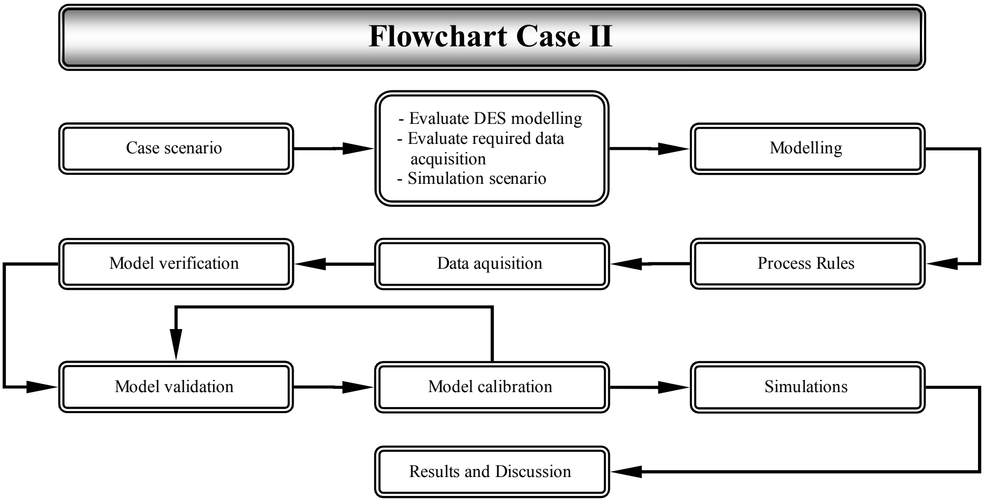


Figure 5.8 Case study flowchart.

5.3.1 Case Scenario

The purpose of this study was to evaluate the modelling process, required data and the potential to create realistic, pedagogic and credible models. Registered stoppage data in Case study I was also included and utilized in the Discrete Event Simulation model. Discrete Event Simulation tools are being used in the mechanical industry with increasing frequency in order to evaluate proposed changes, investments or different strategies. Simulation models can preferably also be used for education of the staff.

5.3.2 The Real Sawmill

The layout, main production setup and data from a local sawmill were used during the modelling phase. The sawmill setup includes a log-grading area, log intake, debarker, two sawlines, edger, green sorting area, stacking area, drying kilns and trimming plant. The plant also contains a section for planing and finger jointing. The sawmill is jointly owned by the local forest owners and produces approximately 150,000 m^3 of sawn lumber per year (Figure 5.9).

Figure 5.9 The Kåge sawmill owned by Norra Skogsägarna.

5.3.3 Aim and Limitations

This simulation study was limited to including the processes between the log intake and the stacking area. The plant layout and process data from the local sawmill were utilized in the DES model. The aim was to build a simulation tool in order to:

- Visualize the production lines and processes in a pedagogical manner
- Increase knowledge about the sawmill processes
- Evaluate the quality of the received process data
- Analyze and evaluate different production strategies in general

The model was developed to be capable of simulating the effects of different production modes and strategies. Thus, all essential rules, attributes and machines from the real production were included in the model. However, some simplifications were made. For example, no operators were included, and logs were always available at the log intake. Due to the security policy at the sawmill, some of the data and facts have been modified.

Figure 5.10 shows a modified layout of the sawmill. The modification was made in order to present a better one-page layout and model overview.

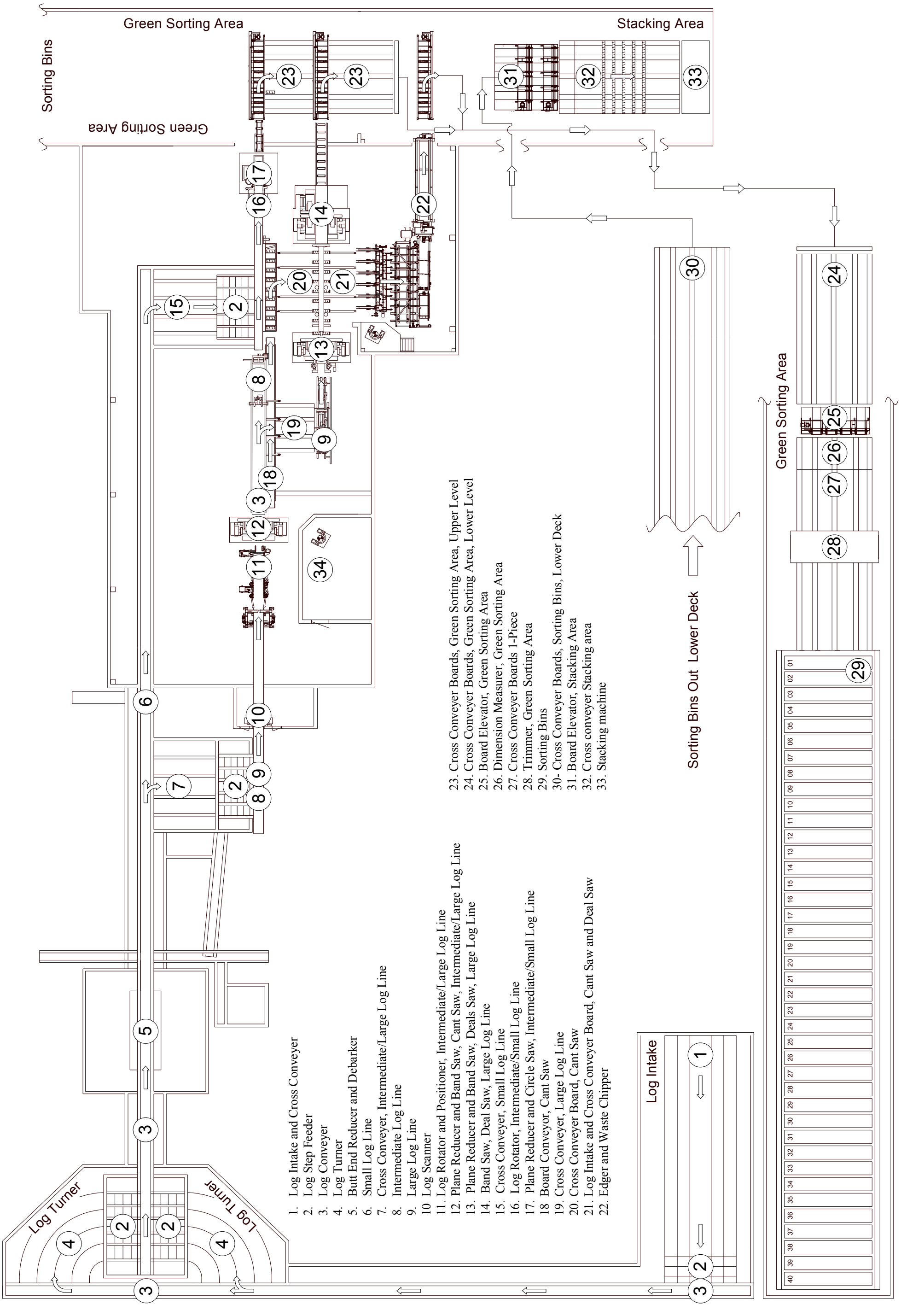


Figure 5.10 Modified sawmill layout. The modification is made in order to present a better one-page layout and model overview.

5.3.3.1 Sawmill paths and process rules

The logs are initially measured and classified into more than 20 sawing classes according to top diameter. Each sawing class also includes subgroups with a variety of defined sawing patterns. This adds up to more than 70 different board dimensions. The scaled logs are grouped into 10–15-mm wide sawing classes and later sawn in batches.

Cant-sawing techniques combined with applied curve-sawing are used in order to achieve high value and volume yield. Even though there are only two main sawlines, these lines can be utilized in three different sawing modes. Hence the three production modes are depicted as usage of the Large, Intermediate or Small Log Line.

The sawing lines are a set of sequential machines connected by a continuous material-handling system. All sawlines and feeders are generally emptied at the end of the Friday shift. This means that there is some loss of capacity both on Friday evening and on Monday morning when there is a delay before the first log arrives on the sawing line. In the following section, bracketed numbers refer to the numbers in Figure 5.10.

When the first log in a sawing class/batch approaches the Log Intake (1), the sawing class is read, thus determining the speed of the sawing line. All logs travel on the same path until they reach the position ahead of the Intermediate/Large Log Cross Conveyer (7). At this point, the path attribute is read, and the log is either routed straight ahead onto the Small Log Line (6) or diverted to the Intermediate/Large Log Cross Conveyer (7). The cross conveyer is connected to a Log Step Feeder (2) that jointly acts as a buffer, and the step feeder pushes one log at a time onto the combined part of the Intermediate/Large Log sawing line (8/9). When the log has passed the Cant saw (12), the board attribute is read, and if there are side boards defined, they are extracted onto the dedicated board path. These boards are then routed to the edger area.

The path attribute is read once again when the cant reaches the Large Log Line Cross Conveyor and is likewise routed, depending on whether it is classified as a large or an intermediate log. When the cant has passed the second saw, it is converted into a number of centre and side boards governed by the board attribute, and all attributes are transferred to the boards and are thus readable in the subsequent processing.

The boards are then transported on the cross conveyers and elevators (23 – 25 and 27) into the Green Sorting area and sorted on dimension into the Sorting Bins (29). When a bin is full, it can be emptied onto the conveyer beneath the bins (30) and routed into the Stacking area (31 - 33) where the boards are stacked and packaged into drying packages. In a more developed model, these attributes can carry information about volume yield, quality distribution and value.

5.3.4 The Sawmill model

The sawmill model was developed in order to imitate the real sawmill production. Hence, the model was built to perform as similarly as possible to the real sawmill and visualize and retain all vital rules, flows and products.

The 2-D software graphics also enabled the sawmill's processes to be visualized. A modified and scaled layout of the real sawmill was used as a background, and the sawmill's functions where then modelled on top of it.

There are some benefits to using an accurately scaled layout:

- It will be easier for the staff to understand the model if it looks like the real sawmill layout
- The predefined conveyer functions included in the ProModel software can then create conveyers with the correct length. The travelling time on the conveyer will be correct if the correct speed is set
- When the size of the different products is defined, the correct number of products will automatically fit on the conveyors with regard to both length and width

The model was then created by degrees adding specific functions and processes until the complete flow was modelled. When fundamental processes were created, routing rules, governing conditions and stoppage data were added.

5.3.4.1 Product Properties and Sawing Order

Products such as logs, centre and side boards and their properties were initially defined in the simulation software as entities and attributes. Log length was set to vary between 3.1 metres to 5.5 metres, with an average log length of 4.3 metres within the sawn class (N4.3, 0.3). When the first order enters the model, it creates the number of logs defined in the order at the log intake. All defined attributes are also instantly applied to the logs. When the last log in the batch has passed a specific point in the model, the next order is issued, containing information about the following sawing order and log batch.

In order to simulate the procedure of the real sawmill, sawing-order information is imported from an external text file. These sawing orders are defined from real production statistical reports and contain the numbers of logs to be sawn in the actual sawing classes, log length distributions, sawing classes and sawing patterns, *etc*. Attributes can be imported and assigned to products in the same manner.

When a new order is generated in the model, it contains all necessary process information, which is applied to every individual log as a readable attribute value. Such attributes are used to describe:

- log length distribution
- number of logs in actual batch
- top diameter
- dedicated sawing line
- sawing class and sawing pattern
- number of centre and side boards in first and deal saw

These attributes are later used to define, monitor or route logs and boards or to control machines throughout the process. For example:

- The sawing-class attribute determines the choice of sawing line and sets the speed of the line
- The sawing pattern attribute governs the number of boards sawn from the actual log and the routing through edger and green sorting area

5.3.4.2 Data input

In order to achieve a realistic model, planned and unplanned stoppages must be included in the model. This includes definitions for shifts and breaks as well as distributions for different kinds of breakdown stoppages. This part of the modelling is often considered the most time-consuming part, depending on the amount and quality of available process data. All sawmills monitor production at some level, but the data is often of poor quality, unreliable or difficult to access.

Data acquisition was found to be complicated in this case, thus requiring manual surveys and development of an automatic monitoring system. In order to be able to proceed without reliable data, the available rough set was inserted with the intention of gradually improving the model. The initial manual survey was made during three shifts in which an operator manually registered and measured all stoppages with a stopwatch.

The collected data were later processed and transformed into appropriate statistical distributions before being entered into the simulation software. The data included in the model can be divided into three main groups: data concerning machines and setup, working hours/shift specifications and stoppage data.

1. Machine related data:
   - Feeder speed
   - Feeder length
   - Capacities
   - Setup time

2. Working-hour and shift specifications:
   - Working hours monthly/weekly
   - Shifts
   - Breaks (frequency)
   - Planned staff meetings (frequency)

3. Process and stoppage data:
   - Stoppages, short and long
   - Breakdowns
   - Allowed idling; for example, minimal log gap
   - Setup rules
   - Planned maintenance
   - Breaks
   - Planned staff meetings

The specific data for machines and feeders and information concerning shifts and breaks were provided by the sawmill staff. In cases where feeder speed or capacity was not known, manual surveys had to be performed.

When this study was initiated, the statistical data received from the sawmill were considered incomplete, unreliable and difficult to interpret; *e.g.*, stoppages shorter than 90 seconds were not registered, and the causes were not easy to find. Due to these circumstances, the modelling strategy was set to build a model including the available data and to refine it as superior data became available.

To solve the problem of missing process data, a project aimed at developing a mobile diagnostic and analysis tool was initiated. A description of this tool can be found in section 3.7.

5.3.4.3 Shifts, Shift Schedule and breaks

Normally, the sawmill runs 9 shifts per week. The normal shift time is extended in order to compensate for the 10th shift (Friday evening).

Monday–Friday: 05:45–15:00; Coffee break 08:00–08:10, 13:00–13:10; Lunch 10:00–10:30.

Evening Shift Schedule:
Monday–Thursday: 15:00–00:05, Coffee break 17:00–17:10, 22:00–22:10; Dinner 19:00–19:30.

All times are given using the twenty-four-hour-clock standard.
All scheduled maintenance is done on Saturdays.

5.3.4.4 Sawing Classes and Pattern

The real sawmill uses more than 20 different sawing classes and corresponding sawing patterns. All these sawing patterns can be utilized in the DES model. However, this information has been concealed due to sawmill security policies.

5.3.4.5 General feed-speed setup

The feed speed is generally governed by the sawing class and season, *i.e.*, the top diameter interval and the outdoor temperature, Table 5.4. The speed is set to achieve correct gullet-feed index and suitable stress on the sawing machine.

Table 5.4 Feeder speed in reference to log top diameter.

Top Diameter (mm)	**Feed Speed (metres/minute)**
90.0 – 149.9	85
150.0 – 179.9	80
180.0 – 219.9	75
220.0 – 249.9	65
250.0 – 299.9	50
> 300.0	42

5.3.4.6 Intervals between changed sawing classes and setup times

The current sawing class is generally sawn until the ordered lumber volume has been achieved. However, the sawing pattern can sometimes be changed while keeping the same sawing class. Whenever possible, sawing classes are changed during breaks. However, when the sawing class is to be changed, 5 to 15 minutes of setup time are required, depending on the sawline.

The sawmill's 3-mode production setup facilitates the reduction of the effects of tool changes and maintenance. For example, if the current sawing order is run on the small log line, and the next order will be executed on the large log line, the setup can be partially completed while the first order is still running. The different sequential setup alternatives were defined and included in the model.

5.3.4.7 Log gaps

The gap between logs on the real sawline is governed mainly by the sawing class/pattern and physical limitations of the machinery. As an example, if the capacity of the green sorting area is limited in the number of boards it is capable of handling every second, it will function as a bottleneck. The performance of the sawing line is directly affected by the green sorting area's capacity and performance, since there are no large buffers between the two areas.

Large logs produce more boards than small logs, thus requiring larger log gaps or lower feed speed in order to decrease the sawline capacity to match the buffer. The minimum distance between the logs is therefore not a mathematically defined value, but a distance defined from staff experience

If the sawing process were performed optimally and capacities optimized, the log gap could be close to zero. The time it takes for the step feeder to execute a stroke is adjustable, but the resulting log gap is governed by two cumulative variables—the time to execute a stroke and the feed speed on the receiving sawline. Small deviations in the stroke cycle will therefore have a large impact on the log gap, even though the speed on the sawline is constant.

Given that the sawline is running at the lowest speed and that the step feeder is delayed 0.1 seconds, the log gap will increase by 7 centimetres. At the highest feed speed, the gap will increase by more than 14 centimetres. At the highest speed, the loss can amount to more than 280 logs per day.

The effects of this phenomenon can be simulated by setting the feeder stroke time as a fixed value or a limited statistical distribution. The default value is set to 0.2 metres, but in a refined model it is vital to define and apply an individual log gap distribution for every sawing class. This feature is not included in the models created and used in this study.

5.3.4.8 Model verification, validation and calibration

A Discrete Event Simulation model must be verified, validated and calibrated. This procedure must be done in order to ensure that the modeled flow works as similarly as possible to the real plant and generates the same output. This is where one of the main watersheds within simulation technique appears. Should the model's output reflect the exact values of the real production, or can relative changes in output be used in order to get appropriate answers? There are different answers to this question, depending on the amount of effort and money involved.

An output that is "close enough" is often considered sufficient to provide support for decision making. However, a model intended for use in continuous and detailed production planning must be more accurate.

5.3.4.9 Verification

Verification is often simplified if the model is built and visualized so as to imitate the real production, in this case the sawmill line. Verification in the present case was done in stages in close cooperation with the sawmill staff as model building progressed. Some simplifications were made, but the model was verified without any further need of major changes.

5.3.4.10 Validation and calibration

A target production plan was created by scaling the sawmill´s actual postings sawn during 31 weeks to scenario production level. Historic production statistics from the sawmill, such as postings used, differentiated sawing speeds, log gaps, log volumes and yield simulation results, were considered and applied to the production plan. This was done in order to enable the model to imitate the real production and reflect the influence of log properties and sawing classes on the simulation output.

A single week's production only reflects the effects from a limited number of postings, and the results are thus probably not representative of the model's performance. However, simulations including all 31 weeks would require unnessecary time consumption without any major gain. A review of sawmill data from the 31 weeks in question shows a cyclical pattern of postings used, and a period of approximately 12 weeks would be sufficient to include most of the postings used.

The intention was thus to perform validation and calibration of the model in two steps:

1. Validation of an ideal model in which no random variables were included.

A perfect model without random disturbances should in this case produce an output equal to the theoretical maximal limit. This ideal model was named Model no. 1 and after further calibration; Calibrated Model no. 1 Figure 5.11.

2. Validation of the model after activation of random variables such as stoppages. The registered stoppage data from the real sawmill showed an average availability of 68%. The model should thus show an equal reduction in output in comparison to the ideal model. This model was named Model no. 2 and after further calibration; Calibrated Model no. 2 Figure 5.12.

The second step may require further calibration of the model in order to make it perform as closely as possible to the target output. The best-fitted 12-week period could then be used as the final model.

The annual theoretical production volume for the sawmill model output equals 176,500 m^3 of centre boards calculated at 100% equipment availability, breaks excluded, an average log length of 4.3 metres and an average log gap of 0.4 meters. Under these circumstances, an average availability of 85% is required in order to achieve the stated production target of 150,000 m^3 of centre boards.The initial validation was made in order to establish the model's capability to achieve an output equal to the theoretical output at 100 percent availability in machinery and raw material. It was also important to determine whether the model was capable of imitating fluctuations induced by postings and log gaps.

No random variables such as disturbances or down times were activated during this part of the validation. Such a model is called *ideal*. Under these circumstances, a correctly built and configured model is expected to perform close to the theoretical output, thus producing close to an equal amount of sawn logs when no disturbances affect the simulated production.

A number of simulations must be performed with the same settings in order to establish an average value. The actual number of simulations necessary is governed by the number of random variables included and complexity of the model; it can be calculated using statistical methods or simply by running repeated simulations until the results converge within stated limits.

However, a rule of thumb employed within Discrete Event Simulation says that at least 5–7 repeated simulations must be performed in order to evaluate a model scenario (Anon. 2000). Thus a set of simulations was performed in order to establish the actual number of simulations needed per scenario. The results showed that 5 sequential simulation runs were sufficient. The average values from these are plotted in Figure 5.11 – 5.13.

Figure 5.11 shows the maximum model output with reference to the scaled sawmill data. Model no. 1 did not imitate the expected output and required calibration. The graph also shows the improved results after some modifications in feeder speed and log gaps (Calibrated Model no. 1).

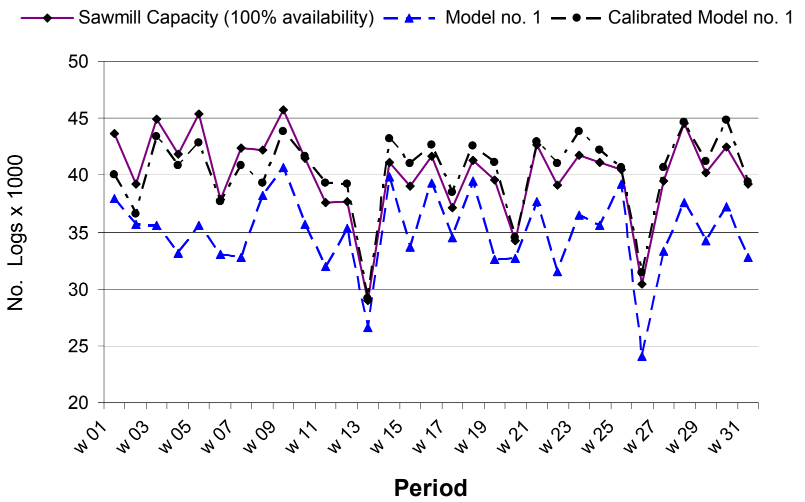


Figure 5.11 Output from Model no. 1 and Calibrated Model no. 1 in comparison to theoretical sawmill capacity at 100% availability.

The initial log-gap setting was based on a simplifying assumption that gaps are equal in distance within all sawing classes. This is, however, only a generally practiced rule in the real sawmill, governed in the end by many exceptions. For example, the green sorting area capacity is an exception that affects the operator’s choice of log gap. Variations in feeder performance also affect the log gap considerably.

To accommodate these circumstances, some modifications in log gaps and cross feeder speed settings were required. The effective log gaps on the Small Log line are actually shorter than the assumed 0.4 metres because of possibilities to minimize the gap, whereas the effective log gap on the Large Log line can be many times larger than 0.4 metres.

In comparison to DES models created within the mechanical industry, the creation of a sawmill model is subject to some particular requirements. Sawmill production is affected by the seasons. For example, logs are frozen during the winter. The commonly practiced feeder speed rules are thus somewhat modified during the winter season, and the stoppage distribution is probably different in comparison to the warm season.

These facts make it more difficult to create a general model applicable to all circumstances during the year. It is therefore sufficient to select a limited part of the 31 weeks this sawmill model embraces.

A sliding time period of 12 weeks was applied to the simulation results during the validation process in which the first 12-week period includes weeks nos. 1 to 12, the second period weeks nos. 2 to 13, and so on. The results in Table 5.5 show a comparison of the planned production and the output from the modified Model no. 1 over different periods. Even though the smallest difference between model output and the production target during a single week is only 1.7%, this exceptional result must be regarded as coincidential and should be used with caution.

Table 5.5 Ideal model output (Calibrated Model no. 1).

Period	Maximum difference to target (%)	Minimum difference to target (%)	Average difference to target (%)
1 week	8.7	1.7	8.7
12 weeks	4.8	3.9	4.2
31 weeks	—	—	4.5

Even after the applied modification, the model output is generally lower per week than the theoretical maximum level. Expressed in number of sawn logs per week, the model's average weekly output shortfall of 1,913 logs amounts to an average output 4.5% below the maximum target level. The most plausible explanation of the decreased capacity is errors in log-gap definitions.

This decrease of the maximum achieveable output is thus to be considered in the last stage of the validation and in case the same model is used in future projects. The relative difference in average between planned production and the model output compared over 12-week periods is 4.2%, and 4.5% calculated on results from the simulation including 31 weeks. The output results were considered close enough to the planned output, and the ideal model was approved.

The second stage in the validation process was to include the collected stoppage data from the real sawmill in order to calibrate the final model capacity. The initial model used during the first validation stage did not include any random variables. Hence only one simulation was needed to evaluate the impact of changes in the basic settings such as feeder speed or fixed log gaps. Random variables such as stoppage time and stoppage frequencies induce spread in simulation results, and a single simulation run per setting is therefore not sufficient to observe possible tendencies.

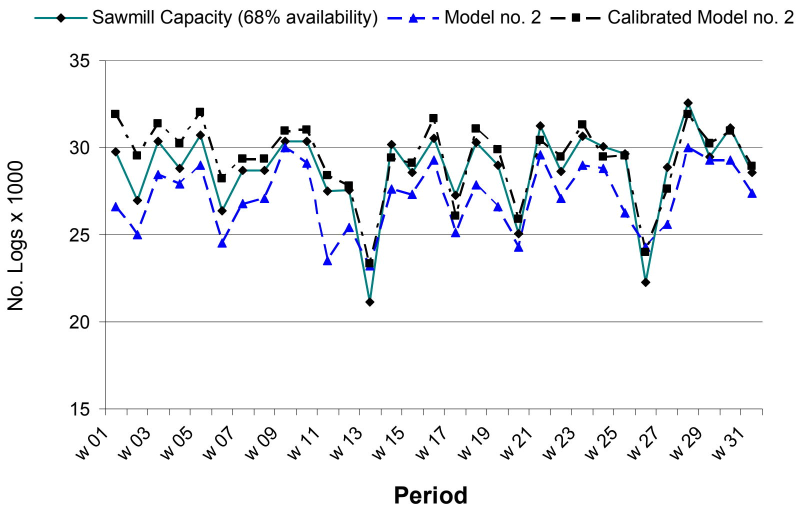


Figure 5.12 Theoretical capacities at 68% availability in comparison to Model no.2 and Calibrated Model no. 2 output.

Theoretical capacities, output of model no 2 and improvement accomplished after further modification (Calibrated Model no. 2) are plotted in Figure 5.12. The model output exceeds the real production target by 1,390 logs (0.4%) calculated on a 12-week period.

The average real production capacity measured during the sawmill survey was 68 percent of the theoretical limit. The aim of the third and final stage in the validation process was to validate the model output with reference to the calculated capacity at 68 percent availability. At this stage it is often more appropriate to convert from output comparisons in percentage to, as in this case, number of logs sawn during a period.

The first results from Model no. 2 show an output that falls short of the target by an average of 1,863 logs per week and by more than 4,000 logs in one particular week (Table 5.5). The results amount to a utilized capacity of 64.2% instead of the expected 68%, calculated on the entire period of 31 weeks.

The model and the established output were thus not approved without further calibration of the model. This result is a plausible effect inherent in the not fully achieved maximum capacity in the ideal model combined with plausible errors in stoppage data.

Table 5.5 Comparison between simulation results obtained from Model no. 2 and the calibrated Model no. 2. Target is real sawmills weekly historical production of sawn logs transformed to scenario level.

Period	**Model no. 2**			**Calibrated Model no. 2**		
	Maximum difference to target (No of Logs)	Minimum difference to target (No of Logs)	Average difference to target (No of Logs)	Maximum difference to target (No of Logs)	Minimum difference to target (No of Logs)	Average difference to target (No of Logs)
1 week	4,024	110	1,863	2,579 (8.7%)	105 (0.35%)	985 (3.4%)
12 weeks	22,722	16,535	18,736	14,098 (4.2%)	1,390 (0.4%)	6,478 (1.9%)
31 weeks			49,686			19,547 (2.2%)

The results obtained from running the model for 31 weeks show the largest difference between simulation results and target level during the cold season, while the difference decreases during the spring period.

No reliable stoppage data were available from the winter period, and the stoppage data included in the model were collected during the warm period. The conclusion is that sawmill models must be seasonally adapted in order to perform optimally. Figure 5.13 and Table 5.5 show the output results in comparison to the stated weekly target for the best-fitted 12-week model. This “part” of the model was thus approved for use during the scenario simulations.

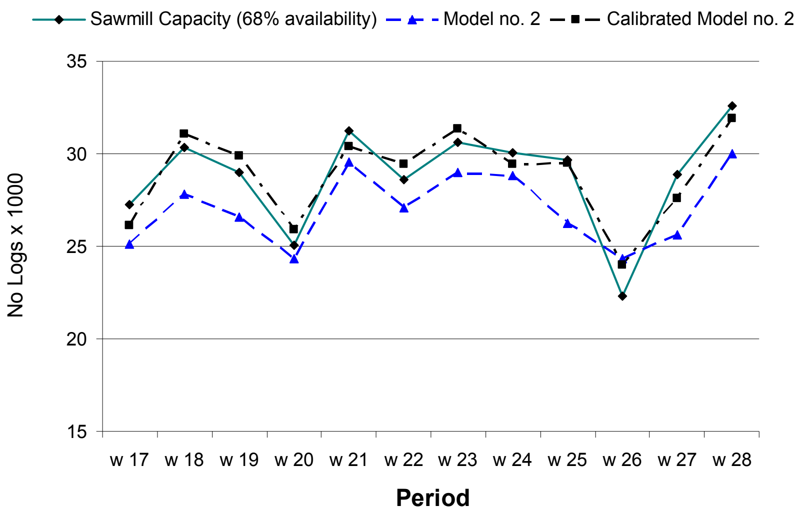


Figure 5.13 Best-fitted Sawmill Discrete Event Simulation model. The model exceeds the planned production target by 1,390 logs (0.4%) calculated on a period of 12 weeks.

The final model corresponds very well to changes in weekly target, and the output is quite acceptable when compared to the planned target. The refined calibration that in the end resulted in a correct model required a large number of time-consuming simulations in order to find an optimal combination of downtimes, frequencies and average time between stops.

An approach that would have saved time would have been to accept a greater discrepancy between target level and model output, since a constant difference can be taken into consideration during analysis of the simulation results.

The resulting model shows that Discrete Event Simulation models can be quite exact if correct stoppage data are available. The effort of measuring the process was clearly required in this case. Nevertheless, some degree of calibration effort is inevitable in order to find the correct model output.

5.3.4.11 Scenario simulation

The stated sawmill scenario places demands on improvements if the production goal is to be accomplished. The monitoring survey that was performed shows that availability and performance must be increased by improvement in material handling-equipment and green-sorting capacity. Theoretical calculations show that availability on the sawline must be increased to at least an average of 85% in combination with shorter log gaps.

5.3.4.12 Discrete Event simulation of capacity

A number of theoretical calculations were performed during this study in order to outline the required production capacity, availability and performance. However, these calculated results cannot fully reflect the production dynamic and random effects caused by erratic problems such as breakdowns or brief stoppages.

A simulation scenario was established in order to verify whether the theoretically calculated availability level was sufficient or not. The results from the sawmill survey and conclusions made from them served as the outline for a simulation scenario and included prerequisites as follows:

- The total loss in valuable production time caused by stops shorter than 90 seconds (type A) can be reduced by 75% by better buffer handling in combination with improvements in green sorting and stacking capacity.
- Losses caused by stops longer than 90 seconds and breakdowns (types B and C) can be reduced by approximately 30%–60% in time.

These stops are mainly caused by malfunctions in debarker, edger or material-handling systems. The effects of variation in these prerequisites were evaluated by changing the amount of type B and C downtimes included in the model. The total time referred to type B and C stops was reduced by 30%, 40%, 50% and 53% with reference to the stoppage data included in the calibrated model (Figure 5.14).

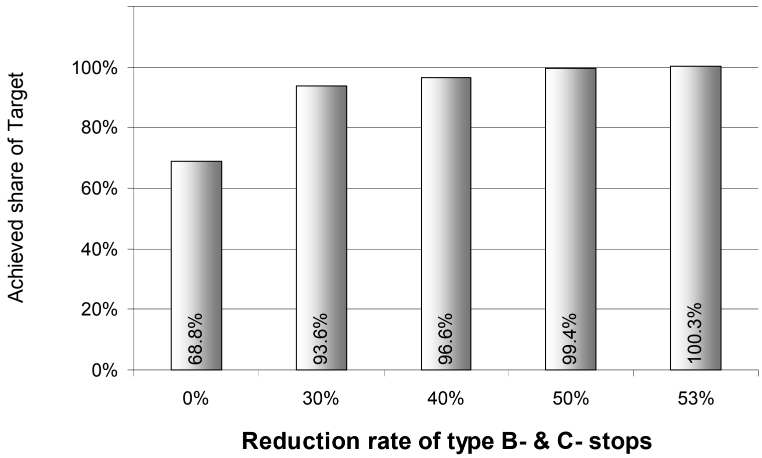


Figure 5.14 Effects on model output from different reduction rates of stops larger than 90 seconds.

The simulation results show that types B and C must be reduced by 53% with reference to the monitored average under the assumption that type-A losses are reduced by 75%. This equals a total average availability of 86% at an average log gap of 0.4 metres. This requires a reduction of category B and C stops by almost 11 hours per workweek in order to reach the production target.

The conclusion is that availability and performance must be improved greatly if the production target is to be achieved. This will require investment in a higher capacity in the green sorting and stacking area in order to eliminate the largest bottleneck. The stoppage-monitoring and error-cause-reporting system developed for this study clearly indicate that at least 3.8% of valuable production time is wasted due to problems in this area.

Because of a still too high number of unspecified stops, the exact amount of time loss caused by the green sorting area is somewhat unclear. The data in Table 5.3 show that the total unspecified time and frequency are similar to the specified loss in the green sorting area, thus indicating that actual accumulated loss in the worst case can be close to 7.5%, or 5.5 hours per work week. This makes it vital to continue surveying in order to establish the true losses and to attend to these problems. Problems caused by material-handling systems such as conveyers, step feeders and log turners will also need attention.

The total amount of more or less unknown losses in performance is indicated in Figure 5.6. Simulation results verify the same amount of loss in performance as the theoretical values shown in Table 5.1. The model output rapidly decreases when the average log gap is widened.

5.3.5 Case study II - Discussion and Conclusions

The development of a simulation model served three main purposes during this study: to gain process knowledge, to evaluate the quality of aquired process data and to run simulation scenarios. The development of a model often focuses on what concrete results the model is expected to supply, and these other purposes are easily forgotten.

Reliable data were needed in part for the OEE concept, but also as a very crucial part in the development of a Discrete Event Simulation model. The initial validation of the model failed because the required stoppage data were hard to access or were incorrect. A limited manual survey was thus performed and the model output somewhat improved but still not acceptable. This fact was the starting point of the parallel process of developing the monitoring system.
The modelling process was highly governed by the aim of creating a realistic model where the real sawmill´s layout and the production setup was easily recognizable by the viewer. This made the basic modelling work somewhat more time consuming but this time was regained during the verification and validation process.

The final calibration, which in the end resulted in an credible and highly accurate model, required a very time-consuming simulations in order to find an optimal combination of downtimes, frequencies and average time between stops. This effort would probably not have been possible to put into a commercial project but within the scope of research, this is valuable knowledge. In a commercial project, a preferable timesaving solution would have been to accept a “good-enough”model, taking into consideration a constant difference during analysis of the simulation results. Analysing simulation results is furthermore often about finding out whether a specific production setup is preferable to another, not to find absolute values.

The final model corresponds very well to the real sawmill´s output viewed over a specific 12 week period. However, a very important finding was that seasonal changes affecting the sawmill process must also be considered in the model. The model is only valid under the prerequisites included in the model, *i.e.,* the best fitted model was in this case valid only for the spring season, since the process data were collected from May to June. The resulting model shows that Discrete Event Simulation models can be quite exact if correct stoppage data are available. Nevertheless, some degree of calibration effort is inevitable in order to find the correct model output. The level of effort chosen in calibrating the model will in the end be a prioritization between how well the model is required to imitate reality and, of course, available time and money.

Skellefteå Church town – “Bonnstan”

5.4 Case study III: Improved log handling at the sawmill yard

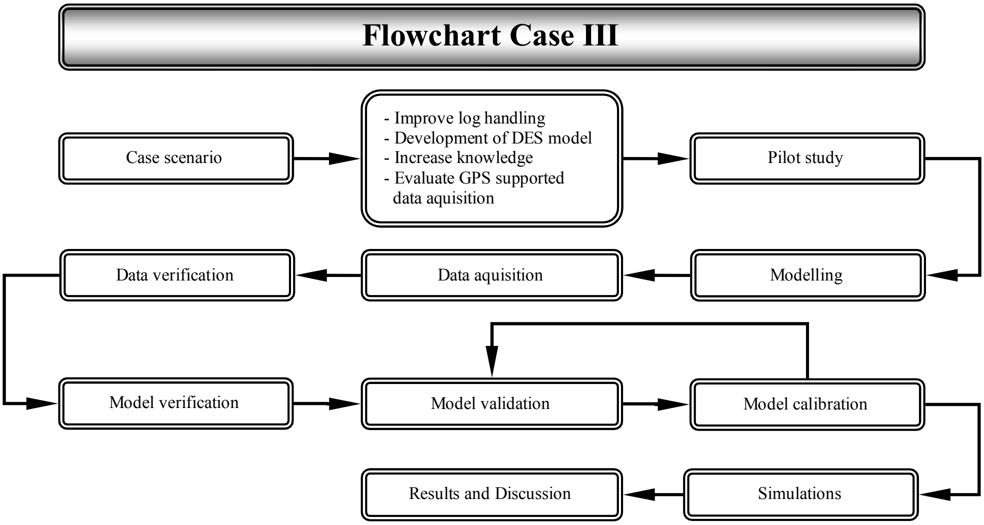


Figure 5.15 Case study flowchart.

5.4.1 Case Scenario

The main objective of this study was to evaluate the potential to improve log handling in Swedish sawmills by minimizing internal transport. The objective was also to evaluate the impact of Discrete Event Simulation models and evaluate the quality of process data acquired by the GPS Timber logging module.

A typical Swedish sawmill purchases and handles 400,000 m^3 of logs, or approximately 2,500,000 individual logs, per year. All logs arriving at the sawmill are sorted and graded into classes according to minimum top diameter and/or quality. This initial scaling procedure serves two main purposes for the sawmill:

- To classify and measure log volume and quality, thus determining the purchase price to be paid to the seller. This classification is done by the independent scaling society.
- To classify logs into the correct sawing classes in order to optimize the volume and/or value yield.

The method commonly used for scaling logs in Swedish sawmills is measurement of the log geometry and ocular quality inspection for determination of top diameter, log volume, crook and surface damage. The number of sawing classes can range to 40 or 50 or more. Logs sorted into individual sawing classes are stored in separate piles until needed. This requires a vast amount of storage space and often results in long driving distances.

The complexity, *i.e.*, the number of sawing classes and the required logistics capacity, will most likely increase in the future, since the number of sawing classes sorted on quality properties will increase through implementation of modern x-ray technology.

Effective and correct log handling at a sawmill is therefore of utmost importance, because errors or inappropriate allocation of log piles will affect production output and logistics negatively. Today, log piles and sorting bins are usually allocated statically. This means that the optimal location of piles and bins is rarely evaluated.

Furthermore, these logistics require a fleet of highly specialized log stackers and dedicated drivers. Mistakes and errors are more frequent during periods when new or temporary truck drivers are initiated. An efficient log-handling process will decrease fuel consumption, thus also emissions and environmental stress.

The accuracy of mobile GPS technology and implemented industrial GPS-supported monitoring applications in log stackers simplifies data acquisition. The technique also enables a comprehensive view of the process, since specific log-stacker activities can be linked to, for example, exact vehicle position, speed and fuel consumption. The level of complexity and dynamics involved in the log-handling process makes Discrete Event Simulation technique appropriate to optimize and evaluate different log-yard strategies.

5.4.2 The Global Positioning System

The NAVSTAR GPS, Global Positioning System was developed by the United States Department of Defence. The first experimental satellite was operational in 1978. In 1994 a complete constellation of 24 satellites was orbiting at an altitude of approximately 20,200 kilometres above the earth and the system was declared to have full operational capability in April 1995. GPS includes a feature called “Selective Availability” (SA), initially used in order to introduce intentional random errors into the publicly available navigation signals.

This feature was introduced in order to prevent civilian GPS-receivers from being used by an enemy or terrorists. In May 2000, Selective Availability was discontinued allowing public users to receive a nondegraded signal. This improved the accuracy and usefulness of GPS for civilian navigation (Massatt *et al.* 2002).

A GPS receiver calculates its position by precisely timing the signals sent by the GPS. The position is displayed, perhaps with a moving map display or latitude and longitude; elevation information may be included. Many GPS units also show information such as direction and speed, calculated from position changes. Finally, GPS enables researchers to explore the Earth environment including the atmosphere, ionosphere and gravity field. GPS survey equipment has revolutionized tectonics by directly measuring the motion of faults in earthquakes.

Many civilian applications such as personal handheld or automobile receivers benefit from GPS signals, using one or more of three basic components of the GPS: absolute location, relative movement, and time transfer. GPS-functionality is today also frequently implemented into every-man´s mobile phone. The low-priced GPS-technology has lately become frequent in industrial applications such as monitoring of vehicles or as an integrated part of anti-theft devices (Prasad *et al*. 2005).

5.4.3 The GPS Timber Decision Support System

The GPS Timber system is a decision support application for timber handling at outdoor storage areas developed by two Swedish companies in a joint venture. The system utilizes GPS, digital maps and wireless WLAN network communication in order to assist the log stacker drivers and ensure that logs are fetched from correct sorting bins, stored in correct log piles or correctly fed into the sawing process at the right time. Information about sorting-bin status and log volumes is continuously transmitted from the log classification area to the log stacker drivers. All information is graphically presented on a Moving Map Display or as text on a monitor in front of the log stacker driver Figure 5.16. When a bundle of logs is fetched from a bin, the preferred pile is highlighted on the monitor and the log stacker driver receives a message on the screen and a warning sound if an error is about to be made. The same practice applies when orders from the sawmill process are received.

By adding a logging module to the existing system acquisition of detailed log stacker data, such as type of activity, travelling speed, fuel consumption and present time and position of individual trucks becomes possible. These detailed data are invaluable to include in a Discrete Event Simulation modelling project and are furthermore difficult to collect during manual surveys.

Figure 5.16 GPS Timber decision support system setup in a log stacker cab.

5.4.4 Project Management and Targets

This ongoing project (June 2009) is being carried out within the TräCentrum Norr programme (WoodCentre North) in cooperation with Tillväxtverket, the Swedish Agency for Economic and Regional Growth. The TräCentrum Norr constellation is a centre formed within Luleå University of Technology with campuses in both Luleå and Skellefteå. Stakeholders are local and regional sawmill and manufacturing enterprises. The common objective for all stakeholders in TräCentrum Norr is a Swedish sawmill and timber industry that is able to increase value added and strengthen competitiveness by means of new products, systems, and services, to the benefit of both the companies and society. The aim is also to boost collaboration within the network and generate new ideas and solutions and contribute to synergies between companies.

A specific work team was formed for the log-yard project with participants from four sawmill enterprises and a local computer-programming company with established network and sawmill-related systems.

Three specific goals were expected to be met after finishing the project:

A. Improvement of the log-handling process.
The target was to achieve a considerable improvement resulting in decreased cost and more effective log-handling activities. Specific key performance indicators such as required logistics, fuel consumption and log-sorting capacity were established and analysed.

B. Development of Discrete Event Modelling software.
The simulation model developed during the project was created with specific process data and rules from Martinson's sawmill in Bygdsiljum, Skellefteå. The ultimate aim to create a generalized piece of software that would be easy for participating sawmills to adapt to their specific processes and optimization purposes.

C. Increased knowledge and awareness.
A major incentive for the project was to increase general knowledge about the log-handling process and the potential to better utilize equipment. Furthermore, results achieved should be communicated, visualized and easily accessed by participants and employees.

5.4.5 Pilot study

A pilot study was initially done in order to achieve a comprehensive overview of requisites and logistics at six local sawmills. A production planner and log-stacker drivers at each sawmill were interviewed about such aspects of the sawmill as methods, the sawmill´s vehicle fleet, fuel consumption, annual production target, average log-yard stock, number of sawing classes, job allocations between trucks, procedures at the log-scaling area, distribution of log bin malfunctions, stoppages, *etc*.

Results from the pilot study were compiled, and differences and similarities were noted. The compiled results later served as a knowledge base for required features in the simulation model. The survey revealed only minor differences between methods used, choice of vehicles and production setup. One particular issue was generally addressed; problems caused by malfunctioning log bins. The extent of these problems is governed by bin design, maintenance, seasonal influences and degree of bin filling.

5.4.6 Sawmill log yard layout

Figure 5.17 shows the sawmill log yard layout at Martinsons sawmill, Bygdsiljum, Skellefteå.

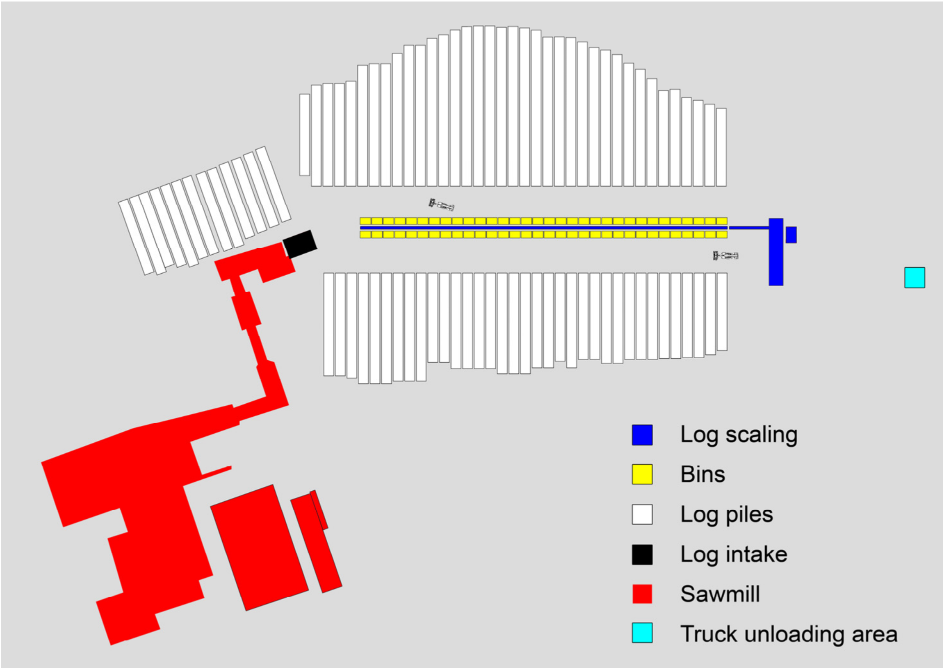


Figure 5.17 Sawmill log yard layout.

5.4.7 Modelling

The simulation model was created with the free TomasWeb simulation software (TomasWeb 2009). All configurations and settings were concentrated to a specific configuration file created in Microsoft Visio. This solution enables an improved user interface and improved accessibility for new users. Layouts, specific log-stacker properties, log supply, sawmill capacity, truck arrivals, *etc.*, are configured in the Visio interface, and configurations can be shared or exported to new models.

A list of globally accessible work orders for log stackers is continuously updated whenever events occur in the model. These orders are prioritized according to how quickly they need to be addressed. Feeding the sawmill and scaling line with logs and emptying bins is of highest priority, while unloading trucks is of slightly lower priority.

For example, when two log stackers are available, a new work order is evaluated with regard to priority, but the log stackers' positions in the log yard will ultimately decide which vehicle is best suited to execute the order. This deployment of orders in the model was created in order to imitate log-stacker drivers' approach to distributing work among themselves.

5.4.8 Data acquisition, verification and model validation

Log-stacker activities and log-sorting process data were collected over a period of two weeks with the aid of the GPS Timber logging module.
Activities such as those listed below were monitored:

- stoppages
- logs supplied to the sawmill intake
- driving with loaded or empty grapple
- loading/unloading logs (bins or stacks)
- attending to troubles in bins
- attending to arriving trucks delivering logs to the sawmill
- shift or lunch breaks
- log-sorting capacity and stoppages

All activities were stored in a database. Log-stacker position at the log yard, driving distance and speed were linked to every activity. The performance of the log-scaling line was monitored over a period of three weeks in order to establish its capacity and stoppage frequency. Data and activities were verified in cooperation with the local sawmill staff and time-synchronized video recorded with the aid of web cameras at the log yard.

Model validation was done on two levels. First, distributions from simulated results regarding individual log-stacker activities, such as those listed above, were compared to measured data and calculated distributions. Second, the sawmill's output was validated against simulation results over a period of three months. The model was approved at both levels after some adjustment and further data acquisition.

5.4.9 Simulation scenarios and problem formulation

The current situation (February 2009) was modelled and configured in order to create a basic model. The most frequent sawing classes are allocated to bins situated at the middle of the sorting line. Corresponding log piles are situated close to the bins. The model was thus validated in reference to this specific situation. The main question was whether this is optimal, or whether bins and corresponding piles ought to be allocated closer to the sawmill´s log intake.
The model was configured according to the present log-yard situation, containing approximately 30,000 m^3 of scaled logs and 5,200 m^3 of unscaled logs. This log stock is approximately half the levels found during 2007–2008.

Three simulation scenarios were created by the project team for evaluation:

1a. Current status (February 2009)
A reference scenario, also used during the model validation, representing current log-yard status with regard to production planning, log supply, physical location of log piles and sawing classes, allocated sorting bins and distribution of trucks arrivals.

2a. Modification of scenario 1a model.
Modified allocation of logs in the most frequent sawing classes to bins close to the sawmill´s log intake. Log piles containing high-volume sawing classes allocated close to the respective bins.

2b. Further modification of scenario 2a.
Analysis of effects from decreased log volumes stored at the log yard. This resulted in smaller, relocated log piles and simpler logistics.

All scenarios were analysed to assess the impact of varying the allowed degree of filling in bins before emptying, for example, 30%, 50%, 70% and 90%.

The required transportation effort calculated on each sawing class was set to be the key value evaluated. This value is governed by annual number of logs per sawing class and log size processed and by required transportation distances caused by the location of bins and log piles. However, the required transportation work for a specific sawing class is the same whether logs are 3.0 metres or 4.5 metres long. Because of these conditions, a specific metric, m^2 x km, square metres of logs times transported kilometres, was establish in order to eliminate the influence of log length, reflecting the influence of the number of logs processed and log diameter per sawing class.

5.4.10 Results

Results from simulations show that transportation work can be decreased if bins are not emptied as frequently as they are at present and by allocating bins and log piles to more appropriate locations (Figure 5.18). However, an exception to note is the 1a scenario when increasing from 30% to 50% filling degree, in which the work required increases. To date, this phenomenon has not been explained; the cause may be more frequent disturbances in the bins or that this specific bin-filling degree induced more frequent and time consuming activities in order to attend to problems or to empty the bins. A similar phenomenon is found in results from scenario 2b, simulations incorporating the 70% filling degree. Regardless of the scenario evaluated, simulation results show that the required transportation work can be reduced by from 18.5 to 23.3 percent, depending on scenario and bin filling degree evaluated.

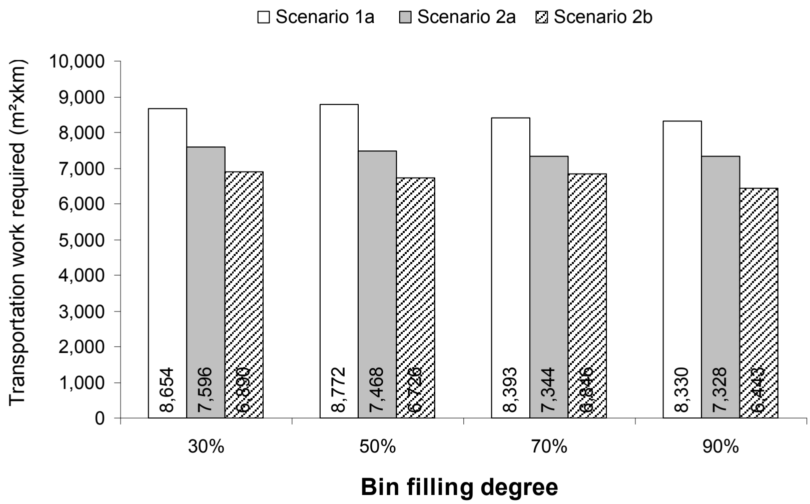


Figure 5.18 Simulation results showing transportation work required according to evaluated scenario.

5.4.11 Discussion and conclusion

The log yard area and connected logistics processes have rarely been subject for comprehensive restructuring. There might be three main reasons why this process has not been evaluated in detail. First. the logistics works well enough. Second, it is a huge effort to rearrange the log yard in order to try a new log-pile layout. Third, data aquisition for a simulation model has up to now been very complicated to perform. Retrieving accurate process data is a commonly large a and time-consuming part of the work involved in creating a simulation model.

Data aqusisition is a relatively easy task when monitoring process activities such as feeder speed or stoppages on a sawline. However, acquisition of such log-yard process data as log-stacker activities, stoppages and breaks becomes highly complicated when constantly and unpredictably moving vehicles are involved. The data verification required new methods besides the commonly used; this was solved by visual analysis of digital video files recorded in the log yard. The conclusion is that data acquisition was simplified by the aid of the GPS decisions support system even though it is not regarded as a prerequisite to perform the project. Modelling was done in a free software without major difficulties nevertheless, defining human behaviour and transforming this into code is a challenge. The work order system performed well and was regarded to imitate the real log yard procedures as intended.

The team work during this project was interesting to join and observe. All project stakeholders were as expected committed nevertheless, the involved log-stacker drivers contributed highly with their detailed knowledge and suggestions.

The results from three simulation scenarios evaluated showed that the basic model performed as intended and that there exist a potential to improve logistics and reduce required transportation work. Two out of three goal were thus regarded to be achieved. The third goal, to improve the log-handling process is indicated by the simulation results to be achieveable but the final verification of the results remains (July 2009). Figure 5.19 show a picture representing the log yard simulation project.

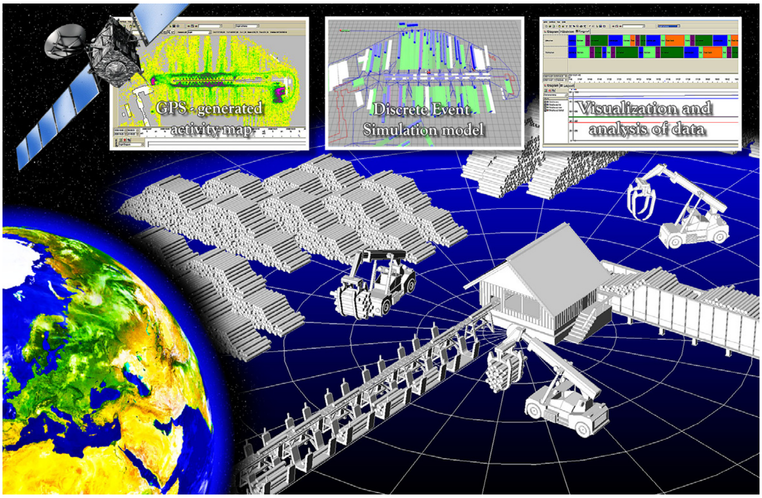


Figure 5.19 Project promotion picture

5.5 Case study IV: Improved log breakdown

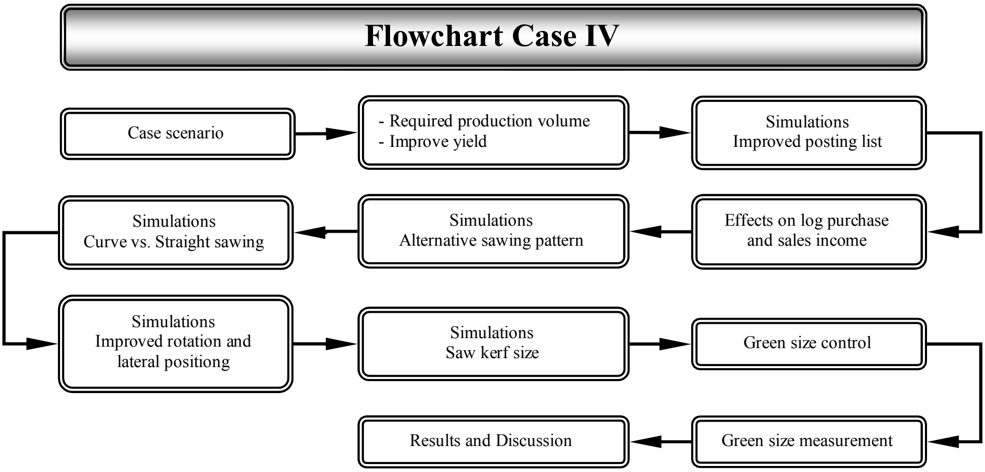


Figure 5.20 Case study flowchart.

5.5.1 Case Scenario

This case study is a comprehensive review of the sawmills posting list, the effects of alternative sawing patterns, techniques, kerf sizes and lateral and rotational positioning. Additionally, a green size control survey was done.

The sawmill is focused on producing an estimated sales market demand of 150,000 m^3 of centre boards distributed across 14 sawing patterns. The maximum demand for side boards is 70,000 m^3 per year. The required centre-board volumes per sawing pattern are shown in Table 5.5.

Table 5.5 Calculated Sales Market Demand for Centre Boards (Grönlund 1992).

SC No.	Sawing Pattern	Diagonal Measure of the Sawing Pattern – DmSP (mm)	Demand Centre Boards (m^3/year)
1.	38 x 75	114	5,400
2.	38 x 100	133	6,000
3.	50 x 100	150	15,800
4.	38 x 125	154	4,400
5.	50 x 125	169	18,300
6.	50 x 150	190	23,800
7.	63 x 150	206	15,500
8.	50 x 175	212	13,100
9.	50 x 200	234	17,200
10.	63 x 200	248	6,100
11.	75 x 200	262	9,300
12	75 x 225	283	6,700
13.	50 x 200 x 4	303	5,000
14.	50 x 225 x 4	321	3,400

5.5.2 Improved Posting List

The lower limit for each sawing class in the posting list is governed by the diagonal measure of each sawing pattern. The sawing-class width is thus set by the distance between the adjacent classes. The choice of position and width of the sawing classes can vary, depending on whether yield or market sales aspects are prioritized (Johansson 1978). For example, in some cases, widening a sawing class may be warranted because the corresponding board dimension is in high demand.

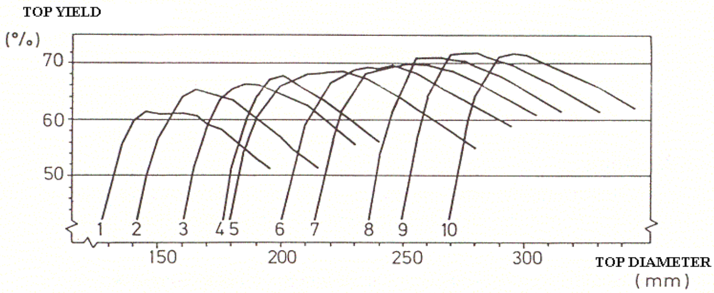
There are some priority areas to set and consider when a posting list is determined. A crucial aspect is the sales market's demand for board dimensions, qualities and lengths. However, optimized yield recovery and available log dimensions as well as sawmill and drying kiln capacity can affect the final configuration (Johansson 1978).

In order to define an improved posting list, recorded volume yield data is needed. It is impossible for many sawmills to monitor the volume yield for individual logs because the boards from different logs are mixed in the green sorting bins, and the result is not calculated before the boards have passed the trimming area. Furthermore, it is next to impossible in this stage to trace which sawing order the actual board pertains to. This situation only allows calculation of an average volume yield over a period of time and a number of sawn batches (Johansson 1978). One possibility is to arrange monitored test sawing in which the logs and boards are traced through the whole process.

Traceability studies done by Chiorescu (2003) and Flodin *et al.* (2008) using the fingerprint or Radio Frequency Identification tag approach show possibilities to identify and trace logs from outer shape and the tracheid effect. The results from the Chiorescu study show that it is possible to trace and individually separate up to 93% of the logs fingerprints. This method is, however, expensive, requires RFID-tags, extra equipment and competence and has not come into full industrial use yet.

An initial and comprehensive overview of positioning and width of the sawing classes can be achieved by establishing yield envelope curves for different sawing patterns.

These curves show the achieved volume yield as a function of log top diameter, thus indicating the top diameter interval in which the highest volume yield can be achieved with a specific sawing pattern applied. Yield envelope curves, as shown in Figure 5.21 can be achieved by recording the volume yield in a sawmill. However, this method is complicated, obstructive to production and time consuming, and thus obviously expensive (Asplund *et al.* 1982). These facts further emphasize the necessity to utilize saw simulation technology.



Numbers	Cant			Distribution					
1	19	100	19		19	38	38	19	
2	19	100	19		19	50	50	19	
3	19	125	19		25	50	50	25	
4	19	125	19		19	63	63	19	
5	19	150	19	19	25	50	50	25	19
6	19	175	19	25	25	50	50	25	25
7	19	175	19	25	25	63	63	25	25
8	19	200	19	25	25	63	63	25	25
9	19	200	19	19	25	75	75	25	19
10	19	225	19	19	25	75	75	25	19

Figure 5.21 Yield envelope curves calculated from a batch of 25 curve-sawn logs (Asplund et al. 1982).

Combined with log geometry data from a 3-D or CT log scanner, logs can be broken down and evaluated repeatedly, and the individual results recorded, thus enabling evaluation of sawing classes and the determination of appropriate sawing patterns.

In order to create yield envelope curves, logs contained in the SPSB were sawn using the Saw2003 breakdown simulation software (Nordmark 2005). The same sawing pattern was applied to all logs during one simulation, and the yield achieved from the individual logs was plotted as a function of the log top diameter. The same procedure was repeated applying all the sawing patterns in question one by one to the logs in the SPSB.

Figure 5.22 shows the plotted simulated yield envelope curve achieved by applying sawing pattern no. 3, “50 x 100 mm”. The results achieved from the individual logs include the accumulated yield from centre boards and side boards.

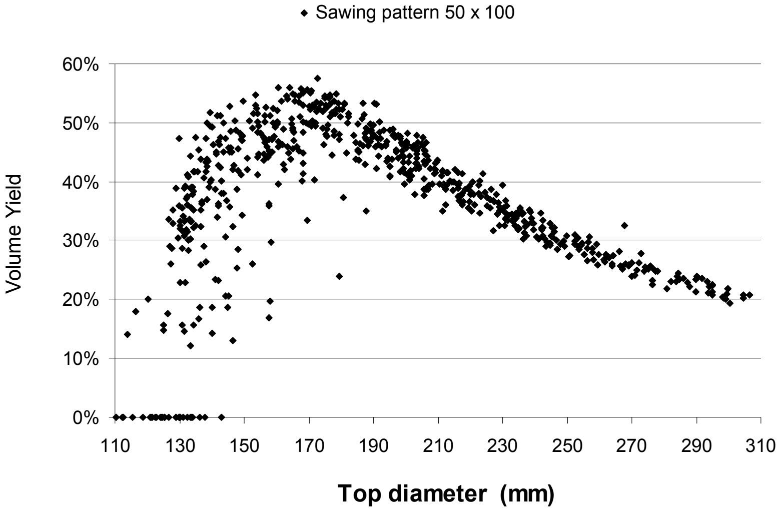


Figure 5.22 Simulated Volume Yield. The results achieved by applying sawing pattern “50 x 100 mm” on all logs in the SPSB, the accumulated yield from centre and side boards included.

However, the yield shows a large distribution between similar log diameters, and a curve function is difficult to observe and define without supplementary statistical data management and curve fitting. In some cases, specific logs constantly show zero or very low volume yield. This can be due to corrupt information in the log data, and these specific logs were removed from the study.

The high spread in yield between logs with similar top diameter makes curve fitting difficult. The yield data were therefore divided into 5-mm groups according to top diameter, and the median values for every group were calculated and plotted. This procedure was repeated, applying all current sawing patterns one by one to the log material. This work created two times fourteen yield envelope curves. Figure 5.23 shows the grouped and plotted median yield values for sawing pattern no. 3, “50 x 100 mm”, containing centre boards and both centre boards and side boards respectively.

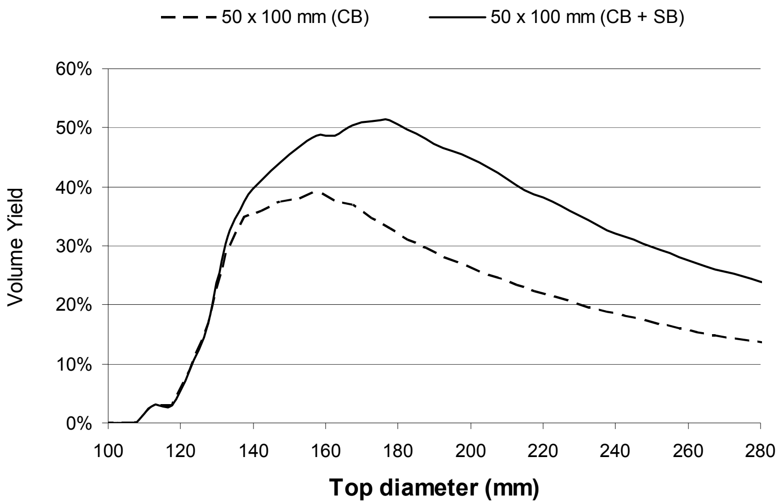


Figure 5.23 Yield envelope curves for sawing patterns containing centre boards (CB) and sawing patterns containing centre boards and side boards (CB + SB). Sawing pattern no. 3, "50 x 100 mm" Table 5.5.

Some unevenness can still be found on the envelope curves. The uneven values, shown, for example, in the 155–160-mm group, can be explained by the fact that some of the 5-mm groups contain only a few logs, and statistical outliers have a high impact on the group yield in such a case. This effect is even more obvious in the groups containing logs with top diameters larger than 260 mm where there are few logs in every group (from 1 to 10 logs).

The data management creates a smoother curve, enabling a fitted curve function to be used for optimal positioning of the sawing class limits. The sawing class yield width and positioning can thus be evaluated depending on whether production of centre boards or of side boards is prioritized. However, these mathematically defined curves need calibration if they are to reflect the real sawmill's output. Figure 5.24 shows the yield envelope curves as a function of the third power for 14 sawing patterns containing centre boards and side boards superimposed in the figure.

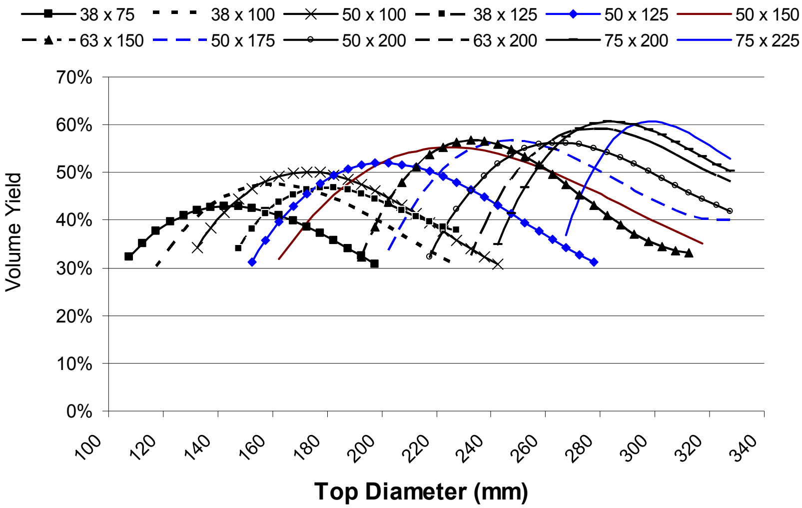


Figure 5.24 Fitted yield envelope curves created from saw simulation data.

The coefficient of determination, R^2, was between 0.79 and 0.98 for the individual envelope curves. In reality, the sawing classes are placed close to the uppermost part of the curves, allowing the curves to be truncated in order to simplify the graph. The intersections between the sawing classes indicate rough positions and limits for the sawing classes. The sales market's demand for centre boards with sharp edges, *i.e.*, no wane allowed on the edges, commonly governs the basic composition of the posting list.

The positioning and width of the final sawing class are mainly governed by of the following criteria:

- The diagonal measure of the sawing pattern
- Potential sales market demand and price of side boards
- The sawing pattern's share of total produced volume and potential income
- Adjacent sawing classes/patterns and their share of produced volume and potential income
- Applied straight- or curve-sawing technique
- Positioning accuracy
- Log taper
- Log crook
- Diameter measurement accuracy

The curves shown in Figure 5.24 give only a rough idea of where the optimal yield segment is situated; yet it is crucial to find the exact position and width of the sawing class. Setting of the optimal position for a single sawing pattern is simplified using saw simulation data combined with dedicated spreadsheets.

Figure 5.25 shows yield curves calculated and plotted as a function of the lower top diameter limit of the sawing class (LLSC) and a 15-mm class width. Curve B is created using a sawing pattern containing centre boards and side boards, while curve A contains a sawing pattern with centre boards only.

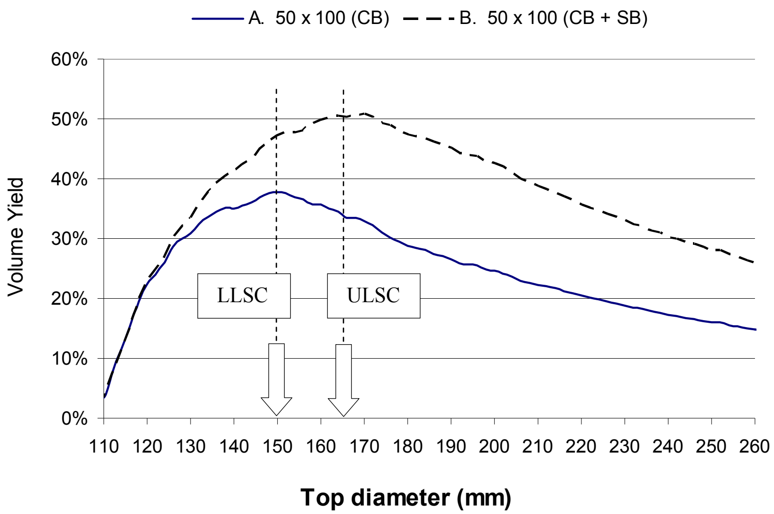


Figure 5.25 Saw Simulation Yield results plotted as a function of the lower top diameter limit for the sawing class, grouped values. LLSC = Lower Limit of the Sawing Class, ULSC =Upper Limit of the Sawing Class. Sawing Pattern A: "50 x 100 mm" CB (centre boards only). Sawing Pattern B: "50 x 100 mm" CB + SB (centre boards and side boards included). Sawing Class width: 15 mm.

Curve A Figure 5.25 shows a maximum true yield of 37.8% achieved when the lower class limit (LLSC) is set to 150 mm. The B curve shows a maximized true volume yield of 50.4% when the lower limit is set to 170 mm. This method simplifies optimization of detached sawing classes. In reality, however, the position and width of the adjacent sawing classes will affect the yield of the intermediate class. A comprehensive evaluation is thus required in order to create an improved posting list with the highest total yield.

A fully optimized posting list should also consider the highest value yield, market demand, sales value and manufacturing costs. The sawing classes containing the highest values and board volumes should be prioritized in order to maximize the aggregated profit achieved from the posting list.

A project was carried out at SP-Trätek (Skog 2004) to develop software for dynamic sawing-class definitions. The software uses saw simulation data to define sawing classes in light of the formed products rather than the original sawing patterns. The software can also be used to optimize the sorting and sawing process in such a way that the required board volumes are generated. This also facilitates evaluation and optimization of the sawing process in order to adapt to changes in purchase market demands as well as changes in the raw material supply.

A number of simulations were performed in order to improve the total accumulated true yield achieved from the sawn dimensions. A basic posting list, named DMSP was used in the initial simulation in order to establish a reference yield.

The posting list alternatives were named as follows and evaluated with focus on the stated centre board production target:

1. DMSP:

Note: The Lower Limit of the Sawing Classes determined and set by the Diagonal Measure of the Sawing Patterns (DMSP) centre yield.
Used as the reference posting list in this study.

2. Simulation:

Note: The optimal Sawing Class position determined and set by Saw Simulations. The optimal Lower Limit of each individual Sawing Class with regard to centre board yield was determined and set by the results from saw simulations. See Figure 5.25.

3. Sensitivity Check:

Note: Sensitivity analysis done by altering the sawing class limits used in the "Simulation" posting list (see above) in a stepwise manner.

4. Envelope Curve:

Note: Sawing class position and width determined by intersecting Yield Envelope Curves. See Figure 5.24.

Improved sawing-class positions, with respect to the centre-board yield, were established for all current sawing patterns with the aid of saw simulations.
Figure 5.25 shows the yield peak when the lower sawing-class limit is set to 150 mm for this particular sawing pattern. These limits were achieved for all sawing classes by simulations and were used to create the posting list named "Simulation".

The posting list named "Sensitivity check" was used in order to find possible yield improvements by stepwise alteration of the sawing-class limits and width settings in the "Simulation" posting list. The sawing class-limits used in the posting list named "Envelope curves" were set by the position of intersecting envelope curves (see Figure 5.24). All four posting lists were established in two separate configurations, a limited version with only the centre board pattern applied and a version applying the full sawing pattern including side boards.

Figure 5.26 shows the yield results from a comprehensive evaluation of the four posting lists. The results show that the true volume yield can be increased from 49.3% to 51.6% by optimizing the sawing class's width and position.

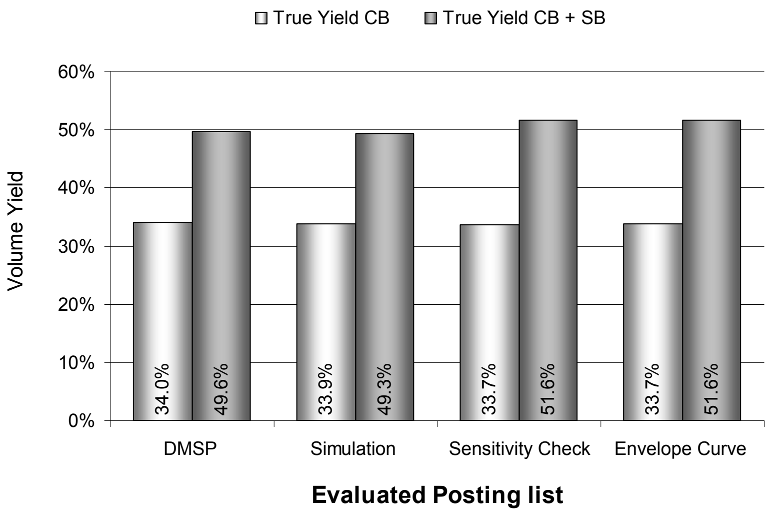


Figure 5.26 Simulation results from the comprehensive evaluation of posting lists 1–14.

The total required log volume and log diameter distribution in this case study are determined by the specified sales market demand of 150,000 m^3 of centre boards.

The aim in this stage is thus to establish the necessary log volume and to improve the total volume and value yield recovery in four steps:

- Evaluation of posting lists 1–4 with regard to the yield for limited centre-board sawing patterns
- Calculation of the log demand based on the limited posting list yield
- Calculation of the additionally produced side-board volume
- Set the optimal posting list regarding the combined yield for centre boards and side boards in order to increase the total achieved value

The results achieved from reference posting list "DMSP" show that it is best suited for production of centre boards, thus requiring the lowest volume of purchased logs.

The yield achieved by sawing exclusively centre boards is, however, very low, and side boards must be produced in order to improve the finacial result. The evaluation was further refined by individually analyzing data for the various sawing classes by splitting the yield results into separate results and graphs for each sawn dimension.

This enables further analysis of the impact on the individual sawing classes. Figure 5.27 shows the yields achieved within the separate sawing classes. The sawing classes are sorted from left to right according to required board production. The results clearly show that the "Envelope curves" and "Sensitivity check" posting lists consistently achieve the highest yield for all individual sawing classes.

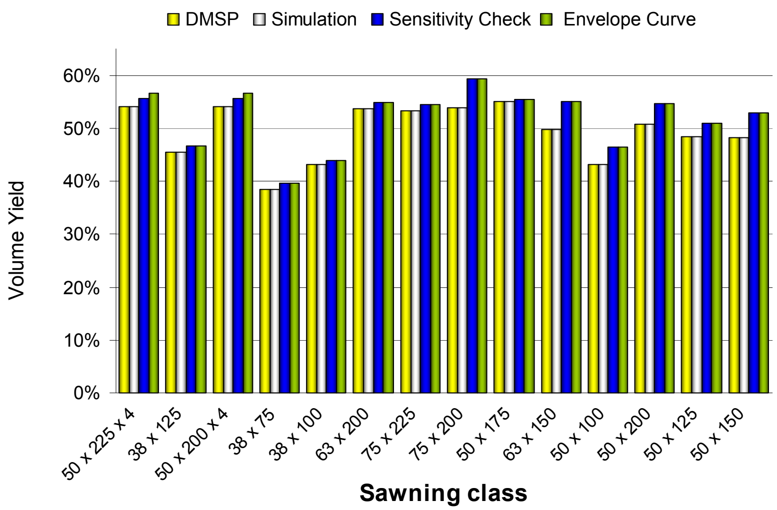


Figure 5.27 Evaluation of different posting-list configurations. Sawing classes sorted according to required centre-board volumes. High volume dimensions to the right.

Figure 5.28 shows the total calculated demand for log volume per year depending on preferred posting list and using the aggregated average yield result for the entire batch in comparison to the detailed results. The detailed yield information (Figure 5.27) achieved by separating the 14 sawing classes enables a more correct calculation of the log demand. The impact of a relatively small yield difference becomes obvious when large volumes are processed.

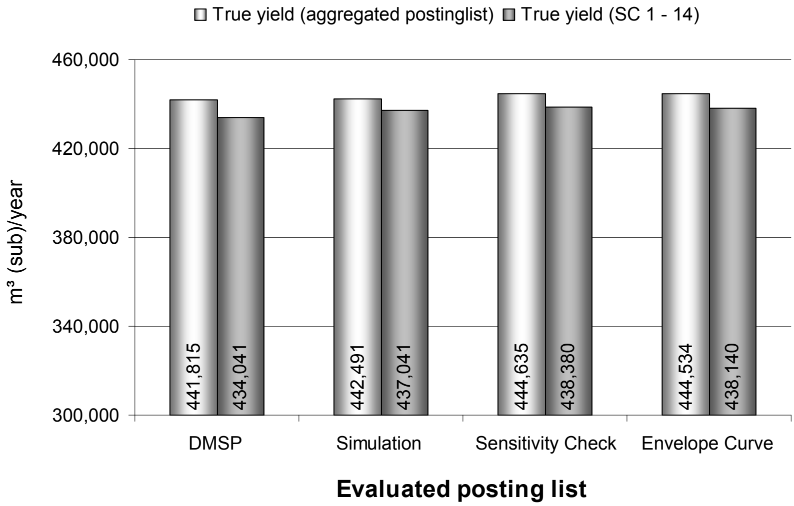


Figure 5.28 Calculated demand for logs in order to produce the required volume of centre boards. Aggregated demand calculated on average true yield for the entire log batch, whereas demand with reference to Sawing Classes (SC) 1–14 is calculated on yield from individual sawing classes.

The maximum difference in log-volume demand between the aggregated true yield calculation and the separate sawing class yield results is close to 6,400 m^3 sub. This volume would cost 3.2 MSEK to purchase at an average price of 500 SEK/m^3. Posting list “Sensitivity Check” shows the highest log demand for production of 150,000 m^3 of centre boards (Figure 5.28), but also the highest total yield (Figure 5.26). This paradox is explained by the fact that posting lists “Sensitivity Check” and “Envelope Curve” produce considerably more side boards than “DMSP” or “Simulation”.

This refined calculation is, however, to be viewed as more correct calculation of the log volume demand and purchase cost, not a part of the improved disjoining process. Nevertheless, this is very important information to have at hand when creating a budget and calculating the expected profit.

The choice of posting list will affect the volume of side-boards produced, thus affecting the sawmill’s total income. Therefore, a financial evaluation of the different posting lists is necessary before the final decision is made. However, the final profit will be greatly affected by the sawmill’s ability to sell the side boards produced on the market.

The calculated result shows that the side-board volume produced will be between 63,800 m^3 and 77,800 m^3, depending on the posting list preferred.

Table 5.6 shows the maximum estimated profit given that all produced boards are shipped at the calculated price. The difference in calculated profit between the posting lists *"Sensitivity Check"* and *"Envelope Curve"* is small.

These financial, should be regarded as ideal values. because they do not take the actual costs for running the sawmill into consideration. Furthermore, the situation can change rapidly if the demand for side boards decreases or if the expected sale price is reduced.

Table 5.6 Estimated maximum expected profit given that all produced boards are shipped at the calculated price.

	DMSP	**Simulation**	**Sensitivity Check**	**Envelope curve**
Total sales value (MSEK)	326.8	330.3	334.6	334.7
Total Purchase cost logs (MSEK)	218.6	218.6	219.1	219.0
Calculated Gross Profit (MSEK)	108.2	111.7	115.5	115.7

A review of the simulation data for the produced boards reveals that posting list "Sensitivity Check" produces side boards of higher quality because there is less wane. This review also indicates that the number of side boards produced using posting list "Sensitivity Check" is lower. This is often to be preferred, because fewer boards, furthermore with higher quality, will mean a decrease in drying and handling costs.

The complexity of the situation increases even more if sales- and production-related variables such as demand for boards of specified qualities and lengths or production cost per board are added to the scenario. In such a case, the further analysis required could be accomplished using the data provided by the saw simulation combined with production-related information. Within the scope of the information presented, the selected and improved posting list will be set to "Sensitivity Check". Table 5.7 shows the final posting list configuration.

Table 5.7 Improved Posting list.

SC No.	Sawing Pattern	Lower Limit SC (mm)	Upper Limit SC (mm)	Post Cant Saw	Post Deals Saw
1.	38 x 75	0	135.9	19, 75, 19	19, 38, 38, 19
2.	38 x 100	136	153.9	19, 100, 19	19, 38, 38, 19
3.	50 x 100	154	169.9	19, 100, 19	19, 50, 50, 19
4.	38 x 125	170	181.9	19, 125, 19	19, 38, 38, 19
5.	50 x 125	182	199.9	19, 125, 19	25, 50, 50, 25
6.	50 x 150	200	221.9	19, 150, 19	19, 25, 50, 50, 25, 19
7.	63 x 150	222	234.9	19, 150, 19	19, 25, 63, 63, 25, 19
8.	50 x 175	235	249.9	19, 175, 19	19, 25, 50, 50, 25, 19
9.	50 x 200	250	264.9	19, 200, 19	19, 25, 50, 50, 25, 19
10.	63 x 200	265	274.9	19, 200, 19	25, 25, 63, 63, 25, 25
11.	75 x 200	275	291.9	19, 200, 19	19, 25, 75, 75, 25, 19
12	75 x 225	292	307.9	19, 225, 19	19, 25, 75, 75, 25, 19
13.	50 x 200 x 4	308	329.9	25, 200, 25	19, 25, 50, 50, 50, 50, 25, 19
14.	50 x 225 x 4	330	499.9	19, 225, 19	19, 25, 50, 50, 50, 50, 25, 19

5.5.3 Alternative sawing pattern

A posting list with static sawing class limits is nevertheless a compromise, because it will not utilize all logs to the maximum. A further analysis of some of the sawing patterns reveals a potential to achieve higher volume recovery. The basic assumption in this study is that the logs are correctly measured and classified according to their top diameter. Logs close to the class limits can in reality be incorrectly classified due to sorting errors, and thus affect the yield.

To exemplify this possibility, Figure 5.29 clearly shows that the aggregated true yield is highest if the normal sawing pattern “50 x 100 mm” is applied to sawing class no. 3. The results also clearly show that the yield decreases when adjacent sawing patterns are applied to the same log.

However, this is the aggregated result presented for the entire sawing class in Table 5.7, and a detailed study of logs situated close to the sawing class limit shows more inconsistent results. A detailed analysis of the data shows that 18.0% of all logs in the reference class produce a higher centre-board yield if the alternative "38 x 125 mm" sawing pattern is applied to these specific logs.

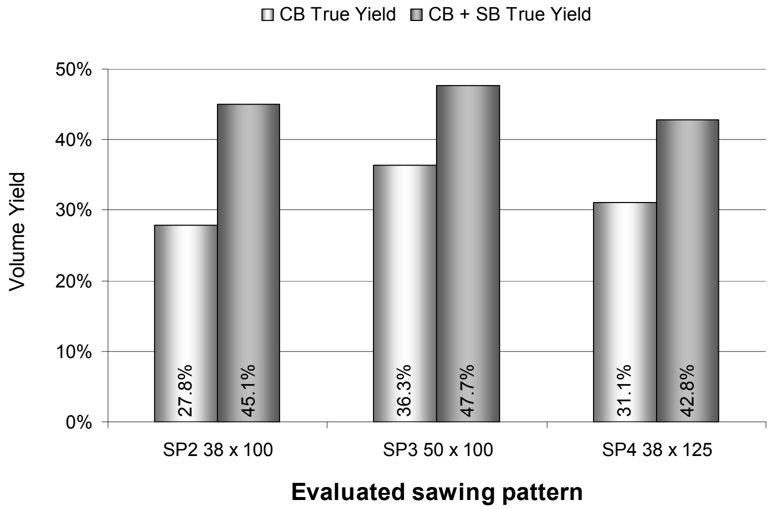


Figure 5.29 Volume yield for reference sawing class no. 3 (sawing pattern "50 x 100 mm") in comparison to yield achieved with alternative sawing patterns applied.

These logs are evenly distributed over the 16-mm-wide sawing class, and, assuming that these logs are correctly sorted, show that even logs in the middle of the range should at times be classified into adjacent sawing classes in order to improve the centre-board yield. In order to improve the yield further, these 14 logs should have been assigned to sawing class no. 4, thus improving the true yield for the specific logs. Simulations show that the accumulated true yield for the log batch could be increased by 2.5 percent points in comparison to the comprehensively improved posting list based on top-diameter classes.

This illustrates the difference in concept between a log being assigned to the "correct" sawing pattern and being assigned to the "optimal" sawing pattern.
Table 5.8 shows the effects on yield when logs close to the sawing-class limit are incorrectly measured and sorted into the adjacent sawing class.

Table 5.8 Results from a sensitivity analysis of 6 logs situated close to a sawing-class limit. The results show the effect on yield, depending on whether logs are sorted into the nominally correct or into the adjacent sawing class because of incorrectly measured top diameter.

Log ID	Dtop (mm)	Limit adjacent SC	Distance to adjacent SC limit (mm)	Normal SP	Alternate SP	Yield – normal SP (%)	Yield – alternate SP (%)
25–5–4	148.6	154.0	5.4	38 x 100	50 x 100	47.5	48.2
52–1–1	149.0	154.0	5.0	38 x 100	50 x 100	47.4	41.2
1–1–1	151.1	154.0	2.9	38 x 100	50 x 100	41.2	37.7
53–4–2	154.3	154.0	0.3	50 x 100	38 x 100	48.5	49.8
32–2–2	156.4	154.0	2.4	50 x 100	38 x 100	51.1	53.1
4–1–3	158.5	154.0	4.5	50 x 100	38 x 100	45.0	46.0

The measured top diameter for Log 52–1–1 is 149.0 mm and should, according to the posting list from Table 5.7, be sorted into sawing class no. 2 and thus be broken down with sawing pattern “38 x 100 mm”.

Assuming a distribution in sorting accuracy of +/- 5 mm, this log could in some cases be classified into the adjacent sawing class no. 3. The simulation results show that the yield in this case would be decreased by 6.2 percent points for this particular log. The results are inconsistent, however. For example, Log 25–5–4, which is even thinner than Log 52–1–1, produces a higher yield when broken down with a larger sawing pattern. The conclusion to be drawn from this is that the inconsistent yield results are caused by variations in log geometry, and an optimized sorting procedure would have to take this in to account, rather than focus only on the measured top diameter.

The results clearly show a high potential to increase yield by evaluating the outer shape of every log, thus sorting each log into the appropriate sawing class. The results illustrate again the need for an improved log-sorting procedure in which logs are treated as single individuals. A study performed at the Swedish University of Agricultural Sciences demonstrates the possibility of presorting logs by different grades and board properties using external log-geometry variables such as taper, surface unevenness, sweep and ovality (Jäppinen 2000).

In order to realize this potential, a more sophisticated sorting process is necessary. This could be accomplished, for example, with an online log sorting system in which 3-D geometry data and simulation software are used to evaluate and find the appropriate sawing pattern for each log in order to achieve the highest yield. 3-D log-measuring frames are becoming increasingly common in Swedish sawmills. Combined with sophisticated and fast simulation software, this makes it possible to establish the optimal sawing pattern with regard to rotation, positioning in the cant and deal saw, *etc*.

5.5.4 Curve sawing vs. straight sawing

Curve-sawing technology has been used for more than a century in Scandinavian sawmills because of the saw kerf's ability to follow the curved form of a cant and the relatively high volume yield it produces.
The advantages of using curve-sawing technology are (Grönlund 1992):

- Higher yield compared to straight sawing (1–4 percent points of volume yield)
- Smaller sorting diameter. The required dimensions can be sawn from logs with smaller top diameter
- Increased centre board yield compared to straight sawing
- Improved board quality due to the removal of the log pith during sawing (2 ex and 4 ex logs)

Straight sawing is still used in sawmills on big and lumpy logs as well on straight and circular logs because it will still be able to produce boards from the full log length. Thus, highly curved logs generally gain most from curve sawing because of the saw blade's ability to follow the log sweep during the sawing procedure (Grönlund 1992).

The theoretical advantages of curve sawing are obvious on highly curved logs. Simulation makes it possible to analyze whether curve sawing is optimal in all cases and to determine when less complicated straight sawing is more applicable.

These straight-sawing simulations were performed with the same posting list as used previously in the study. The applied sawing-class limits are therefore not optimized for straight sawing, and this fact should be taken into consideration.

The results in Figure 5.30 show that the true yield was improved by 1.2 percent points if curve sawing was used instead of straight sawing. However, close to 24% of the 618 logs showed an improved centre- and side-board yield when straight sawing was applied. The yield for the simulated log batch was thus increased by a further 0.4 percent points when the optimal sawing method was applied.

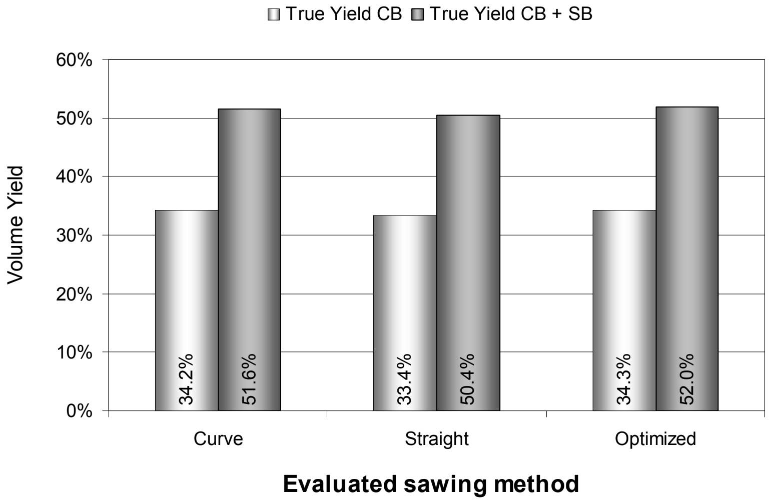


Figure 5.30 Curve- and straight-sawing techniques' impact on true yield. The "optimized" column shows the true yield achieved by applying best sawing technique combined with sawing patterns containing only centre-boards (CB) and full sawing patterns containing centre-boards and side-boards.

Table 5.9 shows the maximum log sweep distribution for 618 logs in the stem bank. 89.1% of all the logs present a sweep value below 25 mm, with an average log length of 4.5 metres.

The main part of all logs gaining from straight sawing is, as expected, found among the straightest logs. However, the 67 logs with a sweep larger than 25 mm should in this case have been expected to suffer more from straight sawing. Nevertheless, some of the crookedest logs still benefit from straight sawing.

Table 5.9 Distribution of log sweep, optimal sawing method and average log length.

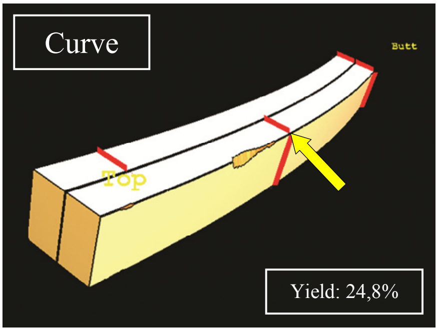
Sweep	No. logs	Fraction (%)	No. logs that benefits from straight sawing	Fraction that benefits from straight sawing (%)	Average log length (m)
< 25 mm	551	89.1	133	21.5	4.5
≥ 25 mm	67	10.9	13	2.1	4.4
Total batch	618	100	146	23.6	4.5

This could be explained by the fact that close to 38% of the logs are situated less than 6 mm from the upper limit of the sawing class. Furthermore, the share of logs with a sweep greater than 25 mm is only 10.9% of the entire log material. For all logs gaining from straight sawing, the calculated average sweep is only 14 mm at an average log length of 4.4 metres. Thus, these logs should be regarded as straight for all practical purposes.

One of these specific logs producing a higher straight-sawing yield was further examined in order to find the cause of the difference in achieved yield. The minimum top diameter of the log is 157.4 mm, thus positioned 3.4 mm from the lower limit of sawing class no. 3. The log is 4.64 metres long, and the maximum sweep is 44 mm. The log was initially rotated to the exact same position in the curve-sawing and straight-sawing simulations.

A review of the images and the simulation results shows that a large area containing wane appears on the upper edge of the right centre board when the log is curve sawn. The left picture in Figure 5.31 shows the wane on the edge and the cutting mark (the yellow arrow) where the boards will be trimmed.

As no wane is allowed in the specified sawmill rules, the part is cut off during the trimming procedure, thus explaining the lower yield for the curve-sawn version. The wane area on the curve-sawn centre board is probably caused by a small unfortunate and coincidental cavity at the log’s surface.



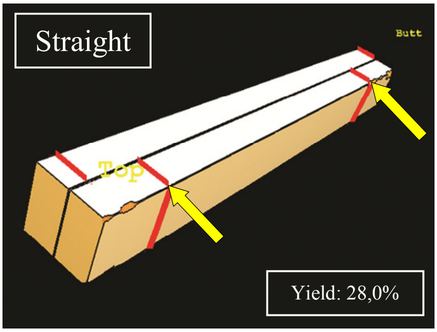


Figure 5.31 Example of straight-sawn centre-board yield in comparison to curve-sawn centre-board yield from the same log.

The centre-board yield is increased from 24.8% to 28.0% by using straight sawing, and the total yield of side boards included is increased from 33.8% to 38.2%. In light of theses facts, the obvious choice would be to recommend straight sawing. This particular log could nevertheless be further improved by using curve sawing combined with altering the rotation in the cant saw.

Simulation results show that the centre-board yield is increased to 31.3% if the log is rotated an additional 50 degrees from the normal horns–down position. Figure 5.32 shows the impact of the applied sawing technique and the effects of horns-down or optimal rotation. The results also show a maximum achievable curve-sawing yield of 42.6% in comparison to 40.0% for straight sawing.

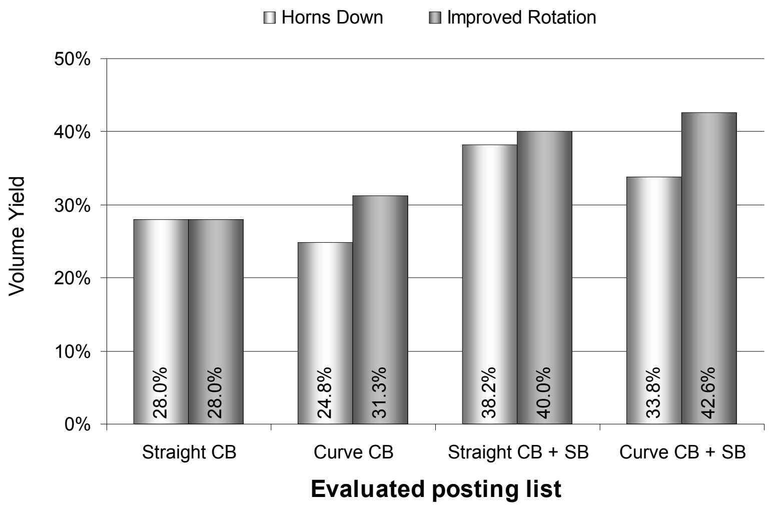


Figure 5.32 Saw technique and rotation impact on true yield. One log.

The main effect of the optimal rotation is explained by the fact that the wane areas that appeared in the centre of a board in the horns-down position do not exist after the additional rotation; thus, longer centre boards are produced. Figure 5.33 shows the moved cutting mark on the right centre board after rotating the log.

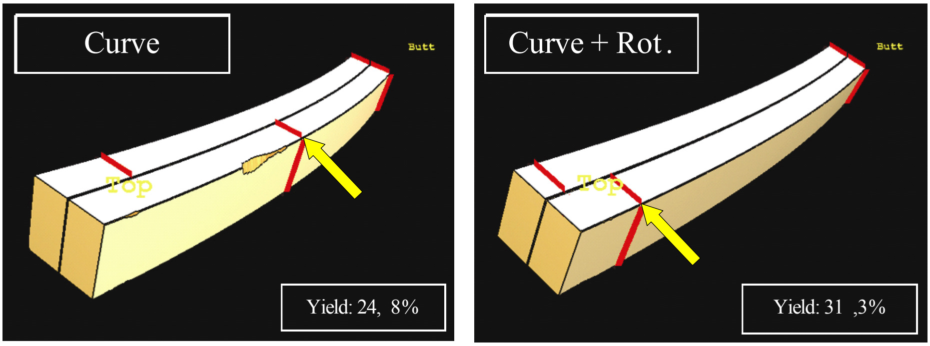


Figure 5.33 Additional potential to increase the yield by optimal rotation combined with improved sawing technique.

The conclusion to be drawn from this is that even though this single log initially would have gained from straight sawing, a better solution is to evaluate and find an improved rotation combined with curve sawing.

The volume yield finally achieved from this particular log is thus affected by several interacting variables. This serves as an example of the complexity of the optimized breakdown process. The complexity becomes even higher when the inner properties of the log are added to the picture, because in reality, the final board quality is greatly affected by the presence and position of knots and defects.

5.5.5 Improved lateral and rotation positioning of logs in sawing machines

The normal log positioning in the cant saw is defined as rotating the log to the horns-down position and an ideal centring to the saw blades (Drake *et al.* 1986). Because of their geometry, straight logs are generally not affected by rotational position, whereas crooked logs are considerably affected by deviations from the horns-down position. This positioning of logs in the cant saw is governed by parametres defined in three degrees of freedom—rotation, parallel and skewed displacement.

Cant optimization requires consideration of the width and position of both plane surfaces. An optimal positioning and rotation of a log results at best in a cant with equally sized and optimally centred plane surfaces. An offset from the normal position is called the positioning error and is defined as the distance between the centre of the log cross-section and the centre of the sawing pattern. The volume yield is sensitive to offsets and highly governed by the log top diameter in relation to the diagonal measure of the centre yield.

However, the yield can sometimes be improved from a deliberate offset positioning or rotation in some cases. An offset in the centre positioning can at best result in more board volume being gained compared to what is lost on the opposite side (Drake *et al.* 1986). This phenomenon is most obvious when a log's top diameter falls short of the lower sawing class limit due, for example, to an error in the log-sorting procedure.

The consequence of a normal centring in first saw is that both side boards may be lost, whereas an offset can produce one side board. This is a risky tactic, however, because an offset can also create an asymetric cant, which in the end can cause volume yield to suffer.

Other factors such as ovality can govern optimal positioning and rotation when logs are relatively straight. The aim is to find the optimal position and rotation of logs in order to minimize the effects of deviations from a circular cross-section. By adapting positioning and rotation to an elliptical cross section, an optimal positioning of the sawing pattern can be achieved.

A log with an ideal sweep and circular cross-section can theoretically produce the same yield as straight logs by using the horns-down concept combined with curve sawing. Figure 5.34 shows the ideal cross-section achieved when the log is positioned with the crook up (reference 0°) and the effect on the cross-section if the log is rotated along its longitudinal axis in 5-degree offsets. The log diameter in the example is equal to the diagonal measure of the centre-board sawing pattern and is thus highly sensitive to an offset rotation.

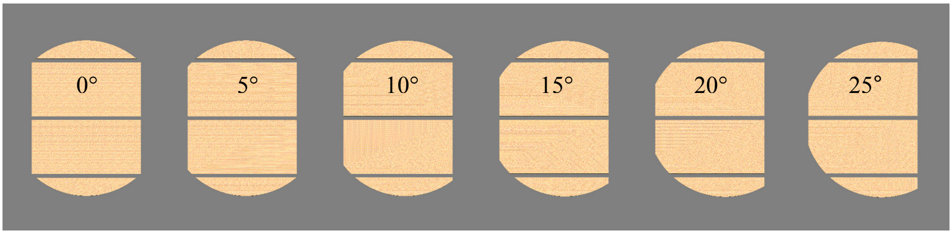


Figure 5.34 Centre yield cross-section of swept log rotated to the right from 0 (horns down) to 25 degrees.

At an offset of 5°, wane already appears on the left side of the cant's edges, causing the volume recovery to decrease. The rotation offset would not have the same impact if the same sawing pattern were applied to a log with a larger diameter, because the sawing pattern is allowed to rotate more freely inside the log's cross-section without exceeding the surface limits.

This maximized-area presumption serves as the basis for rotating logs to the horns-down position in order to maximize the volume yield. For this reason, simulations were performed in order to verify the concept and to find the optimal rotation position. All logs were rotated along the longitudinal axis +/- 90 degrees from the normal horns-down position with an offset of 5-degree steps.

5.5.6 Results

The comprehensive simulation results in Figure 5.35 show that the highest aggregated true yield was achieved when all logs were rotated -10 degrees from the horns-down position. The improvement achieved from the -10 degree offset is very small, though and not significantly determinative.

The horns-down position is not the optimal position in all cases, even though the aggregated results in Figure 5.35 indicate this to be the case. The inconsistent results become obvious when the optimal rotation is evaluated for individual logs.

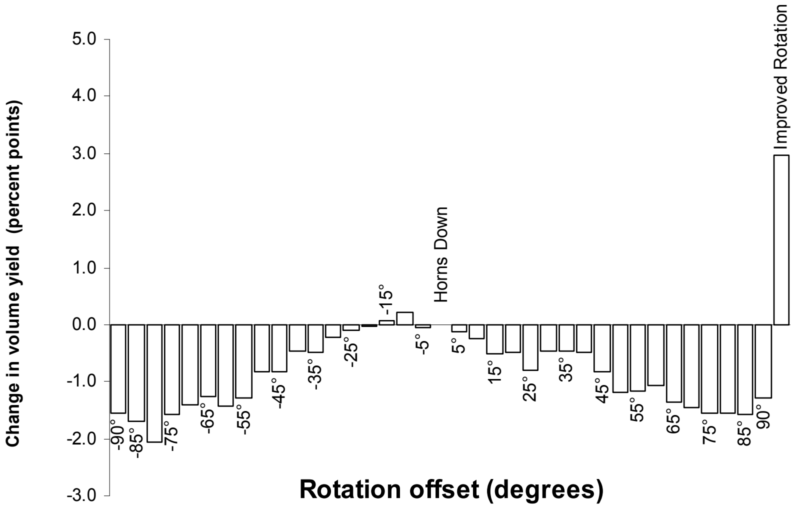


Figure 5.35 Simulated true volume yield in reference to horns-down position. Each position includes simulation yield results from 200 logs. Column "Improved Rotation" shows the total aggregated yield improvement on 200 logs, 3.0 percent points.

A detailed review of one specific log is shown in Figure 5.36. The log properties show that the minimum top diameter is 229.1 mm, maximum sweep is 8.5 mm, and length is 4.5 metres. The log is thus rather straight and located in the centre of the sawing class. This specific log clearly gains from the altered rotation. The yield is increased by 3.6 percentage points from 56.0% to 59.6% when the log is rotated -75°.

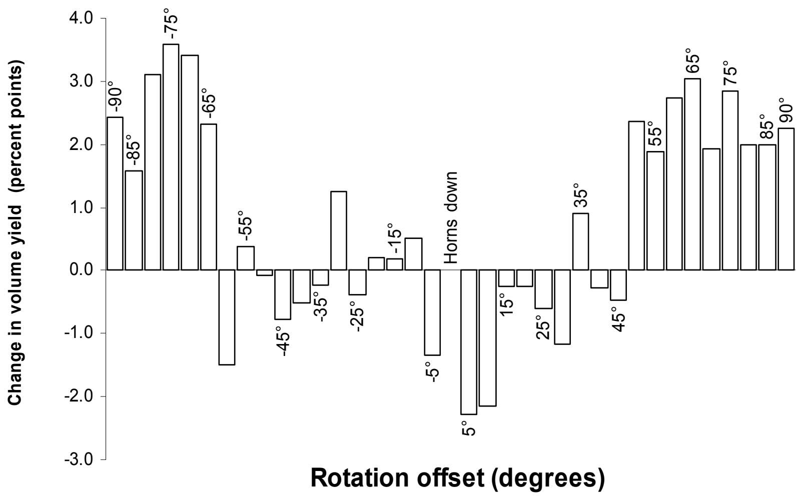


Figure 5.36 Example of simulated true volume yield in reference to horns-down position (one single log). The yield is increased by 3.6 percent points from 56.0% to 59.6% when the log is rotated -75°.

Simulation results show that the increased yield after altered rotation is obtained by the production of one extra side board in the cant saw and one side board of increased length in the deal saw. The altered rotation has in this case decreased the occurrence of wane on the side boards, thus producing more board volume. The graph also shows that the achieved yield can be vulnerable to relatively small positioning errors, since the optimal position is often “pointed”. For example, the yield is decreased by 2.3 percentage points if the log is rotated +5 degrees in comparison to the horns-down position, and 1.3 percentage points if rotated -5 degrees.

The -65-degree is even more vulnerable to a positioning error, and the yield drops rapidly from 58.4 percent to 54.5 percent if the log is rotated to the -60-degree position. The most obvious solution in this case would be to aim for the -75-degree position, thus maximizing the yield. In this specific case, this position is also relatively invulnerable to a positioning error.

One consequent approach to dealing with the challenge of achieving a high yield and at the same time minimizing the vulnerability caused by positioning errors could be to aim for the middle of the safest plateau, in this case between -70 and –75 degrees.

Figure 5.37 shows the plotted location of optimal rotation for every individual log and the yield improvement. If logs show the same maximum yield at two or more rotational angles, the position closest to the horns-down position is plotted. The results also show that the improved rotational position for the logs is evenly spread over the 180º range. The 200 logs used in this part of the case study are relatively straight, since the maximum crook is 28 mm, and a distinct horns-down position can thus be difficult to clearly define. This further accentuates the difficulties and challenges of defining a correct horns-down position.

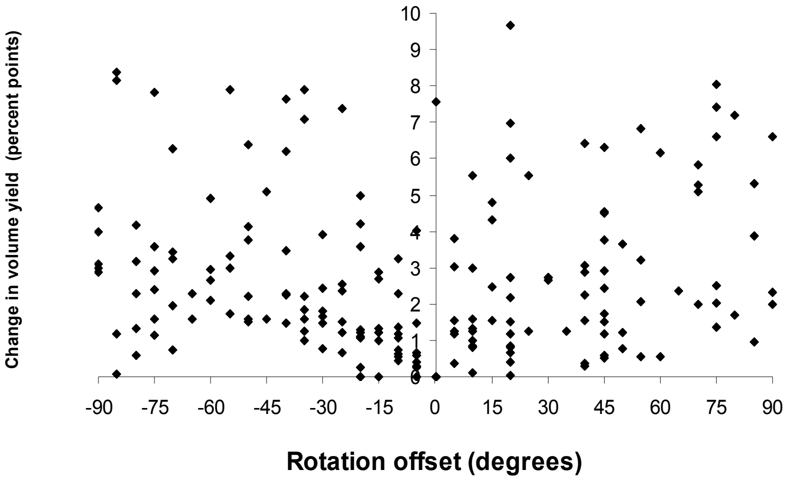


Figure 5.37 Plotted location of optimal rotation for every individual log and the yield improvement, 200 logs. If logs show the same maximum yield at two or more rotational angles, the position closest to the horns-down position is plotted.

Figure 5.38 shows the yield improvement for every single log plotted against the log crook. The improvement is, as previously, achieved by rotating the log to different positions in relation to the horns-down position. The two crookedest logs plotted in Figure 5.38 show no yield improvement.

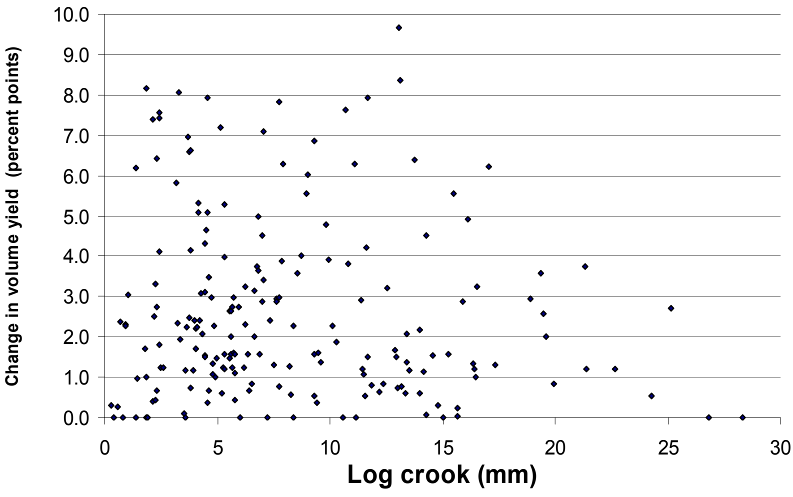


Figure 5.38 Simulated yield improvements at improved log rotation position vs. log crook, 200 logs.

This can be explained by the fact that the optimal yield is found close to the horns-down position, thus producing the highest yield in the regular position. The impact of finding such an optimal position for all logs is highly significant for achieving an improved breakdown process. The graph also indicates less change in yield when the crook exceeds 15 mm. This is concurrent with results presented by Johansson (1978). The explanation may be that it becomes easier to define the correct horns-down position at this bow height. The conclusion may also be that whereas the horns-down concept is most effective on crooked logs, geometrical properties such as taper, ovality and other anomalies probably produce more bias on straight logs.

More extended simulations were preformed in order to evaluate the combined effects of sawing classes/patterns, optimal rotation and parallel positioning in the cant and deal saws. Table 5.10 shows the results from optimization of one log. Key terms Table 5.10: Log 2–2–2 is contained in the SPSB. The number combination denotes a tree grown and harvested in plot no. 2, tree no. 2 in the plot and stem no. 2. The simulation results for this specific log indicate a potential to increase yield from 55.8% to 59.6% when the log positions are altered from horns down and centred to position 40–2–8. Position 40–2–8 denotes a rotation of an additional 40 degrees to the right in reference to the normal horns-down position, a lateral offset of 2 mm in the first saw and of 8 mm in the second saw.

Table 5.10 Impact of improved rotation and parallel positioning in first saw and of improved parallel positioning in second saw. Curve sawing.
T = Board thickness, W = Width, L = Length.

Log 2 – 2 – 2 Top Diameter: 203,6 mm Class Limits: 200 - 222 mm	**Normal lateral positioning and Horns down rotation.**				**Improved positioning and rotation. (+ = right)**			
Sawing pattern: "50 x 150-mm"	First saw		Second saw		First saw		Second saw	
Rotation Position	Horns Down		—		+40°		—	
Parallel Position	Centred		Centred		+2 mm		+8mm	
	Output				Output			
	T (mm)	W (mm)	L (mm)	Value (SEK)	T (mm)	W (mm)	L (mm)	Value (SEK)
First saw Left side board	19	75	1800	7.70	19	75	3300	14.11
Right side board	19	-	-	-	19	75	1800	7.70
Second saw 2nd Left side board	19	75	1800	7.70	19	75	3000	12.83
1st Left side board	25	100	4500	33.75	25	125	4500	42.19
Left centre board	50	150	4500	62.44	50	150	4500	62.44
Right centre board	50	150	4500	62.44	50	150	4500	62.44
1st Right side board	25	100	4500	33.75	25	100	4500	33.75
2nd Right side board	19	75	1800	7.70	19	-	-	-
Yield (%)	55.8%				59.6%			
Board Value (SEK)	215.48				235.46			

Identical results were found at the 45–2–10-position; *i.e.,* a minor change in the previously described positions. This spot is more sensitive to additional offsets.

200 logs were sawn using the Saw2003 software applying alternate sawing patterns, rotation and parallel positioning within the stated limits as follows:

Sawing pattern defined in Table 5.7 applied to adjacent classes.
Rotation in Cant saw: -90 – + 90 degrees, step 5 degrees.
Parallel positioning in Cant saw: -20 – +20 mm, step 2 mm.
Parallel positioning in Deal saw: -20 – +20 mm, step 2 mm.
(Positive sign denotes a rotation or parallel offset to the right.)

The actual number of possible permutations in this simulation is 19 different angles x 11 offsets in the first saw x 11 offsets in the second saw, which equals 2,299 combinations per log, indicating a rapid increase in complexity. Adding a skew variable in the first and second saw and within the 20-mm range would increase the number of simulations required to 278,179.

The simulation results indicate a potential to increase the volume yield by a total of 4.5 percentage points if a more comprehensive optimization is applied (Figure 5.39). In this case however, only a few logs had their yield improved when the nominal sawing pattern was altered to an adjacent pattern

The results show that the highest total simulated board yield does not always correspond to the highest value. In this study, the price of A-quality side boards was set 62.5 percent higher than the price of A-quality centre boards. Production of centre boards is generally prioritized in Swedish sawmills, but a strategy with a higher proportion of extracted high-priced side boards can result in higher value yield and a somewhat lower volume yield.

Figure 5.39 shows that the highest achieved aggregated yield for 200 logs was 56.6 percent when the yield was prioritized in the analysis (Opt Yield). The maximum yield result is somewhat lower when board value is prioritized (Opt Value).

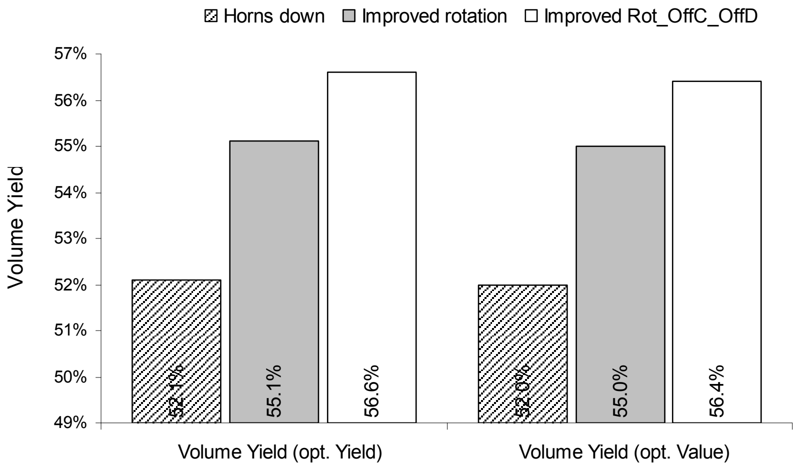


Figure 5.39 Simulated yield results from improved rotation (Opt Rotation) and extended optimization of rotation and parallel offset in cant and deal saws (Opt Rot_OffC_OffD) in comparison to simulated yield achieved by applying the normal horns-down position and nominal sawing pattern. The maximum achievable yield is somewhat lower when board value is prioritized (Opt Value).

Board value can be increased by close to 10 percent by applying a more comprehensive optimization including sawing class, rotation and parallel offsets. These results are based on a limited volume of logs, 37.5 m^3 sub. The difference in calculated income between concepts of prioritizing yield or value is thus relatively small. However, the value-optimization concept scaled onto the full production volume of a typical Swedish sawmill can result in large sums gained.

The fact that the simulation results once again imply a potential to increase the yield by optimizing individual logs makes it interesting to evaluate the effects of alternate rotation and parallel positioning in the first and second saw. The conclusion drawn in the study performed by Drake *et al.* (1986) is that optimized positioning is more sensitive to variations than the horns-down and centred position. The conclusion is also that logs with a top diameter close to the diagonal measure of the sawing pattern, and also smaller logs, are more sensitive to deficient precision in the positioning procedure. Drake *et al.* recommend that log-positioning equipment should be capable of a positioning precision close to 1 mm.

A full investigation of every log could include variables such as:

- saw kerf size – 7 alternatives
  (2.5–5.5 mm , step 5 mm)
- sawing patterns (SP) – 3 alternatives
  (adjacent SP, normal SP, adjacent SP)
  Rotation positions – 19 alternatives
  (horns down–90 degrees, step 5 degrees)
  parallel offsets in first saw – 11 alternatives
  (centred–20 mm, step 2 mm)
- skew offsets in first saw – 11 alternatives
  (centred–20 mm, step 2 mm)
- parallel offsets in second saw – 11 alternatives.
  (centred–20 mm, step 2 mm)
  skew offsets in second saw – 11 alternatives
  (centred–20 mm, step 2 mm)

The total exceeds 5.8 million permutations or simulations per log!
Note: All offsets or rotational alternatives are made to the right in reference to the log feed direction..

5.5.7 Impact of Saw-kerf size

Feed speed is a variable commonly used in order to increase the volume of logs sawn. However, increased feed speed reduces sawing accuracy because of increased vibration and lateral movement (Grönlund *et al.* 1980; Vuorilehto 2001). In order to reduce these negative effects, the width of the saw kerf is often increased in order to stabilize the sawing blade and prevent vibration.

Nevertheless, this solution results in lower yield, because more sawdust is produced, and the sawing class limits may have to be reassessed, because the diagonal measure of the sawing pattern will be changed. Comparisons made by Usenius (1984) show a significant improvement in yield when a 2.8-mm band-saw kerf was used, in comparison to a 4.8-mm circular-saw kerf. The theoretical difference in yield can lie between 2.4% and 3.7%.

The simulation results in Figure 5.40 show the impact on the aggregated true yield for the log batch sawn with the previously established posting list. In this simulation, the saw kerf in the cant saw was set to 4.0 mm, and the saw-kerf width in the second saw was altered in 0.5-mm steps from 2.0 mm to 5.0 mm. A reduction of the saw-kerf width by 1.0 mm will increase the yield by 0.9 percent points.

The posting list was maximized to contain 4 ex log sawing patterns. However, an increased number of boards extracted from every log will increase the impact of reduced saw-kerf width.

Today, sawing patterns containing 6 centre boards are becoming increasingly frequent, and the impact of the saw-kerf width is thus even greater.

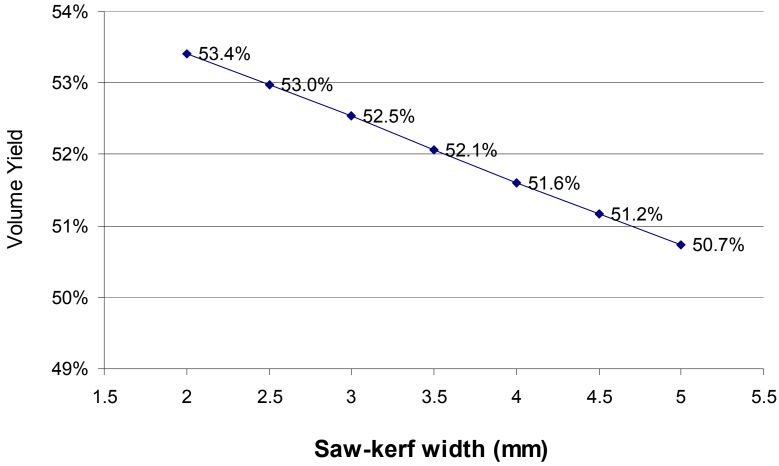


Figure 5.40 Impact of saw kerf width in second saw.

A thinner saw kerf may require a reduction of feed speed in order to guarantee the stability of the saw blade and maintain sawing accuracy (Schajer 1984, Dugdale 1966). This suggests that the choice of saw-kerf width must be evaluated against the loss or gain in production capacity in order to find the optimal feed speed.

5.5.8 Green Size Control

Breakdown control of logs combined with minimized process variation and oversized sawing allowances are essential factors in sawmill profitability (Vuorilehto 2001). This practice will increase the yield and lead to higher profit for a sawmill. Variability cannot be avoided within any process; however, the amount of variability can be controlled.

Currently, sawmills have no practical real-time methods for analyzing saw machine behaviour, and many decisions are thus still not based on facts. Vuorilehto presents a method in his thesis that provides a tool that can be used for investigation and statistical analysis of breakdown processes.

Controlled benchmarking tests are used to establish a mathematical model in order to describe features such as variations in a sawing machine's performance in relation to feed speed, log size and sawing time.

Vuorilehto defines three variables that can be used in order to describe the performance of a breakdown process:
Accuracy – relates to a sawing machine's capability to hit a target size. The sawn sizes should be uniform around a target size so that, on average, the target size is realized. A machine is thus regarded as accurate if the measurements are spread in almost equal proportions on both sides of the target size. Accuracy can be improved by setup adjustments.

Precision – relates to the degree of a sawing machine's standard deviation. Sizes may be off the target, but still be considered precise if the measurement spread is small. Precision reflects a structural and inherent inaccuracy in the machinery that usually cannot be improved by setup adjustments.

Reproducibility – refers to the consistency with which a machine repeatedly produces similar patterns of variations over a longer period. Erratic variations in machinery operations are not consistent, thus not reproducible.
When accuracy and precision are under control, a system will show a consistent reproducibility. Vuorilehto also emphasizes that real-time process control is to be prioritized over deviation detection and inspection in later stages of the production chain. Still, very few systems for measuring board size in the primary and resaw breakdown process have been developed.

Vuorilehto furthermore accentuates the direct relationship between sawing variations—sawing allowance–yield–profit—for sawn products. A real-time control system would also make it possible to track and evaluate the effects of a situation before the problem appears and when it has happened as well as the impact of corrective actions. Lack of information and, in addition, time delays between the occurrence of a deviation in the sawing process and its possible detection in a later process, severely restrict possibilities to find correlations between causes and effects.

It has been shown that well-performing "tight machinery" reduces the sawing allowance by millimeters in comparison to a sawmill with "loose machinery" (Brown 1979). A study shows that the total standard deviation on sawing variation on an optimal and well-performing sawing system can be less than 0.15 mm (Szymani 1999).

Besides originating in the characteristics of the machinery, variations can also be induced by the raw material, tool features or by improper usage of an otherwise normally functioning sawline (Vuorilehto 2001). Cutting parametres such as cutting height, feed speed, raw material properties, saw speeds and saw-blade features such as saw-blade material, tooth geometry and tool sharpening can affect measurement variations.

For example, saw-blade instability may occur due to load strain if the feed speed is too high. Variations in the target size measurement can be summarized as follows:

- Standard deviation is affected by raw material and cutting parametres
- Standard deviation is affected by instability in machinery and inaccuracies in setups
- Accuracy is affected by setup performance and tool maintenance

The saw setup target size is a combination of measures added to the nominal measurement in order to produce the final dimension after drying (Figure 5.41).

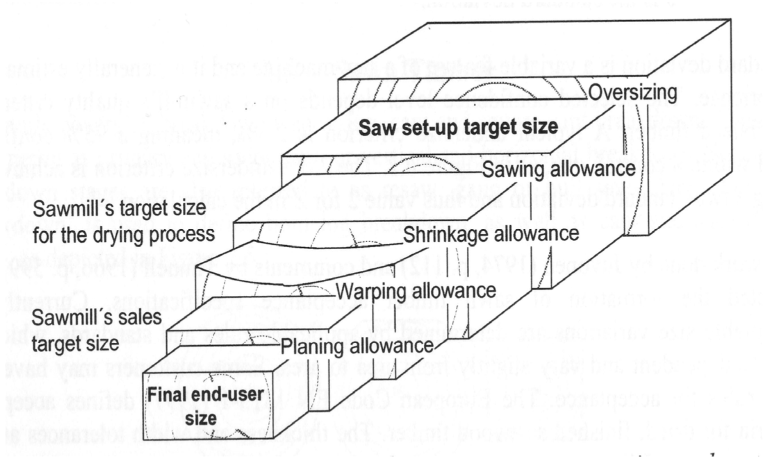


Figure 5.41 Sawmill sales target size on boards and addons needed in order to compensate for shrinkage and variations in sawing accuracy (Vuorilehto 2001).

In order to comply with the requirements specified in the Swedish Standards Institute’s publication SS-EN 1313-1 (Anon. 1997), logs must be sawn with an addition to the nominal measure. An addition to the nominal measure is made in order to compensate for variations caused by inadequacies in the sawing process and for shrinkage and shrinkage variations. This addition is generally called the sawing allowance, and the sum of the nominal measure and the sawing allowance is defined as the green sorting measure (Grönlund 1992) or the green target size.

Sawmills specify limits according to the green target size within which the process is considered acceptable. The thickness and width tolerance at 20% moisture content are, according to the SS-EN 1313-1 standard publication, as follows:

- Mean thickness and width measurements may not fall short of the nominal size
- Tolerance for thickness and width ≤ 100 mm is + 3 mm/- 1 mm
- Tolerance for thickness and width > 100 mm is + 4 mm/- 1 mm

One measure for increasing volume yield is to keep the required sawing allowance as small as possible. The size of the required sawing allowance is directly dependent on the sawline's process quality and performance, *i.e.*, the actual amount of dimensional variations on the sawn boards. A new, optimally adjusted sawline combined with perfect tool maintenance will generally require a lower sawing allowance than an old, worn out one with a higher spread in the process quality.

Such a sawline is estimated to show a maximum spread of 0.25 mm in dimensional accuracy, while a normal sawmill would produce an estimated spread of 0.5 mm (Grönlund 1992).

The required sawing allowance in relation to the dimensional variations is shown in Figure 5.42. The example shows that a decrease in standard deviation by 0.5 mm will reduce the required sawing allowance by 0.8 mm. Simulations show that decreasing sawing allowance by 0.5 is equivalent to a 0.8 percent points increase in yield (Grönlund 1981).

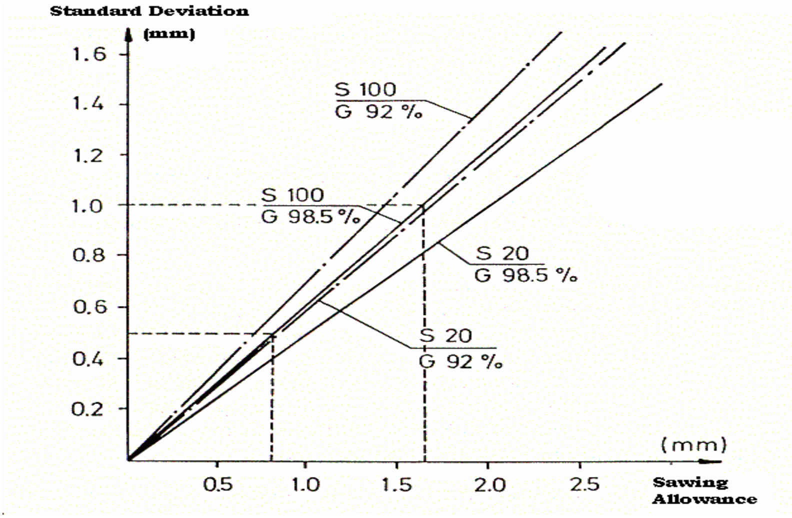


Figure 5.42 The relation between sawing allowance and standard deviation at different likelihoods of acceptance (S) and spot-check size (G). The relation refers to board dimensions smaller than 99 mm (Grönlund 1981).

The annual log purchase at the sawmill is calculated to be approximately 444,000 m^3 sub, the effects of an assumed spread of 0.5 mm on the board dimensions included. A decrease in spread of 0.25 mm would in this case be equivalent to an annual reduction of log purchase by 5,000 m^3 sub, or 2.5 MSEK. Given a sales situation in which the sawmill is able to sell all produced boards at full price, the scenario could be viewed from another angle. The increased yield would render an increase in board production of 1,750 m^3. This equals an increase in income of 3.0 MSEK, given an average board price of 1,700 SEK/m^3.

Calculated against current salary levels, this is equivalent to the cost of 6 employees for one year. This example once again illustrates how small and seemingly insignificant process variations can entail large losses when large volumes are processed. It is therefore vital to understand the factors that cause sawing variations and to take measures to minimize them (Vuorilehto 2001).

In view of these facts, a limited survey was performed in this case study in order to ascertain the actual level of sawing accuracy by way of a thickness-size accuracy check on a number of the produced board dimensions. The aim was also to identify possible measurement variations caused by, for example, wear on the saw blade or variations in the machinery setup over time.

The measurements were thus performed on the first and last stack in the posting in question, directly after leaving the stacking area. The sawn postings where logged for board dimension, date, speed and setups by the operator. The logs where sawn either in a double-arbor circular saw or in a triple band saw, depending on dimension. The sawmill controls the feed and saw speed in order to keep the gullet-feed index to a maximum of 0.3–0.7, depending on sawing method.

The standard SS-EN 1309-1 (Anon. 1997) defines the requirements for green-size thickness measurements on boards as follows:

- Reading accuracy of a measuring device must be at least 0.1 mm
- Measurement shall take place at at least at three clean spots with no defects
- Two of the measurements shall take place near the ends, not closer than 150 mm
- Additional measurements shall be spaced between the two end measurements

A digital caliper connected to a mobile logger was used in order to register the green measurement thickness at the middle and at a distance of 20 cm from both board ends. Studies show that this kind of measurement is commonly found to be distributed normally (Vännman 2002). Figure 5.43 shows a histogram for one of the measured board dimensions. The superimposed curve shows the fitted normal distribution, thus verifying that the achieved thickness measurements do not deviate from normally distributed data.

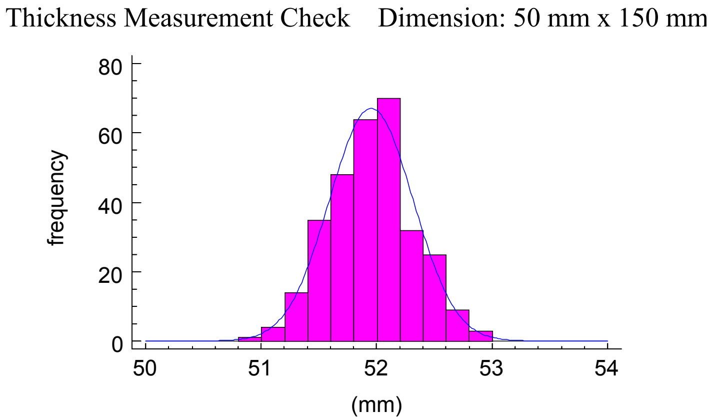


Figure 5.43 Histogram showing results from measurements on board end thickness for dimension "50 x 150 mm". The superimposed curve shows the fitted normal distribution (N52.0, 0.36). Sample size 306.

The results from the limited survey show a small spread in the thickness measurement in general and very small differences between board measurements in the first and last stack (Table 5.11).

Table 5.11 Results from green size measurements on the first and last board stack in a sawn posting. LLs = Lower Limits size, Ts = Green Target size, ULs = Upper Limits size. The average sample size was per dimension 88 (end) and 47 (middle).

Dimension	Green Target size LLs/Ts/ULs (mm)	First/Last Stack Average (end)	First/Last Stack Std Dev. (end)	First/Last Stack Average (middle)	First/Last Stack Std Dev. (middle)
A. 32 x 110	33.0/33.3/35.7	33.0/33.6	0.50/0.41	33.1/33.6	0.49/0.24
B. 38 x 150	39.3/39.6/42.0	39.4/39.5	0.27/0.32	39.4/39.5	0.26/0.29
C. 38 x 165	39.3/39.6/42.0	39.7/39.7	0.20/0.39	39.6/39.6	0.31/0.33
D. 50 x 125	51.8/52.1/54.5	52.2/52.3	0.26/0.21	52.2/52.3	0.23/0.22
E. 50 x 150	51.8/52.1/54.5	52.3/52.1	0.29/0.23	52.2/52.1	0.21/0.30
F. 63 x 150	65.3/65.6/68.0	65.4/65.6	0.35/0.20	65.5/65.5	0.18/0.18
G. 75 x 150	77.8/78.1/80.5	77.5/78.3	0.27/0.66	77.3/77.6	0.38/0.40
H. 75 x 175	77.8/78.1/80.5	77.1/77.8	1.32/0.68	77.9/77.8	0.63/0.30

This fact indicates a sawline process that is stable presumably because of well-performing equipment and mechanical maintenance. The only exception found is on the coarser 75-mm dimensions (G and H) where board end measurements show a greater spread in addition to an increased deviation between the measurements in the first and last stack. These two dimensions were sawn in a band saw.

The results in Table 5.11 also show that the measurements are generally situated close above the lower green size limit. The green target size is, as previously mentioned, governed by factors such as shrinkage and variations in the sawing process. The sawmill applies a general 4.0% add-on percentage to the nominal dimensions. The actual available space for variation caused by the machinery, expressed in millimeters, varies, depending on the actual dimension and the level of shrinkage (Figure 5.44). The total sawing allowance is a combination of one part shrinkage add-on and one part compensation for variations in machinery and shrinkage.

As opposed to variations occurring in the machinery, however, changes in dimension caused by shrinkage are not controllable by the sawline operators.

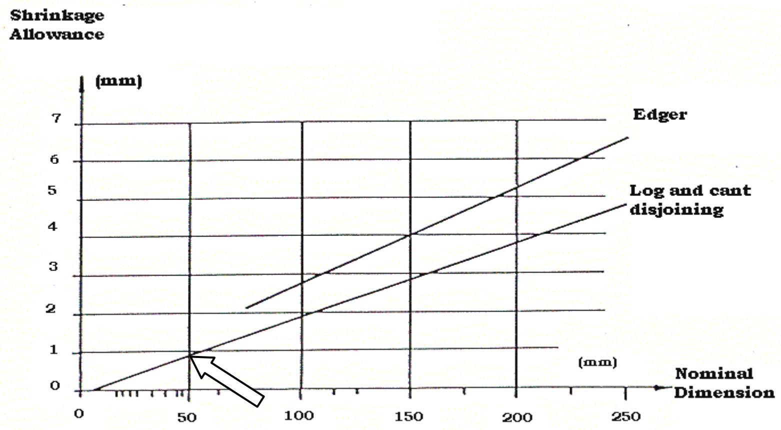


Figure 5.44 Size of the shrinkage allowance depending on dimensions, with levelling lines across the shrinkage allowances established by the STFI. Figures refer to a moisture content of 20% (Bråkenhielm et al. 1969).

For example, Figure 5.44 shows the shrinkage allowance on the 50-mm thickness value (marked by arrow). Given a 4% allowance add-on to the nominal measure and a moisture content of 20% after drying, the available space for variations in board thickness is approximately 1.1 mm (Bråkenhielm *et al.* 1969). Shrinkage, of course, also shows up as a standard deviation. Nevertheless, a sensitivity analysis can still be performed in order to evaluate the effects of sawing variations at different levels of shrinkage. In order to establish the final level of sawing accuracy, the stacks in question should have been measured in the same the manner after drying, thus establishing the final variations in the dried boards. However, this was not possible during this study, and the actual variations in the dried boards are unknown.

In order to perform a rough evaluation of the process quality, some simplifications were made. An assumption was made that the average shrinkage is linear when boards are dried to 20% moisture content. Furthermore, the assumption was made that variation in the thickness measurement is identical to the standard deviation found for the green size measurement, thus merely moving the green size distribution average and identical spread linearly towards the nominal measurement.

The implication of this is that if the green size measurement and spread are found to be within the limits, the dried boards will be approved. According to the Swedish Standards Institute's publication SS-EN 1313-1, 10% of a board consignment is allowed to fall short of the nominal measure by 1.0 mm or 2.0 mm, depending on dimension. The size of the total sawing allowance is thus directly dependent on the green target size and the spread.

The survey shows that the spread found on the measured board dimensions is in general very low, implying well-functioning tool maintenance. A calculation also confirms that few boards in general fall short of the stated SS-EN 1313-1 limit. Applying the sawing allowance values from Figure 5.44. on the measurement results from Table 5.11 shows that dimensions B–G will be approved. Dimension A (32 x 110 mm) will not be approved, mainly due to too low green target size. Dimension H will also fail, mainly due to too high standard deviation.

5.5.9 Process Capability

Process capability represents the performance of a monitored and controlled sawing process (Vuorilehto 2001). Sawing machines are complex. Some of the features that cause variation are structural errors built into the machinery, and these will remain. Some new ones will appear because of wear and tear. Measurements on sawn boards can be used in order to calculate the sawline process capability (Vuorilehto 2001):

$$C = \frac{\text{Green Target size} - \text{Smallest Allowed Green Size}}{2\text{s}}$$

where C is the process capability index of a saw machine and s is the standard deviation of the sawing process. The equation above shows that if the spread is increased by a factor of x, the numerator must be increased by a factor of 2x. In other words, an increase in spread by 0.1 mm requires an increase in green target size by 0.2 mm in order to maintain a specified capability index.

A sawing process is considered capable if the process capability index C > 1. In this case, the lower limit is well within the allowed lower sawing limit, and the boards will be approved. An excessively high index implies an oversized green size target and will reduce the yield.

A capability index C = 1 shows that the process is barely approved, and small variations towards thinner size than the target size will produce boards that are not approved. If the capability index C < 1, the process is regarded as not capable at all, and C < 0 implies that the measured average size appears below the smallest allowed sawn size. Figure 5.45 shows the calculated capability index for the measured postings and processes. The results indicate a low performance of the sawline, as few of the measured dimensions show an approved capability index.

However, there is a strong contradiction between the concept of a capability index and the struggle to achieve a high yield. Oversizing of the green target measurement will render a lower yield even though the capability index is high.

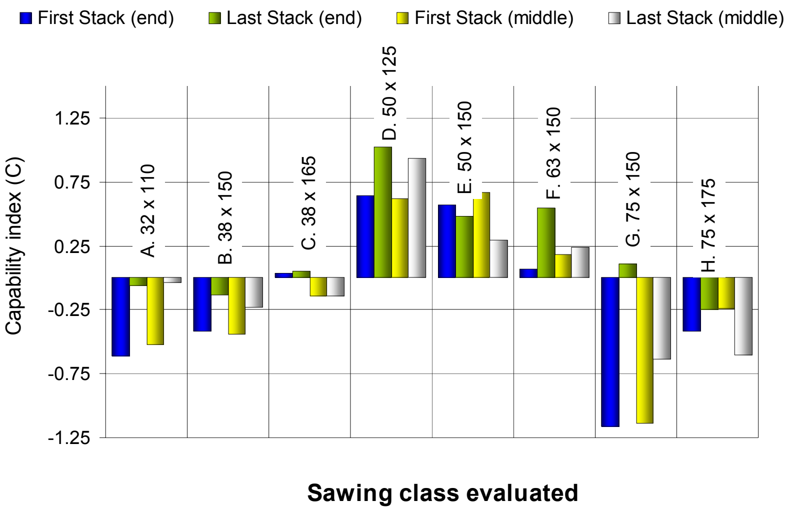


Figure 5.45 Calculated capability index (C) for measured sawing classes and processes.

The results of this rough study serve as an example of the importance of setting the correct green target size and of obtaining and maintaining a low spread of the board dimensions. A fully performed sawing-accuracy benchmarking should nevertheless include measurement of the dried boards in order to establish the final measurements and standard deviation.

In his study, Vuorilehto has created a mathematical model for calculation of the standard deviation found in different types of sawing machines. The sawmill resaw machinery in this case study consists of a double-arbor circular saw situated on the combined log line. Coarser dimensions are broken down using band-sawing machines situated on the large log line.

According to Vuorilehto's mathematical model, the theoretical sawing variations can be calculated as follows:

$$S_T = \alpha e^{\beta tnkFL} \pm \varepsilon$$

Where:

- α is the inherent saw constant
- β is the time-dependent constant
- ε is the range
- ST is the total standard deviation (mm)
- t is the sawing time (h)
- n is the number of saw blades in the setup
- k is the kerf size (m)
- F is the feed speed (m/min)
- L is the cutting-path length (m)

The descriptor functions contained in the equation describe differences between types of saw machines. Descriptor α is the inherent saw constant, which describes the built-in precision in the sawing machine, and the saw-time-dependent constant, β, describes effects of saw blade wear and saw load.

The two equations of interest in this study are shown in the following equations.

$S_T = 0{,}22e^{0{,}04tnkFL} \pm 0{,}05$ Double-arbour circular saw

$S_T = 0{,}39e^{0{,}26tnkFL} \pm 0{,}05$ Triple band saw

The α and β constants show that the double-arbor circular saw machine presents a higher mechanical precision than does the band saw machine. Furthermore, a double-arbor machine is almost immune to sawing time according to the β descriptor, 0.04 (Vuorilehto 2001).

Figure 5.46 shows a theoretical example of the impact of sawing time on the calculated average standard deviations for identical postings broken down by a double-arbor machine and a triple band saw respectively. Saw-kerf width, feeder speed and cant height were identical in the calculations. The graph clearly shows higher spread caused by inherent features in a band saw and the limited saw-time effects found in a double-arbour machine.

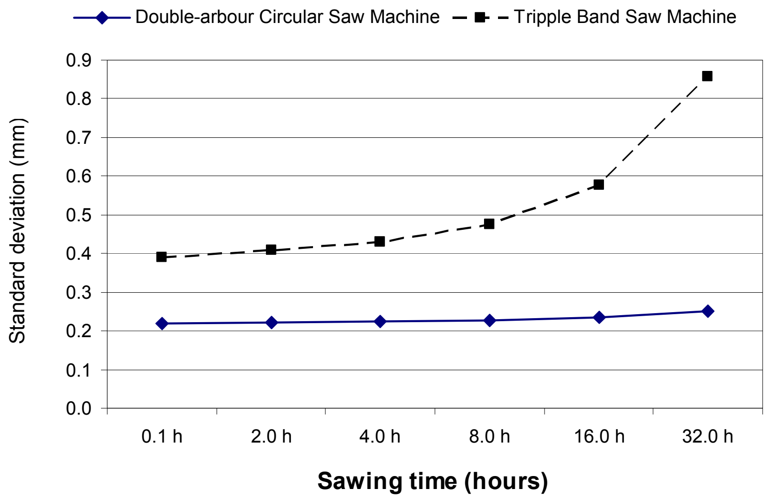


Figure 5.46 Comparison between theoretical standard deviation in double-arbour and triple-band saw machines. Saw-kerf width 0.35 mm. Feeder speed 60 m/minute. Cant height 150 mm.

All process-related variables were recorded during the sawmill measurement survey. The actual variations in the sawing machines could thus be compared to the theoretical values.

Standard deviations shown in Table 5.12 are calculated averages including measurements from board middle and ends.

Table 5.12 Measured standard deviation compared to calculated values according to the Vuorilehto equation. All dimensions, with one exception, were sawn in a double-arbor circular sawing machine. Sawing pattern G (75 x 150) and H (75x175) was broken down by a band saw machine.

			Std. Dev. First Stack		Std. Dev. Last Stack	
Dimension	**Feed speed (m/min)**	**Sawing time (h)**	**Measurements (mm)**	**Calculated (mm)**	**Measurements (mm)**	**Calculated (mm)**
A. 32 x 110	72	1.8	0.50	0.22	0.33	0.22
B. 38 x 150	54	0.6	0.31	0.22	0.27	0.22
C. 38 x 165	50	1.6	0.25	0.22	0.36	0.22
D. 50 x 125	70	0.9	0.24	0.22	0.23	0.22
E. 50 x 150	78	1.3	0.25	0.22	0.26	0.22
F. 63 x 150	66	1.9	0.19	0.22	0.26	0.22
G. 75 x 150	60	1.1	0.32	0.22	0.53	0.22
H. 75 x 175	60	0.8	0.97	0.39	0.49	0.40

The measured standard deviation values on the first and last stack in postings D, E and F correspond well to the calculated values. The large differences between spread measurements on some dimensions are mainly caused by a greater variation in the machines. The measured standard deviation is in most cases between 0.2 and 0.3 mm. Nevertheless, boards broken down on the same sawing line in other cases show a standard deviation of 0.50 mm and 0.97 mm respectively. At the same time, the results show that spread has actually decreased within the last stack.

This can be explained by the fact that the green size measurement has increased during the sawing period, thus implying that possible mechanical slack induced by the saw setup has disappeared, stabilizing the process.

Band-saw performance demonstrates a similar tendency, although the standard deviation is found to be higher, as expected. The calculated values shown in Figure 5.46 verify that the sawing-time-related effects are limited during the first hours.

All sawn postings in the survey nevertheless contain relatively few logs. Thus the sawing time is too short to have noticeable impact on the calculated spread. The coefficient of determination, R^2, for a model indicates how truly it can describe and predict the phenomena in question. A perfect model shows $R^2 = 1$, because the results from the model agree fully with the data used to create the model. The R^2 values on prediction of the total standard deviation in Vuorilehto's model show very low coefficients, 0.02 on double-arbor machines and 0.07 for band saws (Vuorilehto 2001). The same author claims, however, that the model's reproducibility is a better indicator of the predictability of an equation than the R^2 values.

5.5.10 Case study IV - Discussion and Conclusions

The results in this study show a large potential for sawmills to increase volume and value yield. The challenge is to be able to identify optimal breakdown settings online for every single log and execute them during the breakdown procedure without loss of production capacity.

Knot definitions were deactivated in the simulation software in order to achieve an explicit volume yield optimization without knot-related influences. The simulation results presented in the present study show a potential to increase the yield by 3.0 percentage points (5.8 percent) by optimizing the rotation position and 4.5 percentage points (8.8 percent) by optimizing rotation and lateral positioning in first and second saw. Studies indicate that the impact on value of applying the optimal rotation for each log is up to 22 percent higher when knots are taken into account (Johansson *et al.* 1988).

A typical Swedish sawmill produces about 200,000 m^3 of sawn boards per year. An increase in average volume yield by 4.5 percentage points (8.6 percent) would enable such a typical Swedish sawmill to produce a further 17,300 m^3 of boards. This would increase potential income by 30 MSEK per year at an average value of 1700 SEK per m^3. The impact of an increased yield can also be calculated as a reversed scenario and would decrease log demand by close to 31,000 m^3 sub. This scenario would result in a decrease in log purchase expenses by 22 MSEK per year, calculated at an average purchase cost of 700 SEK per m^3 sub.

This approach to improved breakdown requires, in reality, that a single log`s inner and outer properties are known. This detailed knowledge can be gained by implementation of modern industrial x-ray technology, (Birkeland *et al.* 1987; Oja *et al.* 2004). The aim is to rotate and displace the log to an optimal position in order to minimize the influence of knots or wane on board edges (Oja *et al.* 1998; Rinnhofer 2003). Oja *et al.* (1998) show that the number of high-quality boards increased by 11 percent when the sawing position was controlled based on x-ray log scanning technique.

Studies done on pine logs by Johansson *et al.* (1988) show that knots are a highly significant factor governing value yield. Final yield and quality classification of boards is governed by size and position of knots on boards, and specifically edge knots cause board quality to degrade. Superimposing the results presented in the study by Johansson *et al.* (1988) indicates that the true potential from rotational optimization could be even higher in comparison to the concept of horns-down position with pure volume optimization. A full optimization including both rotation and parallel positioning thus provides an even higher potential to improve yield and value.

Log geometry commonly governs the sawing classes, but the study performed by Johansson (1978) also states that sawing classes should be defined tighter in reference to the log geometry when knot influence is taken into account. This is because the amount of knots decreases close to the log's surface.

X-ray equipment is becoming more common in Swedish sawmills today, commonly situated and used in the log-scaling process. Regrettably, lack of reliable traceability techniques means that the valuable link between the detailed information, gained during the scaling procedure and individual logs is lost when measured logs are stored in large piles in the log yard.

Loss of linked log information means that the logs properties must thus be identified once again in order to optimize the breakdown settings. This places higher requirements on sawmill technology and equipment than can commonly be fulfilled today. Automated tracing and tracking are proposed by McFarlane *et al.* (2003), where the use of RFID tags is one possible approach. However, this technique was regarded to be too expensive for continuous usage (Uusijärvi 2003). Studies done by Chiorescu (2003) and Flodin *et al.* (2008) using the fingerprint approach show possibilities to identify and trace logs from their outer shapes and the from the tracheid effect.

Nevertheless, these concepts are vulnerable to errors in measurement accuracy and changes in log properties during the log handling process, *e.g.,* debarking and butt-end reduction. An alternative but more expensive approach could be to place one additional X-ray log scanner on the saw line prior to the first sawing machine. This concept is mostly regarded to be too costly.

The sawing and log-handling machines must furthermore be fast and precise enough to execute desired settings and log positioning. The machinery of today is limited in its capabilities to perform all the necessary tasks needed to achieve a fully optimized breakdown. Machinery capable of positioning logs in the sawing machines without errors simply does not exist.

The actual number of possible log positioning permutations in this limited simulation study is 3 different sawing patterns x 37 different angles x 11 offsets in the cant saw x 11 offsets in the deal saw, which equals 13,431 combinations. Further adding a skew variable within a similar +/- 20-mm range in the cant and deal saws would increases the number of simulations required to more than 1.625 million combination, indicating a rapidly increasing complexity. However, the results from this study show a relatively small number of logs gaining from changed sawing class, and a simplifying approach could be to ignore this factor.

This example shows a rapidly increasing complexity to the optimization of the breakdown process, which is a serious challenge, since some of these procedures must be performed online within a split second in order to accommodate demands on production speed. With full traceability available, the optimal sawing pattern for each log could be predefined during the log-sorting procedure, thus reducing the number of combinations to be considered during the breakdown.

A combination of industrial x-ray equipment, individual log traceablility, breakdown-simulation software, high-performance computers and improved handling equipment will someday make it possible to evaluate and optimize all logs online at full production speed.

Skellefteå Church town – "Bonnstan”

5.6 Case study V: Prerequisites for effective production of Heartwood products

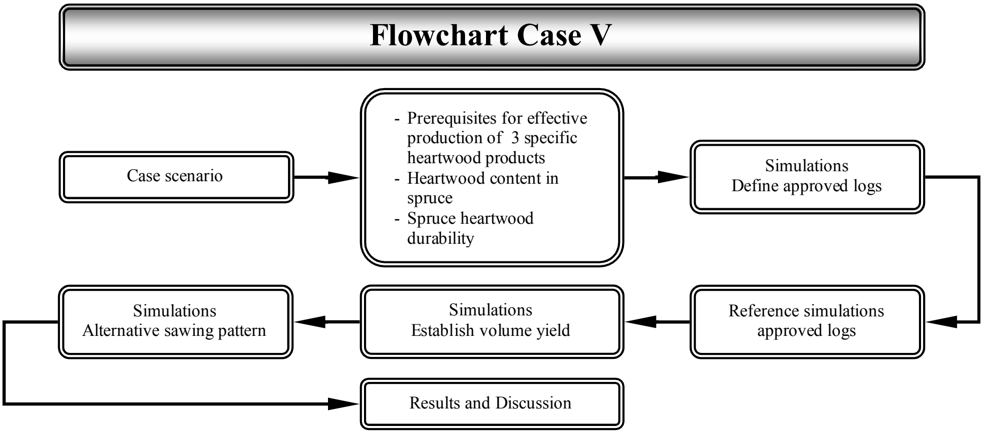


Figure 5.47 Case study flowchart.

5.6.1 Case Scenario

The objective of this study was to evaluate the prerequisites to minimize loss of volume yield during production of three given products from Norway spruce heartwood. The sawmill has identified a demand of three different outdoor paneling products from Norway spruce with high heartwood content. These products have become increasingly attractive for costumers since heartwood is known to have a longer life-span and less need of maintenance in comparison to sapwood content products. The challenge involved in this production strategy is to identify appropriate logs and to find measures to minimize loss of volume yield during production of the three given products.

5.6.2 Limitations

Knot definitions were deactivated in the simulation software, and equal price was set for all products in order to achieve an explicit volume yield optimization without knot- or price-related influences. Final results presented in this study were achieved from a relatively limited number of logs

5.6.3 Introduction

The properties of Norway spruce (*Picea abies*) sapwood and heartwood differ from one another, although the two are visually quite similar. For instance, spruce heartwood absorbs less water in end grain and dries faster than sapwood (Sandberg 2006), and the heartwood is less subject to cracks (Sandberg 2008) and growth of discoloration fungi (Sandberg 2008; Frühwald 2007; Bergström *et al.* 2005).

Less absorption of water leads to faster drying and thus a shorter wetting time, less moisture-related movement in the wood and worse living conditions for fungi. These properties are important for attaining a long service life in aboveground conditions, as cracks promote water absorption and provide places where dirt can accumulate, thereby increasing the risk of decay and reduction of strength. Apart from that, growth of discoloration fungi and cracks are an aesthetic liability.

Spruce has on average larger heartwood content than pine (*Pinus silvestris*) (Kollman 1982) and that is an advantage looking toward volume yield of heartwood products. Generally, heartwood content increases with the age of the trees for many species, but there are considerable variations due to environmental and site conditions, genetic control, *etc.* (Hillis 1987; Taylor *et al.* 2002).

For trees of the same age there is a great spread in heartwood content (Eneroth 1922), and this makes it difficult to predict the heartwood content and to ensure 100% heartwood in products for outdoor use (Wilhelmsson *et al.* 2002; Lycken *et al.* 2009).

Spruce is regarded and used as a homogeneous material, and spruce heartwood has not been utilized in products for use in aboveground conditions in a controlled way. One reason for this may be that is impossible to visually distinguish sapwood from heartwood when dried. Today, there are two possible nondestructive industrial techniques to distinguish heartwood of spruce. Both of these methods measure differences in moisture between heartwood and sapwood and are used for pine as well. Visual separation of pine heartwood and sapwood is possible in green state by X-ray LogScanner in timber sorting (Oja & Grundberg 2004; Skog & Oja 2009) or with laser technique in green sorting line (Oja *et al.* 2006).

Studies have been done in order to create algorithms for automatic detection of the heartwood/sapwood boundry from x-ray retrieved information (Longuetaud *et al.* 2007). Simulations have also shown that it is possible to sort spruce heartwood by x-ray scanning (Oja *et al.* 2001).

5.6.4 Heartwood content

The heartwood share of logs in the Spruce Stem Bank varies substantially between individual logs, from 16 percent to 89 percent of the log top diameter. The heartwood diameter also varies when comparing two similar logs. For example, two logs in the Spruce Stem Bank show the same measured top diameter, 161.6 mm. However, one log shows a heartwood top diameter of 77 mm, the other one 119 mm.

The first log is a butt log harvested in the south of Sweden, the other one a top log harvested in the North of Sweden. Figure 5.48 shows the log top diameter plotted versus heartwood share of top diameter for 750 individual logs. The R^2 value is relatively high, 0.89 thus indicating a high degree of explanation. However, the prediction accuracy is still too low to satisfy requirements in this study.

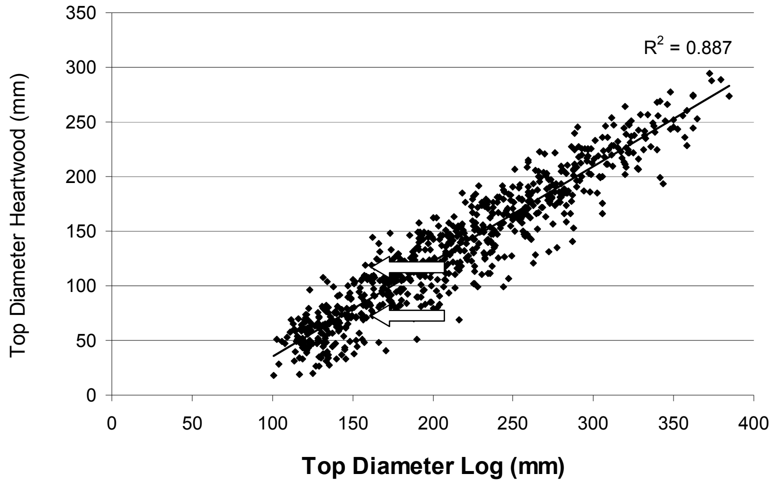


Figure 5.48 Heartwood top diameter plotted versus log top diameter of 750 logs in the Spruce Stem Bank.

Logs with identical top log diameter can show a large spread in heartwood top diameter. Two logs in the Spruce stem bank show the same top diameter, 161.6 mm, but the heartwood diameter is in one case 119 mm and in the other case 77 mm Figure 5.48 (positions marked by arrows).

5.6.5 Simulation scenario

A scenario for a specific sawmill stated a demand for centre-board products (44 x 150 mm, 63 x 150 mm and 63 x 175 mm) with high heartwood content. The centre boards are later split into two 21 x 150 mm (44 x 150 mm), three 19 x 150-mm (63 x 150 mm) or three 19 x 175 mm (63 x 175 mm) panel boards before planing and profiling.

In present study, all logs in the Spruce Stem Bank were sorted into 15-mm intervals according to top diameter, and the different intervals were evaluated and compared. Sawing patterns used in step 1, Figure 5.49, included only 2 centre boards; steps 2 and 3 included 2 centre boards and 2–4 side boards per log. Sawing patterns used in step 4 included 2 centre boards and in some cases up to 10 side boards. In order to optimize yield, the applied sawing pattern must be adapted to the heartwood top diameter in the same manner as sawing patterns are commonly adapted to the log top diameter during normal production conditions Figure 5.50, scenario a.

The present scenario required that approved logs should produce two centre boards at full log length containing an allowed share of sapwood on the peripheral edges of the centre boards (see Figure 5.50, scenario b and c), since these parts of the panel will be removed during profiling. A minimum of 4 mm heartwood on the final panel board's edge side was required.

The study was performed in four steps:

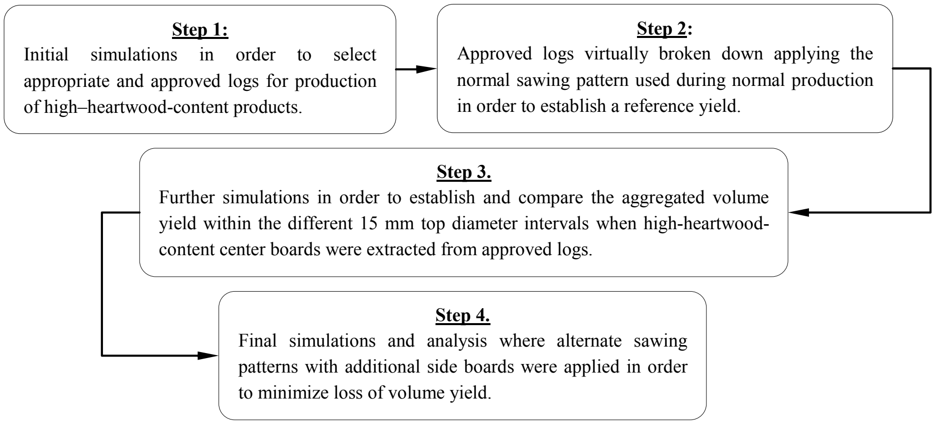


Figure 5.49 Simulation flowchart of performed steps.

Initially, a number of simulations were performed in order to find appropriate logs for production of panels with high heartwood content (Figure 5.49, step 1). For each product, three different scenarios were simulated and evaluated:

Scenario a (step 2, Figure 5.49)
The reference scenario presented as "Reference (R)" specifies the potential volume yield achieved by sawing the approved logs within the interval under a normal production scenario, applying sawing patterns governed by sawmill rules (Figure 5.50, scenario a).

Scenario b (step 3, Figure 5.49).
"Postlist (Hw)" specifies the simulated volume yield achieved when the same logs within the interval were sawn according to the high heartwood (Hw) content scenario, applying one of three different sawing patterns (44 x 150, 63 x 150 or 63 x 175) (Figure 5.50, scenario b).

Scenario c (step 4, Figure 5.49).
"Postlist Alt (Hw)" specifies the simulated volume yield achieved when the same logs within the interval were sawn according to the high-heartwood-content scenario, applying an alternate sawing pattern with more side boards added to the basic sawing patterns in order to minimize loss of volume yield (Figure 5.50, scenario c).

Figure 5.50 shows the principles for adapting the sawing pattern to logs under normal production conditions in comparison to production of high-heartwood-content products and stated requirement of heartwood on panel side edges.

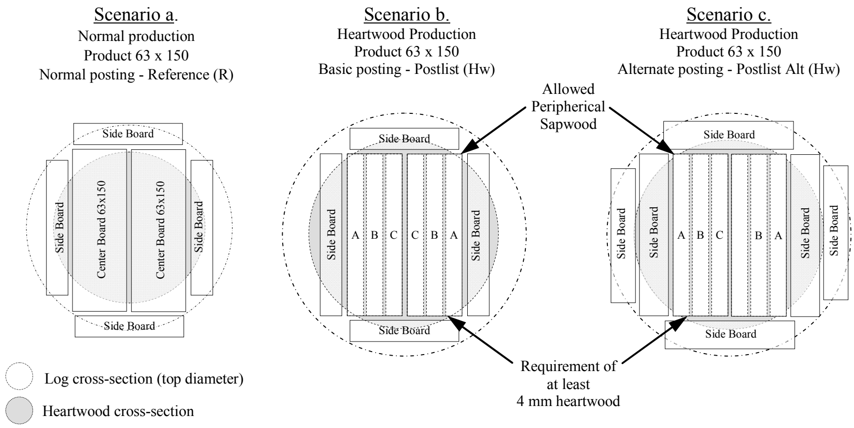


Figure 5.50 Principles of posting for normal production of product 63 x 150 (scenario a) in comparison to the two evaluated sawing patterns for production of high-heartwood-content products (scenarios b and c).

Centre boards are split into panels A, B and C after drying (scenarios b and c). Additional side boards are added to the sawing pattern in scenario c in order to maximize volume yield. Sapwood content on panels "A" can be allowed up to a certain limit since these parts will be removed during the final profiling procedure. Requirements of at least 4 mm on the A-panels side edges (scenarios b and c) must consist of heartwood was stated in the scenario. Allowed sapwood and requirement of heartwood content on panel side edges marked by arrows in figure 5.50.

5.6.6 Simulation Results

Approved logs

The specific requirements in the scenario makes it important to find the exact heartwood diameter for every single log. The simulation results showed that zero approved logs were found in the commonly used top diameter intervals, regardless of product. For example, product 44 x 150 (cross-section 44 mm x 150 mm) is commonly sawn from logs with a top diameter of approximately 180–195 mm. The results in Figure 5.51 show the share of approved logs within the top diameter intervals for the respective products.

Definitions in Figure 5.51: 3p = heartwood centre boards are split into three panels after drying. 2p = heartwood centre boards are split into three panels after drying from which only the two panels closest to the pith show approved heartwood content and are further refined. The concept presented in column D could be an alternate method for increasing the number of approved logs for a specific product.

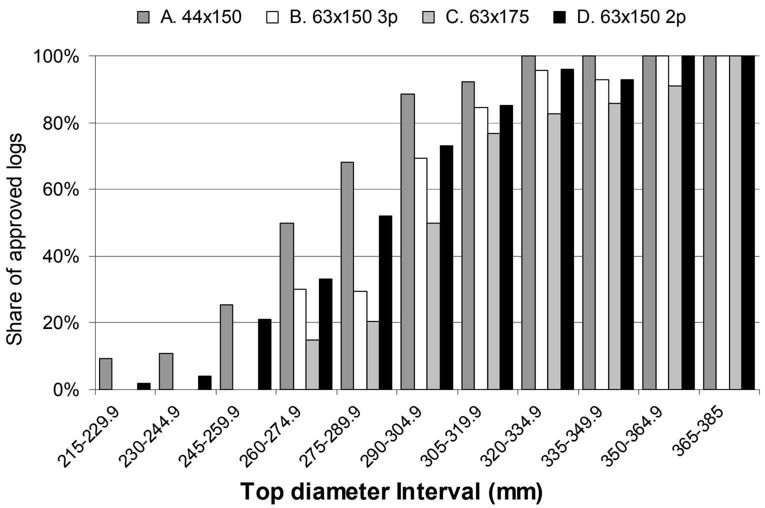


Figure 5.51 Share of logs approved for production of high-heartwood-content panels within stated top diameter interval. Present scenario required that approved logs should produce two centre boards at full log length, allowing a limited share of sapwood.

The graph shows, furthermore, that no logs were approved beneath a top diameter of 215 mm. Note that logs approved for production of product 63 x 175 mm are also approved for products with smaller cross-sections, thus also theoretically competing for the same log volume.

Twenty-three percent of all logs contained in the Spruce Stem Bank were approved for production of product 44 x 150 mm, 15 percent for 63 x 150 mm and 12 percent for 63 x 175 mm.

The graph also shows that more logs can be approved if, for example more sapwood is allowed on the most peripheral third panel, later removing this specific panel from the high-heartwood content panels (Figure 5.51, column D). Figures 5.52 – 5.54 show a comparison of the impact on simulated volume yield for respective breakdown strategies and products (44 x 150, 63 x 150 and 63 x 175).

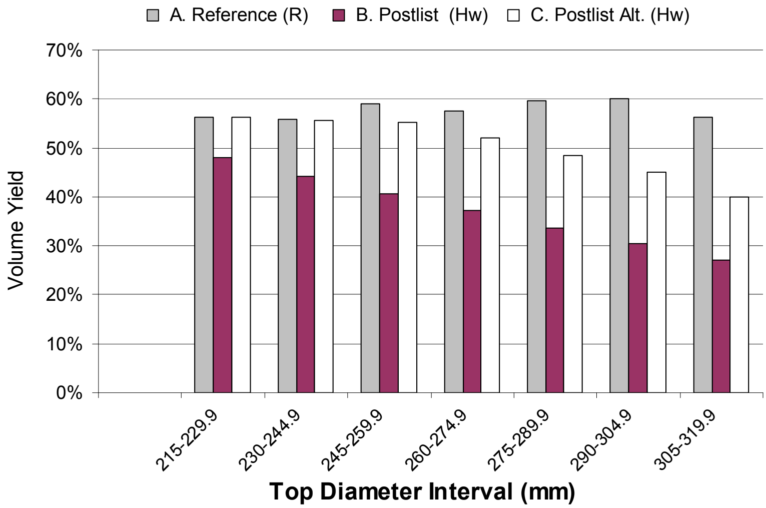


Figure 5.52 Comparison between three breakdown strategies for product 44 x 150 and achieved simulated volume yield.

"Reference (R)", columns A Figures 5.52-5.54 represents a simulated reference value achieved during normal production. "Postlist (Hw)", columns B specifies the simulated volume yield achieved in the heartwood scenario using the basic sawing pattern. "Postlist Alt (Hw)", columns C specifies the simulated volume yield achieved in the heartwood scenario using an alternate sawing pattern with added side boards.

The results show that individual products must be extracted from the most favourable top diameter groups in order to minimize losses. The simulated volume yield generally decreases when high-heartwood-content boards are produced, since the boards are extracted from logs with a larger top diameter in comparison to regular breakdown procedures (Figures 5.52–5.54, column B).

At best, initial simulation results indicated unacceptable losses in volume yield of 4.5–30 percent points, depending on product and diameter group. For example, when applying the heartwood sawing pattern to logs in the 215–230-mm top diameter interval, volume yield decreased by 8.2 percent point in comparison to the reference value for product 44 x 150 and by 11.7 percent points in the 230–245 interval. However, simulation results from step 4 indicate that volume yield losses could be reduced by adding more side boards to the sawing pattern, in effect also producing side boards with larger widths.

This side-board approach means, for example, that product 44 x 150 can favourably be sawn from approved logs with a top diameter of 215–245 mm, minimizing the loss of yield by extracting more side boards (Figure 5.47, column C). The basic sawing pattern included two centre boards and potentially 2–4 side boards per log (Figure 5.50, scenario b). The alternate sawing patterns included additional side boards, producing up to 10 side boards per log (Figure 5.50, scenario c). Extraction of this product from the 245–260 mm interval would result in a loss of 3.8 percent points.

Product 63 x 150 is preferably extracted from the 260–275-mm group (Figure 5.53), but consequently also competes for the same log volume as the 63 x 175 product (Figure 5.54). The latter product can, however, be extracted from the 275–290-mm group with relatively small losses of 0.8 percent points.

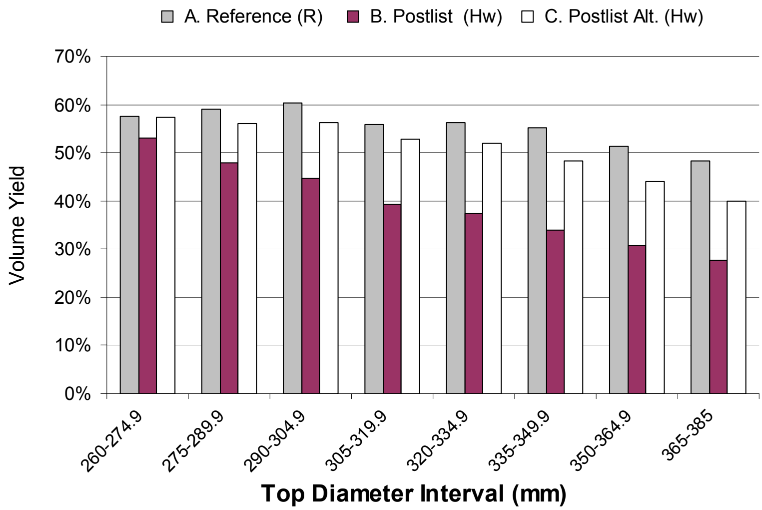


Figure 5.53 Comparison between three breakdown strategies for product 63 x 150 and achieved simulated volume yield. Definitions on "Reference (R)", "Postlist (Hw)"and "Postlist Alt (Hw)" equal to Figure 5.52.

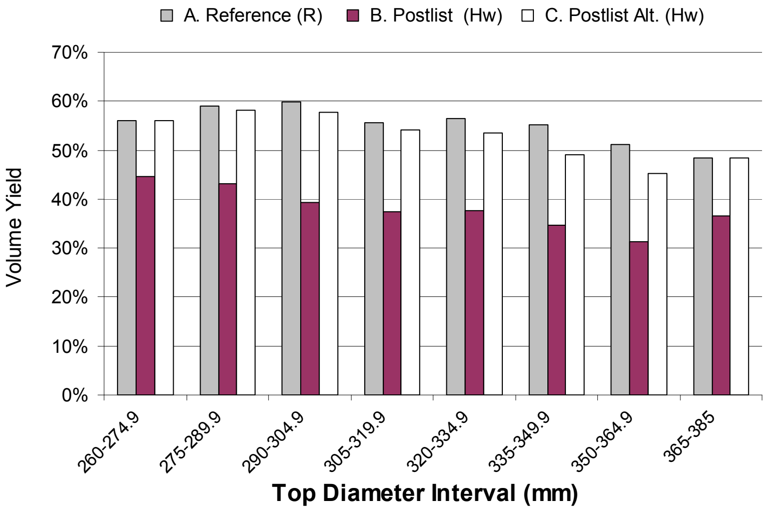


Figure 5.54 Comparison between three breakdown strategies for product 63 x 175 and achieved simulated volume yield. Definitions on "Reference (R)", "Postlist (Hw)"and "Postlist Alt (Hw)" equal to Figure 5.52.

Figure 5.55 shows the total volume yield of heartwood centre-boards achieved from approved logs in the most favourable top diameter interval. The heartwood top-diameter share varied between 63% and 84% on all approved logs and between 70% and 84% on logs in favourable log diameter intervals.

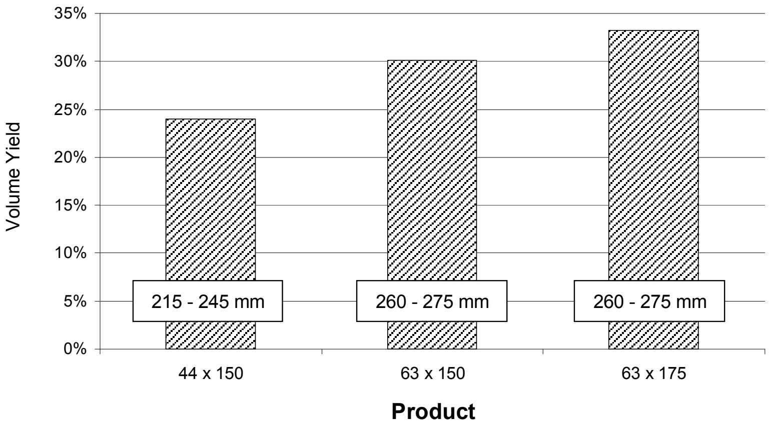


Figure 5.55 Total volume yield calculated on heartwood centre board volume extracted from approved logs within given top diameter interval.

5.6.7 Case study V - Discussion and Conclusions

This study shows that an effective production of high-heartwood-content products is possible. A fundamental issue is to effectively select the most appropriate logs, for example by utilizing industrial x-ray technology. This type of specialized production will also require changes in sawmill strategies, product pricing and measures to compensate for loss of yield.

The focus in the present study was set on evaluating a method in which logs best suited for the purpose were broken down under optimized conditions rather than sorting out solitary high-heartwood-content boards in regular production. The three main challenges in production of high-heartwood-content products are to find the most appropriate logs, take measures to compensate for yield losses caused by changed production strategies and to find sufficient log volumes.

An increased production of high-heartwood-content products also entails competition with regular products, since the total available volume of logs is generally limited. Furthermore, products are competing for the same log volume, since simulation results show that they are preferably extracted from adjacent top-diameter intervals.

This study shows that high-heartwood product must be extracted from logs with a larger top diameter in comparison to regular production, and these groups of logs are an even more limited asset. Consequently, this specific production strategy requires comprehensive strategic decisions in order to satisfy customer demand for sawn products and simultaneously maximize sawmill profit.

Measures are needed to select appropriate logs and compensate for losses in volume yield. Present methods commonly used for sorting logs in Swedish sawmills by measurements of log geometry and ocular inspection are sufficient to determinate top diameter, log volume, ovality, taper, crook and surface damage. However, a log's inner structure, containing information about heartwood share, knots and defects, is very difficult to determine by using only these methods. Primarily, improved quality sorting methods, *i.e.,* industrial x-ray equipment, must be applied in order to sort out the best-suited logs for the purpose.

It is also shown that the number of approved logs is limited. The top-diameter interval for favourable production of product 63 x 175 contains only 6 logs. This may affect the results presented in the study. A further conclusion could be that, given that the Spruce stem bank reflects the forestry supply, the specific product 63 x 175 is not suitable for heartwood products since it requires bulky logs with a very limited supply.

However, there is a potential to increase the number of approved logs by modifying rules governing the selection of appropriate logs.. The products discussed in this study could be extracted from thinner logs if more sapwood is allowed on peripheral parts of the centre boards, and the undesirable peripheral panels are screened out later after splitting.

Furthermore, the approved board length could be allowed to be shorter than the original log length. This would place demands on the equipment in the green sorting area to be able to sort out panels with too high sapwood content and to cut low-heartwood parts from the centre boards. The consequence would also be, apart from loss of yield, that the extracted volume would not increase at the same rate as the increased volume of approved logs. Even more logs could be approved by allowing a higher loss of volume yield.

The yield loss for scenario b, Postlist (Hw), is high in comparison to regular production (Figures 5.52–5.54). It can be judged that scenario c, “Postlist alt (Hw)”, is more realistic, since scenario b would not be used in reality. It must also be pointed out that the yield loss will only take place for the approved (selected) logs. Logs not approved and sorted out during the first procedure would in practice be cut according to the sawmill’s normal sawing procedure (scenario a, Figure 5.50).

Results show that effective production of high-content-heartwood products is possible but requires measures to compensate for loss of yield due to the fact that the log top diameter must be increased in comparison to regular production. Pinto *et al.* (2005) showed that log yields of heartwood products could attain between 13% and 16% of log volume, depending on the evaluated case. The higher volume yields achieved in the present study can be explained by the fact that products where extracted from logs particularly selected for the purpose.

This conclusion is also supported by Pinto *et al.* (2005), who claim that log selection will produce the highest potential yield. Furthermore, differences in achieved yields in the present results can be explained by deactivated knot definitions, breakdown performed with different sawing patterns and fewer sawing cuts in used sawing patterns.

This study has evaluated the measure of adding more side boards to the sawing pattern. The results indicated that this could reduce the loss of volume yield to a minimum by production of more side boards. However, the sawmill must be able to sell these side boards and panels at full price, compensating for losses in yield and regular production output.

The main problem in this scenario would arise in increased handling and costs caused by the high number of side boards, in some cases up to 10 side boards per log, in the green sorting area, drying kilns and the trimming area. These costs must be compensated for when setting the final price on the high-heartwood-content products. One possible way of dealing with the high number of side boards could be to add more centre boards to the sawing pattern instead of side boards. This would reduce the number of boards, the handling costs and also the number of sawing cuts

.

6 Discussion and Conclusions

6.1 Discussion

It has been shown that there is a large potential to improve yield recovery and utilization of equipment in the sawmill process. A review shows that the average yield in Swedish sawmills in 2000 was 47.1 percent (Staland *et al.* 2002). This present study has shown that volume yield can be improved by 3.0 percent through improved rotational positioning of logs. This would have produced an additional 1.1 million m^3 of sawn boards calculated on the production volumes for 2007. The export value of these boards would have been close to 2.8 billon SEK. The sawmill equipment has furthermore been shown to often be underutilized utilized due to a large number of time-consuming stoppages or unbalanced production lines containing bottlenecks.

This means that there ought to exist a logical argument and incentive enough for politicians and sawmill enterprises to stake more money on new research to find better methods and equipment. A limited supply of raw material and increasing competition between sawmills makes improved log breakdown highly important. Nevertheless, improved utilization of the existing sawmill equipment is today to a high degree already in the power of sawmill management and staff.

Appropriate methods, tools and a higher awareness are required in order to achieve improvements. A toolbox containing appropriate methods, process-monitoring or decision-support tools, such as quality management, process measurements, visualization and benchmarking methods, analysis tools and simulation software creates a solid base for implementation of process control, knowledge and improved productivity. Simulation software provides tools with which log-breakdown or production scenarios can be evaluated repeatedly without causing disturbances in the sawmill. Flexible diagnostic systems can, besides providing a sawmill with diagnosis and process knowledge, provide process data required for simulation models.

The goal must always be to solve problems, not just the effects of the problems. A brief allegory: An annoying water-tap drip caused by a leaking gasket can be solved in two different ways. One way is to change the gasket. Another way is to put a towel under the water tap in order to silence the annoying sound. The former solution deals with the problem, whereas the latter solution only attends to the symptom. The actual problem remains and will thus cause problems in the future. This must be avoided. Tightening the handle could be looked upon as an improvement, but not an optimization.

Regrettably, symptoms such as loss of production capacity due to low availability and low performance are commonly worked around with extended working hours during weekends, regardless of whether the symptoms manifest it in sawmills or in mechanical industries.

According to dictionaries, there is an obvious difference between the technical terms *improving* and *optimizing* a production line. The concept of improvement may be self-explanatory, while optimization is an often-misused word. Improve is explained in an English thesaurus as “make something better” while one explanation of optimize is “to modify to achieve maximum efficiency in capacity or cost”. To optimize can thus be described as a refinement of a process where the goal is to extract the last ounce of capacity or value.

A process can be described as a series of dependent operations conducted with the aim of achieving clearly stated results. This definition hinges on every single operation on a production line being dependent on or governing other operations involved. This means that every operator, machine, computer system or vehicle must be improved and synchronized in order to optimize the final output. Yet this is not the same as every operation working at its maximum. Suboptimizations of individual operations or departments without consideration of adjacent functions can and will induce counteracting effects.

A process showing very large losses initially can´t necessarily be optimized; it has to be improved to a certain level first. The struggle to find an optimized process can be an ambivalent matter. There is always a potential for improvement, though, which makes the struggle fruitful. On the other hand, the improvement process is never completely finished—thus remains further struggle. This might be good news for the ambitious, but somewhat disappointing for the “lazy”.

The work to find and maintain an optimal production process can also be described as an act of balancing on a thin line. A small step outside the optimal position can result in a worse result in comparison to results achieved before the performed optimization. These drawbacks must nevertheless not be allowed to discourage anyone from a process of constant improvement; such problems can be overcome.

Total Quality Management deployment is based on values, methods and tools.
A core value included in the Total Quality Management concept is “base decisions on facts”.

This is the first cornerstone and a consistent thread in this research project and in the following discussion. It is furthermore supported by Lords Kelvin's motto: "*If you cannot measure it, it does not exist*".

The work with process improvement and optimization is very much a matter of knowing "how much?" and "why?", and if one doesn´t know, one has to find out. The implication of Lord Kelvin´s statement is that proposed changes or improvements must be based on facts, measurements and knowledge rather than habits, tradition or notions. Fact-based decisions will promote credibility in proposed changes.

Process monitoring and diagnostic measurements enable the instant supply of valuable information to the entire production chain. In a manner of speaking, let the left hand know what the head concluded from the information supplied by the eye while monitoring what the right hand did. Early response and corrective actions are supported by an instant and correct data supply. The longer the process chain and the higher the process complexity, the higher the gain (Ericsson 1997). Process variables are not always directly measurable with conventional methods. However, it is often possible to measure indirect variables or to analyse data with multivariate process analysis. For example, final volume yield is not possible to establish until the boards are dried and trimmed, but yield can indirectly be monitored by measuring and optimizing the saw-face width in first saw.

A successful deployment of the somewhat sprawling TQM concept requires a focal point, and OEE can serve this purpose well if supported by management and a suitable set of tools and methods. Furthermore, one plus one will likely add up to more than two, thus also adding a holistic perspective to the OEE concept. Deployment of TQM requires top management support and commitment. One certain way to fail is not to make required resources available.

The intention of OEE and measurement is not to present neat figures, exact or optimum measure or graphs but to create an incentive and framework for improvement-related work (Ljungberg 1998; Jonsson/Lesshammar 1999). This means that the most important incentive is that the process required to establish the OEE values involving the staff´s process knowledge, process measurements, development of user-friendly systems, *etc*., creates a basis for discussion and the use of cross-functional teams (Ishikawa 1982). Not to be ignored or forgotten, the work can create a sense of belonging for all actors in the organization (Lebas 1995).

The second cornerstone is thus the staff and the Modus Operandi (approach, way to work) deployed. Preferably interacting in cross-functional teams, their commitment and knowledge will be supported and sanctioned by a leadership committed to continuous improvement.
These two cornerstones have been successfully used for a long time in the common mechanical industry and are easily adaptable to the sawmill environment. Of course, there are today ISO-EN 9000/14000-certified sawmills present, serving as role models, successfully adapting methods and new tools.

The deployment of TQM in sawmills is thus suggested to focus on the OEE concept with two main pillars and with the required tools acting as support pillars:

- Base decisions on facts supported by improved monitoring systems and simulation tools
- Create a favourable Modus Operandi clearly supported by the management, of working and collaborating in internal as well as external cross-functional groups. Visions, targets, decisions, actions and gained knowledge and improvements should constantly be communicated to everybody

The picture of the generic PDSA-improvement circle is well known but commonly shown as a single process, somewhat detached from other TQM-tools and methods. A considerably more appropriate visualization is suggested in figure 6.1 and 6.2. The single PDSA wheel shown in Figure 4.2 is here transformed into a cogwheel (Figure 6.1) and attached other functions as in Figure 6.2.

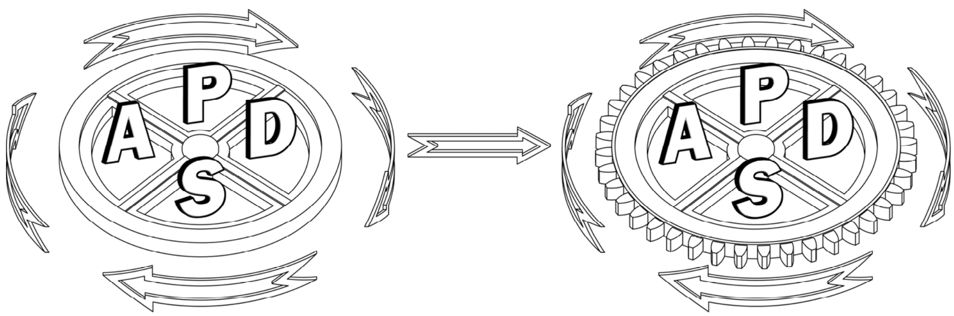


Figure 6.1 The continuous PDSA-improvement (Plan-Do-Study-Act) cycle transformed into a cog wheel.

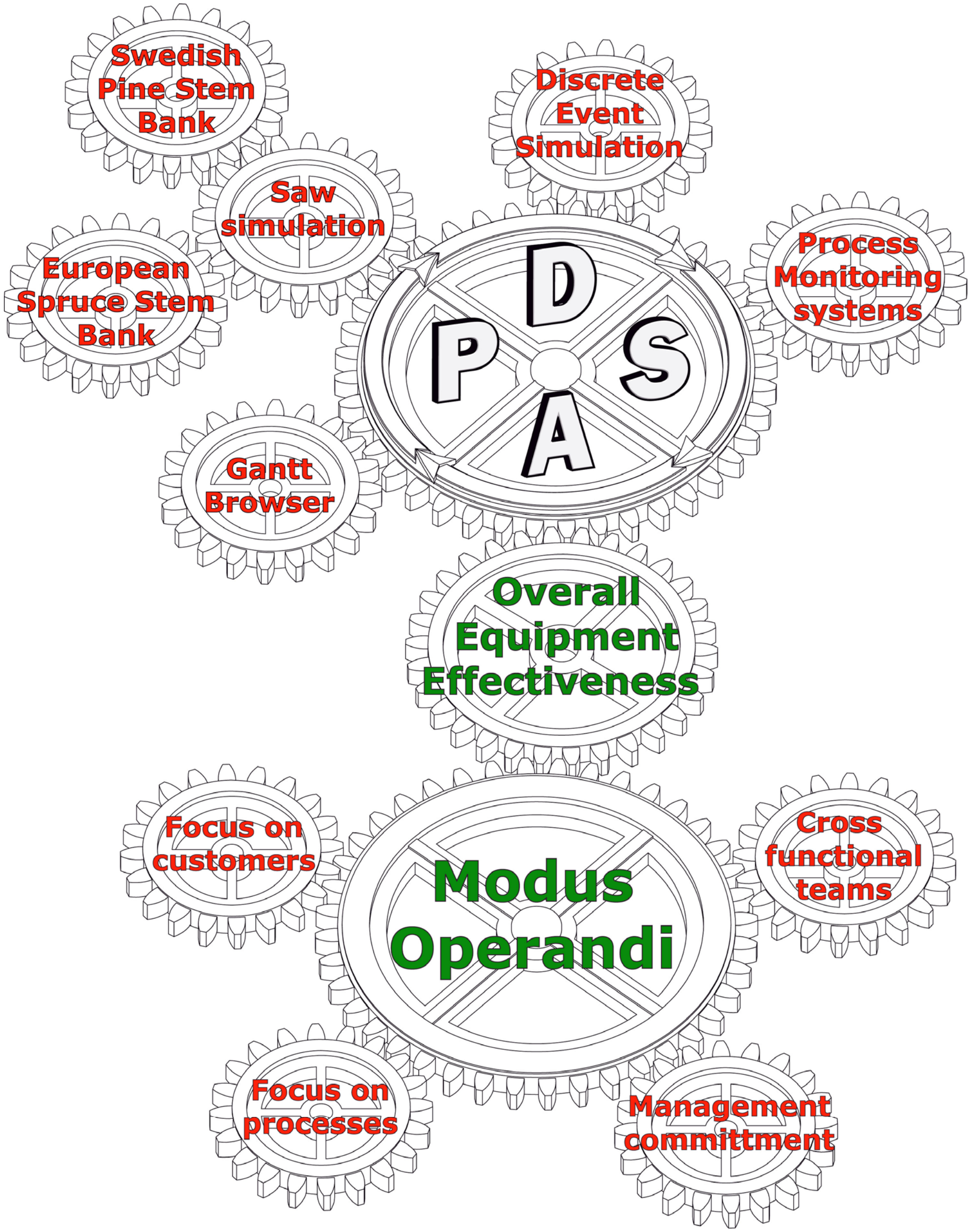


Figure 6.2 The continuous PDSA-improvement (Plan-Do-Study-Act) cycle attached to other TQM-functions.

The connection between the PDSA circle and other tools and methods becomes more obvious when visualized as in the figure above. The whole system is dependent on how well other parts perform and can furthermore be propelled by one or more functions.

The PDSA cogwheel with its satellite wheels in Figure 6.2 represents the work with continuous improvement connected to, or in reality, aided by, tools and bodies of knowledge for decision support. The PDSA-combination represents the base-decision-on-facts cornerstone supported by tools for measuring processes and for simulation software. Simulation models are supported by knowledge databases represented by the Swedish Pine Stem Bank and the Spruce Stem Bank. The bottom combination of cogwheels represents the second cornerstone in the shape of staff, forms of teamwork and commitment, the so-called Modus Operandi, Latin for method of operating or functioning. The common link between these systems in this case is OEE.

Implementation of OEE is suggested to start with initial monitoring of a system focused on simplified measurement of frequency of losses in order to establish a simplified and comprehensive view of the situation. A complete and detailed recording of numerous process parameters is more precise, but also more time consuming (Dal *et al.* 2000). Implementation of OEE can be done rather simply, but a word of caution is in its place: avoid including uncontrollable factors in comparisons. This is likely to make things much more difficult and complex.
This can be factors such as short term effects caused by the sales market or effects on log delivery caused by seasonal effects on harvesting or logistics.

The OEE benchmarking concept can be a powerful tool, because the work involved reveals and reflects the impact of three distinct areas commonly subject to losses. Generally, the focus is always set on availability and quality issues, but the performance of the equipment is regrettably easy to ignore. The OEE concept takes all three factors into account, and availability or performance issues are in many ways identical to those of the mechanical industry. The surveys performed during this study certainly show large losses in availability caused by bottlenecks, by malfunctioning equipment and even by obstinate logs.

Still, there exists one more major and often anonymous perpetrator when it comes to losses, namely idling equipment. The goal must always be to reduce all log gaps, thus enabling sawing machines to cut wood during as much as possible of the available time.

Modernized or newly designed sawmills are often equipped with material-handling systems that remove log gap, but this also places demands on process capacity downstream in the sawline. Bottlenecks have one large disadvantage besides the common strangulation of capacity. When a bottleneck is removed from one operation, a new and freshly obstinate one has a tendency to immediately appear somewhere else on the production line. Minimized idling time will nevertheless ease the strain on equipment availability and can be used as a production accelerator without increasing the feed speed.

A potential to increase production and perhaps even lower feed speeds while preserving capacity arises when stoppages and idling are minimized. Lower feed speed may also further diminish downtime, since machine wear is generally known to decrease at lower speed.

The advantages of high performance and availability are obvious but requires improved machinery design and a balanced production process without major bottlenecks. To be or not to be is a continuous issue when buffers are discussed. Some advocate them because they can be used to momentarily balance a production line and reduce the vulnerability of a single line production system. Other ban their presence because they are too often used to diminish the effects of bottlenecks, because they do not solve the problem or because they may even divert attention from the real cause. The need for buffers is in any event symptomatic of an unbalanced system and may be even more accentuated by frequent disturbances.

The mechanical manufacturing and assembly industry can in this case serve as a good example and a role model for how logistics and handling equipment can be designed for best performance and reliability. This kind of equipment will likely be available when sawmills set these requirements and are prepared to pay what is required in order to meet them. The error-cause survey showed that the green sorting area frequently acted as a bottleneck, thus causing 30% of all stoppages and the highest loss in production time.

OEE is a comprehensive method preferably also used to visualize the impact of disturbances, changes and improvements made. However, the real work is done by the staff with the support of the different tools included in the TQM framework. These tools can, as in this study, be a flexible process-monitoring system developed and used in order to collect process and error-cause data together with simulation models developed to imitate real sawmill log breakdown or sawline production flow.

Simulation technology deployed as Discrete Event and breakdown models is a vital part of the present work and of the proposed toolbox. Reliable process data were needed, in part for the OEE concept, but also as a very crucial part in the development of the Discrete Event Simulation models. The log-yard project was in reality made possible by the presence of the GPS Timber support system. Manual measurement on simultaneously moving vehicles such as the log stackers is a challenge and requires time and personnel.

The development of a simulation model served three main purposes during this study: to gain process knowledge, to evaluate the quality of acquired process data and to run simulation scenarios. The development of a model often focuses on what concrete results the model is expected to supply, and these other purposes are easily forgotten. A DES model built and visualized in order to imitate the real sawmill simplifies the process of model building, verification and validation. Furthermore, is it easier to achieve acceptance for the tool if the viewer can understand and relate to what he/she is viewing, the included data and the way the model is used.

Experiences from simulation projects performed in this study and a number of commercial simulation projects done previously as consulting assignments for the automotive and mechanical industries show a higher degree of knowledge and awareness among the involved staff after cooperating in such a project. The staff involved often regards the process knowledge gained and the structured way of working with simulations as almost as important as the concrete results achieved from simulations.

This awareness is achieved by the structured work of defining and mediating all the rules and data needed by the modeller. Surprisingly few operators are aware of the important part they play in the production process and, furthermore, in which way their manner affects the entire process. In similarity to the common production view in which every machine is regarded as a detached system, people have a tendency to focus only on their own part of the production or support systems, thus detaching their world from their surroundings.

The final models created in this study shows a high degree of validity, *i.e.*, the model is credible and imitates the real sawmill production very well. This makes it possible to evaluate new strategies and/or layout changes as a decision support in development projects and prior to investment in new equipment. However, sawmill production is influenced by warm and cold seasons, and models must therefore be calibrated and results interpreted according to the actual conditions they are expected to reflect.

The process data supplied by the sawmill were immediately found to be incorrect when they were fed into the simulation model. This made better process-monitoring systems an obvious requirement. The final model containing reliable data supplied by the monitoring system showed that it is possible to create models with a high similarity to the real production flow and output.

The need for a diagnostic monitoring tool was clearly revealed during the acquisition of process-related data. The Distributed Process Monitoring system enabled an invaluable supply of both stoppage data and the registered causes for the stops and revealed the true level of losses of valuable production time. Modern sawmills are generally equipped with improved comprehensive monitoring systems. However, the flexible diagnostic system developed in this study serves a purpose in diagnosing the true level of losses in both older sawmills and modern ones. Sawmill monitoring systems and machinery are often developed by a number of external companies and designers. This means that these systems are rarely adapted to communicate with other subsystems or with a comprehensive monitoring system.

This tool also makes it possible to handle and visualize time-related data without large, time-consuming efforts from the staff. This should not be seen as the final destination of this tool, because it can be further developed in order to become an integrated part of a comprehensive process-control system connecting equipment for online measurement surveillance or log traceability to the existing database.

The sawmill process investigated suffered from a large amount of availability and performance losses. These documented losses reduce the valuable production time on the sawline by 32% on average due to downtime and by 23% on average due to ineffective material-handling systems. The sawmill staff and management long had the notion that availability was low, but the influence of the previously unregistered short stoppages proved to be even greater than expected.

Due to increased awareness, management allocated time and resources to one specific operator in order to work with continuous follow-ups and troubleshooting. This effort has, according to personell at the sawmill, increased availability on the sawlines by 5–7 percent on average, equal to more than 170 production hours per year. The sawmill is presently (July 2009) investing in new green sorting facilities in order to minimize the bottleneck problem.

The OEE concept also deals with quality issues. The common way of counting the share of approved or unapproved products is not applicable to sawmill production, because boards are rarely unapproved or scrapped. A more appropriate quality index in sawmills is the extracted yield. A yield of 100% is obviously not achievable; more realistic would be a yield closer to 50%. The theoretically achievable yield varies, governed by every single log´s specific properties, and probably also varies depending on the sawmill and its geographic location. This fact makes the quality factor more complicated to establish. Nevertheless, a credible 100% quality level must be established in order to fit into the OEE framework.

Breakdown simulations performed in this study established the improved average target yield for every single sawing class. This yield can serve as the 100% OEE quality index. Sawmills can establish these target values by utilizing x-ray technology and breakdown simulation technology as shown in case study IV.

Figure 6.3 shows a suggested approach in which the average yield is transformed into a polynomial to the third power, enabling the calculation of average yield for 10-mm sawing classes. This equation enables calculation of yield, for example when sawing classes are temporarily modified. The curve is smoothed with a sliding average.

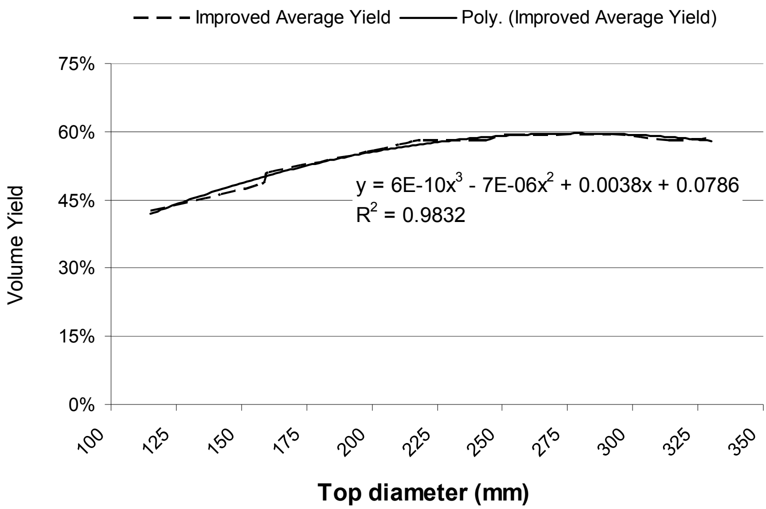


Figure 6.3 Example of an approach where the 100% quality index can be calculated from a polynomial to the third power based on yield simulation results.

The final yield is governed by sorting rules, postings and setup accuracy stated or induced by the sawmill staff and the sales market on one hand, and by the drying procedure, sawing accuracy and measurement spread caused by the sawing machines on the other hand. This means that every link in the sawing and drying process, the staff included, must perform as expected in order to achieve the highest yield. When one link fails, the whole chain is weakened.

A further challenge is to separate effects on yield caused by, for example, changes in raw material supply or log properties, from effects on yield caused by changes in the machinery. An appropriate way of dealing with the quality index used in the OEE concept would perhaps be to differentiate the main quality index into two subindexes that separately describe yield-related and machine-related issues.

A further complicating factor is that final yield and verification of whether the process quality is high or merely acceptable occurs downstream from the sawing process, possibly weeks later. A very low quality in breakdown would certainly be detected by skilled operators, but this fact makes it more difficult for the individual sawline operators to clearly see their contribution in the daily work. Jonsson (1998) addressed this problem and remarked that this fact makes it difficult to rapidly identify causes and apply corrective actions in time.

To view, monitor and control the entire breakdown procedure as a process is therefore of utmost importance, because all included functions and changes affect the entire output of the system. This means that production capacity will suffer if online optimization of the breakdown requires too much time to perform, thus diminishing the impact of yield improvement that has been achieved.

The final yield is thus difficult to monitor during the breakdown process, although indirect variables such as board-dimension accuracy can always be monitored with the aid of appropriate tools. An evaluation of the total process quality should include both the yield and an index that describes the setup quality and performance of the machinery. This would enable rapid corrective action when problems occur.

The quality issue is the main challenge to master in order to be able to adapt OEE fully to sawmill prerequisites. Log-breakdown simulation supported by industrial X-ray scanning can, as shown in the case study, favourably be used to establish a theoretical but credibly achievable 100% quality-factor level.

These two techniques in combination with reliable log traceability enable an improved scaling and breakdown procedure in which every single log is assigned to a correct sawing pattern with individual settings for log rotation and lateral positioning in the sawing machines. This would indeed establish an OEE value, but this gain is of secondary importance. The highest return is in fact that by actually being able to establish the best set positioning variables for every single log, a basis for improvements, actions and machinery requirements can be established.

Breakdown simulations performed during this study show a potential to increase yield by treating logs as individuals by applying optimal breakdown settings to every log. Even though the main results were achieved from a single-factor test, they still show a large potential to increase yield. A multi-factorial experiment on 200 logs indicates an even greater potential when the influences of three or more breakdown variables were evaluated simultaneously.

The results show that the commonly used horns-down rotation and cross-section centring positioning may produce the best average yield. Nevertheless, new, improved tools can facilitate further improvements by finding optimal positioning for individual logs.

Improved scaling accuracy and the capability to screen substandard logs serve two purposes simultaneously, as both value and yield will increase. The sawmill avoids expenses for the purchase of low-value raw material, and at the same time, the average yield increases when logs are sorted into the correct sawing classes.

Online breakdown simulation is in use on sawlines today. However, a breakdown simulation performed on the sawline using static postings can only optimize the position of the sawing pattern onto predetermined logs. It would be preferable for the simulation to be performed during the scaling procedure in order to be able to optimize the logs.

An evaluation for optimal sawing pattern performed in the scaling procedure can enable application of the best sawing pattern to every log, thus classifying it into the correct sawing class. Nowadays, some modern sawmills are equipped with sawing machines with some degree of capability to change sawing patterns between logs and are thus capable of applying the best sawing patterns to individual logs.

An interesting feature in OEE is the “Best of the Best” approach. This promotes a positive attitude by focusing on the fact that availability, performance or quality in reality can reach higher levels during specific weeks. These facts can thus be used as a basis for discovering why other weeks are not as good as the best and finding ways of improvement. The target can consequently be set to achieve the best recorded level for each factor during the same week in the future. This target is obviously reachable given that everybody involved agree about established values. Initially the best weeks are not always improved but the worst weeks are probably improved. A new challenge arises for the staff when the worst weeks are improved up to the previously recorded best of the best-level.

A vital part of a favourable modus operandi promoted in this study is to enable communication and visualization of measurements and the impact of proposed or implemented changes. OEE is a concept well suited to the purpose, since it considers three vital process-related factors and highlights “where we were and where we are.”

The OEE concept has flaws, as all concepts do, and there are ambiguous definitions dependent on application or author. Nevertheless, this apparent vagueness can be regarded as a feature, since it enables the OEE concept to be adapted to the particular process under evaluation. This makes it more of a prerequisite than a drawback.

OEE percentage is not statistically valid. A calculated OEE percentage assumes that all equipment- or yield-related losses are equally important and that improvement in OEE is a positive improvement for the business. This is generally not the case.

It would thus be a mistake to consider a percentage in the three OEE factors as equally important to the production output and income. For example, the calculated OEE percentage does not consider the fact that a one-percent improvement in yield may have a greater impact on business, thus returning more income than a one-percent improvement in availability. OEE percentage can furthermore actually decline while output volume improves if availability, for example, is increased, but quality is decreased by an equal amount of percentage points.

Huang *et al.* (2003) report that OEE has been widely accepted in the semiconductor industry. The concept of OEE is becoming increasingly popular and has been widely used as a quantitative tool essential for measurement of productivity of semiconductor-manufacturing operations because of an extreme capacity and capital investment in production equipment.

The literature regarding appropriate levels of OEE is far from unanimous or clear (Eldrige *et. al.* 2005; Dal *et al*. 2000). However, 85 percent OEE has been cited frequently, mainly based on Nakajima´s statement that this is a good benchmark for a typical manufacturing capability.

This proposed level is based on requirements to show Availability > 0.90, Performance > 0.95 and Quality > 0.99. Kotze (1993), on the other hand, argues that an OEE close to 50% is more realistic, thus also more useful as an acceptable target. This figure corresponds to the summary of different OEE measurements presented by Ericsson (1997) and Ljungberg (1998), in which OEE varies between 30% and 80%. An average of the OEE was found to be 55%, while the Availability figure was found to be 80% in the same sample cases.

If a sawline is to be considered top class in relation to the manufacturing industry in general, the total OEE value would have to be at least 85% according to Nakajima. Achievement of this level would effectively require each of the percentages for Availability, Performance and Quality to be at least 93%. This level is not achievable today even for modernized or newly built sawmills. Some parts of the sawmill processes are quite sensitive, and small deviations in the flow and in log gaps can have a large impact on the OEE value. This fact should nevertheless not discourage people from using OEE.

The optimum level of OEE for a sawmill or other enterprise depends greatly on the capability or capacity of the asset, on business demands and on whether it is a constraint in the process flow. This means that an OEE level of 100% does not automatically mean that production is running at its theoretical maximum at all hours. For example, the maximum availability factor is rarely set to 100% in relation to 24/7 working hours (24 hours 7 days per week, 8760 hours/year). There are always deductions for planned stops or allowing the staff time to eat. This means that it is up to management and staff to unanimously decide levels and the appropriate OEE target value.

OEE measures the effectiveness of individual equipment over a period of time and at different instances. However, the OEE value does not directly reflect productivity or production output. OEE could be supplemented by extending the concept to factory level, termed OTE (Overall Throughput Effectiveness) or OFE (Overall Factory Effectiveness). The terms OTE and OFE are commonly used in the TPM paradigm to represent the integrative performance measurement of a manufacturing system, combining all activities, relationships, information, decisions and actions across many independent subsystems (Muthiah *et al.* 2007).

It may a mistake to compare OEE levels originating from different enterprises or production setups. OEE only returns a fair benchmark when the same machine or production line is monitored and compared over an appropriate period. This is a fundamental cornerstone in the OEE concept. Different sawmills can thus not easily be justly compared to each other. This is a typical misuse of OEE.

Sawmill conditions are governed by seasonal effects from the raw material that affect feeder speeds and sawing accuracy. Jonsson and Lesshammar (1999) addressed this issue as it applies to the manufacturing industry, emphasizing that it is important to use the same speed (same conditions) for every single measurement. Otherwise, it is not possible to compare measurements over time.

.A number of authors addressed the issue of staff commitment and how to create creative and constructive approaches to continuous improvement. Nakajima (1998) suggests that a “favourable work environment” is one of the two prerequisites for the successful deployment of OEE.

Bamber *et al.* (2003) emphasize that working in cross-functional teams is the most successful method of deploying OEE and making continuous improvement. The key factor according to the authors is found in the fact that cross-functional teams posses the combined and required skills and knowledge of the production system they manage.

This is invaluable when dealing with complex systems and, as shown in this study, building valid simulation models. The concept is effective in internal projects as well as when applied as a modus operandi to clusters of sawmill enterprises. The work done during the case studies and development projects has given valuable and positive experiences.

Decision support systems such as the GPS-aided log yard support system or similar system can minimize errors and makes life easier for the staff. These systems opens possibilities for further improvement in other areas such as the log yard process. Process measurement on moving vehicles becomes manageable and the precision of the GPS is accurate to within one metre.

Development of the diagnostic system involved students, teachers, sawmill management and staff, personnel at a local programming company, professors, researchers and PhD students. The work was done within the framework of the regional TCN cluster. All parties contributed commitment, special skills and knowledge in order to achieve results. A similar constellation was created for the log-yard case. Sawmill staff from 6 sawmill organizations is committed to the TCN cluster. Thus, enterprises that are usually in competition with each other are collaborating in a vide range of sawmill-related development projects.

The importance of a favourable work environment and methods of dealing with interwork problems was furthermore highlighted during my work as supervisor for a student working on a master's thesis in wood technology. The assignment was similar to case study III, that is, improvement of logistics and log handling at a Swedish sawmill. The problem area was apparent: the capacity of the log scaling process was too low and had been in decline during the last year. No one could really explain why, but there were, as always some suspected perpetrators.

The target was to increase log-scaling capacity by 43% in order to supply the sawline without interruptions. One obvious problem was immediately revealed by the student. The sawmill management, the entrepreneur managing the log stackers and the independent log scaling society did not cooperate, but rather suspected and opposed each other. The suspected perpetrators were thus also revealed.

But then the graduate student came to assistance!
She initiated a survey in order to identify and register why the log-scaling process did not produce at its designed capacity. The second mission was to find the causes of the noncommunicative relations between the opposing parts. Muffins were the solution!

The survey revealed among, other things, problems in the scaling equipment and a high frequency of disturbances in the log bins. These main problems lowered scaling capacity and occupied the log stackers with a lot of nonvaluable work.

By gathering the three parties in meetings, initially only group-by-group, all were able to express their opinions and suggest solutions.
Coffee and freshly baked muffins were served at these meetings.

The initial meetings evolved into joint meetings in which all parties were represented. Regarded as an objective part in an infected environment, the nonthreatening student became a mediator and a “spider in the centre of the web”.
Muffins continued to be served.

Even though few of the suggested changes had been implemented on the scaling line when the operative work with the thesis was completed, the scaling capacity increased by 23%. The result did not reach the intended target, but was seemingly achieved by an improved working climate, improved awareness on the part of management and the involvement of all parties in the struggle for improvement.

Two cornerstones in the TQM concept have until now been left out of this discussion. The first of these two is customer focus. This is, of course a very vital part, but was not intended for inclusion in this study. A customer is generally defined as the buyer of products or services, but the relationship with the customer is not to be driven by a requirement of money being involved.
A common definition is that a customer is the one we want to create a value for. This implies two things: that we have something to offer and that we want to offer it to someone. Everybody has something to offer, whether it is a commercial service or a helping hand.

However, this customer viewpoint is an invaluable feature in the work with continuous improvement. The kiln operators need a constant and on-time supply of green boards in order to supply the kilns and create an optimized drying process. They are thus customers of the sawline operators, who in turn are the customers of the log stacker drivers, and so on.

This connects to the second part not discussed—focus on processes. Process thinking is very much about knowing one’s part in the process and seeing the totality. In the best of worlds, every part of the conversion chain is happily dependent on the others and is hopefully intended to create value for others in the process.

Some operators may saw boards; others are sawing boards in order to build bridges.

Skellefteå Church town – "Bonnstan”

6.2 Conclusions and recommendations

1. Great potential to improve yield.

The results in this study indicates that there is a great and obvious potential to improve volume yield by handling and evaluating logs as separate individuals during the scaling and breakdown process, rather than as parts in a batch. The yield achieved from logs can be increased by finding optimal rotation and centring positions, rather than the commonly used horns-down and centred position. Seemingly small improvements in yield can affect income and raw material demand considerably when large volumes are processed. Log-rotation equipment may need to be improved in order to distinctly execute the best rotation angle.

2. Great potential to improve availability and performance.

The surveys performed show a large loss of valuable production capacity due to stoppages and idling or malfunctioning equipment. The commonly ignored stoppages shorter than 90 seconds turned out to be equivalent to 2 weeks of valuable production per year, based on double shifts. Intermediate stops were equvivalent to 7 weeks per year, double shift. The sawmill industry in general is not sufficiently focused on this problem and is somewhat more inclined to accept losses than the mechanical industry is. This attitude is slowly changing, and there are sawmills successfully adapting a TQM-inspired approach.

3. Saw simulation and DES models, valuable decision support tools.

The resulting models show that Discrete Event Simulation models can be credible and quite exact if correct stoppage data are available. However, the final model is only valid under the prerequisites included in the model. The production-line setup in a sawmill with few or no subprocesses does not always justify spending a large amount of time and money on a modelling effort when theoretical calculations can come close enough. Simulation models are motivated when complexity is increased. The dynamics of independently occurring events on the sawmill log yard serve as an excellent example of a situation to which Discrete Event Simulation is well suited. Breakdown simulation models in combination with stem-bank data make possible detailed studies from which optimal breakdown configurations can be derived.

4. Continuous improvement powered and supported by the management.

A successful continuous effort to improve production processes must be powered and supported by sufficient resources and a committed top management promoting appropriate methods and approaches. Lack of sufficient resources or support will cause the best intentions to fail. For example, the work with simulation model requires continuous resources in the form of time and personnel.

5. Use the OEE concept as an appropriate focal point for continous improvement.

OEE can serve as an appropriate focal point in a favourable modus operandi for minimizing losses and making continuous improvements. The OEE concept is a useful tool, because it offers possibilities to separately evaluate and trace improvements in availability, effectiveness and quality factors. The successful computation of OEE depends on the ability to collect correct process data and on the definition of achievable yield targets. Focus should be based on facts and on the OEE factor that is expected to return the most profit. The "Best of the Best" concept is promoted as a winning approach by which the targets are set from actually measured facts.

6. Adapt generic tools and methods used in the mechanical industry

Sawmill enterprises would gain by adapting the generic quality management approaches that have been used in the mechanical industry for more than a half century. TQM is in many ways directly adaptable from the mechanical industry. Sawmill logistics is not to be regarded as special in comparison to the prerequisites of the mechanical industry, with one exception—the raw material. Log properties can vary substantially between individuals and over seasons. The sawmill staff must constantly relate to this fact in order to improve sawmill yield and output. This requires the OEE quality factor to be adapted to the sawmill environment since the quality concept is differently defined in the mechanical industry.

7. Implement modern technology

Online scanning of logs with X-ray techniques in combination with breakdown-simulation software facilitates optimization of sawing-class limits or individual logs. X-ray technology also makes it possible to select appropriate logs for extraction of specific products, for example, high-heartwood-content boards from spruce. Modern technology such as the GPS-aided decision-support system or similar systems can minimize errors and improve working conditions for the staff.

Improved and comprehensive process monitoring systems with automatic error -report systems would improve continuous process-data acquisition. A flexible diagnostic monitoring system serves its purpose when performing shorter surveys.

8. Promote work in cross functional teams.

No one knows everything but everybody know something. The cross-functional work performed within the TCN network serves as a role model for teamwork within sawmills and between generally competing sawmill enterprises.

9. Toolbox configuration

An appropriate toolbox for sawmill improvement work will preferably contain a flexible process-monitoring system, saw simulation software and Discrete-Event Simulation software for decision support and a stem bank data base, with OEE serving as a benchmarking tool. The main resource is nevertheless always the staff and a creative work environment. This should not be considered as a static configuration. The toolbox proposed in order to deploy TQM in the sawmill environment is portrayed in Figure 6.4.

Figure 6.4 The Toolbox

The Bear tower, Skellefteå. A work of art created by Lars Wilks.

7 Future Work

Some areas of further research and development are of interest:

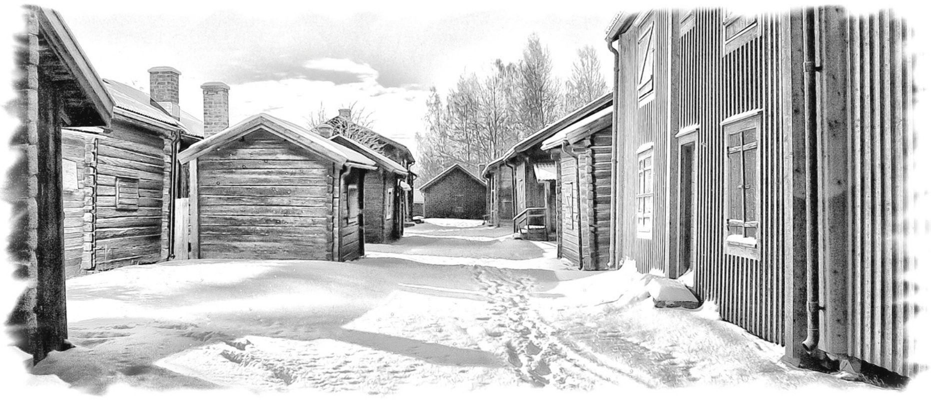
- Integration of process control systems and development of refined monitoring systems with automatic error reporting systems.

- Applied OEE integrated to the entire sawline conversion chain

- Dynamic allocation of sawing classes to bins in the scaling process.

- 3D DES models as a support tool during planning and layout design of new sawmills.

- Optimal sawline feeder speed with regard to optimized volume yield and total volume output.



Skellefteå Church town – "Bonnstan”

Epilouge

This has been a long but worthwhile research journey, sometimes running on the intended single track, more frequently on two or even four parallel tracks. The journey is pictured in a technical manner in Figure 3.1.

The research tasks have in many ways dealt with issues closely connected to sawmill production, thus causing the research to constantly balance on a thin line bordering on the area of development. The saw-simulation studies may be considered as the most theoretical part of the research governed by a limited number of rather straight logs and with knot definitions deactivated. Nevertheless, these breakdown studies serve as an example of how simulation techniques can be applied in order to reveal the potential to improve yield, supported by prior research asserting that there is more to be gained when knots are taken into account.

Some of the outcome from this project has now been implemented in sawmills. The staff at Kåge sawmill have increased their loss awareness and are working more on reducing losses. The diagnostic measuring system has been further improved, in productive use and is purchasable. The outcome from the still ongoing log-yard project has been evaluated, the software has been finalized, and the sawmill is planning the implementation of an alternative log-handling strategy.

Total Quality Management and production technology are very much a matter of human psychology and realizing what one really wants to see. The famous picture of the old woman…or is it a young woman is an excellent example of how the human mind sometimes blocks out the possibility of perceiving hidden or even obvious information (Figure 6.5). Both faces are present but we may have to open our minds and look twice.

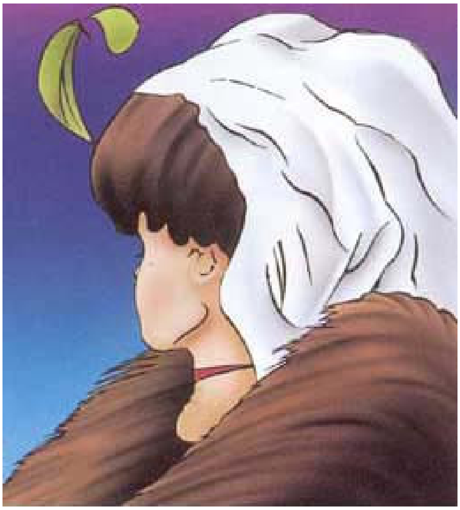


Figure 6.5 Old woman or young woman? Published in Puck humor magazine 1915.

To summarize, I have learned a lot, achieved some, but there is still much to do!

Would I do it all again?
Probably, but in another way!

The cure for boredom is curiosity.
There is no cure for curiosity.

—Dorothy Parker (1893–1967)

8 Literature cited

Alvesson M. and Sköldberg K. 1994 *Tolkning och Reflektion – Vetenskapsfilosofi och kvalitativ metod* (in Swedish). Studentlitteratur AB 1994-01.

Anon. 1997. Round and sawn timber - Permitted deviations and preferred sizes – Part 1: Softwood sawn timber. SS-EN 1313-1, SIS, Swedish Standards Institute publication.

Anon. 1997. Round and sawn timber - Method of measurement of dimensions – Part 1: Sawn timber. SS-EN 1309-1, SIS, Swedish Standards Institute publication.

Anon. 1999. *Nordiskt Trä, Sorteringsregler för sågat virke av furu och gran*. Markaryd: Markaryds Grafiska. ISBN 91-7322-175-9 (in Swedish).

Anon. 2000. I*mproved spruce timber utilisation (STUD).* Final report, European shared-cost research project within FAIR (DGXII/E2), contract no. FAIR CT 96-1915.

Asplund, T. and Sederholm, J. 1982 Volymsutbytets påverkan av krok, sortering och felinläggning. STFI-meddelande serie A. nr 744.

Balci, O. 1988. "The Implementation of Four Conceptual Frameworks for Simulation Modeling in High-level Languages". In: *Proceedings of the 1988 Winter Simulation Conference* (M. A Abrams, P.L. Haigh and J.C. Comfort, eds.). IEEE, Piscatawnay, New Jersey, pp. 287–295.

Bamber, C. J., Castka P., Sharp J. M., and Motara, Y. 2003. Cross-functional team working for overall equipment effectiveness (OEE). *Journal of Quality in Maintenance Engineering* 9(3):223–238.

Banks, J. 2004. *Getting Started with AutoMod*. Second Edition. Chelmsford: Brooks Automation, Inc.

Banks, J., Carson, J. S., Nelson, B. L. and Nicol, D. M. 2000. *Discrete-Event System Simulation*. 3d Edition. Upper Saddle River, NJ, USA: Prentice-Hall.

Bergman, B. and Klevsjö, B. 2003. *Quality - from Customer Needs to Customer Satisfaction*. Lund: Studentlitterartur.

Bergström, M., Å. Rydell and T. Thörnqvist. 2005. *Durability and moisture dynamics of Norway Spruce (Picea abies) heartwood and sapwood.* In: Proc. The Woodframe Housing Durability and Disaster Issues Conference, organized by the Forest Products Society, Las Vegas, Nevada, USA, October 4–6 2004.

Birkeland, R. and S. Holöyen. 1987 *Industrial Methods for internal scanning of log defects: A progress report on an ongoing project in Norway.* Proceedings of the 2nd International conference on scanning technology in sawmilling, October 1–2, 1987, Oakland/Berkley Hills, California USA, pp. X1-X18.

Brown, T. D. 1979. Determining Lumber Target Size and Monitoring Sawing Accuracy. *Forest Products Journal* 29(4):48–54.

Bråkenhielm, C., Jonsson, T. and Sundkvist, I. 1969. *Förslag till tärningsmått för lättmetalltärningar och trätärningar vid försågning till metriska mått*. STFI-meddelande serie B nr 2. Stockholm: Swedish Forest Products Laboratory.

Camp, R. C. 1998. Benchmarking: The search for Industry Best Practices That Lead to Superior Performance. Milwaukee, WI: ASQC Quality Press.

Carmines, E. G. and Zeller, R .A. 1979. *Reliability and Validity Assessment – Quantitative.* Sage University Paper. Series: Applications in the Social Sciences.

Chiorescu, S. and A. Grönlund. 2000. Validation of a CT-based simulator against a sawmill yield. *Forest Prod. J.* 50(6):69–76.

Chiorescu, S. 2003. *The Forestry – Wood Chain. Simulation Technique – Measurement Accuracy – Traceability Concept*. Doctoral Thesis ISSN 1402 – 1544. Luleå University of Technology, Division of Wood Technology, Skellefteå Campus.

Clifford, G.P. and Sohal A.S. 1998. *Developing self-directed work teams.* Management Decision Vol. 36. Issue 2. pp. 77-84.

Dal, B., Tugwell, P. and Greatbanks, R. 2000. Overall equipment effectiveness as a measure of operational improvement – a practical analysis. *International Journal of Operations & Production Management* 20(12):1488–1502.

DataPolarna AB. 2006. *GanttBrowser*. DataPolarna AB Software Development. 2006. Vretgatan 5, 93133 Skellefteå.

Deming, W. E. 1988. *Out of the Crisis*. Cambridge University Press.

De Ron, A. J. and Rooda, J. E. 2005. Equipment Effectiveness: OEE Revisited.*IEEE Transactions on semiconductor manufacturing* 18(1):190–196.

Dettmer, H. W. 2003. *Brainpower Networking: Using the Crawford Slip Method*. Victoria, BC: Trafford Publishing.

Dogan, C., McClain, T. and Wicklund, S. 1997. Simulation Modeling and analysis of a hardwood sawmill. *Simulation Practice and Theory* 5(5):387–403.

Drake, E., Johansson, L-G. 1986. *Positionering av stockar i första såg*. Trätek-rapport I8610060. Skellefteå, Sweden: SP Trätek.Dugdale, D. S. 1966. Theory of circular saw tensioning. *International Journal of Prouction Research* 4:237–248.

Ericsson, J. (1997), *Disruption Analysis – An Important Tool in Lean Production*, Department of Production and Materials Engineering, Lund University, Lund.

Eldridge, S., Reyes, J. A. G. and Barber, K. D. 2005. An analysis of OEE performance measurement for an automated manufacturing system. In *Proceedings of the 15th International Conference on Flexible Automation and Intellegance Manufacturing*, University of Deusto, Bilbao, Spain, 18th–20th July, 2005.

Emory, C. W. 2002. *Business Research Methods*. 8th rev. ed. D. R. Cooper and P. S. Schindler, eds. New York: McGraw-Hill Education.

Eneroth, O. 1922. *Vedens Byggnad, Handbok i skogsteknologi.* Viktor Petterssons Bokindustriaktiebolag, Stockholm, Sweden.

Farrell, M. J. 1957. The Measurement of Productivity Efficiency. *Journal of the Royal Statistical Society*. Series A, Vol. 12, pp. 253–290. Blackwell Publishing for the Royal Statistical Society.

Flodin, J., J. Oja and G. Grönlund. 2008. Fingerprint traceability of logs using the outer shape and the tracheid effect. Article 10369 *Forest Products Journal* 58(4):21–27.

Frühwald, E., Y. Li and L.Wadsö. 2007. *Mould growth on high-temperature dried and heat-treated Norway Spruce*. Nordic Workshop on Wood Engineering, Skellefteå February 21 2007, Woodtech Sweden, www.woodtech-swededen.org, http://epubl.ltu.se/1402-1528/2007/06/LTU-FR-0706-SE.pdf.

Grundberg, S., Grönlund, A. and Grönlund, U. 1995. *The Swedish Stem Bank – a Database for Different Silvicultural and wood Properties*. Luleå University of Technology, Research Report LULEA 1995:31.

Grundberg, S., Grönlund, A., Oja, J. and Israelsson, M. 1999. "Log models reconstructed from Xray LogScanner signals". In: Proceedings of IUFRO WP S5.01-04 Third Workshop "Connection between Silviculture and Wood Quality through Modelling Approaches and Simulation Software" (G. Nepveu, ed.), La Londe-Les-Maures, France, September 5–12, 1999. Publication France 1999: Topic 6:394–398.

Grönlund, A. and Karlsson L. Skärdata vid bandsågning
STFI-meddelande serie A nr 666. Stockholm: Swedish Forest Products Laboratory.

Grönlund, A. 1981. *Ekonomisk optimering vid bandsågning*. STFI-meddelande serie D nr 122. Stockholm: Swedish Forest Products Laboratory.

Grönlund, A. 1992. *Sågverksteknik del 2 – Processen*. Sveriges Skogsindustri-förbund. p 270.

Gouvêa da Costa, S. E. and Pinheiro de Lima, E. 2002. Uses and Misuses of the Overall Equipment Effectiveness for Production Management. *IEEE International Engineering Management Conference, 2002. IEMC '02. 2002* Vol. 2 pp. 816-820.

Hansen, R. C. 2001. Overall Equipment Effectiveness (OEE): A Powerful Production/Maintenance Tool for Increased Profit. 1st editon. New York: Industrial Press.

Helling, J. 1991. *Världsmästarna – en ny generation av tillverkningsföretag*. Stockholm: Sellin & Partner (in Swedish).

Hellsten, U. and Klefsjö, B. 2000. TQM as a management system conssisting of values , techniques and tools. *Total Quality Management* (14)4:238–244.

Hillis, W. 1987. *Heartwood and Tree Exudates.* Ed. Timell T.E, Springer series in Wood Science, Springer Verlag, New York.

Holme, I. M. and Solvang B. K. 1997. *Forskningsmetodik.* Lund, Sweden: Studentlitteratur (in Swedish).

Huang, S. H., Dismukes, Shi, J., Su, Q., Razzak, M. A., Bodhale, R. and Robinson, D. E. 2003. Manufacturing productivity improvement using effectiveness metrics and simulation analysis. *International Journal of Production Research* 41(3):513–527.

Imai, M., 1986. Kaizen, the Key to Japan´s Competitive Success. Random House, New York.

Ishikawa, K. 1982. *Guide to Quality control*. Tokyo: Asian Productivity Organization.

Jeong, K. Y. and Phillips, D. T. 2001. Operational efficiency and effectiveness measurement. International Journal of Operations & Production Management 21(11):1404–1416.

Johansson, J. 2002. Modelling and Simulation in the Early Stages of the Development Process of a Manufacturing System – A case study of the development process of a wood flooring industry. Licentiate Thesis, Luleå University of Technology. LTU 2002:27 ISSN 1402-1757.

Johansson, L. G. 1978. *Sågverksmodeller – Datorbaserade hjälpmedel för att utreda ekonomiska och tekniska problem i trävarubranschen*. STFI-meddelande Nr. 502, Serie B, Del 3. Stockholm: Swedish Forest Products Laboratory.

Johansson, L. G. and Liljeblad Å. 1988.. Några tillämpningsexempel inom projektet ”kvalitetssimulering av sågtimmer”. TräteknikCentrum Rapport I 9005020.

Jonsson, P. and Lesshammar, M. 1999. Evaluation and improvement of manufacturing performance measurement systems – the role of OEE. *International Journal of Operations & Production Management* 19(1):55–78.

Juran, J. M., Gryna F. M. 1988. *Juran's Quality Control Handbook*. 5th ed. Sydney: McGraw-Hill.

Jäppinen, A. 2000. *Automatic Sorting of Sawlogs by Grade*. Doctoral Thesis. Swedish University of Agricultural Sciences, Department of Forest Management and Products. Uppsala, Sweden. ISSN 1401-6230.

Kano, M., Nagao, K., Ohno, H., Hasebe, S. and Hashimoto, I. 1999. *New Methods for Process Monitoring Using Principal Component Analysis*. AIChE Annual Meeting, Dallas, TX, Oct. 31–Nov. 5, 1999. Paper 224a.

Klefsjö, B., Eliasson, H., Kennerfalk, L., Lundbäck, A. and Sandström, M. 1999. The Seven mangement tools. Studentlitteratur, Lund.

Kollman, F. 1982. *Technologie des Holzes und der Holzwekstoffe* Band 1, Zweite 2 Auflage, Springer Verlag, 3-4.

Kotze, D. 1993. Consistency, accuracy lead to maximum OEE benefits. *TPM Newsletter* 4(2):1–4.

Kourti T. and MacGregor J. F. 1995. Process analysis, monitoring and diagnosis, using multivariate projection methods. Chemometrics and Intelligent Laboratory Systems 28(1):3–21.

Kourti, T. and MacGregor J. F. 1996. Multivariate SPC Methods for Process and Product Monitoring. J. Qual. Tech. 28(4):409–428.

Law, A. M. and Kelton, W. D. 2000. *Simulation Modeling and Analysis*. 3d ed. New York: McGraw-Hill,.

Leachman, R.C. 1997. Close-loop Measurement of Equipment Efficiency and Equipment Capacity. *IEEE Transactions on Semiconductor Manufacturing* 10(1):84–97.

Lebas, J. M. 1995. Performance measurements and performance management. *International Journal of Production Economics* 41:23–35.

Ljungberg, Ö. 1998. Measurements of overall equipment effectiveness as a basis for TPM activities. *International Journal of Operations & Production Management* 18(5):498–507.

Longuetad, F., F. Mothe and J.M. Leban. 2007 Automatic detection of the heartwood/sapwood boundry within Norway spruce (Picea abies (L.) Karst.) logs by means of CT images. Computers and Electronics in Agriculture archive Volume 58 , Issue 2, September 2007 pp. 100-111. ISSN:0168-1699.

Lundahl, C. G. 2007. *Optimized processes in Sawmills.* Licentiate Thesis, Luleå University of Technology, Division of Wood Technology, Skellefteå Campus.

Lycken, A., J. Oja and C.G. Lundahl. 2009. *Kundanpassad optimering i såglinjen – Virkeskvalitet On-line.* SP Rapport 2009:05 (in Swedish). ISBN 91-7848- 978-91-85829-76-7.

MacGregor, J. F. and Kourti, T. 1995. Statistical process control of multivariate processes. Control Engineering Practice 3(3):403-414.

Maness, T. C. and Stuart, D. W. 1994. The effect of log rotation on value recovery in chip and saw sawmills. *Wood and Fiber Science* 26(4):546–555.

Martens, H.; Næs, T. 1989. Multivariate Calibration, John Wiley & Sons, Chichester.

Massatt, P. and Wayne, B. 2002. Optimizing performance through constellation management. *Satellite Navigation* 3(2):17–21. http://www.aero.org/publications/crosslink/summer2002/index.html. Accessed March 20, 2009.

McFarlane, D. and Sheffi, Y. 2003. The impact of automatic identification on supply chain operations. *The International Journal of Logistics Management* 14(1):1–17.

McKellen, C. 2005. Total productive maintenance. *MWP* 149(4):18.

Muthiah K.M.N. and Huang S.H. 2007 *Overall Throughput Effectiveness (OTE) Metric for factoryl-level Performance Monitoring and Bottle-neck detection. International Journal of Production Research vol. 45 No.20 October 2007 pp 4753 – 4769.*

Nakajima, S. 1988. *Introduction to TPM: Total Productive Maintenance*. Cambridge, MA: Productivity Press.

Nakajima, S, 1989. *TPM Development Program, Implementing Total Productive Maintenance*. Cambridge, MA: Productivity Press. Originally published as *TPM tenkai* by the Japan Institute for Plant Maintenance.

Nord, C. and Pettersson, B. 1997. *TPM Total Productive Maintenace med erfarenheter från Volvo*. Upplaga 2. IVF-skrift 97849. Sverige: IVF Industriforskning och utveckling AB.

Nordmark, U. 2005. *Value Recovery and Production Control in the Forestry-Wood Chain using Simulation Technique*. Doctoral Thesis. Luleå University of Technology, Division of Wood Technology, Skellefteå Campus.

Oja, J., S. Grundberg, P. Berg, and P.-A. Fjellström. 2006. *Mätutrustning för bestämning av fibervinkel och kärnvedsinnehåll vid tvärtransport av träprodukter i råsorteringen*. SP Rapport 2006:16. ISBN nr 91-85533-01-7 (In Swedish).

Oja, J. and S. Grundberg. 2004. *Industrial methods of measuring heartwood in logs and sawn wood*. Poster, The forestry wood chain conference. Edinburgh, Scottland, September 28–30, 2004.

Oja, J., S. Grundberg and A. Grönlund. 2001. Predicting the stiffness of sawn products by X-ray scanning of Norway spruce saw logs. *Scand. J. Forest Res.* 16:8896.

Oja. J. 1999. *X-ray Measurementof Properties of Saw Logs*. Doctoral Thesis. Luleå University of Technology, Division of Wood Technology, Skellefteå Campus.

Oja J., S. Grundberg and A. Grönlund. 1998. *Simulated Control of Sawing Position based on x-ray Logscanner Measurements. In*: Proceedings of the 3rd IWSS. August 17–19 1998, Lövånger Sweden. Technical Report 1998:27, pp. 51–58.

Patel, R. and Davidsson, B. 2003. *Forskningsmetodikens Grunder*. Lund, Sweden: Studentlitterartur (in Swedish).

Pinto, I., H. Pereira and A. Usenius. 2002. *Sawing Simulation of Pinus pinaster Alt.* In: Proc. Fourth Workshop of IUFRO Connection between forest resources and wood quality: modelling approaches and simulation software. WP S5.01.04 British Columbia, Canada, 8–15 September 2002 pp 429–348.

Pinto, I., H. Pereira and A. Usenius. 2003. *Analysis of log shape and internal knots in twenty maritime pine (Pinus pinaster Ait) stems based on visual scanning and computer aided reconstruction.*
Ann. For. Sci. 60: 137-144.

Pinto, I., A. Usenius, T. Song and H. Pereira. 2005. Sawing simulation of maritime pine (Pinus pinaster Ait.) stems for production of heartwood containing components. *Forest Products Journal* 5(4):88–96.

Prasad, R. and Ruggieri, M. 2005. Applied Satellite Navigation Using GPS, GALILEO, and Augmentation Systems. Boston, MA: Artech House.

ProModel v6 Manufacturing Simulation Software User Guide 2004. ProModel Corp. 556 East Technology Ave. Orem, UT 84097, USA.

Rinnhofer, A., A. Petutschnigg and J.-P. Andreu. 2003. Internal log scanning for Optimizing Breakdown. *Computers and Electronics in Agriculture* 41(1–3):7–21

Sandberg, K. 2008. Degradation of Norway spruce (Picea abies) heartwood and sapwood during 5.5 years above ground exposure. *Wood Mat. Sci. Eng.* 3(3–4) (accepted for publication).

SCB, Statistiska Centralbyrån. 2009. http://www.scb.se
Accessed May 20, 2009.

Schajer, G. S. 1984. Understanding saw tensioning .Holz als Roh- und Werkstoff 42(11):425–430.

Schreiber, T. J. 1991. *An Introduction to Simulation Using GPSS/H*. New York: John Wiley & Sons.

Selin, A. 2001. Form following Curve Sawing Out-Performs. Oct. 1, 2001. *TimberLine online newspaper*.
http://www.timberlinemag.com/articledatabase/view.asp?articleID=558.

Shewhart, W. A. 1931. Economic Control of Quality of Manufactured Product. New York: Van Nostrand.

Siemens AG, Wittelsbacherplatz 2 D-80333 Munich Federal Republic of Germany.

Skog, J. and J. Oja. 2009. Heartwood diameter measurements in Pinus sylvestris sawlogs combining X-ray and 3D scanning. *Scandinavian Journal of Forest Research* Vol. 24. Nr 1. pp. 182-188.

Skog, J. 2004. *Dynamisk Timmerklassläggning - Metod för kontinuerlig optimering av råvarustyrning vid sågverk*. (Adaptive timber sorting - Method for continuous optimization of raw material control at sawmills). Examensarbete. Umeå universitet, Institutionen för fysik. (http://www.acc.umu.se/~jskog/exjobb/JohanSkog_Dynamisk.pdf).

Staland, J., Navrén, M. and Nylinder, M. 2002. *Såg 2000 Resultat från Sågverksinventeringen 2000*. Rapport nr 3, Institutionen för skogens produkter och marknader, Sveriges Lantbruksuniversitet, Uppsala (In Swedish).

Stern, A. R., Hallock, H. and Lewis, D. W. 1979. *Improving sawing accuracy does help*. Madison, WI: USDA Forest Serv. Res. Pap. FPL 320. (Available at: http://www.fpl.fs.fed.us/documnts/fplrp/fplrp320.pdf). Date: 20071024.

Swedish Forest Industries Federation 2009. http://www.skogsindustrierna.org/LitiumInformation/site/page.asp?Page=16&IncPage=712&Destination=712. Accessed March 12, 2009.

Szymani, R. 1999. Selecting the right saw blade: how to reduce operating costs and maximize yield. *Modern Woodworking August 1999*.

Taylor, A. M., B. L. Gartner and J. J. Morrell. 2002. Heartwood formation and natural durability: a review. *Wood Fiber Sci.* 34:587–611.

Todoroki, C. L. and Rönnqvist, E. M. 1999. Combined Primary and Secondary Log Breakdown Optimization. *Journal of the Operational Research Society* 50(3):219–229.

TomasWeb Simulation software. 2009. http://www.tomasweb.com/tomas.html. Accessed June 19, 2009.

Umetrics 2001 SIMCA P+ 10 Software. Umetrics AB, P.O.B 7960, SE-90719 Umeå, Sweden.

Usenius, A. 1996. "Optimizing the activities in the wood conversion chain from the forest to end users". In: Proceedings of the 2nd IUFRO Workshop on the Connection Between Silviculture and Wood Quality Through Modelling Approaches and Simulation Software. August 26–31, 1996, Kruger National Park, South Africa. 1996. (G Nepveu, ed.) IUFRO, Rome, Italy. pp. 214–219.

Usenius, A. 1999. "Wood conversion chain optimization". In: Proceedings of IUFRO WP S5.01-04 3rd Workshop "Connection Between Silviculture and Wood Quality Through Modelling Approaches and Simulation Software". (G. Nepveu, ed.), La Londe-Les-Maures, France, September 5–12, 1999. Nancy: INRA Pp. 542–548.

Uusijärvi, R. 2003. *Linking raw material characteristics with industrial needs for environmentally sustainable and efficient transformation processes*. (LINESET). QLRT-1999-01476 Final Rept. Res. report no. P 0309034. SP Tech. Res. Inst. of Sweden, Wood Tech. (SP Trätek).

VMR, Virkesmätningsrådet 2007.
http://www.virkesmatningsradet.org/Admin/html/vmr/html/pdf/Virkesforbrukning/4126BB5C-389E-4B3A-8989-F949694C60B4.pdf.
Accessed May 20, 2009.

Vokurka, R. J. 2001. Using the Baldrige Criteria for personal quality improvement. *Industrial Management & Data Systems* 101(7):363–369.

Vuorilehto, J. 2001. *Size Control of sawn timber by optical means in breakdown saw machines*. Doctoral Thesis. Helsinki University of Technology, Department of Forest Products Technology, Laboratory of Wood Technology. Report 88. ISSN: 1456-6419.

Vännman K. 2002 Matematisk statistik. Studentlitteratur Lund.

Wilhelmsson L., J. Arlinger, K. Spangberg, S.-O. Lundqvist, T. Grahn, Ö. Hedenberg and L. Ohlsson. 2002. Models for predicting wood properties in stems of Picea abies and Pinus silvsetris in Sweden. *Scand. J. For. Res.* 17:330-350.

Watson, G. H. 1992. The Benchmarking Workbook: Adapting Best Practice for Performance Improvement. Portland, OR: Productivity Press.

Williamson, R. M. 2006 Using Overall Equipment Effectiveness: the Metric and the Measures. Strategic Work Systems, Inc. Columbus, NC 28722.

This happens if we accept that 99% correct is sufficient:

Nine words are incorrect spelled at each side in your paper

Almost four times per year you will not get your daily newspaper

You should be without electricity, water or heating for about 15 minutes each day

At least 8,500 prescriptions should be incorrect each year

About 23,700 transfers should each day be made to the wrong account

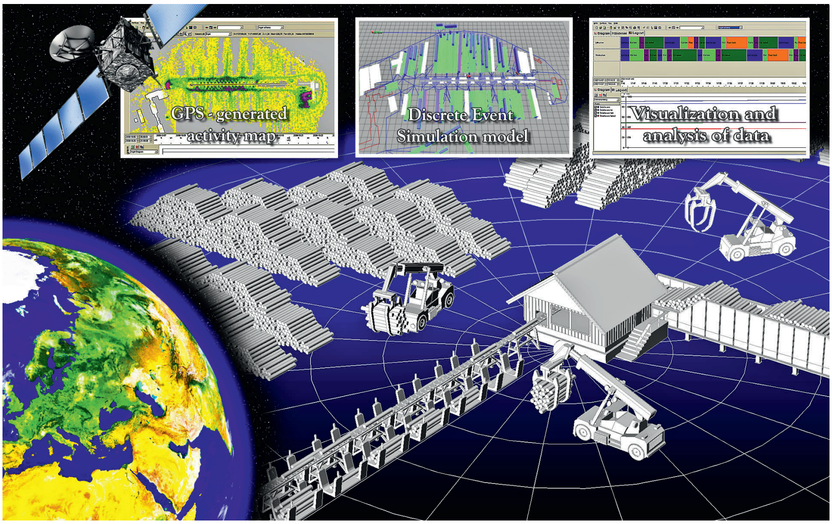
Drinking water in the water pipe system would be unusable about one hour per month

Source: Bergman *et al.* 2003

LTU Skellefteå
Division of Wood Science and Technology

ISSN: 1402-1544 ISBN 978-91-86233-71-6

Luleå University of Technology 2009



LULEÅ
UNIVERSITY
OF TECHNOLOGY