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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. Accessible and reliable production data are crucial information concerning the area of process control; hence the objective in this study was to create a “toolbox” of suitable tools for decision support, surveys and analyses.

Modern sawmills are becoming increasingly like process industries. Process control and optimization tools in sawmills have, however, not followed the rapid development of automation and increased production speed. Each machine, monitoring system or data system is commonly viewed as a detached system rather than as part of the same process. This fact makes it difficult to access process data and monitor the performance of a sawmill and, further, to address problems at the sawmill. 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 measures that have been decided on back to the production line.

Reliable and relevant information is also vital to creating a measure of confidence that changes are indeed implemented based on facts, not merely on assumptions or prior experiences. Thus, reliable systems for collecting process data and benchmarking methods such as Overall Equipment Effectiveness must be implemented. A mobile diagnostic monitoring and analysis tool developed during the study enables detailed and simplified registration of downtime and error causes in the sawmill. An increased and optimized usage of a suitable “tool package” including benchmarking methods, simulation software and process monitoring and analysis tools creates a solid base for implementation of process control and for increased productivity.

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.

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

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

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Skellefteå, January 2007
C G Lundahl

Preface

As a former miner, I can readily admit that my career took a turn straight upwards in 1992 when I decided to leave the bottom of an 850–meter-deep mine shaft and go back to school. Nevertheless, my profound mining experience and the knowledge obtained during years of bare-chested struggle in the dark are still often called upon when it becomes necessary to educate my dear, ignorant colleagues during lunches or coffee breaks.

Still, I hope that I in some way have made other, more important contributions to the world.

Don´t part with your illusions.

When they are gone you may still exist, but you have ceased to live.

—Mark Twain

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Glossary:

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 center 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”.

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.

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

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

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

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.

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

1 Introduction

Better to ask what can be improved rather than why we fail.
—Unknown thinker

1.1 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 raw material cost is known to be the single largest budget item for sawmills, followed by labor, 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 other 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 volume of log sawing. Hence, sawing accuracy and volume yield are known to diminish. Even though the breakdown process in sawmills is difficult to control and optimize fully, it is important to ceaselessly 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 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 states that a reduction by 0.8 mm in the sawing allowance increases volume yield by up to 1.3%.

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, centering 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)

As simple as they might appear, in reality some of these actions must be performed in a split second to fulfill 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.

In order to perform an optimal sawing 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 LOG-scanner is at present in use in some Swedish sawmills.

The 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 centered 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 mid line of the cant. Curve sawing technique has been used for more then 50 years 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.

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

1.2 Quality Management Techniques

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)

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 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 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 labor, 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.

A more adequate definition of productivity is *"profit per time unit*", because this statement takes equipment performance, process and product quality and profit into consideration.

However, this definition 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. Nevertheless, if overall equipment performance is maximized in a sawmill during difficult periods, will it be well prepared when and if the market is prepared to pay the “right” amount of money for the refined products. In other words, the import of optimizing production processes in order to increase productivity is twofold. An effective and profitable sawmill must utilize its staff, raw material and equipment at their maximum.

In the comprehensive view, this 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 common 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 properties of every single log are different.

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 common sawmill production-flow process cannot, however, in any way 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.

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. 1994; Nord 1998) are known 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, hardly any sawmill knows 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.

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).

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.

1.2.1 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 they 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):

1. Maximize equipment performance – improve overall effectiveness.
2. Develop a system of productive maintenance for the life of the equipment.
3. Involve all departments that plan, design, use or maintain equipment.
4. Actively involve the entire staff, from top management to operators.
5. 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.
- Startup 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 1.1 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. Startup yield losses	minimize	

Table 1.1 shows the Six Big Losses, targets to achieve and examples from the mechanical industry (Nakajima 1989). The specific losses are further explained below.

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. In the worse case, 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. Startup Losses

Startup losses are yield losses that occur during the early stages of production, from machine startup 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.

1.2.2 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

1.2.3 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*, Dettmer H. William (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.

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 areas are (Bergman et al. 1994):

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

The basic message is simple and easy to understand: make the staff aware of how their behavior, 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 honor W. Edwards Deming and his contribution and pioneering work for quality development in Japan (Bergman et al. 1994). 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, 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. 1994).

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.

1.2.4 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. 1994). 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 to 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.

1.2.5 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 modeling 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 modeled, 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 behavior.

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.

2 Objective and Limitations

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

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

- Improved process control, monitoring systems and analysis methods.
- Optimized volume and value recovery in the breakdown process.
- Optimized availability and performance of the production process.

The project was carried out independently, but in association with a local sawmill in order to achieve a close industrial influence and for experimental purposes. The focus of this work is limited to processes between the log intake and stacking area, represented by blocks 3 and 4 in Figure 2.1. However, some discussions and analyses will include the Log Sorting procedure.

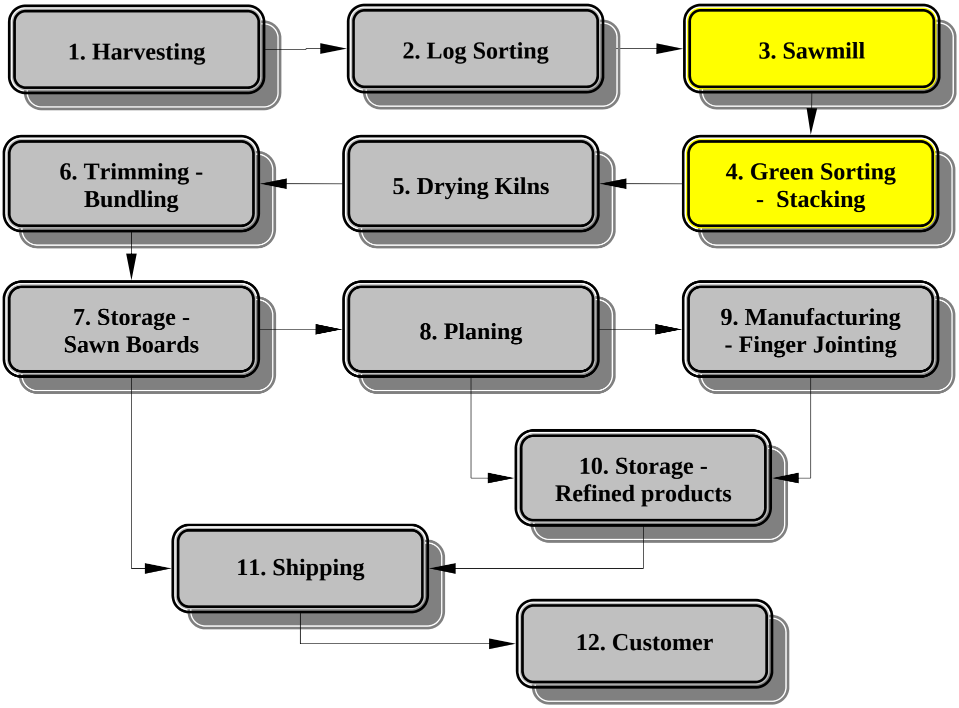


Figure 2.1 Sawmill Process

Figure 2.1 shows the structure for an entire sawmill process involving the whole conversion chain. The tools used in this work and in the toolbox were selected mainly because they were considered adequate for the purpose. No complete benchmarking was done during the selection phase.

3 Process Control Tools

Every operator or technician in the sawmill needs a toolbox containing the means to excecute 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.

3.1 Overall Equipment Effectiveness (OEE)

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

- Availability.
- Performance.
- Quality.

Process analysis commonly focuses on availability and quality issues, but the OEE tool also takes into consideration the changes and impact on performance. In assessing the performance of equipment in relation to the ideal production output, the ultimate goal is equipment that performs as follows (McKellen 2005):

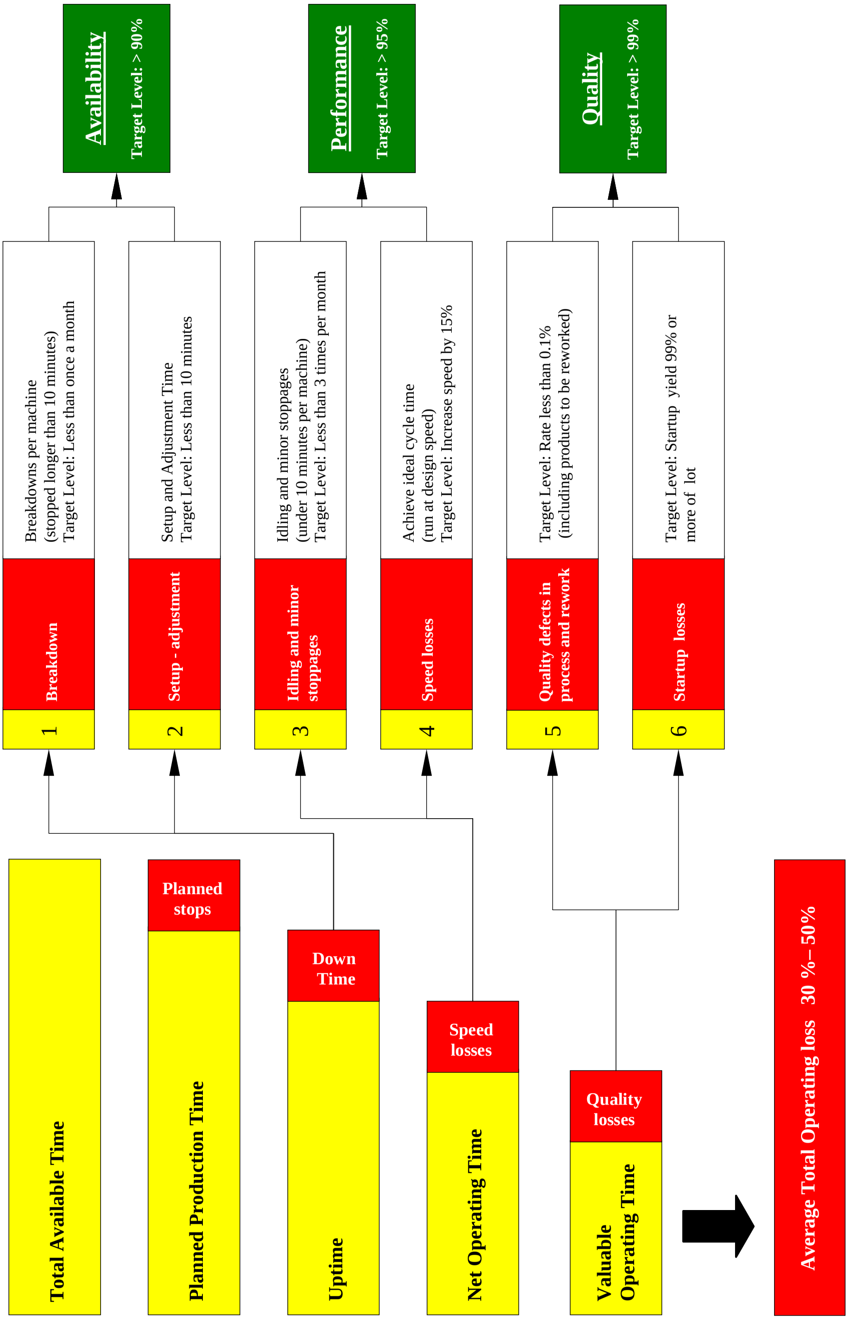
- Operates 100% of the available time (availability 100%).
- Produces at 100% of the specified output (performance 100%).
- Produces 100% approved products (quality 100%).

However, things are never perfect in reality—OEE quantifies current effectiveness as percentages of the ideal state. The concept of Availability shows the fraction of the total time a machine is in full function. Nevertheless, 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. The Performance statement, "*to produce 100% of the specified output,*" can be problematical with regard to sawmill production, however, because the staff can define whether log gaps are to be regarded as losses or not. Log gaps are nevertheless equivalent to idling machines and should hence be classified as losses.

If a sawmill was to be considered top class in relation to the manufacturing industry in general, the total OEE value would have to be at least 80%. Achievement of this level would effectively require each of the percentages for Availability, Performance and Quality to be at least 93%. Some parts of the sawmill processes are quite sensitive, and small deviations in the flow can have a large impact on the OEE value. For example, given a 4.5-meter average log length, the performance rate drops from 100% to 95.7% if the log gap is increased from zero to 20 cm. The required equipment availability must simultaneously increase by 2.8% in order to compensate for the decreased performance rate.

Figure 3.1 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.

Focus is then set on the impact and causes of downtime, speed losses and quality losses. Within the OEE Performance factor, OEE also depicts the impact of idling equipment. Absence of logs as well as excessive log gaps on a sawing line are to be considered idle time. This is an example in which the OEE tool manages and calculates the effects of availability as well as the performance of the equipment.



gure 3.1 The OEE concept with examples of target levels from the mechanical industry
ord et al. 1997).

In mechanical manufacturing industries, the Quality factor is often defined as the rate of accepted parts or products in a batch. However, this is not an adequate method in a sawmill, because 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.

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.

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 3.1 ”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 3.1 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 together. 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.

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 at 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.

A paradox that 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).

In his book Business Research Methods (Emory 2002), C. William Emory presents a list of characteristics of good 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.

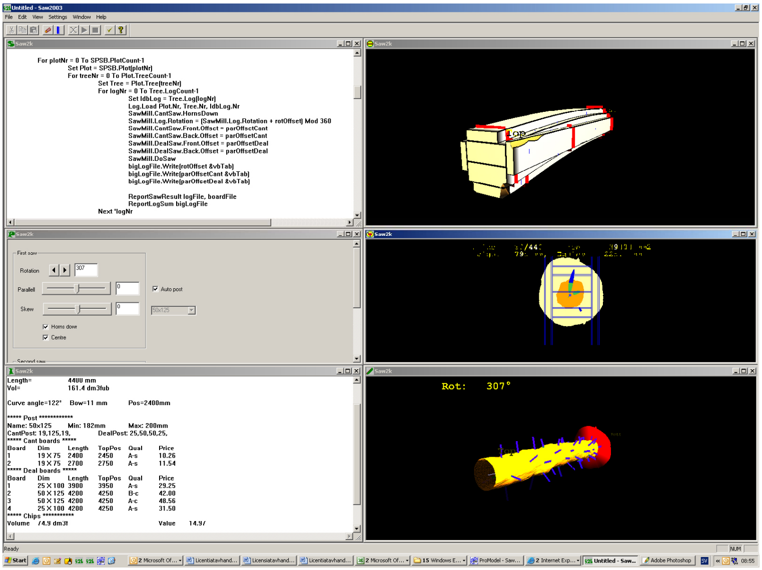
Performance benchmarking methods are also highly suitable for achieving and improving knowledge about the actual processes as well as the result of the work done. When measures have been decided upon and implemented, the next vital step is to verify and show the impact of changes made. Availability and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

3.2 Breakdown Simulation

Detailed log data containing information about log shape and inner structure make it possible to regenerate logs in PC-based software where logs can be evaluated over and over again while applying any number of different breakdown scenarios.

3.2.1 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 3.2 shows the Saw2003 breakdown simulation software interface.



```
For plotNr = 0 To SPSB.PlotCount-1
        Set Plot = SPSB.Plot(plotNr)
        For treeNr = 0 To Plot.TreeCount-1
                Set Tree = Plot.Tree(treeNr)
                For logNr = 0 To Tree.LogCount-1
                        Set IdbLog = Tree.Log(logNr)
                        Log.Load Plot.Nr, Tree.Nr, IdbLog.Nr
                        SawMill.CantSaw.HornsDown
                        SawMill.Log.Rotation = (SawMill.Log.Rotation + rotOffset) Mod 360
                        SawMill.CantSaw.Front.Offsct = parOffsctCant
                        SawMill.CantSaw.Back.Offset = parOffsetCant
                        SawMill.DealSaw.Front.Offset = parOffsetDeal
                        SawMill.DealSaw.Back.Offset = parOffsetDeal
                        SawMill.DoSaw
                        bigLogFile.Write(rotOffset &vbTab)
                        bigLogFile.Write(parOffsetCant &vbTab)
                        bigLogFile.Write(parOffsetDeal &vbTab)

                        ReportSawResult logFile, boardFile
                        ReportLogSum bigLogFile
                Next 'logNr
```

First saw
Rotation 307
Parallell 0
Skew 0
☑ Auto post
50x125
☑ Horns dowr
☑ Centre
Second saw

```
Length=         4400 mm
Vol=            161.4 dm3fub

Curve angle=122°  Bow=11 mm      Pos=2400mm

***** Post ************
Name: 50x125    Min: 182mm       Max: 200mm
CantPost: 19,125,19,        DealPost: 25,50,50,25,
***** Cant boards *****
Board   Dim     Length  TopPos  Qual    Price
1       19 X 75 2400    2450    A-s     10.26
2       19 X 75 2700    2750    A-s     11.54
***** Deal boards *****
Board   Dim     Length  TopPos  Qual    Price
1       25 X 100 3900   3950    A-s     29.25
2       50 X 125 4200   4250    B-c     42.00
3       50 X 125 4200   4250    A-c     48.56
4       25 X 100 4200   4250    A-s     31.50
***** Chips ***********
Volume  74.9 dm3f                       Value   14.97
```

Figure 3.2 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.

3.2.2 Sawing Patterns

A sawing pattern is a set of usually 2 to 4 center 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 can be assigned to the same sawing class.

3.2.3 Sawing Classes

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.

3.2.4 Diagonal Measure of the Sawing Pattern

Figure 3.3 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 added to the nominal value of each center board crosscut dimension.

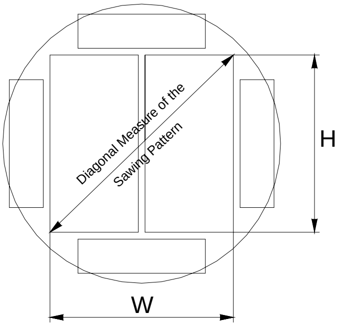


Figure 3.3. The Diagonal Measure of the Sawing Pattern, DMSP

3.2.5 Sawing allowance - Trimming

The market generally demands center 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 center 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.

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.

3.2.6 Cant Sawing (Square sawing)

Cant sawing is by far the most-used sawing method in Sweden. Initially, the log is rotated with the crook up (Horns Down), and the log face is centered to the first sawing machine. The log is then cut into a cant and 2 to 4 side boards. The cant is rotated 90 degrees, centered, and the second saw machine cuts the cant into 1 to 6 center boards and 2 to 6 side boards. It is then possible to apply curve or straight sawing technique during the second breakdown procedure. In this study, the default value of the saw kerf width was set to 4.0 mm in both sawing machines. However, the saw kerf width is easily changeable in the software.

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.

3.2.7 Volume Yield

The volume yield is defined as:

$$\left(\frac{\text{Nominal volume of Board(s)}}{\text{True volume Log(s)}}\ x\ 100\ (\%)\right) \qquad (\textit{Equation 3.1})$$

The volume of each board was calculated by the software based on the nominal trimmed and dried volume (18% MC). The volume yield of center 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.

3.2.8 Quality Definitions

The Saw2003 simulation software was set to utilize the Nordic Timber Rules for grading and trimming. The different products are normally defined and reported as qualities A, B and C. The center boards were always graded as A quality because of demand for least allowed wane presence on center boards and because knot definition was turned off during the simulations performed in this study. The strict wane limitations on the center boards allow a maximum of 3 mm of wane on the edge. However, the allowed wane on the center boards was governed by the common rules stated in Nordic Wood (Anon. 1999).

3.2.9 Price List

The boards were priced according to Table 3.3 Boards classified as D are chipped. The chip price was set to 200 SEK per m^3.

Table 3.3 Pricelist used during simulations. B and C qualities are not applied on center boards because of allowed wane presence and turned-off knot definition.

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

3.3 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 grayscale 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 center 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.

3.4 Discrete Event Simulation (DES)

When a process becomes complex, whether it is production related or some complicated economical transaction, its behavior 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.

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 has been used for more than a decade 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 also describes the benefits of simulations used as a decision support, but also 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 modeling phase can easily overrun both time and budget. Saw simulation software offers similar possibilities for optimizing the breakdown process.

This kind of software combined with virtual logs makes it possible to saw logs with the same attributes repeatedly with different setups. This makes it possible to evaluate different strategies and scenarios.

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 modeled. 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.

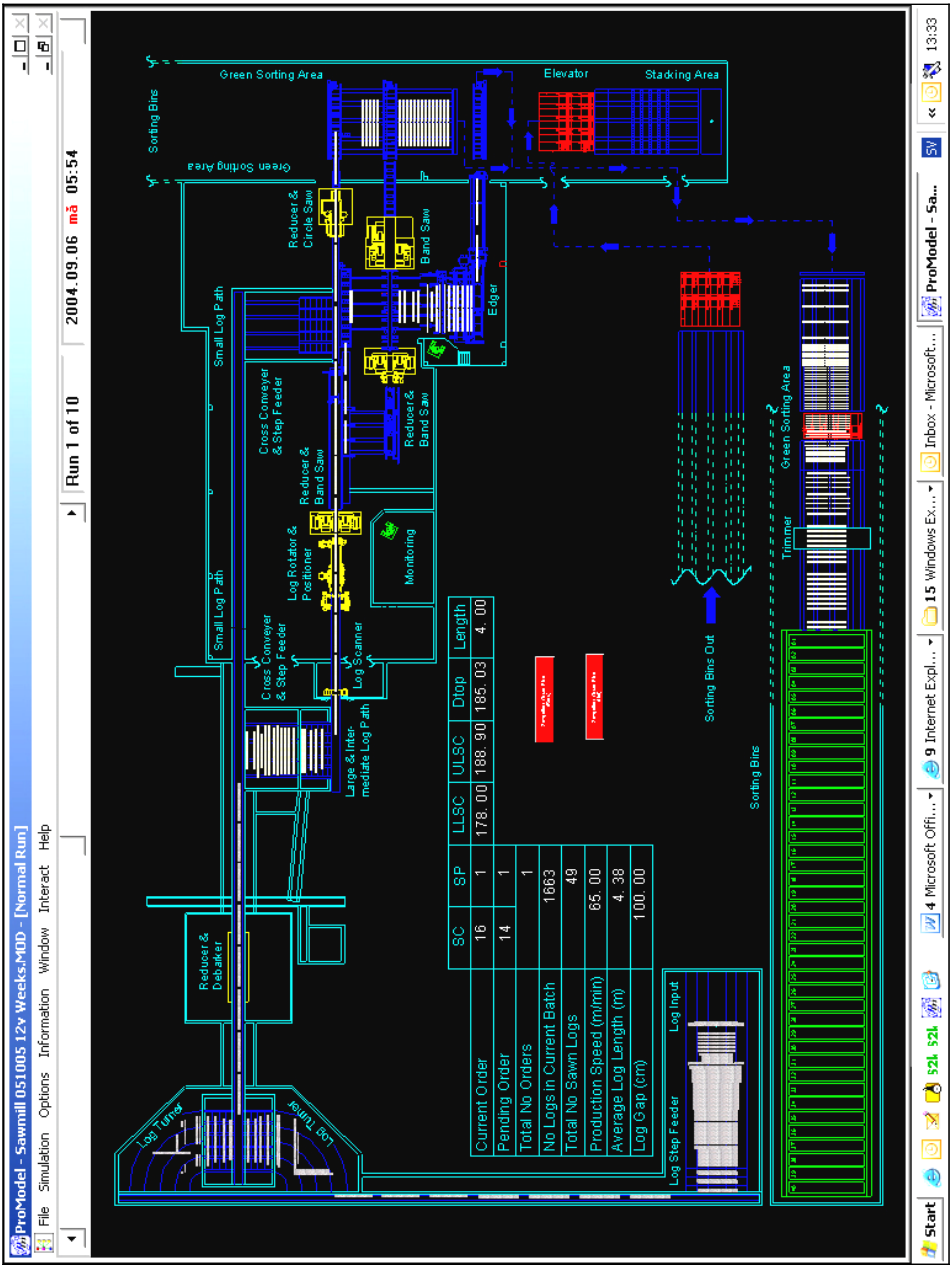
Modeling requires detailed knowledge about the system and is therefore never a one-man job, and it is important to execute the work as a structured project. The team selected must always consist of personnel from all areas of the simulated system.

DES modeling 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.

A DES model should contain enough details to provide a proper representation of the system without containing unnecessary information. If the modeled 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.

Figure 3.4 shows the simulation software interface and the developed sawmill model.



ProModel - Sawmill 051005 12v Weeks.MOD - [Normal Run]

Run 1 of 10

2004.09.06 må 05:54

	SC	SP	LLSC	ULSC	Dtop	Length
Current Order	16	1	178.00	188.90	185.03	4.00
Pending Order	14	1				
Total No Orders		1				
No Logs in Current Batch		1663				
No Sawn Logs		49				
Production Speed (m/min)		65.00				
Average Log Length (m)		4.38				
Log Gap (cm)		100.00				

Figure 3.4 ProModel Discrete Event Simulation Model

3.4.1 Benefits of using Discrete Event Simulation

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 modeling 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.

3.4.2 Disadvantages

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 modeling and analysis can be time consuming and expensive

Limited financial resources for modeling 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 modeling 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.

3.4.3 Steps in a simulation study

The flow chart in Figure 3.5 shows a set of steps to guide a model builder in a thorough and sound simulation study (Banks et al. 2000).

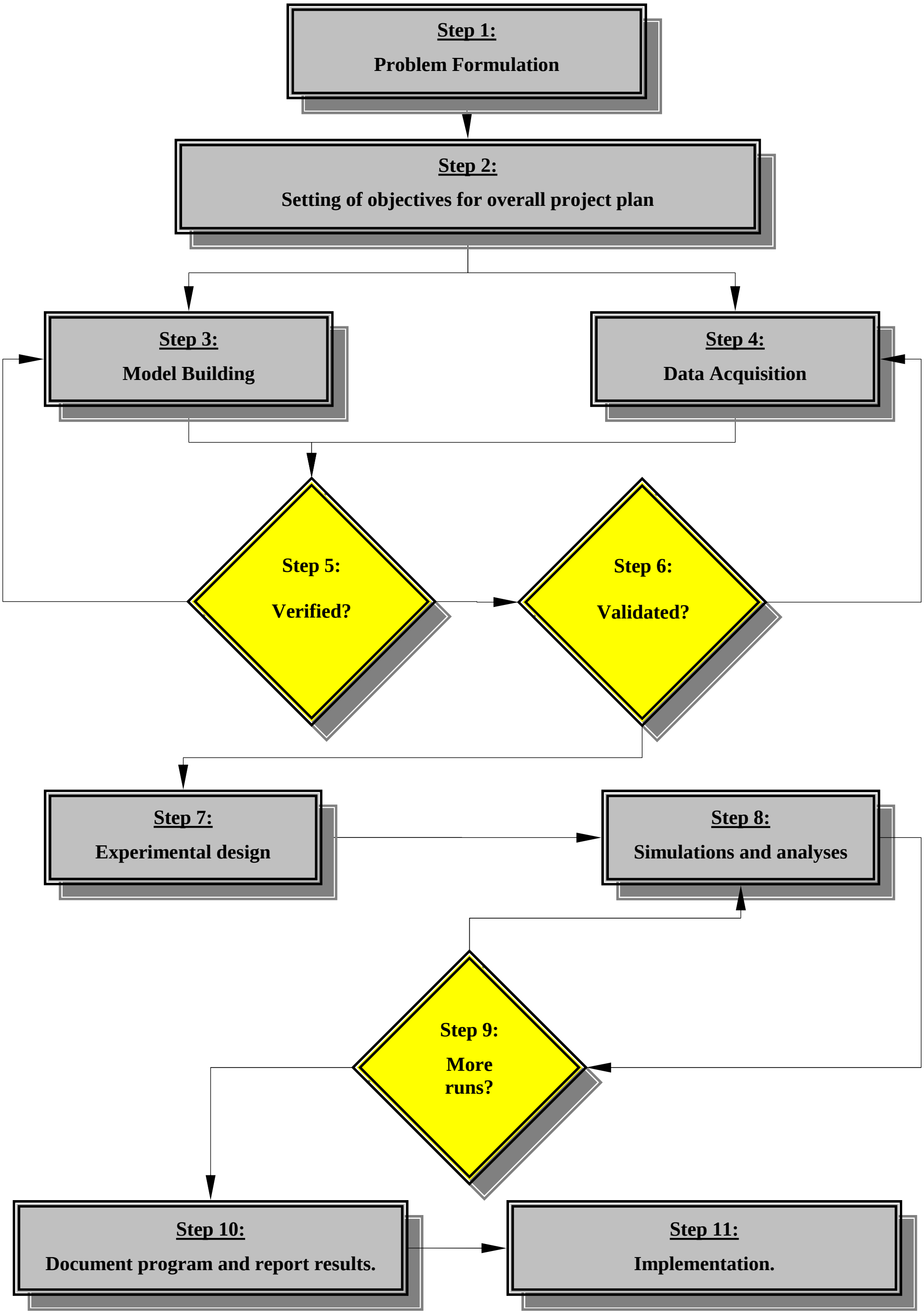


Figure 3.5 DES project flow chart

Step 1: Problem formulation

Every simulation study should begin with a statement of the problem. It is very important to make a detailed description of which questions should be answered, what results are expected and why discrete event simulation is needed. What is the problem? What do we want to improve? A simple rule states that if you can’t explain why simulation technique is need, you should not use it. Furthermore, if the assignment is performed by an external consultant, the project manager must ensure that the problem is clearly formulated and understood.

Step 2: Setting of objectives and overall project plan

The objectives and overall plan for a simulation study must be determined. Another way to state this step is "prepare a proposal." The objectives are the questions to be answered by the simulation study. The project plan should include a statement of the various scenarios that will be investigated. The plan for the study should also include:

- The assigned time schedule.
- Personnel that will be used and their areas of responsibility.
- Hardware and software requirements.
- Level of detail in the model.
- Stages in the investigation, checkpoints.
- Output at each stage.
- Plan for the validation and verification process.
- Cost of the study and billing procedure.
- Plans for actions if the objective of the study is changed during the performance.

Step 3: Model building

The system to be examined is to be represented as a conceptual model, which is a series of mathematical and logical relationships concerning the equipment and the structure of the system. It is recommended that modeling begin simply and that the model grow until a model of appropriate complexity has been developed.

Modeling is performed in stages by adding:

- The material handling system(s).
- The basic process system.
- The resource cycles (maintenance, breakdowns and shift schedules).
- Special features.

A common pitfall in this stage is to create a model that is unnecessarily complex or complicated. This will add to the cost of the study and to the time for its completion without increasing the quality of the output. Furthermore, it is important to involve the client throughout the entire model construction process regardless of whether it is an internal or external client. This is vital, since it will enhance the quality of the resulting model and increase the client's confidence in its use.

The model elements and data are preferably added to the model in three phases (ProModel v6 Manufacturing Simulation Software User Guide 2004).

1. Basic Model Elements

- Background graphic (layout).
- Locations (machines, equipment).
- Entities (parts, products).
- Arrivals (arriving parts, products).
- Processing Logic with fixed operational times (production rules and processing time).
- Simple Entity graphics.

2. Resources and variability

- Resources (operators, equipment).
- Path Network.
- Additional operations.
- Adding Attributes (the properties of parts).
- Defining appropriate downtimes for Locations and Resources.
- Changing operational times to distributions.
- Adding features that ensure accurate entity processing .
- Adding more enhanced graphic elements.
- Adding variables for on-screen display.

DES software often contains predefined modules or locations representing, for example, machines, buffers, conveyers, operators, etc. The graphical interface can be two-dimensional or three-dimensional, depending on the stated demands in the project.

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 often 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 predefined modules are then inserted on top of the layout to represent the production line equipment. These predefined modules can easily be modified to look like the real machines or conveyers.

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. All rules that govern products and the production must be defined and implemented in the model. Without detailed reviewing and implementation of the process rules, the model will not work properly, and the results will be erroneous.

However, this is the part where people involved in a simulation project are known to increase their knowledge about the production, regardless of how many years they have been employed.

Depending on the number of products, rules and paths, this can be the most complex part of model building, but in certain software it is 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.

When this part is finished, it is possible to verify the model, i.e., perform a final check to ensure that the model is working properly according to the defined rules. When this checkup is concluded and potential faults are corrected, an ideal model has been created created.

However, an ideal discrete event simulation model is only usable for one purpose, to evaluate the maximum potential of the manufacturing system. When it comes to creating a model as close as possible to reality, breaks, stoppages and breakdowns must be added to the model. This is the third stage of the modeling process.

Step 4: Data Acquisition.

Model building and data collection are shown as parallel processes in the flow chart, Figure 3.5. This is because the simulation analyst can build the model while data collection is progressing. As soon as possible after the project is initiated, a schedule of data requirements should be submitted to the client. In the best of circumstances, the client has been collecting the necessary data in the required format and can submit this data to the simulation analyst electronically. However, sometimes the delivered data is quite different from what was anticipated. For example, it is common that the simulation analyst is told, "we have every bit of data that you want over the last years."

However, it is also common that the data delivered is an average value for a period. Individual values are usually needed, not summary measurements. Lack of reliable data is usually the cause when a simulation project exceeds its time limit.

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.

One major problem is that even though each end 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 whether the model is performing as expected. Even small and simple models can be difficult to verify, and it is highly advisable that the verification is performed as a continuing process throughout the model-building process, rather than waiting until the model is complete.

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.

5a. Follow the principles of structured programming.

The basic principle is to use program modularity, that is, to break the simulation model into submodels. The simulation model should be created in a logical, well-ordered manner. It is highly advisable to prepare a detailed flow chart indicating the macro activities that are to be accomplished.

5b. Make the model as self-documenting as possible.

This requires comments on most lines, and sometimes between lines, of logic. The logic should be written in such a way that it is understandable even if the creator is not available.

5c. Have the model checked by more than one person.

There are several software-engineering techniques used to review simulation models. One example: The team meets and reviews the design of the model part by part. The documentation is also reviewed. Errors are reported, classified and fixed. Another inspection occurs to make sure all issues have been addressed.

5d. Ensure that the values of the input data are being used appropriately.

For example, if the arrrival times are in minutes, but the model is using seconds, the model is inaccurate.

5e. For a variety of input data values, ensure that the outputs are reasonable.

Some simulation analysts are satisfied when they receive output, but that is far from sufficient.

5f. Debugging

Use the software's built-in debugger to check that the program operates as intended. The debugger is a very important verification tool that should be used for all real-system models.

5g. Watch the model's animation.

Using animation, the simulation analyst can detect illogical actions. For example, missing products and failed resources can be detected.

Step 6: Model validation

Validation is the determination of whether the model is an accurate representation of the real system. Can the model be substituted for the real system for the purposes of experimentation? 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. It is possible to use a variety of subjective and objective techniques to validate the conceptual model. Balci (1998) and Sargent (2003) offer many suggestions for validation.

Subjective validation techniques include the following:

6a. Face validation

A simulation model of a real-world system must appear reasonable "on its face" to those who are most familiar with the real-world system. Eliminating small but obvious errors enhances the credibility of the conceptual model.

6b. Validation using historical input data

Instead of running the operational model with assumed input data, it is an effective method to run the operational model with actual historical records. It is reasonable to expect the simulation to yield output results within acceptable statistical error of those observed from the real-world system.

6c. Sensitivity analysis

As model input is changed, the output should change in a predictable direction. For example, if the arrival rate increases, the time loads spend in queues should increase if the queue capacity is constant.

6d. Extreme-condition tests

Does the model behave properly when input data is at the extremes? If the arrival rate is set extremely high, the output should reflect this change with increased numbers in the queues, increased time in the system, etc.

6e. Validation of conceptual model assumptions and simplifications

There are two types of conceptual model assumptions:

- Structural assumptions of how a system works.
- Data assumptions.

It is possible to validate structural assumptions by observing the real-world system and by discussing it with the appropriate personnel. This is a useful method, because no one knows everything about the entire system. Data as well as data assumptions should also be validated, because submitted data can easily withhold and hide errors. It is therefore important to consult with appropriate personnel to determine whether the data are correct and correctly processed.

6f. Consistency checks

Continue to examine and update the operational model over time. For example, if the simulation model is used annually, before using the model, a check must be performed to make sure that there are no changes in the real system that must be reflected in the model. Similarly, the data should also be validated to ensure that new data from modified processes are included in the model.

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 any additional scenarios need to be simulated.

Step 10: Document program and report results

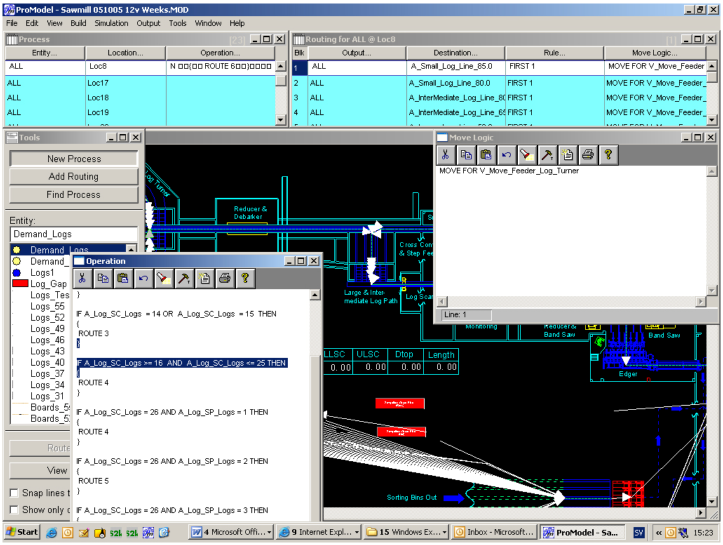
Documentation is necessary for numerous reasons. If the simulation model is going to be used again in the future, and perhaps by other users, it is imperative to understand how the simulation model operates. This will also create confidence in the performance of the simulation model so that the client can make confident decisions based on the analysis. Additionally, modifying a model is much easier with adequate documentation. One experience with an inadequately documented model is usually enough to convince a simulation analyst of the necessity of this important step. The results of all the analyses should be reported clearly and concisely and presented to the staff. This will enable the client 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 analyst recommendations, if any.

Step 11: Implementation

The simulation analyst acts as a reporter rather than an advocate. The report prepared in step 11 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.

3.4.4 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 for 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 modeling 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.



Entity...	Location...	Operation...
ALL	Loc8	N □□{□□ ROUTE 6□□}□□□□
ALL	Loc17	
ALL	Loc18	
ALL	Loc19	

Blk	Output...	Destination...	Rule...	Move Logic...
1	ALL	A_Small_Log_Line_85.0	FIRST 1	MOVE FOR V_Move_Feeder
2	ALL	A_Small_Log_Line_80.0	FIRST 1	MOVE FOR V_Move_Feeder_
3	ALL	A_InterMediate_Log_Line_80	FIRST 1	MOVE FOR V_Move_Feeder_
4	ALL	A_InterMediate_Log_Line_65	FIRST 1	MOVE FOR V_Move_Feeder_

```
}

IF A_Log_SC_Logs  = 14 OR  A_Log_SC_Logs  = 15  THEN
{
 ROUTE 3
}

IF A_Log_SC_Logs >= 16  AND  A_Log_SC_Logs <= 25 THEN
{
 ROUTE 4
}

IF A_Log_SC_Logs = 26 AND A_Log_SP_Logs = 1 THEN
{
 ROUTE 4
}

IF A_Log_SC_Logs = 26 AND A_Log_SP_Logs = 2 THEN
{
 ROUTE 5
}

IF A_Log_SC_Logs = 26 AND A_Log_SP_Logs = 3 THEN
{
```

```
MOVE FOR V_Move_Feeder_Log_Turner
```

Figure 3.6 ProModel Simulation software interface.

The modeling procedure focuses on twelve main modeling elements (ProModel v6 Manufacturing User Guide 2004):

1. **Locations** – the physical positions where something occurs or machines where a product is processed. Variables such as Capacities and Number of Units are defined within the element. The capacities value sets the number of parts the location can handle at a time, for example, if a location acts as a queue or buffer. If the location's "number of units" is set to 2, the specific location represents two parallel machines. This feature enables simplified modeling, since similar processes can be modeled within one location. The Queuing rules for a location, e.g., First-in, First-out, and Downtime Distributions are also individually specified here.

2. **Entities** – define specific parts or products processed in the model. If a log is broken down, the Entity list should then contain logs, center boards or side boards with different lengths and dimensions.

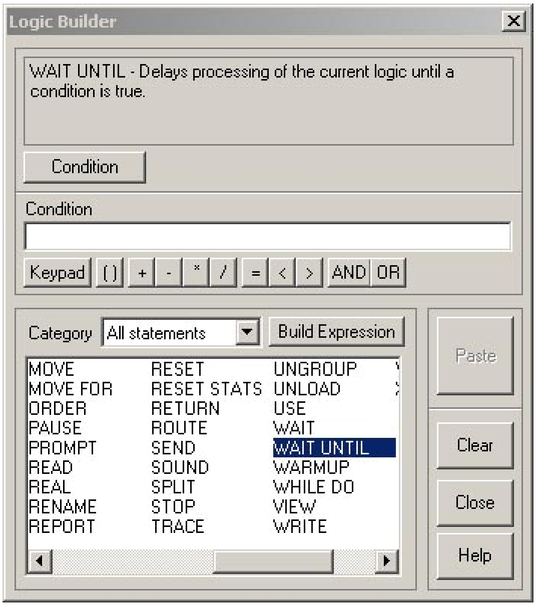
3. **Arrivals** – defines when and where parts arrive in the model. The arrivals element can also define the quantities, events or model logic variables from external files.

4. **Attributes** – labels containing a specific name and value that can be attached to Entities or Locations. The label can describe part properties or be a value used to route parts. When a part is split into new Entities, the original attribute is cloned to the new parts, enabling the routing commands or process settings to be used further along. Attributes are used to carry information along with an entity. The information can subsequently be used to control process time in machines, route parts or set variables.

5. **Graphics** – defines the graphic visualization. The Graphics module enables an enhanced graphical representation of the modeled flow. Graphics representing and visualizing products and flows combined with a background layout can create a recognizable model of a real flow.

6. **Processing** – defines the logic and rules that govern parts through the production process. The logic for every location is defined with a simulation language or with the aid of an incorporated toolbox (Figure 3.7).

   The logic sets the rules for how the parts, resources and equipment should behave and for all vital conditions that govern the process. This includes routing rules, waiting, variables, counters, etc.



WAIT UNTIL - Delays processing of the current logic until a condition is true.

Figure 3.7 ProModel Toolbox.

7. **Resources** – define resources such as personnel, forklifts or other equipment.

8. **Path Networks** – define the paths available for resources to move between Locations.

9. **Variables** – Global and Local Variables can be defined for use as counters or for setting attributes. A Global Variable is readable in the model, but a Local Variable exists only within the specified location. Global variables can also act as on-screen counters.

10. **External Files** – a method to import or export data. For example, actual production data including information about products, batch sizes, process times or downtimes can be read into the model. Resulting data from simulations can also be exported to files readable in MS Word or Excel.

11. **User Distributions** – Defined statistical user distribution is used to set all kinds of variables such as time or attribute values. They are commonly used to set operational times, frequencies between stops and downtimes defined from surveys (Figure 3.8).

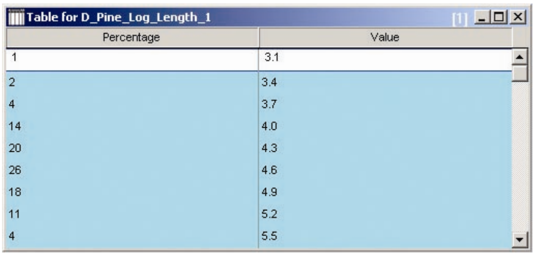
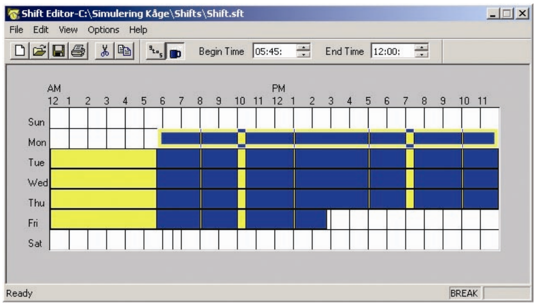


Table for D_Pine_Log_Length_1

Percentage	Value
1	3.1
2	3.4
4	3.7
14	4.0
20	4.3
26	4.6
18	4.9
11	5.2
4	5.5

Figure 3.8 User-defined distribution.

12. **Shifts** – define shifts and breaks. The model is governed by the shift files and will go down during breaks and at night (Figure 3.9).



Shift Editor-C:\Simulering Kåge\Shifts\Shift.sft

Begin Time 05:45:

End Time 12:00:

Figure 3.9 Shift file definition.

3.5 Distributed Process Monitoring System

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 3.10 shows the principal structure of the mobile diagnostic tool.

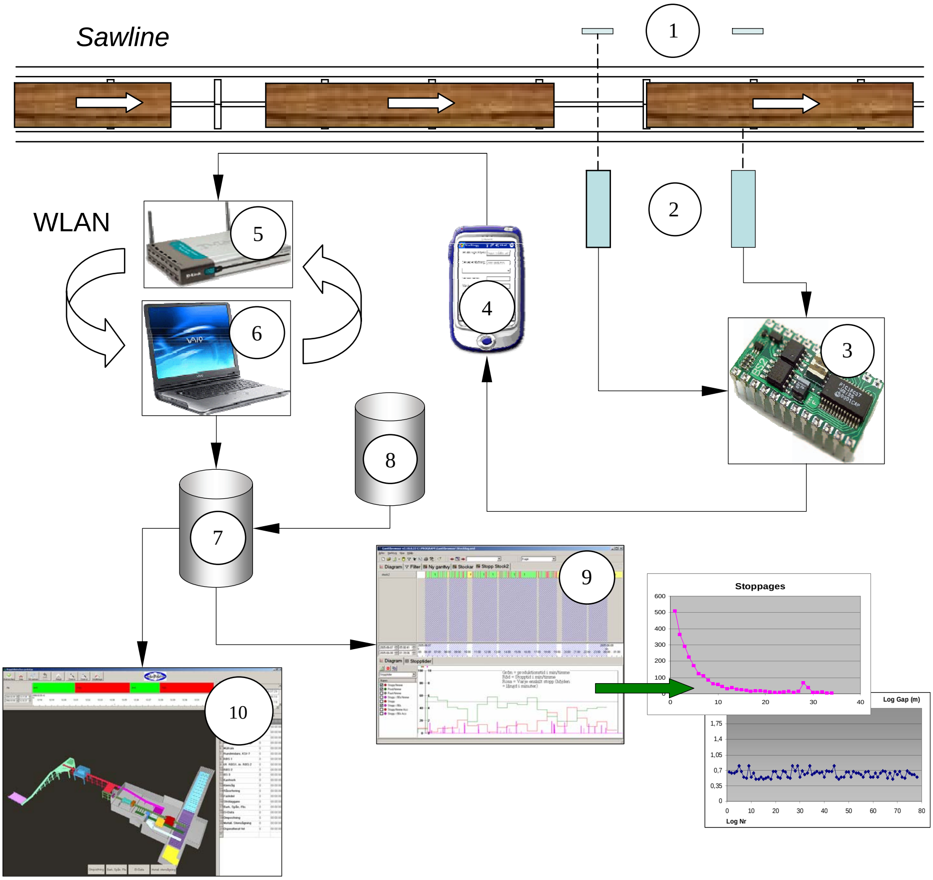


Figure 3.10 Basic structure of the Distributed Process Monitoring System, DPMS.

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

3.5.1 Basic Concept

The system consists of a PC server hosting a database (6 and 7, Figure 3.10). The server is preferably located in the monitoring room, and a number of sensor units are bi-directionally 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.

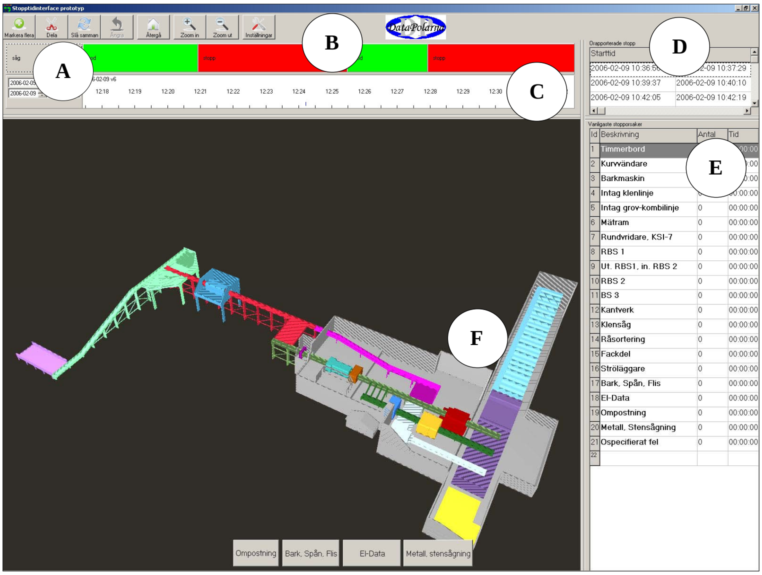
The Basic Stamp 2 I/O unit utilizes a built-in software language. If analogue sensors are used, the unit can handle these signals if an A/D converter is added.

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 Gantt Browser software (9) developed by DataPolarna AB was used.

3.5.2 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 3.11).



Orapporterade stopp

Starttid	
2006-02-09 10:36:5	2-09 10:37:29
2006-02-09 10:39:37	2006-02-09 10:40:10
2006-02-09 10:42:05	2006-02-09 10:42:19

Vanligaste stopporsaker

Id	Beskrivning	Antal	Tid
1	Timmerbord		00:00
2	Kurvvändare		:00
3	Barkmaskin		0:00
4	Intag klenlinje	0	0:00:00
5	Intag grov-kombilinje	0	00:00:00
6	Mätram	0	00:00:00
7	Rundvridare, KSI-7	0	00:00:00
8	RBS 1	0	00:00:00
9	Ut. RBS1, in. RBS 2	0	00:00:00
10	RBS 2	0	00:00:00
11	BS 3	0	00:00:00
12	Kantverk	0	00:00:00
13	Klensåg	0	00:00:00
14	Råsortering	0	00:00:00
15	Fackdel	0	00:00:00
16	Ströläggare	0	00:00:00
17	Bark, Spån, Flis	0	00:00:00
18	El-Data	0	00:00:00
19	Ompostning	0	00:00:00
20	Metall, Stensågning	0	00:00:00
21	Ospecifierat fel	0	00:00:00
22			

Figure 3.11 Graphical Error-report Interface.

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

The concept is based on a graphical process view of the sawmill and includes features such as:

- A touchscreen (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 hence 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.

3.5.3 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.

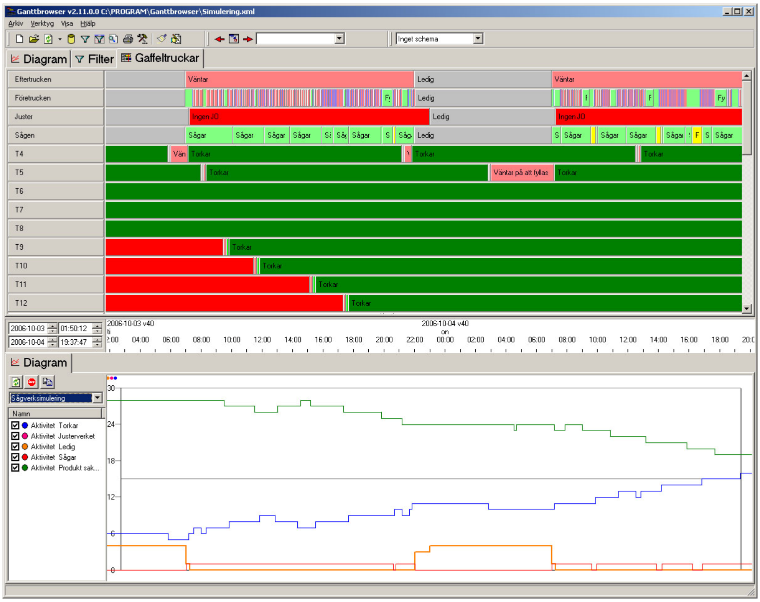


Figure 3.12 The GanttBrowser developed for analysis and visualization of time related production data (DataPolarna AB 2006).

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 (Figure 3.12).

The registered activities and events are visualized on a timescale in the Gantt-Browser as color-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.

3.5.4 Verification of the monitoring system

The performance of the DPMS was verified in two stages:

1. Laboratory-environment tests.
2. Sawmill-environment tests.

3.5.4.1 Laboratory-environment tests

The first verification test was made to check measurement accuracy for distance and speed as well as noticeable differences between types of sensors. A test unit with a linear feeder with a movable platform and variable speed was used in order to simulate the flow of logs and log gaps. A set of five wooden blocks with known lengths was firmly fitted onto the movable platform with known distances (Figure 3.13). The “simulated” log gaps between the wooden blocks could also be closed in order to simulate a single 3.49-meter-long log.

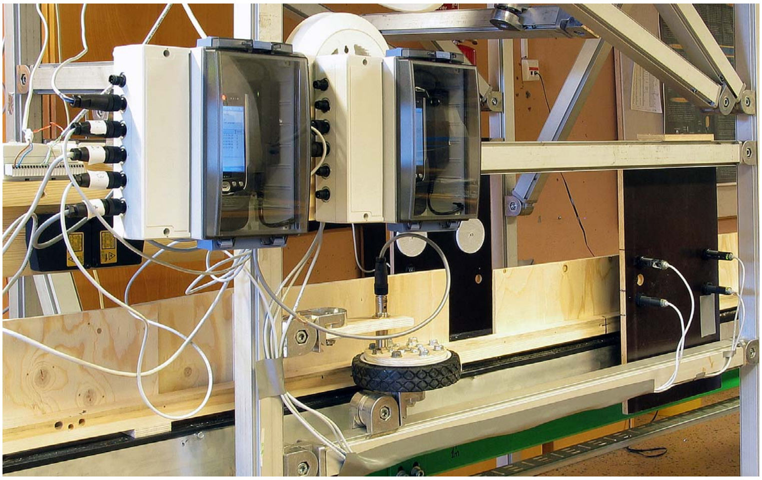


Figure 3.13 Laboratory test rig.

Four different types of sensors were used in the test in order to evaluate possible differences.

- Inductive sensors – used to monitor speed and stops. The sensor registers pulses from metal objects such as bolt heads on rotating wheels or links on a chain. The number of registered pulses per revolution of the wheel is converted into a know distance, thus defining a measured speed in meters per minute. Lack of pulses indicates a stoppage.
  Sensor used: Balluff BES 516-355-S 4-C

The three remaining sensor types are mainly used to register events and measure distances; for example, presence of logs and distance between logs.

- Reflective sensors – a sensor unit consists of a sensor and a separate reflector. The sensor's emitted light beam is reflected back to the sensor by the reflector. The digital signal remains 0 as long as the beam is not interrupted.
  Sensor used: Balluff BOS-18KF-PA-1QD-C-02
  Switching frequency: 1kHz

- Thru-beam sensors – a sensor unit consist of a transmitter unit and a receiver. Both units demand power supply. The digital signal remains 0 as long as the beam is not interrupted.
  Sensors used: Balluff BLE 18K-UU-1K-E4-C-02 (transmitter) and Balluff BLS 18K-XX-1K-E4-C-02 (receiver)
  Switching frequency: 250 Hz

- Diffuse sensors – a sensor that emits a light beam and detects reflected light from surfaces within a detectable range.
  Sensor used: Balluff BOS 18K-UU-1PC-E4-C-02
  Switching frequency: 1kHz

The Laboratory-environment verification process was performed in two steps:

1a. Verification of potential variation in speed of the linear feeder.

1b. Verification of the registered speed, measurement accuracy and sensor-type performance.

1a. Verification of potential variation in speed of the linear feeder

In this test, the individual blocks were linked together, creating a continuous 3,490-mm-long “log”. The platform with its virtual sawline was run 5 times with the same settings in order to establish an average and variation for the measured time over the distance.

Results:

No loss of signals or other malfunction of equipment was registered during the tests. The results show that the average speed over the distance was relatively constant with a small spread. Tests performed at different speeds also show a limited spread, thus verifying that there were only small differences in the overall performance of the equipment during several test runs.

1b. Verification of the registered speed, measurement accuracy and sensor-type performance

This part of the study was made in order to verify whether the equipment registered correct speed and measurements and whether there might be potential differences between the three sensor types used. Speed was registered with the two parallel-mounted reflective sensors. The feeder was run 5 times in the same direction with the same settings, and transport speed and block lengths were registered in the database. Similar test runs were performed at higher speed.

The exact time it took each block to pass the sensors was determined by the equipment during every run. This was done in order to enable a manual calculation of the average speed for every section of the five wooden blocks.

The passing times registred in the system were used to manually calculate a reference speed and the block lengths. These values were then compared to the values registered and caluculated by the monitoring system.

The results show that short block measurements, 400–800 mm, registered by the monitoring system are generally 1% higher than the manually measured reference values. Furthermore, the results show a small, but obvious, difference between the sensor types. The results for the diffuse sensor show even greater deviation from the reference measurement. These results may indicate a possible difference between the sensors’ trigger points and small errors in the speed registration.

Measurements made on the entire 3,490 mm distance generally show a 0.5% higher value than the manually measured reference value. Some limited testing with thru-beam sensors and calibrated speed showed that the measured value for the 3,490-mm block can be improved to an average of 3,487 mm, or an average error less than 0,1%.

Results:

The results show an overall acceptable measurement accuracy, and measurement with calibrated speed shows a very good accuracy on the 3,490-mm-long measurement object. The speed and measurement registrations are, however, dependent on a high level of accuracy in the reference measure, i.e., the distance between the two sensors. Relatively small errors in the reference measure will affect the accuracy of registered speed and measurement. The situation is even more sensitive when the reference distance is related to a rotating wheel, because a 1-mm error in measuring the diameter will generate an error 3.14 times larger. Therefore, systems of this kind must undergo an initial calibration when a high level of measurement accuracy is required.

The thru-beam sensor and the reflective sensor produced equal results for measurements on short blocks, a maximum error of 0.6%, whereas the diffuse sensor produced a 2.6% error on the same 400 mm block. Compared on the 3,490-mm-long object, the diffuse sensor produced the smallest error.

3.4.5.2 Sawmill-environment tests

The equipment was also verified during a sawmill-environment test. This was done in order to establish that all registered stoppages actually occurred at the correct time and were of the correct length. Because of the critical calibration of the speed registration and its impact on the calculated log length and log gap, the accumulated sawn log length was checked against the true output. Registration of stoppages was done manually during two 4-hour sessions by clocking the occurring events and later checking them against the occurrences registered by the monitoring system.

Results:

The manual survey showed no major deviations or missing events in comparison to the events registered by the monitoring system. The few occurring deviations, such as delayed clock time between results from the manual survey and monitored data, can be ascribed to tiredness or slow reactions on the part of the PhD student who performed the survey.

4 A Sawmill case study

This case study was performed in order demonstrate how quality-management tools and simulation techniques can be used to improve the sawline processes in a sawmill. The sawline process was monitored over a period of 5 weeks utilizing the Distributed Process Monitoring System developed for this study. 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 stoppage data were also included and utilized in the discrete event simulation model. The sawmill's sawing patterns were not used during this study because of secrecy policies. Therefore, a general posting list was used as a starting point for the studies on optimized log disjoining.

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

Log geometry data from the Swedish Pine Stem Bank provided log 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.

4.1.1 Annual production target

Calculated Sales Market Demand is 150,000 m^3 of sawn center boards per year. The sawmill is focused on producing a required volume of 150,000 m^3 of center boards distributed across 14 sawing patterns. The maximum demand for sideboards is 70,000 m^3 per year. The required center board volumes per sawing pattern are shown in Table 4.1.

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.

Table 4.1 Calculated Sales Market Demand for Center Boards (Grönlund 1992)

SC No.	Sawing Pattern	Diagonal Measure of the Sawing Pattern – DmSP (mm)	Demand Center 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

4.1.2 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 true yield for the batch is 59.2 / 116.3 m^3 = 0.509
Method 2: The arithmetical average yield: 0.472
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.

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

4.2 Optimized sorting and breakdown

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.

4.2.1 Optimized Sorting

The initial sorting procedure serves two main purposes for the sawmill:

- To classify the log quality, thus determining the purchase price to be paid to the seller.
- To classify the logs into the correct sawing class in order to optimize the volume and/or value yield.

It is therefore important to optimize sorting accuracy, because it will affect the final yield recovery and financial outcome (Johansson 1978). When substandard logs are allowed to pass through the sorting procedure undetected, they will be fully paid for, but the value recovery derived from them will be low.

The present method used for sorting logs in Swedish sawmills by measurements and ocular inspection is appropriate for determining top diameter, log volume, crook and surface damage. However, a log’s inner structure, containing knots and defects, is impossible to determine using these methods. Nevertheless, knots and defects will affect the final recovery and the board quality. This forces sawmills to pay for an excessive volume of raw material with a large share of unknown properties in order to produce the required qualities and volumes.

Sorting accuracy is also affected by the equipment’s ability to correctly measure the minimum top diameter of every log (Johansson 1978), bark thickness, damage, snow and ice. Narrow sawing classes make measuring accuracy even more critical, because more logs will appear close to the sawing-class limits and thus be more likely to be classified into an ”incorrect” sawing class (Oja et al. 1999). The complexity increases even more as the aggregated effects of sorting errors is compounded by rotation and positioning errors in the sawing machines (Johansson 1978).

Table 4.2 shows that the average volume yield will increase if the substandard logs are removed during the sorting process. An analysis of the simulation data utilizing the log material shows that the average yield can be improved by 1.1 percent points if refused logs with an expected yield lower than 25% are removed from the process during sorting. The total volume share of refused logs in this case is 3.6%. These refused logs in the SPSB material do not show noticeably large defects such as sweep, bumps or damage and would likely have been appraised as logs of full value.

Table 4.2 Effects of improved detection and removal of substandard logs during the sorting procedure on average yield. The table also shows the necessary amount of purchased logs in reference to the sorting procedure’s capability to detect low-valued logs.

Sorting Accuracy – Detection of Refused Logs	**True Yield (%)**	**Volume Share Refused Logs (%)**	**Purchase Log Volume (m^3) (220,000 m^3 boards)**
All logs in the material processed	49.0	0	449,000
Refused logs (yield < 15% refused)	49.4	1.1	445,300
Refused logs (yield < 20% refused)	49.8	2.4	441,800
Refused logs (yield < 25% refused)	50.1	3.6	439,100
Refused logs (yield < 30% refused)	50.5	5.1	435,600

Table 4.2 also shows the necessary amount of purchased logs in reference to the sorting procedure’s capability to detect low-valued logs.

An improved sorting capability according to the example in Table 4.2 demonstrates a potential to reduce the purchased volume of low-quality logs by 7,200 m^3 sub if logs with an expected yield below 20% are refused and classified as waste. The purchase price for this log volume would be 3.6 MSEK at an average log purchase price of 500 SEK/m^3 sub.

Studies show that improved sorting accuracy and optimized sawing-class limits can improve yield and reduce the required raw material supply. For a sawmill producing 165,000 m^3 of sawn lumber, the raw material supply could be decreased by 13,000 m^3 sub (Skog 2004).

The log properties contained in the SPSB are not necessarily to be regarded as representative of sawmill stock in general. Nevertheless, the comparison shows a potential for reduction of log purchase cost by improving the log-sorting process. The level of expected yield where logs should be classed as waste or pulpwood is primarily decided by the Mesurement Society rules, but can also be a strategic and financial matter to be decided by the management. The sawmill’s effectiveness and true production cost to saw, sort, dry, trim and handle the boards and chips during the whole chain will set an economically justifiable level.

However, the potential to increase the yield is not to be confused with yield improvements achievable by optimizing the breakdown process. An improved sorting process would nevertheless decrease the volume of logs the sawmill is forced to pay for without being able to obtain valuable boards that can be sold at full price.

4.2.2 Optimized 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.

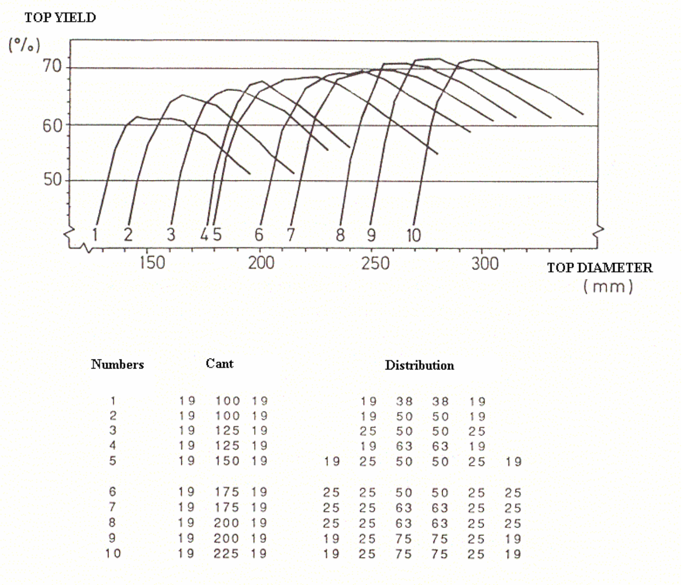
There are some priority areas to set and consider when a posting list is determined. A crucial aspect is the sales market's demand for board dimensions, qualities and lengths. However, optimized yield recovery and available log dimensions as well as sawmill and drying kiln capacity can affect the final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

In order to define an optimized 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 have been done on logs (Chiorescu 2003) in which the *finger-print method* and Radio Frequency Identification tags are used in order to trace individual logs between the log sorting station and the saw intake. The results from this study show that it is possible to trace and individually separate up to 93% of the logs. This method is, however, expensive, requires 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 4.3, 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 4.3 Yield envelope curves calculated from a batch of 25 curve-sawn logs with an average top diameter of 270 mm (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 4.4 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 center boards and side boards.

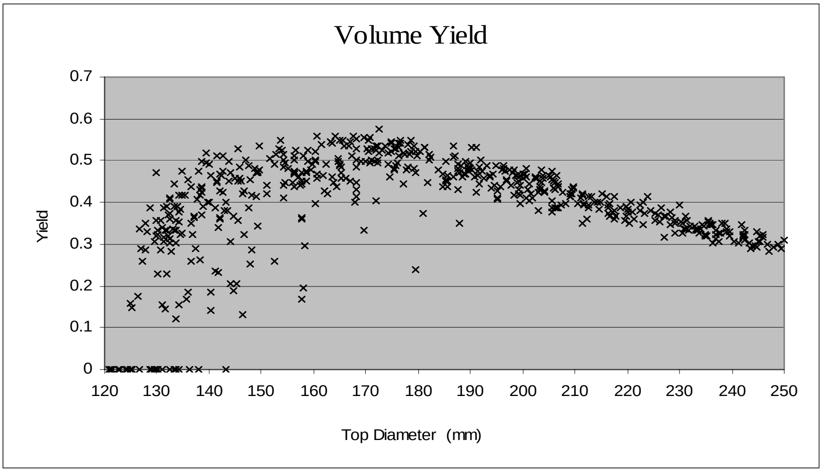


Figure 4.4 Simulated Volume Yield. The results achieved by applying sawning pattern "50 x 100-mm" on all logs in the SPSB, the accumulated yield from center and side boards included.

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 average and median values for every group were calculated and plotted (Figure 4.5). This procedure was repeated, applying all current sawing patterns one by one to the log material. This work created a number of two times fourteen yield envelope curves.

Figure 4.5 shows the grouped and plotted median yield values for sawing pattern no. 3, "50 x 100-mm", containing center boards and both center boards and side boards respectively.

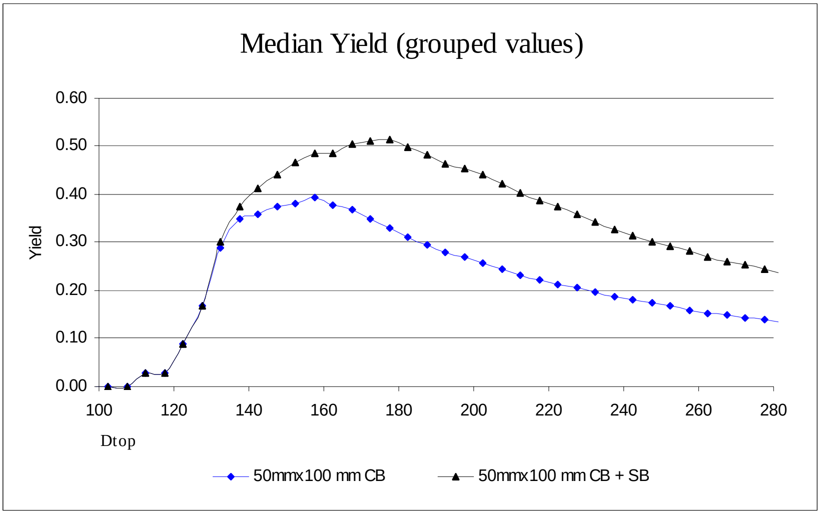


Figure 4.5 Yield envelope curves for sawing patterns containing center boards (CB) and sawing patterns containing center boards and side boards (CB + SB). Sawing pattern no. 3, "50 x100-mm".

Some unevenness can nevertheless 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 center boards or of sideboards is prioritized. However, these mathematically defined curves need calibration if they are to reflect the real sawmill's output.

Figure 4.6 shows the yield envelope curves as a function of the third power for 14 sawing patterns containing center boards and side boards superimposed in the figure.

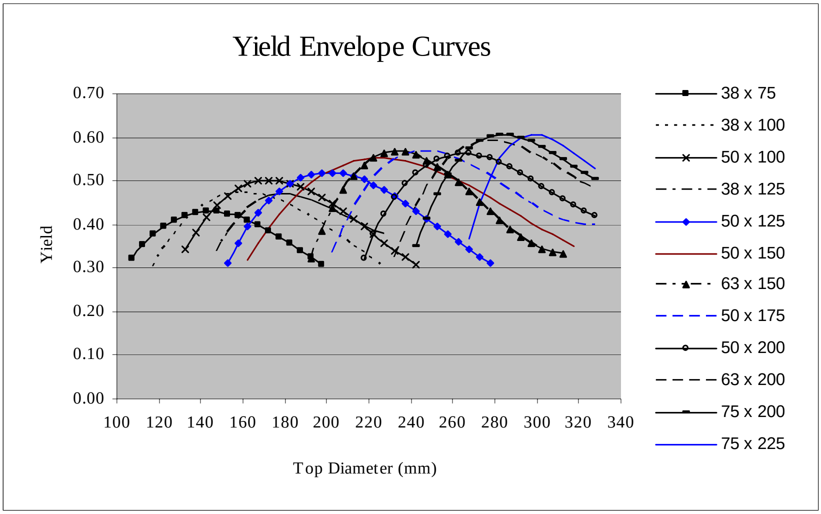


Figure 4.6 Fitted Yield Envelope Curves created from Saw Simulation data

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 intersection between the sawing classes indicates rough positions and limits for the sawing classes.

The sales market's demand for center boards with sharp edges, i.e., no wane is 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 4.6 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 4.7 shows yield curves calculated and plotted as a function of the optimal lower limit of the sawing class (LLSC) and a 15-mm class width. Curve B is created using a sawing pattern containing center boards and side boards, while curve A contains a sawing pattern with center boards only.

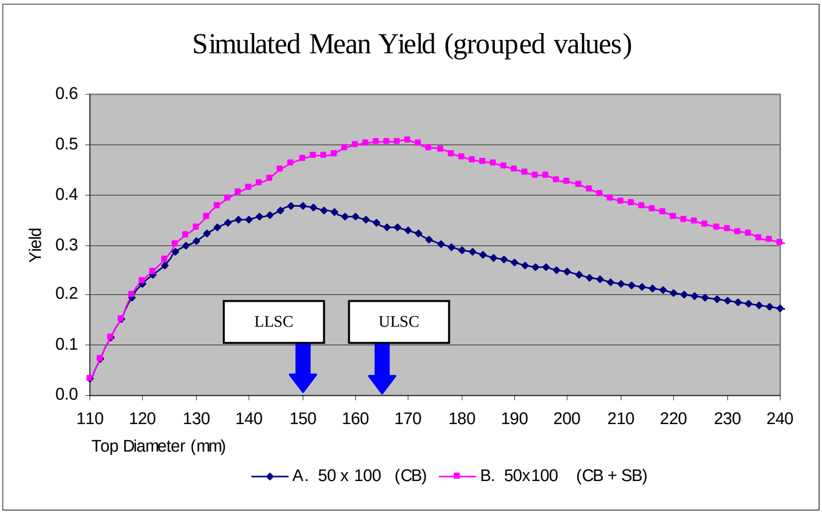


Figure 4.7 Saw Simulation Yield results plotted as a function of the lower limit for the sawing class, grouped values. LLSC = Lower Limit of the Sawing Class, ULSC =Upper Limit of the Sawing Class. Sawing Pattern A: "50 x 100-mm" CB (center boards only).
Sawing Pattern B: "50 x 100-mm" CB + SB (center boards and side boards included).
Sawing Class width: 15 mm.

Curve A shows a maximum true yield of 0.378 achieved when the lower class limit (LLSC) is set to 150 mm, figure 4.7. The B curve shows a maximized true volume yield of 0.504 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 optimized posting list with the highest total yield.

A fully optimized posting list should also consider the highest value yield, 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 performed at SP-Trätek (Skog 2004) in order to develop software for dynamic sawing-class definitions. The software uses saw simulation data in order 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 case study at a midsize Swedish sawmill shows a potential to increase the pine volume yield by up to 2 percent points. This would decrease the annual raw material supply by 13,000 m^3 sub, given a production of 300,000 m^3 sub sawn logs per year. This represents a value of more than 6 million SEK. The conclusion from this study is that the software provides a suitable method with which to address sorting and sawing class related problems.

A number of simulations were performed in order to optimize 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:

<u>1. DMSP:</u>	Note: The Lower Limit of the Sawing Classes determined and set by the Diagonal Measure of the Sawing Patterns (DMSP) center yield. Used as the reference posting list in this study.
<u>2. Simulation:</u>	Note: The optimal Sawing Class position determined and set by Saw Simulations. The optimal Lower Limit of each individual Sawing Class regarding center-board yield was determined and set by the results from saw simulations. See Figure 4.7.

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 4.6.

The optimal lower sawing class limits, with respect to the center-board yield, were established for all current sawing patterns with the aid of saw simulations. Figure 4.7 shows the yield peak when the lower sawing class limit is set to 150 mm for this particular sawing pattern.

These limits were achieved 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 altering 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 4.6).

All four posting lists were established in two separate configurations, a limited version with only the center board pattern applied and a version applying the full sawing pattern including side boards.

Figure 4.8 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 49.6% to 51.6% by optimizing the sawing class’s width and position.

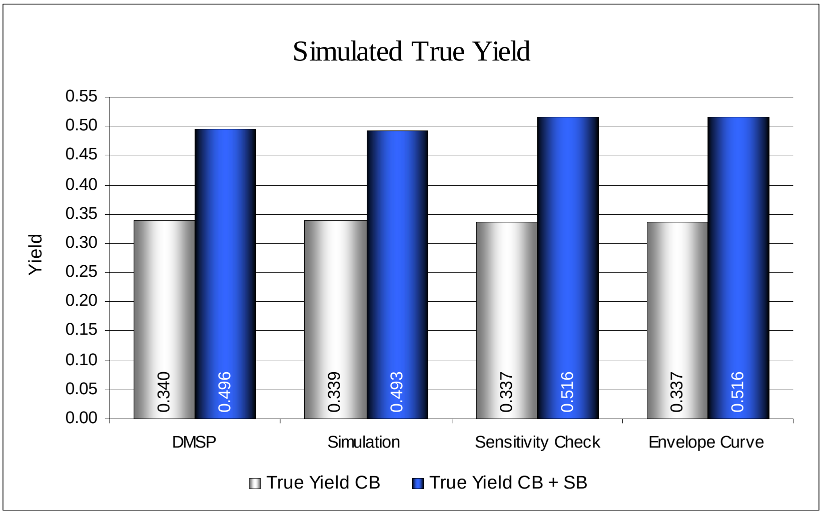


Figure 4.8 Simulation results from the comprehensive evaluation of posting lists 1–14.

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

1. Evaluation of posting lists 1–4 regarding the yield for limited center board sawing patterns.
2. Calculation of the log demand based on the limited posting list yield.
3. Calculation of the additional produced side board volume.
4. Set the optimal posting list regarding the combined yield for center boards and side boards in order to increase the total achieved value.

The results achieved from reference posting list *“DMSP”* show that it is optimized for production of center boards, thus requiring the lowest volume of purchased logs.

The yield achieved by sawing exclusively center 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 4.9 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 consitently achieve the highest yield for all individual sawing classes.

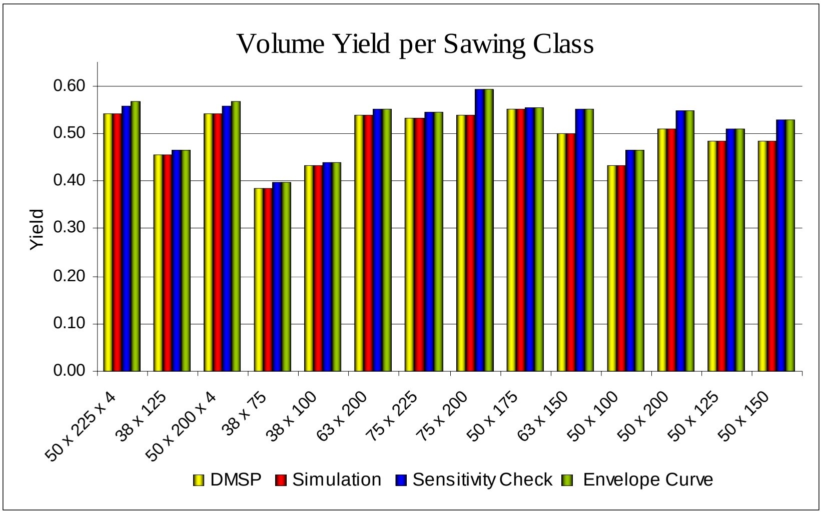


Figure 4.9 Evaluation of different posting-list configurations. Sawing classes sorted according to required center board volumes. High volume dimensions to the right.

The detailed yield information established by separating the 14 sawing classes enables a more correct calculation of log demand. The impact of a relatively small yield becomes obvious when large volumes are processed.

Figure 4.10 shows the calculated demand for logs using the aggregated average yield result for the entire batch in comparison to the detailed results. The detailed yield information (Figure 4.9) 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.

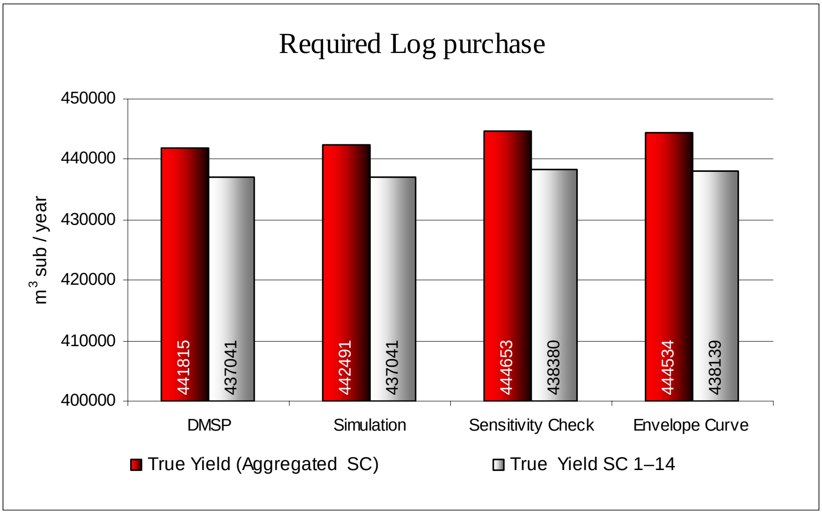


Figure 4.10 Calculated demand fo logs in order to produce the required volume of center boards. Aggregated demand calculated on average true yield for the entire log batch, whereas demand with reference to Sawing Classes 1–14 (SC) is calculated on yield from individual sawing classes.

Figure 4.10 shows the total demand for log volume per year, depending on preferred posting list and calculation method. 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 center boards (Figure 4.10), but also the highest total yield (Figure 4.8). 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 optimized 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 4.3 shows the maximum expected 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, however, small.

Table 4.3 Calculated profit with reference to posting list selection.

	DMSP	**Simulation**	**Sensitivity Check**	**Envelpe 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 boards of higher quality because there is less wane. This also indicates that the number of boards produced using posting list *"Sensitivity Check"* is lower. This is often to be preferred, because fewer boards will mean a decrease in drying and handling costs.

These financial estimates 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 sales price is reduced.

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 optimized posting list will be set to *"Sensitivity Check"*. Table 4.4 shows the final posting list configuration.

Table 4.4 Optimized 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

4.2.3 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 4.11 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 4.4, 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 center board yield if the alternative "38 x 125-mm" sawing pattern is applied to these specific logs.

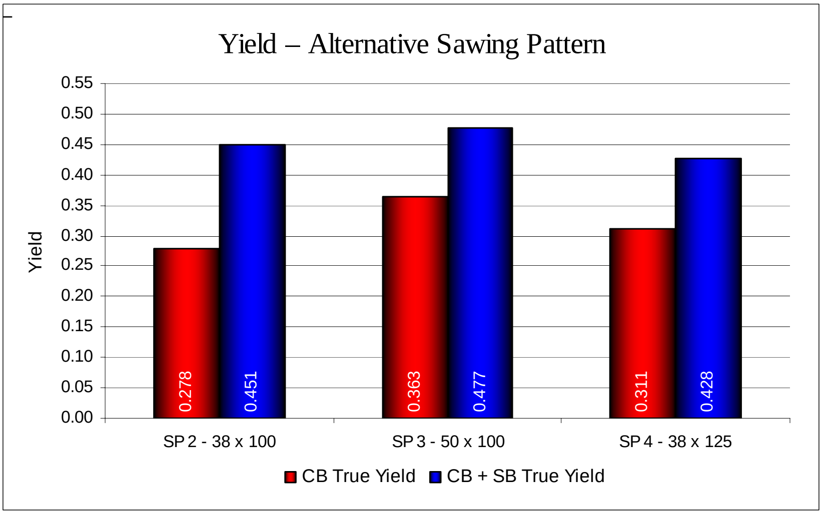


Figure 4.11 Volume yield for reference sawing class no. 3 (sawing pattern "50 x 100-mm") in comparison to yield achieved with alternative sawing patterns applied.

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 center board yield. In order to optimize 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 optimized posting list based on top diameter classes. This further yield improvement from 51.6% to 54.1% is achieved by applying a correct sawing pattern to every individual log, rather than applying a predefined batch processing for all logs in a sawing class.

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 4.5 shows the effects on yield when logs close to the sawing-class limit are incorrectly measured and sorted into the adjacent sawing class.

Table 4.5 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 4.5, 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 the 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 frequent 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 deals saw, etc.

4.2.4 Curve sawing vs. straight sawing

Curve-sawing technology has been used for more than half 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 center 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 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 4.12 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 center- 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.

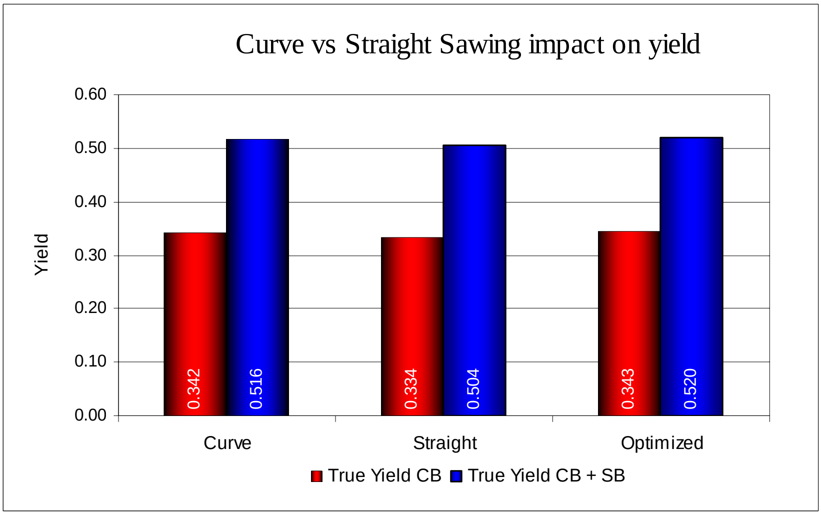


Figure 4.12 Curve- and straight-sawing techniques' impact on true yield. Optimized column shows the true yield achieved by applying the optimal technique combined with sawing patterns containing only center boards (CB) and full sawing patterns containing center boards and side boards.

Table 4.6 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 meters.

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

	No. logs	Fraction (%)	No. logs optimized by straight sawing	Fraction optimized by straight sawing (%)	Average log length (m)
Sweep < 25 mm	551	89.1	133	21.5	4.5
Sweep ≥ 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 meters. 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 meters 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 center board when the log is curve sawn. The left picture in Figure 4.13 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 center board is probably caused by a small unfortunate and coincidental cavity at the log's surface in combination with displaced saw kerf.

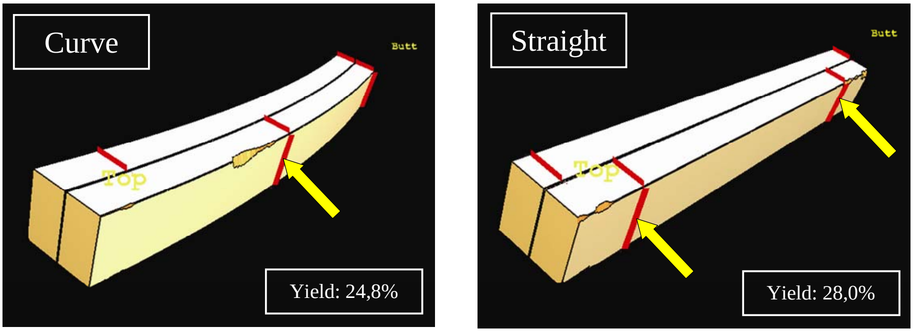


Figure 4.13. Example of straight-sawing center-board yield in comparison to curve-sawing center-board yield from the same log.

The center-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.

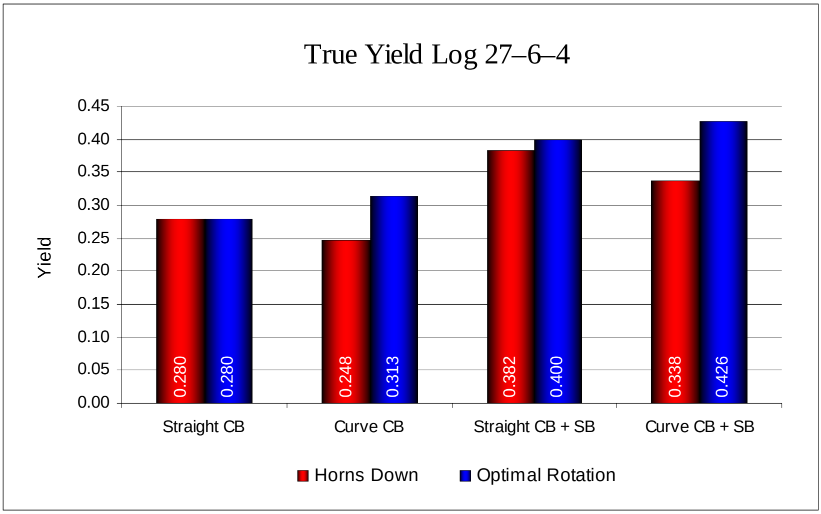


Figure 4.14 Saw technique and rotation impact on true yield.

This particular log could nevertheless be further optimized by using curve sawing combined with altering the rotation in the cant saw.

Simulation results show that the center-board yield is increased to 31.3% if the log is rotated an additional 50 degrees from the normal horns–down position. Figure 4.14 shows the impact of 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.

The main effect of the optimal rotation is explained by the fact that the wane areas that appeared in the center of a board in the horns-down position do not exist after the additional rotation; thus, longer center boards are produced.

Figure 4.14 shows the moved cutting mark on the right center board after rotating the log.

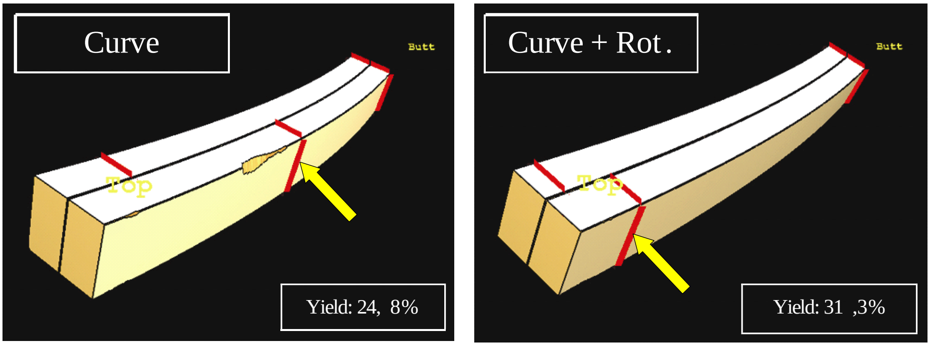


Figure 4.14. Additional potential to increase the yield by optimal rotation combined with optimal sawing technique.

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 a more optimal 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.

4.2.5 Optimized 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 centering 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 parameters defined in three degrees of freedom—rotation, parallel and skewed displacement.

The yield can, however, gain from a deliberate offset positioning or rotation in some cases. An offset in the center 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 centering 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 4.15 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 center-board sawing pattern and is thus highly sensitive to an offset rotation.

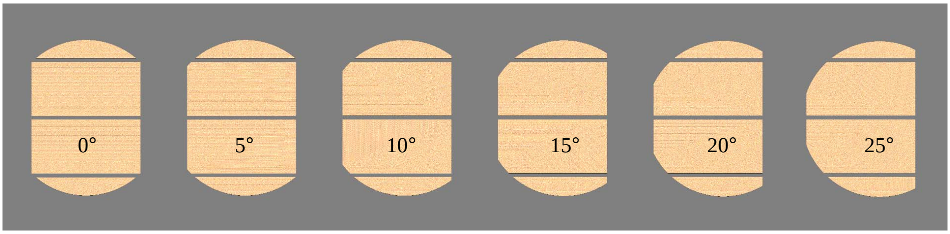


Figure 4.15 Center yield cross-section of swept log rotated to the right from 0 to 25 degrees.

At an offset of 5°, wane already appears on the left side of the cant's edges, causing the yield 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.

The comprehensive simulation results in Figure 4.16 show that the highest aggregated true yield was achieved when all logs were rotated -10 degrees from the horns-down position. The improvement is very small, however, and the comprehensive results are small and not statistically determinative. The results nevertheless indicate that volume yield benefits from the horns-down concept in general.

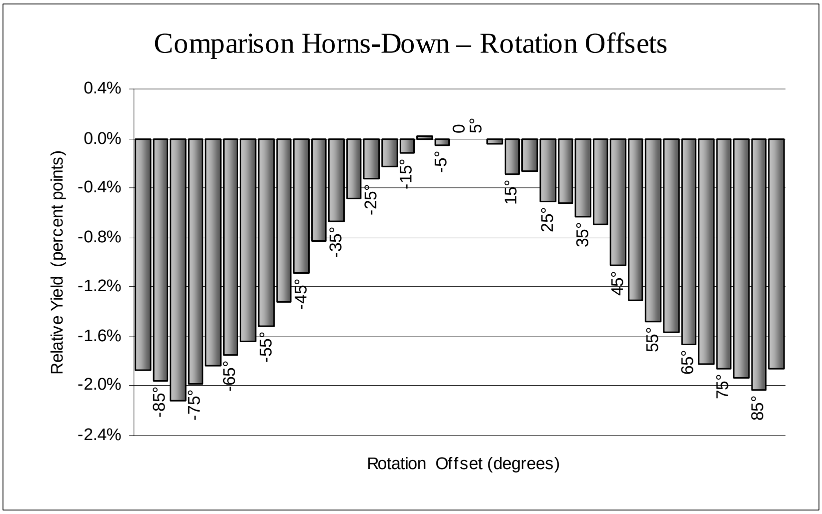


Figure 4.16 True Yield in reference to horns-down position and various rotation offsets.

The horns-down position is not the optimal position in all cases, even though the aggregated results in Figure 4.16 indicate this to be the case. The inconsistent results become obvious when the optimal rotation is evaluated for individual logs. Figure 4.17 presents the horns-down yield result for a single log in comparison to rotation in 5-degree steps within a +/- 90-degree range from the horns-down position.

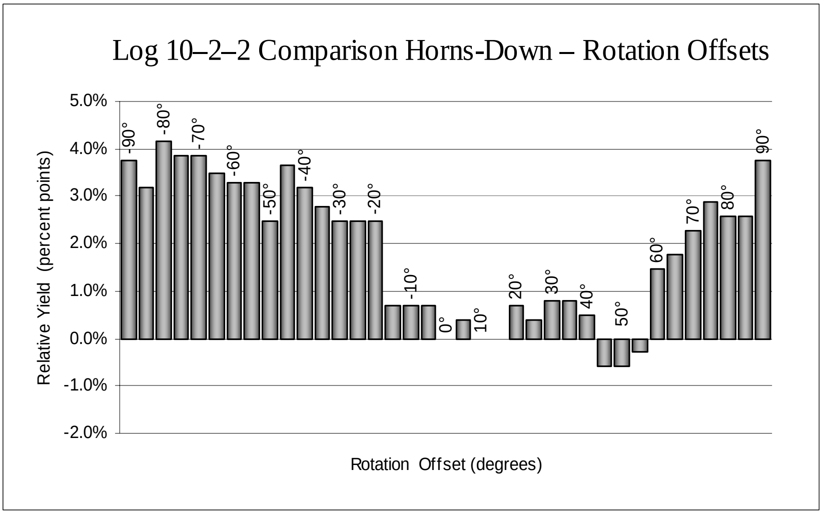


Figure 4.17 True Yield Log 10–2–2. The yield obtained in the horns-down position serves as a reference value in comparison to the yield obtained after altered rotation.

A detailed review of the specific log shows that the minimum top diameter is 175.8 mm, maximum sweep is 6 mm, and length is 4.85 meters. The log is thus regarded as straight and located in the center of the sawing class.

This specific log clearly gains from the altered rotation. The yield is increased by 4.2 percent points from 46.7% to 50.9% if the log is rotated -80°. The simulation results (Table 4.7) show that the increased yield after altered rotation is obtained by the production of one extra side board (2c) in the cant saw and one side board of increased length (4d) in the second saw. The altered rotation has in this case decreased the occurrence of wane on the side boards, thus producing more board volume.

Table 4.7 Comparison of results from log rotated to horns-down position and rotated to an optimal position respectively.

```
****** Log data *******
Plot, Tree, Log (10–2–2)
LogCut (0, 4850)
Diam = 175.8 mm
Length = 4850 mm
Vol = 143.7 dm3 sub
Curve angle = 221°            Bow = 6 mm     Pos = 900 mm

Results
Rotation: Horns Down:

***** Post ************
Name: 38 x 125              Min: 170 mm        Max: 182 mm
CantPost: 19, 125, 19                          DealPost: 19, 38, 38, 19
***** Cant boards *****
Board     Dim               Length             TopPos             Qual               Price
1c        19 x 75           2700               2720               A-s                11.54
***** Deal boards *****
Board     Dim               Length             TopPos             Qual               Price
1d        19 x 100          4800               4820               A-s                27.36
2d        38 x 125          4800               4820               A-c                42.18
3d        38 x 125          4800               4820               A-c                42.18
4d        19 x 125          3600               3620               A-s                25.65
148.92
***** Chips ***********
Volume    71.1 dm3 s                                              Value              14.21
---------
Total     163.13
Yield = 46.72%


Rotation: -80 degrees

***** Post ************
Name: 38 x 125              Min: 170 mm        Max: 182 mm
CantPost: 19, 125, 19       DealPost: 19, 38, 38, 19
***** Cant boards *****
Board     Dim               Length             TopPos             Qual               Price
1c        19 x 75           2700               2720               A-s                11.54
2c        19 x 75           2700               2720               A-s                11.54
***** Deal boards *****
Board     Dim               Length             TopPos             Qual               Price
1d        19 x 100          4800               4820               A-s                27.36
2d        38 x 125          4800               4820               A-c                42.18
3d        38 x 125          4800               4820               A-c                42.18
4d        19 x 125          4500               4520               A-s                32.06
166.87
***** Chips ***********
Volume    64.6 dm3 s                           Value              12.92
---------
Total     179.79
Yield = 50.88%
```

This example once again illustrates the problems with processing logs in batches and the possibility of improving the yield by viewing and handling logs as individuals, i.e., optimizing sorting, sawing patterns and positioning. Modern 3-D log-scanning systems are capable of registering the log geometry in detail, and by evaluating combinations of rotation and positioning, the optimal settings can be applied to every log.

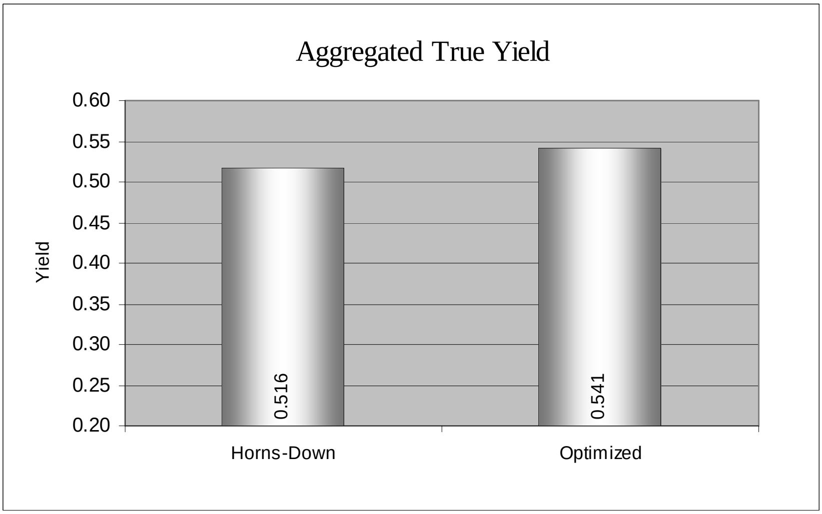


Figure 4.18 True yield obtained by applying horns-down in comparison to true yield obtained by utilizing the optimal rotation position.

The fact that this specific log gains from the altered rotation can be explained by the fact that it has a very low sweep and that it is therefore hard to even define a horns-down position for it. Minor bumps on the log surface could further explain local occurrences of wane on the side boards when the rotation is altered. The simulation results shown in Figure 4.18 clearly show a potential to increase the yield by a further 2.5 percent points if the optimal rotation is applied to every single log.

4.2.6 Positioning error in first and second saw

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 centered plane surfaces. An offset from the normal position is called the positioning error and is defined as the distance between the center of the log cross-section and the center 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 center yield.

Figure 4.19 shows a comparison of achieved center-board yield when a consistent offset to the right in the first saw is applied to all logs in a batch. All logs were ideally centered in the second saw. The results show that an optimized positioning of every log in the cant saw would increase the accumulated yield by 0.4 percent points. An offset of 4 mm causes center-board yield to drop 0.5 percent points. Applied to the sawmill scenario, this would increase log purchase requirements by 6,500 m^3 sub.

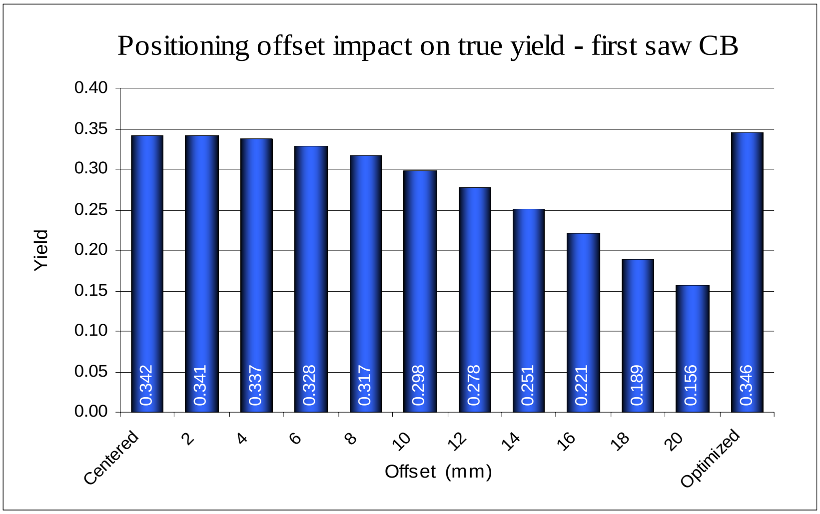


Figure 4.19 Comparison of center-board yield achieved when a consistent offset is applied to all logs in a batch. Offset range was set from 0 mm to 20 mm to the right in reference to feed direction.

The yield rapidly declines when the offset is increased further, thus limiting the allowed offset error to a maximum of 2 mm. This is a very short range in which the log batch produces the highest yield. This is probably caused by narrow sawing classes positioned close to the diagonal measure of the sawing pattern. This could thus be referred to as an inherited effect of the optimized posting list, as it was created in order to prioritize production of center boards. These specific results nevertheless raise questions about accumulated effects caused by deviations resulting from variations in the machinery and/or tools. A limited spread on the board size combined with a limited spread in the positioning accuracy could in some cases produce larger cumulative effects on the total yield than expected.

Figure 4.20 shows the impact of offset on yield when the full sawing pattern is utilized. Optimization of every log increases yield by 1.1 percent points.

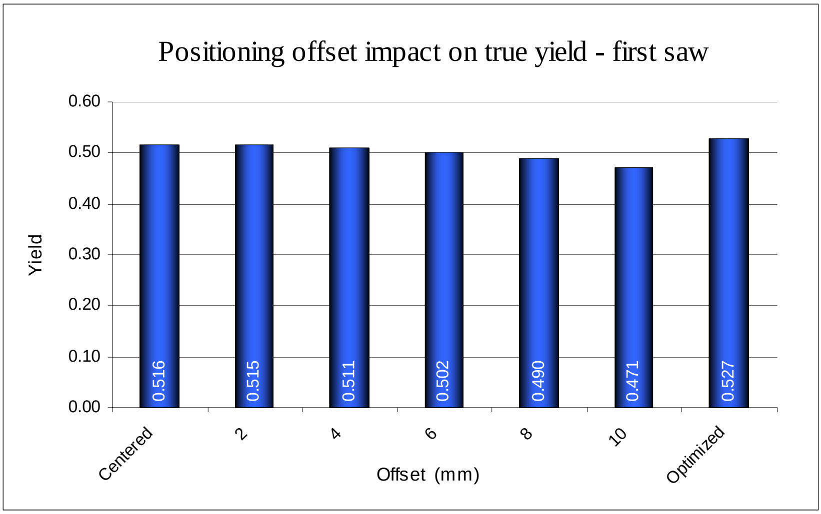


Figure 4.20 Comparison of achived center-board and side-board yield when a consistent offset is applied to all logs in a batch. Offset range was set from 0 mm to 20 mm to the right.

As explained previously, an offset exceeding 2 mm would not allow the stated production volume of center boards to be achieved without increasing the amount of raw material purchased.

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.

One specific log was therfore sawn with alterations in the rotation and parallel positioning within the stated limits as follows:

- Rotation in first saw: 0 – +90 degrees, step 5 degrees.
- Parallel positioning in first saw: 0 – +20 mm, step 2 mm.
- Parallel positioning in second saw: 0 – +20 mm, step 2 mm.

(Positive sign denotes a rotation or parallel offset to the right.)

The actual number of possible permutations in this limited simulation is 19 different angles x 11 offsets in the first saw x 11 offsets in the second saw, which equals 2,299 combinations, 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.

Key terms:
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.
Position 40–2–8 denotes a rotation of an additional 40 degrees to the right in reference to the normal horns-down position, an offset of 2 mm in the first saw and of 8 mm in the second saw.

Table 4.8 Impact of optimized rotation and parallel positioning in first saw and of optimized parallel positioning in second saw. Curve sawing.

<table>
<tr><th>Log 2 – 2 – 2
Top Diameter: 203,6 mm
Class Limits:
200 -222 mm</th><th colspan="6">Normal positioning and Horns down rotation</th><th colspan="6">Optimal positioning and rotation (+ = right)</th></tr>
<tr><td></td><td colspan="3">First saw</td><td colspan="3">Second saw</td><td colspan="3">First saw</td><td colspan="3">Second saw</td></tr>
<tr><td>Rotation (degrees)</td><td colspan="3">Horns Down</td><td colspan="3">—</td><td colspan="3">+40°</td><td colspan="3">—</td></tr>
<tr><td>Parallel Positioning (mm)</td><td colspan="3">Centered</td><td colspan="3">Centered</td><td colspan="3">+2 mm</td><td colspan="3">+8 mm</td></tr>
<tr><td>Sawing pattern: “50 x 150-mm”</td><td colspan="6">First saw</td><td colspan="6">Second saw</td></tr>
<tr><td>Output</td><td colspan="2">Width (mm)</td><td colspan="2">Length (mm)</td><td colspan="2">Value (SEK)</td><td colspan="2">Width (mm)</td><td colspan="2">Length (mm)</td><td colspan="2">Value (SEK)</td></tr>
<tr><td>Left side board</td><td colspan="2">19</td><td colspan="2">1800</td><td colspan="2">7.7</td><td colspan="2">19</td><td colspan="2">3300</td><td colspan="2">14.1</td></tr>
<tr><td>Right side board</td><td colspan="2">19</td><td colspan="2">Null</td><td colspan="2">Null</td><td colspan="2">19</td><td colspan="2">1800</td><td colspan="2">7.7</td></tr>
<tr><td>1st Left side board</td><td colspan="2">19</td><td colspan="2">1800</td><td colspan="2">7.7</td><td colspan="2">19</td><td colspan="2">3000</td><td colspan="2">12.1</td></tr>
<tr><td>2nd Left side board</td><td colspan="2">25</td><td colspan="2">4500</td><td colspan="2">35.7</td><td colspan="2">25</td><td colspan="2">4500</td><td colspan="2">42.2</td></tr>
<tr><td>Left center board</td><td colspan="2">50</td><td colspan="2">4500</td><td colspan="2">62.4</td><td colspan="2">50</td><td colspan="2">4500</td><td colspan="2">62.4</td></tr>
<tr><td>Right center board</td><td colspan="2">50</td><td colspan="2">4500</td><td colspan="2">62.4</td><td colspan="2">50</td><td colspan="2">4500</td><td colspan="2">62.4</td></tr>
<tr><td>2nd Right side board</td><td colspan="2">25</td><td colspan="2">4500</td><td colspan="2">35.7</td><td colspan="2">25</td><td colspan="2">4500</td><td colspan="2">33.8</td></tr>
<tr><td>1st Right side board</td><td colspan="2">19</td><td colspan="2">1800</td><td colspan="2">7.7</td><td colspan="2">19</td><td colspan="2">3000</td><td colspan="2">Null</td></tr>
<tr><td>Yield (%)</td><td colspan="6">55.8%</td><td colspan="6">59.6%</td></tr>
<tr><td>Board Value (SEK)</td><td colspan="6">215.5</td><td colspan="6">235.5</td></tr>
</table>

The yield is increased from 55.8% to 59.6% when the log positions are altered to positions 40–2–8. The yield is also relatively stable within the same angle and offset position in the first saw.

However, the yield is sensitive to further offsets in the second saw. The simulation results show that yield is decreased by 11.6 percent points in comparison to the horns-down position if the offset in the second saw is increased to 12 mm.

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

The conclusion made in the study performed by Drake et al. (1986) is that optimized positioning is more sensitive to variations than the horns-down and centered 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 achieve a precision close to 1 mm in the positioning procedure. The simulation results in this study confirm their recommendation, showing that the yield decreases if the offset in the first saw exceeds 2 mm.

Most of the studies performed in this work pursue yield optimization through one-factor tests. The limited study on one log shows the potential to increase yield by evaluating logs on three parameters simultaneously instead of one at a time. Unfortunately, the level of complexity increases rapidly, requiring time-consuming simulations. The simulation performed in order to evaluate one log within the described range and parameters lasted 5.25 hours. The simulation time would increase to almost 636 hours per log if the skew parameter in both sawing machines were to be added to the evaluation.

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 alt. (adjacent SP, normal SP, adjacent SP).
- rotation positions – 19 alt. (horns down–90 degrees, step 5 degrees).
- parallel offsets in first saw – 11 alt. (centered–20 mm, step 2 mm).
- skew offsets in first saw – 11 alt. (centered–20 mm, step 2 mm).
- parallel offsets in second saw – 11 alt. (centered–20 mm, step 2 mm).
- skew offsets in second saw – 11 alt. (centered–20 mm, step 2 mm)

The total exceeds 5.8 million permutations or simulations per log!

Note: All offsets or rotation alternatives are made to the right in reference to the log feed direction. These simulations were performed with a simplifying presumption that the log’s shape is symmetrical. This is of course a limitation in the simulation as compared to dealing with real logs and their outer shapes.

4.2.7 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 4.21 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 center boards are becoming increasingly frequent, and the impact of the saw-kerf width is thus even greater.

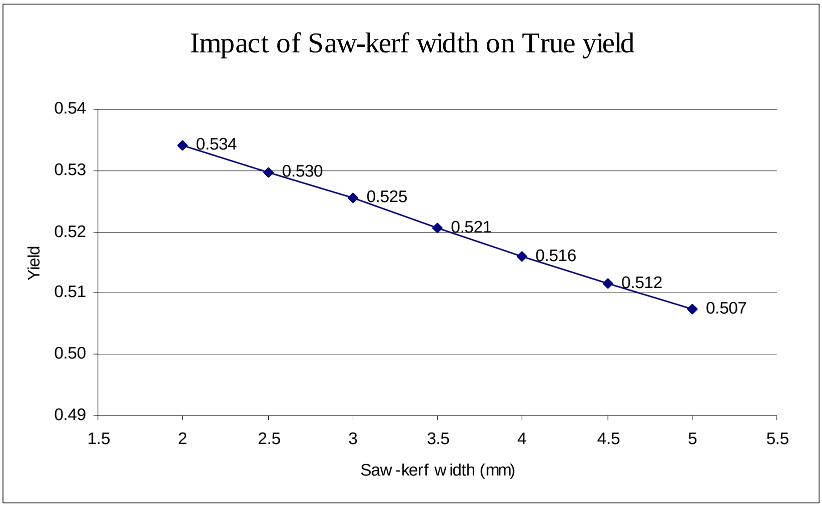


Figure 4.21 Impact of saw kerf width in second saw.

A thinner saw kerf will require a reduction of feed speed in order to guarantee the stability of the saw blade and maintain sawing accuracy. 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.

4.2.8 Green Size Control

Breakdown control of logs combined with minimized process variations 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 behavior, 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 appeared and when it 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, furthermore 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 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 parameters such as cutting height, feed speed, saw material properties, saw speeds and saw-blade features such as saw-blade material, tooth geometry and tool sharpening can affect measurements 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 parameters.
- 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 4.22).

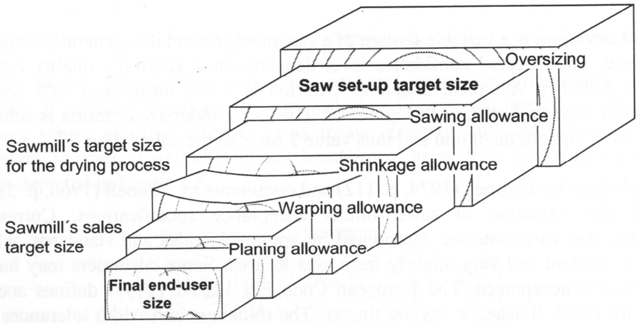


Figure 4.22 Sawmill sales target size on boards and addons needed in order to compensate for shrinkage and variations in sawing accuracy (Vuorilehto 2001).

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 and 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 4.23. 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).

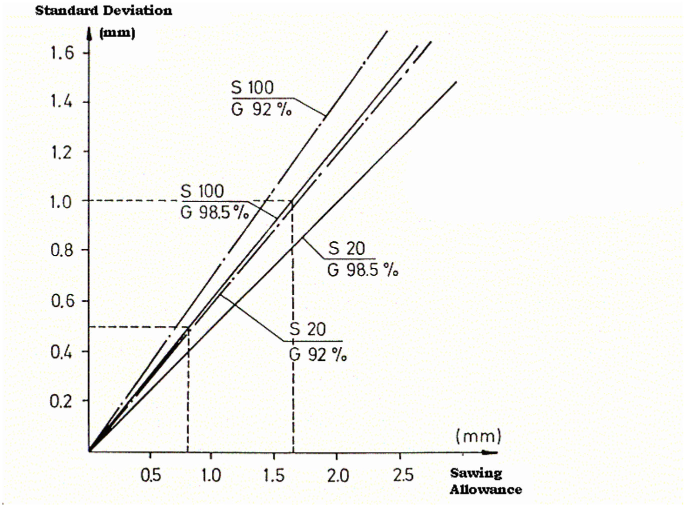


Figure 4.23 The relation between sawing allowance and standard deviation at different likelihoods of acceptance (S) and spot-check size (G). The relation refers to board dimensions smaller than 99 mm.

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 2.6 MSEK, given an average board price of 1,500 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 render 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 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 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 4.24 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.

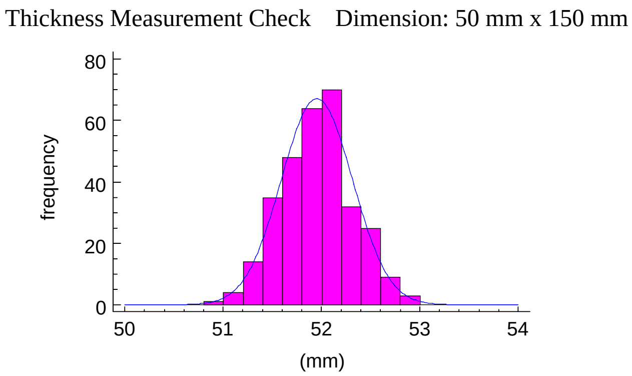


Figure 4.24 Histogram showing results from measurements on board end thickness for dimension "50 x 150 –mm". The superimposed curve shows the fitted normal distribution N (52, 0, 0, 36). Sample size 306. Chi-Square: 4.74, P value: 0.70.

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 4.9).

Table 4.9 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 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.

The results in Table 4.9 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 4.25). The total sawing allowance is a combination of one part shrinkage add-on and one part compensation for variations in machinery for a total of 4.0% on the nominal measure. As opposed to variations occurring in the machinery, however, changes in dimension caused by shrinkage are not controllable by the sawline operators.

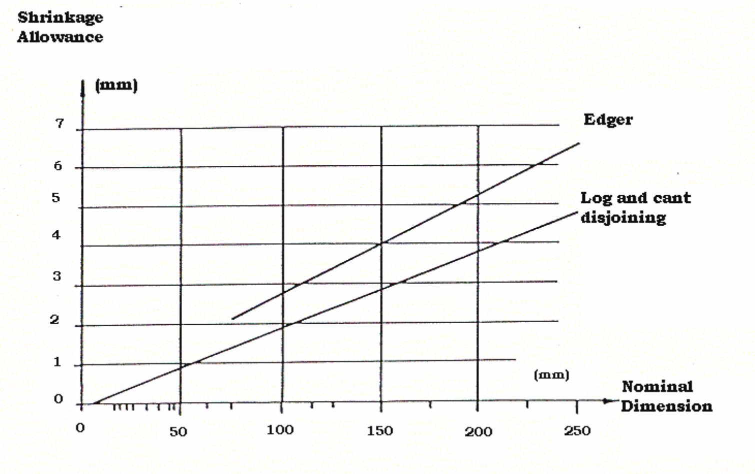


Figure 4.25 Size of the shrinkage allowance depending on dimensions, with levelling lines across the shrinkage allowances established by the STFI. Figures refer to a moisture content of 20% (Bråkenhielm et al. 1969).

Figure 4.25 shows the shrinkage allowance on the 50-mm thickness value. 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 4.25 on the measurement results from Table 4.9 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 because of too high standard deviation.

4.2.9 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).

$$C = \frac{\text{Green Target size} - \text{Smallest Allowed Sawn Size}}{2\text{s}} \qquad \textit{(Equation 4.1)}$$

where C is the process capability index of a saw machine and s is the standard deviation of the sawing process. Equation 4.1 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 4.27 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.

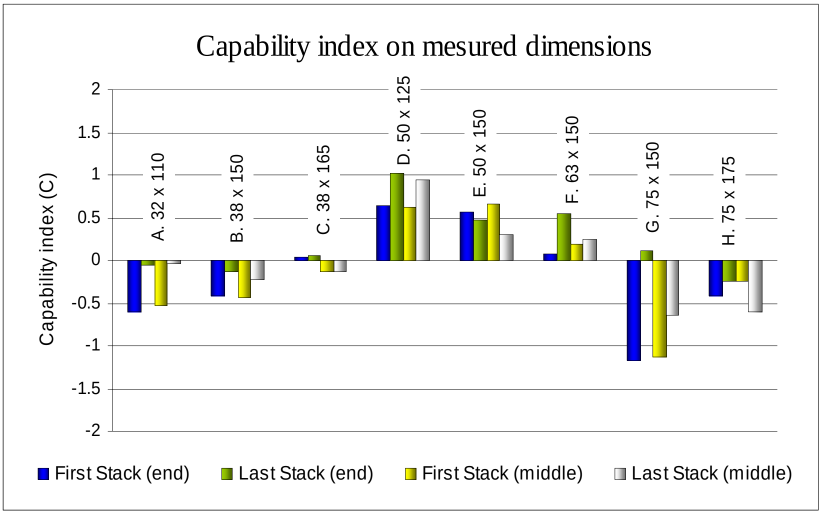


Figure 4.27 Calculated capability index (C) for measured postings and processes.

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:

$$S_T = \alpha e^{\beta tnkFL} \pm \varepsilon$$ *(Equation 4.2)*

Where: α is the inherent saw constant

β is the time-dependent constant

ε is the range

S_T 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 Equations 4.3 and 4.4.

$S_T = 0{,}22e^{0{,}04tnkFL} \pm 0{,}05$ Double-arbor circular saw *(Equation 4.3)*

$S_T = 0{,}39e^{0{,}26tnkFL} \pm 0{,}05$ Triple band saw *(Equation 4.4)*

The α and β constants show that the double-arbor circular saw machine presents a higher mechanical precision 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 4.28 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-arbor machine.

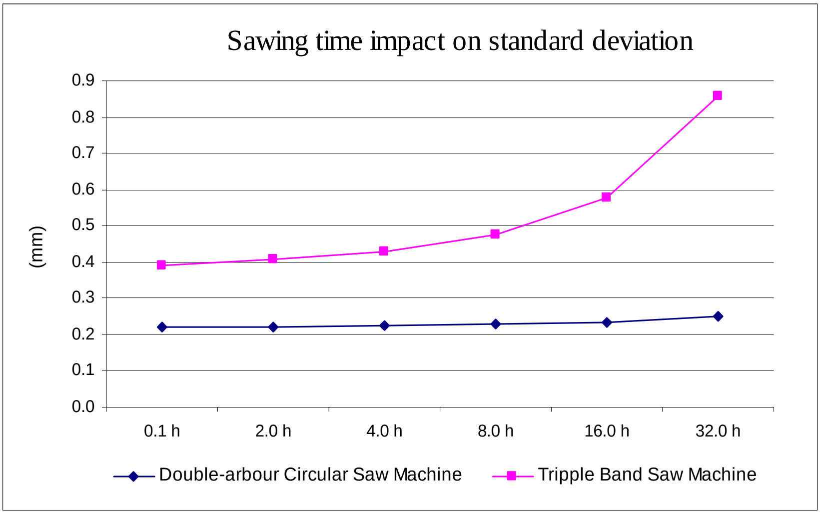


Figure 4.28 Comparison between theoretical standard deviation in double-arbour and triple-band saw machines. Saw-kerf width 0.35 mm. Feeder speed 60 m/minute. Cant height 150 mm.

All process-related variables presented in Equation 4.2 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 4.10 are calculated averages including measurements from board middle and ends.

Table 4.10 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 H (75 x 175) 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 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 4.28 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 any 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 author claims, however, that the model's reproducibility is a better indicator of the predictability of an equation than the r^2 values.

4.3 Valuable production time

The aim is always to minimize stops and to achieve the shortest possible log gaps in order to minimize the time wasted when no wood is being cut.

4.3.1 Required Production Time

The required net production time to saw the required volumes is 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 4.11 shows the required net time in reference to an average log gap. This gap can be induced by equipment requirements or by operator behavior. 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 4.11 shows the required process availability in reference to altered feed speed. The results 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 meters to 0.8 meters. This is the equivalent of 16 shifts per year.

Table 4.11 Required net time to saw 150,000 m^3 of center 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.

Log Gap (m)	Net time to saw demand (h/year)	Sawline feed speed: 90%	Sawline feed speed: 100%	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	2,681	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 is expected to be constant in time and size during the processing of a sawing class. However, the log gap can still vary in size, depending on feeder malfunctions, sawing speed or operator preferences.

Table 4.11 shows that, 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 meters to 0.8 meters. 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 meters 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 4.11 shows. A 10.0% overall decrease in feed speed on the sawing line increases availability requirements by 10%, given a 0.4-meter 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.

4.3.2 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. The stoppage data from this period was also included and utilized in the discrete event simulation model.

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 effectiveness was also measured.

The effectiveness measure is often presented as the number of sawn logs per hour. This measure is, however, 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 missing logs and/or the actual log gap.

4.3.3 Availability

The stoppages classified into the A group represent 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. A survey shows that few of the occurring problems 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 fast action from an operator. Examples of this are logs that get stuck in the debarker or a log that needs to be lifted 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 4.29. This equals a total of 27.2 hours for the week in question, or 3.4 hours per shift.

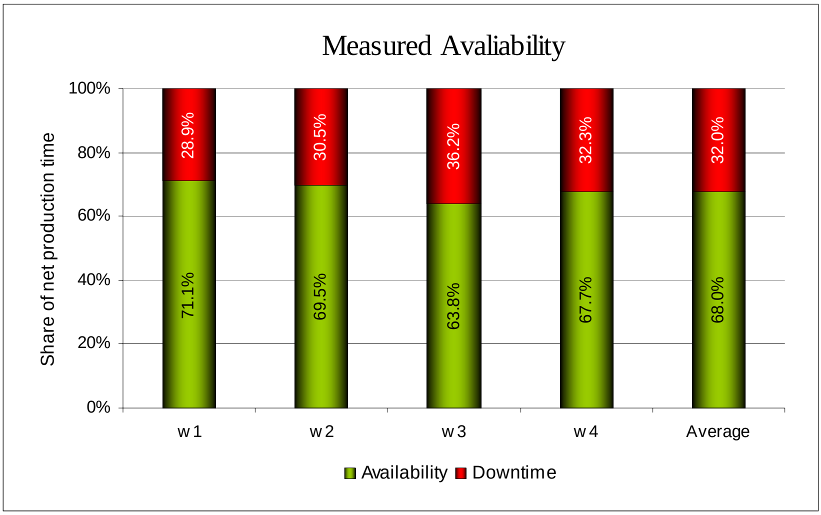


Figure 4.29 Accumulated downtime and availability on the sawline.

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 4.30 and 4.31).

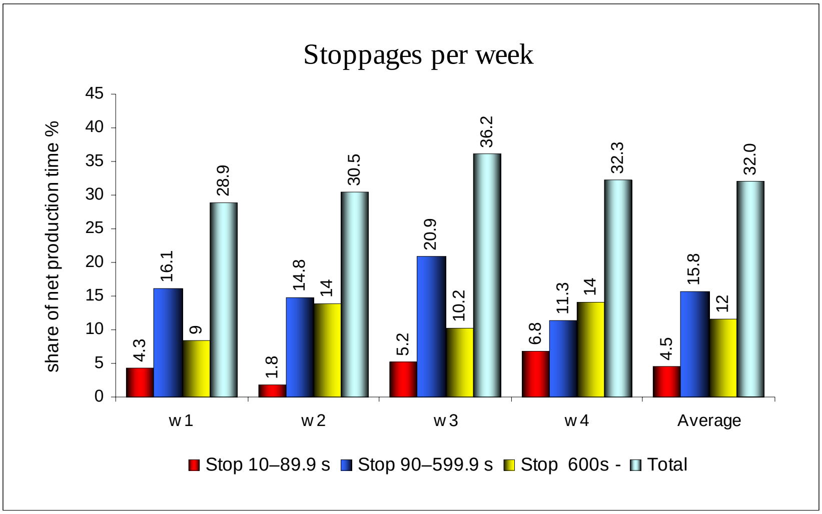


Figure 4.30 Short and long stoppages expressed as percentage of the net operating time. Nominal operating time is 74.5 hours per week.

For example, given sawing class no. 9 ("50 x 200-mm"), the specified nominal feeder speed and a 0.4-meter log gap entail an annual board-production loss of 210 m^3. Simulation results show that expressed in income this equals a loss of 482,000 SEK. Short stoppages during one particular week, w4, totaled 834, i.e., an average of 11 short stoppages per hour, and the accumulated time was 5.1 hours (Figure 4.32).

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 4.31 and 4.32 show that the accumulated B-category time and stoppage frequency are higher during w1 and w3 than during w2 and w4.

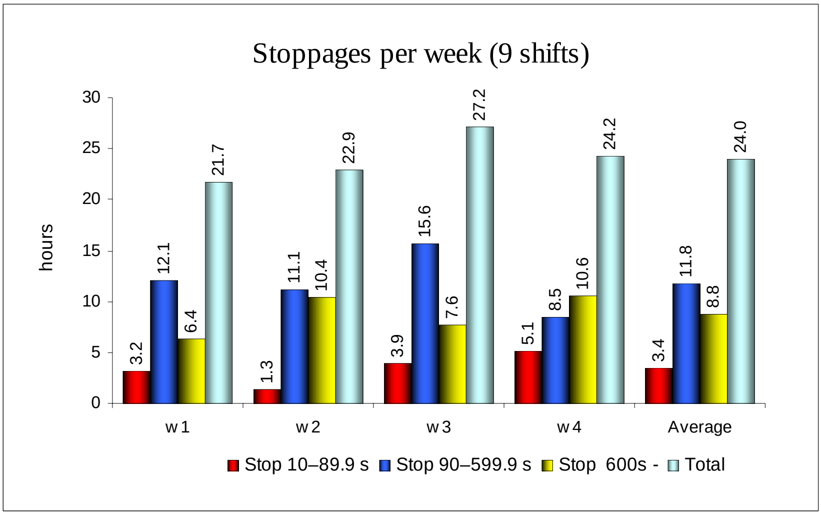


Figure 4.31 Short and long stoppages expressed as total time per week.
Nominal operating time is 74.5 hours per week.

Figures 4.31 and 4.32 show that the accumulated B-category time and stoppage frequency are higher during w1 and w3 than during w2 and w4.

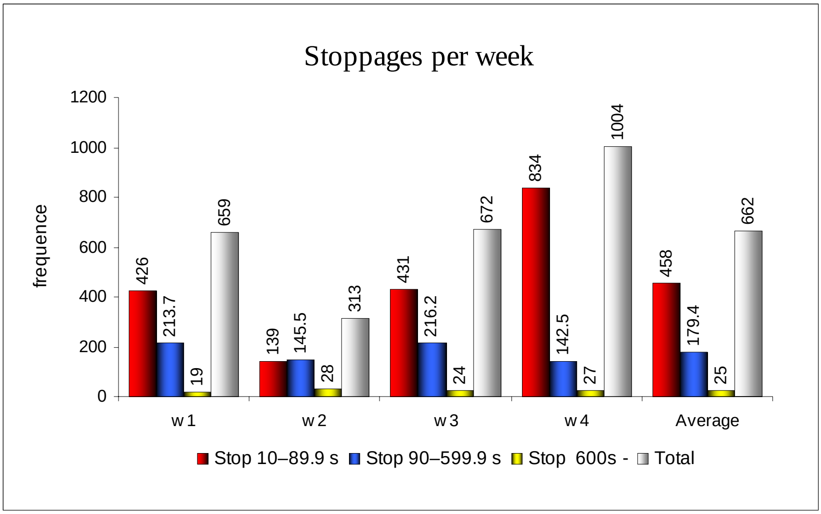


Figure 4.32 Short and long stoppages expressed as total frequency per week. Nominal operating time is 74.5 hours per week.

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, and 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 meters are applied for all postings, an availability of 85% is required in order to achieve the specified production target (Table 4.11). 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.

4.3.4 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 correct 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 meters and an average log gap of 0.4 meters.

Figure 4.33 shows the net available production time separated into theoretical sawing time, registered downtimes and share of unspecified losses.

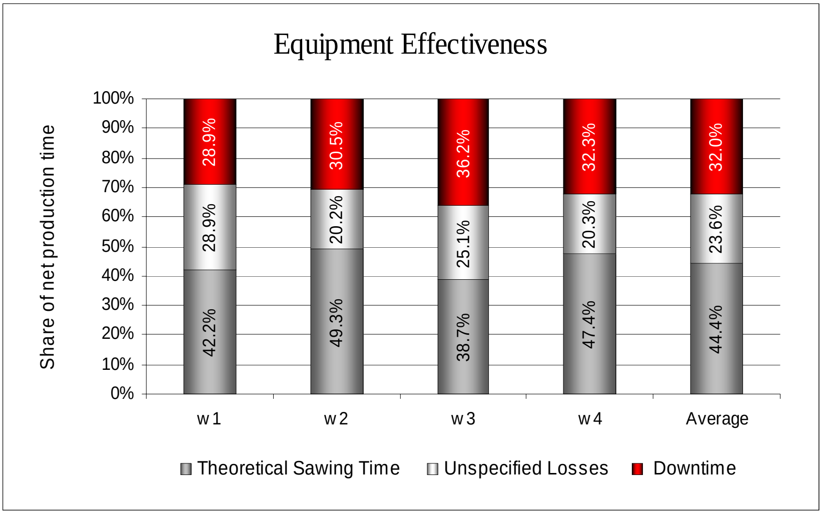


Figure 4.33 Total available production time sepatated into valuable time and losses. Theoretical sawing time calculated at an average log length of 4.3 meters and average log gap 0.4 meters.

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 4.12 imply a large share of log gaps or idling equipment.

Table 4.12 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 registred weekly true performance rate (Table 4.12) 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 4.12).

Example Performance calculation:
x = log gap (meters)

$$\frac{4.3}{(4.3+x)} \approx 0.591 \Rightarrow x \approx 2.97 \text{ } meters.$$

The total preformance 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 4.12). The calculated true average log gap in this case is 2.97 meters rather than the assumed 0.4 meters. The actual average log gaps during test weeks 2, 3, and 4 were calculated to be 1.20, 2.97 and 2.45 meters respectively (Figure 4.34).

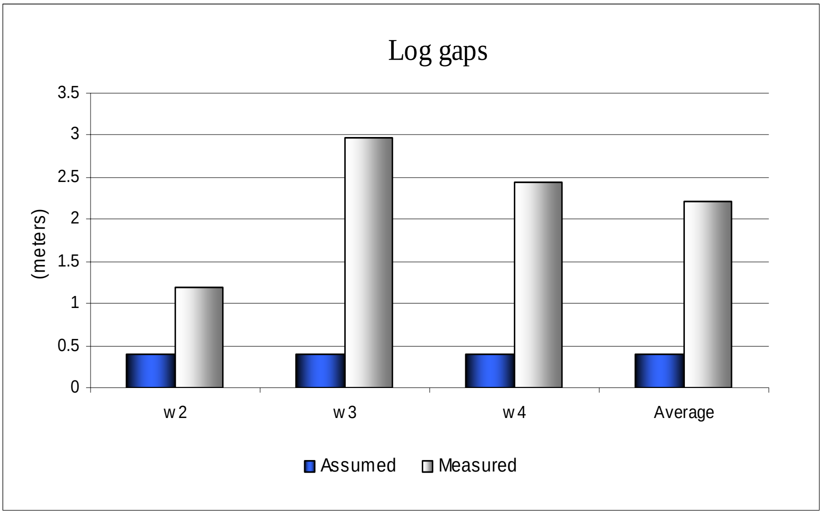


Figure 4.34 True measured average log gaps in comparison to assumed.

The conclusion is that the share of idling equipment in high. Excessive idling of equipment can occur, for example, when log gaps exceed a stated limit and become the equivalent of missing logs. This can be caused by intermittent malfunctions in log intake or debarker. 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 particular weeks that were monitored may not be representative of the sawmill’s 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.

4.3.5 Error causes

Stoppages such as category A and B in this case are mainly caused by bottlenecks, operator behavior 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 4.13 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 4.13 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.**	**Share 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 touch-screen, 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.

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 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 4.13 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 optimized 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.

4.4 Discrete Event Simulation modeling

DES models are used in the mechanical industry in order to evaluate proposed changes, investments or different strategies. Simulation models can preferably also be used for education of the staff.

4.4.1 The Real Sawmill

The layout, main production setup and data from a local sawmill were used during the modeling 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.

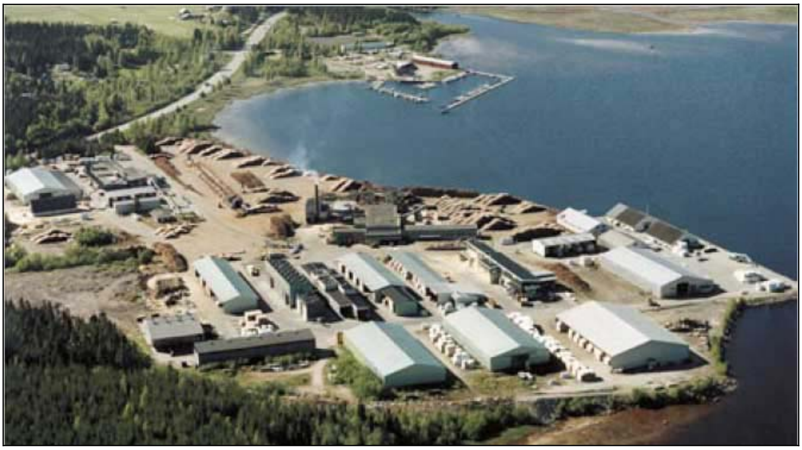


Figure 4.35 The Kåge sawmill owned by Norra Skogägarna.

Figure 4.36 shows a modified layout of the sawmill. The modification is made in order to present a better one-page layout and model overview.

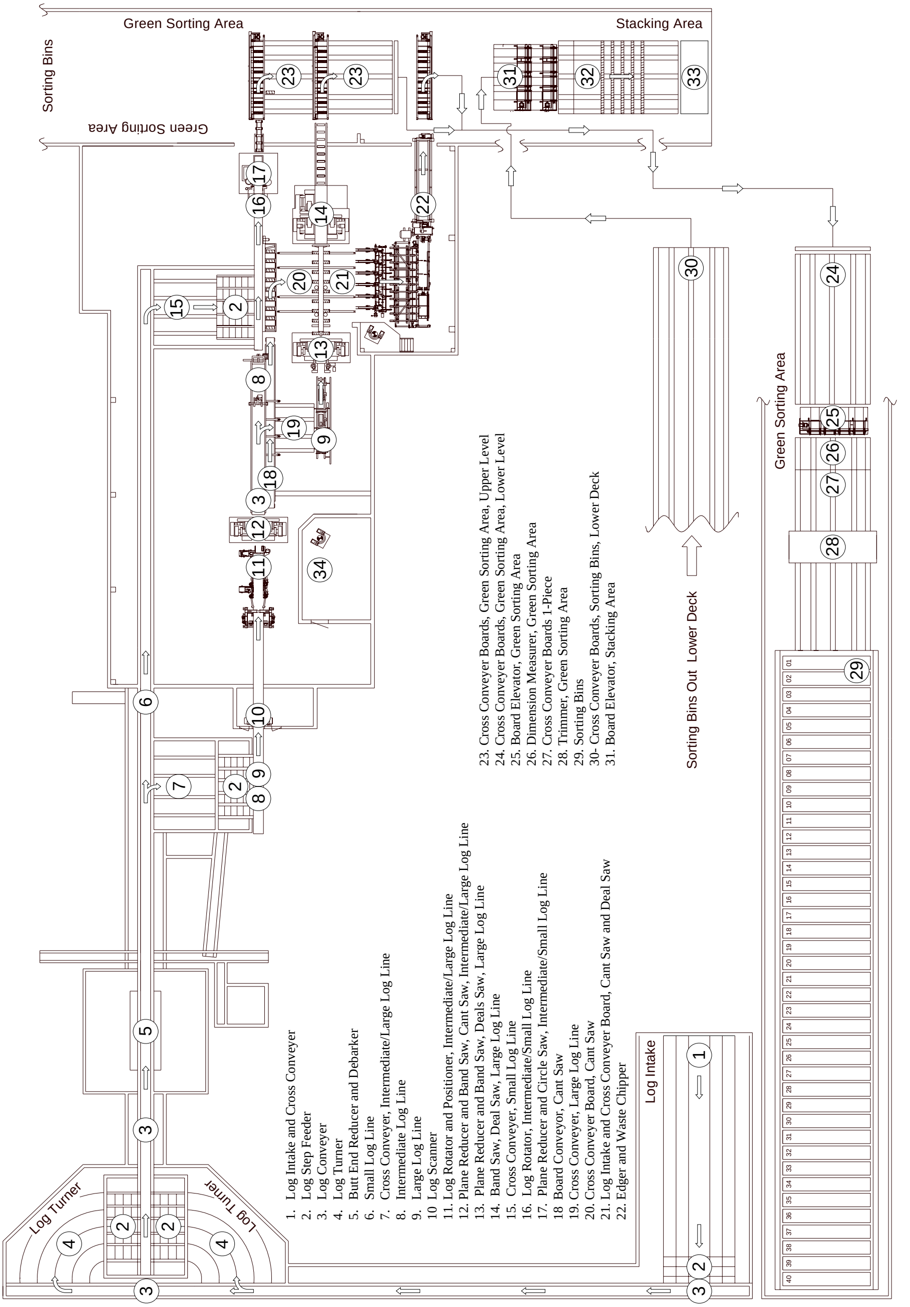


Figure 4.36 Modified sawmill layout. The modification is made in order to present a better one-page layout and model overview.

Cant-sawing techniques combined with applied curve-sawing are used in order to optimize 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 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 sawing classes and later sawn in batches.

4.4.2 Aim and Limitations

This simulation study was limited to include the processes between the main 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.

The model was created with the intention that it should perform as similarly as possible to the real sawmill. 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 modeled on top of it.

There are some benefits from 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 traveling 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 step by step by adding specific functions and processes until the complete flow was modeled. When fundamental processes were created, routing rules, governing conditions and stoppage data were added.

4.4.3 The Sawmill modell

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

4.4.4 Product Properties and Sawing Order

Products such as logs, center and side boards and their properties were initially defined in the simulation software as entities and attributes. Log length was set to an average of 4.3 meters with a normal distribution and 0.2-meter offset from 3.1 meters to 5.5 meters. 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.
- Top diameter within actual sawing class.
- Number of logs in actual batch.
- Top diameter.
- Dedicated sawing line.
- Sawing class and sawing pattern.
- Number of center 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.

4.4.5 Paths and Process Rules

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 4.35. 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 center 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 into the Green Sorting area and sorted on dimension into the Sorting Bins. When a bin is full, it can be emptied onto the conveyer beneath the bins and routed into the Stacking area 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.

4.4.6 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 modeling 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 to be 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 modeling strategy was set to build a model including the available data and to refine it as superior data became available.

To solve this problem with 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 3.5.

4.4.7 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 8th 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.

4.4.8 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.

4.4.9 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. The speed is set to achieve correct gullet-feed index and suitable stress on the sawing machine.

Table 4.14 Feeder speed in reference to log top diameter.

Top Diameter (mm)	Feed Speed (meters/minute)
90.0 – 149.9	85
150.1 – 179.9	80
180.1 – 219.9	75
220.1 – 249.9	65
250.1 – 299.9	50
> 300.0	42

4.4.10 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.

4.4.11 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 centimeters. At the highest feed speed, the gap will increase by more than 14 centimeters. 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 meters, but in a refined model it is vital to define and apply an individual log gap distribution for every sawing class.

4.4.12 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.

4.4.12.1 Verification

Verification is often simplified if the model is built and visualized in order 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 the model building progressed. Some simplifications were made, but the model was verified without any further need of major changes.

4.4.12.2 Validation and calibration

A target production plan was created by scaling actual postings sawn during 31 weeks. 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 class 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 show 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 should in this case produce an output equal to the theoretical limit. This ideal model was named Model no. 1.
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.

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 center boards calculated at 100% equipment availability, breaks excluded, an average log length of 4.3 meters 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 center 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. 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.

Figure 4.37 shows the maximum model output with reference to the scaled sawmill data. The graph also shows the improved results after some modifications in feeder speed and log gaps.

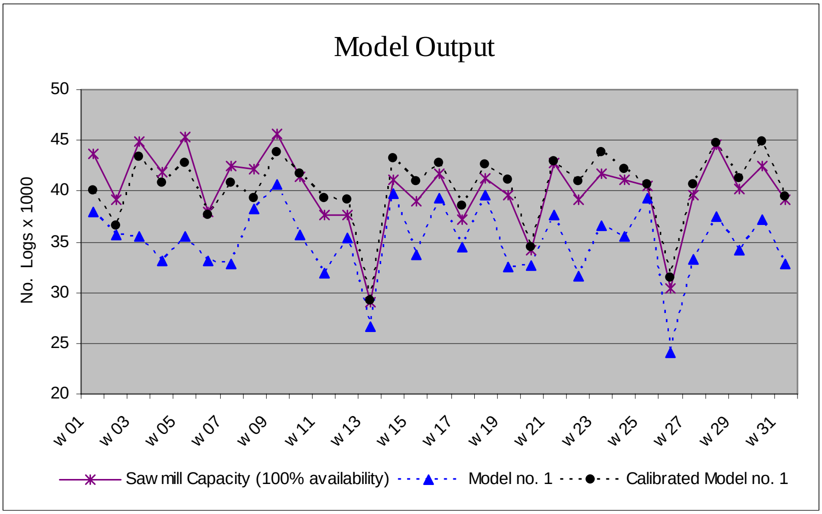


Figure 4.37 Output from Model no. 1 in comparison to theoretical sawmill capacity at 100% availability.

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 meters 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 meters.

In comparison to DES models created within the mechanical industry, the creation of a sawmill model is subject to some particular demands. 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 4.15 show a comparison 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 shold be used with caution.

Table 4.15 Ideal model output (Model no. 1)

Period	Maximum rel. difference to target (%)	Minimum rel. difference to target (%)	Average rel. 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.

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 and is possible to calculate by 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 subsequent simulation runs were sufficient, and the average value from these was plotted in Figure 4.38.

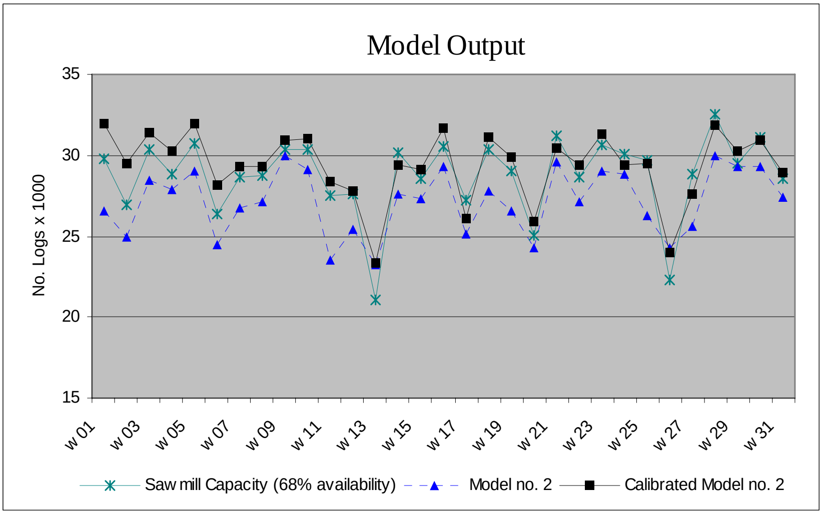


Figure 4.38 Theoretical capacities at 68% availability in comparison to model output.

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 4.16). 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.

The improvement accomplished after further modification of the stoppage data input is shown in Figure 4.38 and Table 4.16. The best-fitted model output exceeds the target by 1,390 logs (0.4%) calculated on a 12-week period.

Table 4.16 Comparison between simulation results obtained from Model no. 2 and the calibrated Model no. 2.

	Model no. 2			**Calibrated Model no. 2**		
Period	Maximum difference to target	Minimum difference to target	Average difference to target	Maximum difference to target	Minimum difference to target	Average difference to target
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 was available from the winter period, and the stoppage data included in the model was collected during the warm period. The conclusion is that sawmill models must be seasonally adapted in order to and perform optimally.

Figure 4.39 and Table 4.16 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 useduring the scenario simulations.

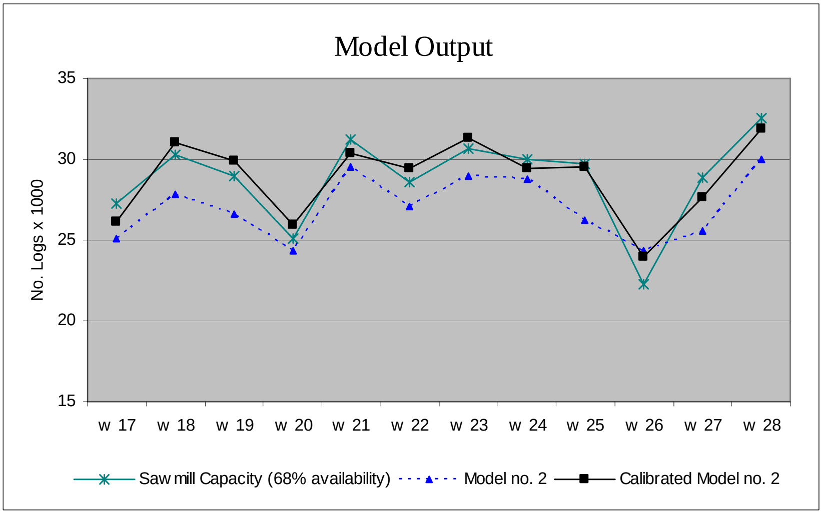


Figure 4.39 Best-fitted Sawmill Discrete Event Simulation model. The model exceeds the planned production target by 1,390 logs (0.4%) calculated on a period of 12 weeks.

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 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 uder consideration during analysis of the simulation results.

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

4.5 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.

4.5.1 Discreet 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 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 in steps of 10% with reference to the stoppage data included in the calibrated model (Figure 4.40).

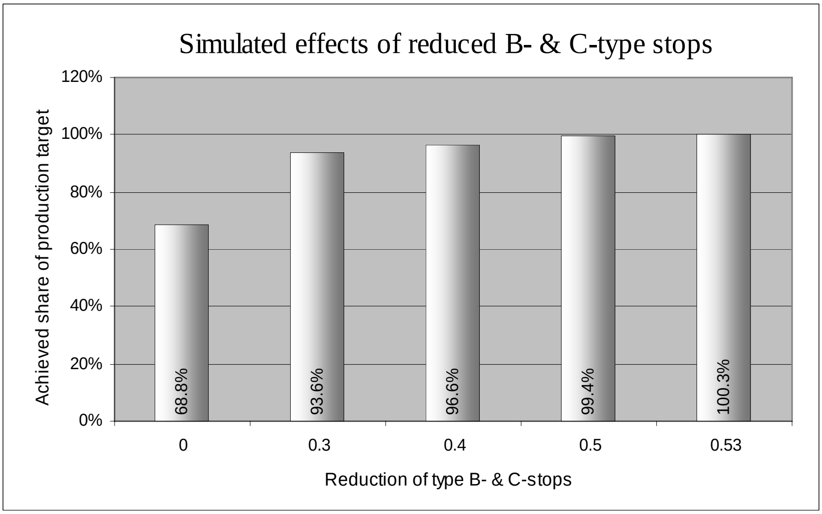


Figure 4.40 Effects on model output from reduction of stops larger than 90 seconds.

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 meters. 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 indicates 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 4.13 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 4.33.

Simulation results verify the same amount of loss in performance as the theoretical values shown in Table 4.11. The model output rapidly decreases when the average log gap is widened.

5 Discussions and Conclusions

A process can be described as a series of dependent operations conducted with the aim to achieve 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 optimized 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 comprehensive view that includes all functions in its scope, for example, that supplied within the TPM concept, is vital in order to achieve optimum production and most importantly, to attend to the causes, not the symptoms.

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.

There is an obvious difference between 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 someting 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 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 is a two-sided matter. There are always improvements available, which makes the struggle fruitful. On the other hand, the process never becomes completely finished.

The work to maintain optimal production 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 improvements; such problems can be overcome.

The OEE benchmarking concept can be a powerful tool, because it reveals and reflects the impact of three distinct losses. Generally, the focus is always set on availability and quality issues, but the performance of the equipment is regrettably easily ignored. 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 perpetrator when it comes to losses, namely idling equipment. The goal must always be to reduce, or preferably remove 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 equiped 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 one is removed from one operation, it has a tendency to immediately appear somewhere else on the production line. Minimized idling time will nevertheless ease the strain on equipment availability. A potential to increase production or perhaps even bring down feed speeds while preserving capacity arises when these two separate factors are minimized. Lower feed speed may also further diminish downtime, since machine wear is generally known to decrease at lower speed.

The OEE concept also deals with quality issues. The common way of counting the share of approved or not approved products is not applicable to sawmill production, because boards are rarely unapproved. A more appropriate quality index in sawmills is, first of all, the extracted yield.

This value is governed by on one hand sorting rules, postings, feeder speeds, setup accuracy stated or induced by the sawmill staff, and on the other hand by sawing accuracy and measurement spread caused by the sawing machines. This means that every link in the sawing process, the staff included, must perform as expected in order to achieve the highest yield. When one link fails, the whole chain is weakened.

The final yield is difficult to monitor during the breakdown process, although indirect variables such as board-dimension accuracy can always be monitored with the aid of approriate 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.

A clearly defined quality index is difficult to articulate based on the results achieved in this study, because it is difficult to establish the correct 100% level. On the one hand, the breakdown results indicate that yield can be increased by 3.8% on individual logs by applying the optimal position and sawing pattern. On the other hand, the dimension measurements performed on sawn boards show a very low deviation from the target value and spread, thus indicating well-performed machine and tool maintenance. The main problem is to separate effects on yield caused by, for example, changes in raw material supply 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 differenciate this index into two subindexes that describe both yield-related and machine-related issues.

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 limited multifactorial experiment on single logs indicates an even greater potential when the impacts of three or more breakdown variables were evaluated simultaneously.

The results show that the commonly used horns-down rotation and cross-section centering positioning may produce the best average yield. Nevertheless, new, improved tools can facilitate further improvements by finding optimal positioning for individual logs. Improved sorting accuracy and capability to screen substandard logs serve two purposes simultaneously, as both value and yield increase. The sawmill avoids expenses for the purchases of low-value raw material, and at the same time, the average yield increases when logs are sorted to 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 sorting procedure in order to be able to optimize the logs. An evaluation for optimal sawing pattern performed in the sorting 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 capable of changing sawing pattern between logs and are thus capable of applying optimal sawing patterns to individual logs.

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 a true level of losses of valuable production time. Modern sawmills are generally equipped with improved monitoring systems.

However, the new diagnostic system developed in this study serves a purpose when it comes to diagnosing the true level of losses in older 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.

Reliable data was needed in part for the OEE concept, but also as a very crucial part in the development of a Discrete Event Simulation model. 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.

Experiences from simulation projects performed in the mechanical industry show a higher degree of knowledge and awareness among the involved staff after cooperating in such a project. This awareness is achieved by the structured work to define and mediate all the rules and data needed by the modeler. 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 fact that process data supplied by the sawmill was found to be incorrect, as was immediately disclosed when it was fed into the simulation model, shows that the second stated goal was achieved, thus also setting requirements for better process-monitoring systems. 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.

Nevertheless, some excluded effects must be taken into consideration, because real sawmill production is affected by warm and cold seasons, in contrast to regular mechanical industries.

Conclusions:

- There is a great and obvious potential to improve volume yield by handling and evaluating logs as separate individuals during the sorting and breakdown process, rather than as parts in a batch.
- 3-D measurements of logs combined with online breakdown simulation in the sorting procedure make it possible to increase sorting accuracy and volume yield, thus decreasing the demand for raw material.
- The yield achieved from logs can be increased by finding optimal rotation and centering positions, rather than the commonly used horns-down and centered position. Seemingly small improvements in yield can affect raw material demand considerably when large volumes are processed.
- The sawmill process investigated suffers from a large amount of availability and performance losses. These documented losses reduce the valuable production time on the sawline by 32% due to downtime and by 23% on average due to ineffective material-handling systems.
- Simulation software provides tools with which log-breakdown or production scenarios can be evaluated repeatedly without causing disturbances in the sawmill.
- A toolbox containing appropriate process-control tools such as quality management, benchmarking methods, simulation software and process monitoring and analysis tools creates a solid base for implementation of process control and increased productivity.
- The OEE concept is a useful tool, because it offers possibilities to separately evaluate and trace improvements in availability, effectiveness and quality factors.

- The process monitoring and analysis system developed during this study makes it possible to perform diagnostic surveys in which detailed process data such as downtimes, log gaps, performance, and error causes are registered and vizualized.
- Data and information registered by operators and the process monitoring system provide detailed and reliable data useable in Discrete Event Simulation models and benchmarking tools such as Overall Equipment Effectiveness.
- Discrete Event Simulation models developed in the sawline show a high accordance between model output and planned production target. However, sawmill production is influenced by warm and cold seasons, and models must therefore be calibrated according to the actual conditions they are expected to reflect.
- A DES model built and visualized in order to imitate the real sawmill simplifies the process of 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.
- The production line setup in a sawmill with few or no subprocesses does not always justify spending a large amount of time and money in a modeling effort when theoretical calculations can come close enough. However, simulation models are motivated when complexity is increased.

The cure for boredom is curiosity. There is no cure for curiosity.
—Dorothy Parker (1893 - 1967)

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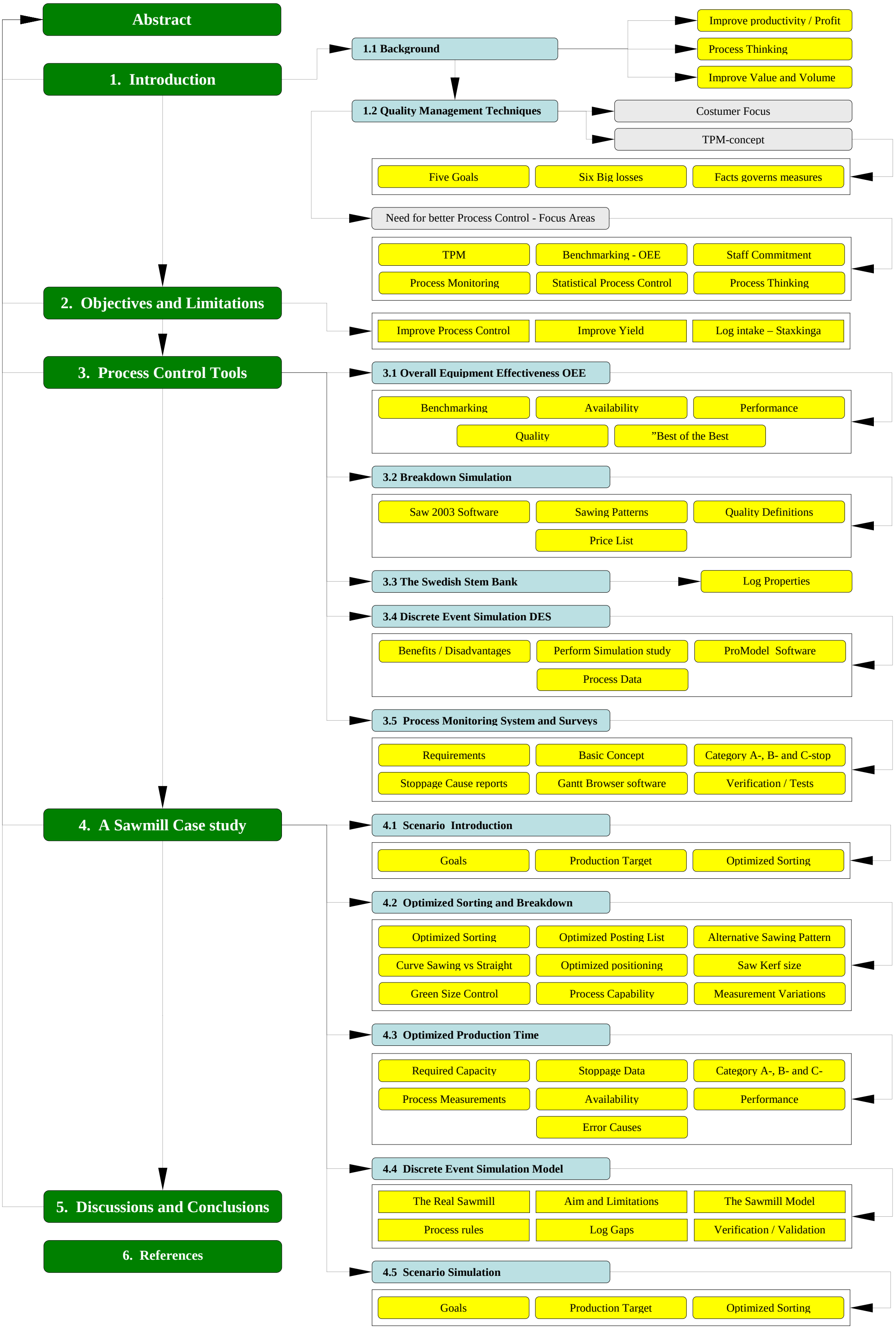
Appendix A

Flowchart and Outline of the Thesis


Abstract
1. Introduction
1.1 Background
Improve productivity / Profit
Process Thinking
Improve Value and Volume
1.2 Quality Management Techniques
Costumer Focus
TPM-concept
Five Goals
Six Big losses
Facts governs measures
Need for better Process Control - Focus Areas
TPM
Benchmarking - OEE
Staff Commitment
Process Monitoring
Statistical Process Control
Process Thinking
2. Objectives and Limitations
Improve Process Control
Improve Yield
Log intake – Staxkinga
3. Process Control Tools
3.1 Overall Equipment Effectiveness OEE
Benchmarking
Availability
Performance
Quality
"Best of the Best
3.2 Breakdown Simulation
Saw 2003 Software
Sawing Patterns
Quality Definitions
Price List
3.3 The Swedish Stem Bank
Log Properties
3.4 Discrete Event Simulation DES
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Perform Simulation study
ProModel Software
Process Data
3.5 Process Monitoring System and Surveys
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Category A-, B- and C-stop
Stoppage Cause reports
Gantt Browser software
Verification / Tests
4. A Sawmill Case study
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Production Target
Optimized Sorting
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Alternative Sawing Pattern
Curve Sawing vs Straight
Optimized positioning
Saw Kerf size
Green Size Control
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Measurement Variations
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Required Capacity
Stoppage Data
Category A-, B- and C-
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Availability
Performance
Error Causes
4.4 Discrete Event Simulation Model
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Aim and Limitations
The Sawmill Model
Process rules
Log Gaps
Verification / Validation
4.5 Scenario Simulation
Goals
Production Target
Optimized Sorting
5. Discussions and Conclusions
6. References