IMPROVEMENTS IN SAWMILL PRODUCTIVITY

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ABSTRACT

We developed a sawmill flow simulation model to identify production bottlenecks and determine where productivity improvements could be made. Sawmills often invest in a new machine center and then find out that the processing bottleneck just moves somewhere else. Our approach was specifically designed to investigate the effects of such changes on the entire system. We determined that the trimmer was the system bottleneck when both the small log and large log lines were running concomitantly. Under base case conditions, the model predicted an average board output of 13,147 boards. An increase in the processing capability of the trimmer resulted in a shift of the bottleneck from the small log line to the large log line (at the edger). This bottleneck shift was further investigated and, by allowing the simulation model to manipulate machine settings for the trimmer and edger, it was able to maximize the modeled average board output to 17,996 boards per shift (when edger set up times were not considered) and 16,708 boards per shift (with edger setup times included). These findings were presented to the sawmill management and subsequently implemented as specific improvements at the trimmer machine center, which in turn resulted in an actual increase of 10% in their sawmill's lumber volume output.

Keywords: Flow simulation, sawmill manufacturing, production bottleneck, productivity

INTRODUCTION

From an operational standpoint, a sawmill is a complex manufacturing system designed to produce dimensional lumber products from raw logs, through a series of manufacturing operations at various machine centers connected by a system of conveyors and buffer areas. At any given time while in the manufacturing flow, the intermediate products (i.e., work in process) are either a) being processed at a machine center, b) traveling between machine centers and buffer areas, or c) accumulating in a buffer area awaiting to be processed. The throughput of such mass-production systems, essentially represented by the intermediate products' movement (both in terms of volume and speed) through the system, is dependant on the processing capacities of the machine centres (including the human/operator component), the conveyor speeds, and the capacities of buffer areas. Often the production is limited by bottlenecks, defined here as processes whose limited capacities reduce the capacity of the whole system. Identifying these bottlenecks and finding solutions to reduce or eliminate them is a problem that sawmills must address when seeking to increase production during periods of strong demand. To alleviate bottlenecks, sawmills often invest in a new machine center (with typically higher capacities) and then find out that the bottleneck just moves somewhere else. Our approach was specifically designed to investigate the effects of such changes on the entire system.

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The research objective of this study was to analyze an existing sawmill and determine the potential improvement in production throughput that can be achieved by reducing or eliminating bottlenecks, through finding optimal combinations of process and machine parameters, for a given raw material and product profile.

A British Columbia sawmill was selected to be modeled for this research. The mill produces dimensional lumber, timbers, remanufacturing blanks, both dimensional lumber and custom cuts, from fir-larch (Douglas fir - *Pseudotsuga menziesii* & western larch - *Larix occidentalis*), white pine (western white pine - *Pinus monticola*), and lodgepole pine (lodgepole pine - *Pinus contorta*) species. A flow simulation model of their lumber production process was developed, to investigate the impact of a change in the manufacturing process on the entire system.

The simulation technique most commonly used to model the flow of a whole sawmill is discrete event simulation (DES). Early whole-mill simulation models were programmed using special purpose DES simulation languages: GASP II, GPSSV, and SLAM (Aune 1974, Kempthorne 1978, and Wagner and Taylor 1983). Later, sawmill models created by Kline and Araman (1990) and Dogan *et al.* (1997) were developed using SIMAN/Cinema and Arena simulation software packages.

Simulation was first used in sawmilling to analyze specific production issues like optimal log mixes or downtimes (Aune 1973, 1974). Simulation models were also used to plan new mills (Kempthorne 1978) and for improving an existing mill. Wagner and Taylor (1983) applied sawmill simulation to analyze a southern pine sawmill. Kline *et al.* (1992) simulated a furniture roughmill to assist in making management decisions for wood products manufacturing systems. Lin *et al.* (1995) modified the previous model to evaluate four alternative mill designs. Wiedenbeck and Araman (1995) created a new rough mill model to analyze the productivity of processing short lumber.

Dogan *et al.* (1997) simulated a hardwood sawmill to determine production bottlenecks. The methodology of the study, software used, and end result, were similar to this research. However, the method used to breakdown logs into lumber was different. In the Dogan model, specific board information was tracked from a log by painting one end, and collected lumber data at the green chain. The relationship between log type, quantity, and quality of lumber was then determined. In this research, specific cut patterns used at the headrig determined what board was cut from each log.

MATERIALS AND METHODS

We used the framework proposed by Law (2003) to design the simulation model and conduct an analysis of the mill process flow, consisting of the following seven steps: formulate the problem; collect information/data and construct conceptual model; verify validity of the conceptual model; program the model; validate the programming model; design, conduct and analyze experiments; and, document and present simulation results.

We formulated the problem as being to determine whether an improvement in the production throughput can be achieved by identifying and reducing or eliminating bottlenecks, through finding optimal combinations of process and machine parameters, for given raw material and product profiles.

To develop the conceptual model, two types of data were collected at the mill: preliminary data and model realization data. Preliminary data, such as plant layout and flow of material, was required to gain an understanding of how the mill is set up and how it operates. A simplified version of the sawmill machine layout and material flow is shown in Figure 1 below.
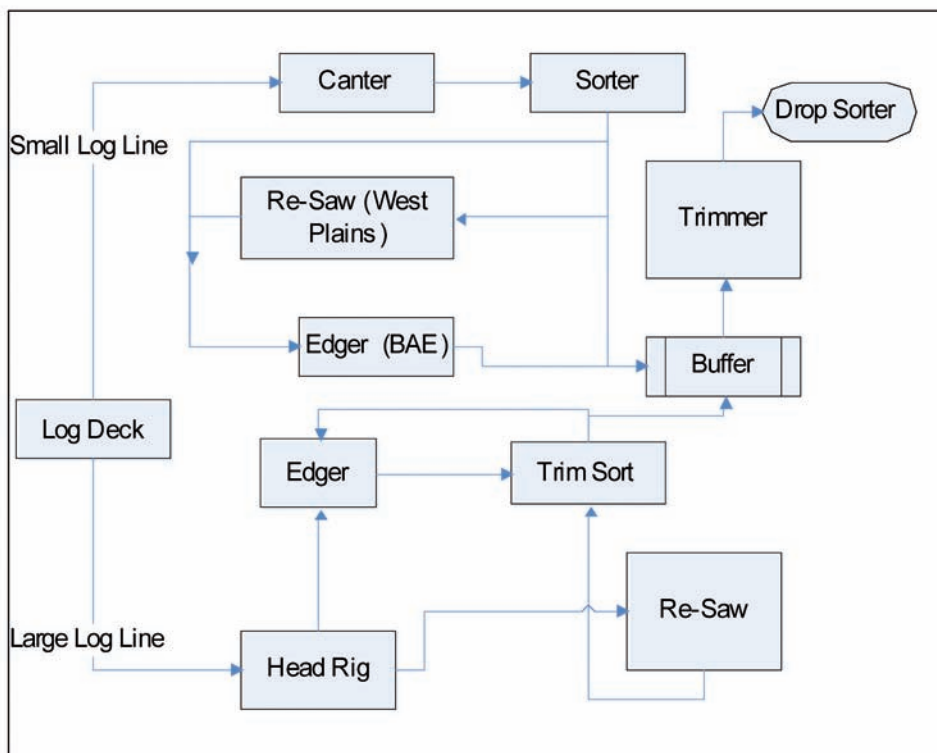
Figure 1: Sawmill layout and flow

The sawmill had two manufacturing lines: the small log line, called the canter line, processed smaller logs up to 28 cm (11 inches) in diameter, while the large log line, called the headrig line, processes larger logs over 28 cm (11 inches) in diameter.

The other key data required to understand the flow of material through the sawmill were the sawing patterns used at both the headrig and canter machine centres. The log breakdown solution implemented at the headrig was solely dependent on the choices made by the headsaw operator. In order to model and simplify this subjective decision making process, four main sawing patterns were identified for study, from observations and information collected from the headsaw operator and mill management: "lumber", "free of heart timber", "box heart timber", and "Japanese squares". Each of the four patterns were different in their breakdown of logs into lumber, and would also have a particular subsequent effect on the downstream machine centers. The sawing patterns developed for the canter were different. Unlike the headrig, which used a laser sight line and setworks control program to assist the sawyer with his manual cutting decisions, the canter used a single axis light scanner and a cutting optimization program to automatically derive which sawing pattern should be used. These patterns were then grouped based on the number of boards cut from the log in order to simplify the model programming.

Model realization data was used to drive the simulation. A time and motion study was used to collect data on the machine centers that had variable set up characteristics or processing times: the headrig, the re-saw, the canter, and the BAE edger (brand name of that machine). The trimmer process time was based on its associated conveyor speed, as it is an inline process. Machine downtime periods were collected from log books recorded by the machine operators. However, short downtimes were not recorded by operators, and we collected them by observations made within the mill. This was particularly important at the trimmer, which had frequent short failures throughout the day. The conveyor lengths were obtained from mill drawings, and their operating speeds were measured. Buffer capacities

were estimated by the mill personnel. Data for log lengths and small end diameters were collected from shift reports for both the headrig and canter machines.

A conceptual model was developed, shown in Figure 2, outlining the information required for programming the simulation model. Each general area (Canter Line, Headrig, Resaw, etc.) consisted of the machine centers associated with it. For example, the Canter Line included the Canter machine center as well as the BAE edger.
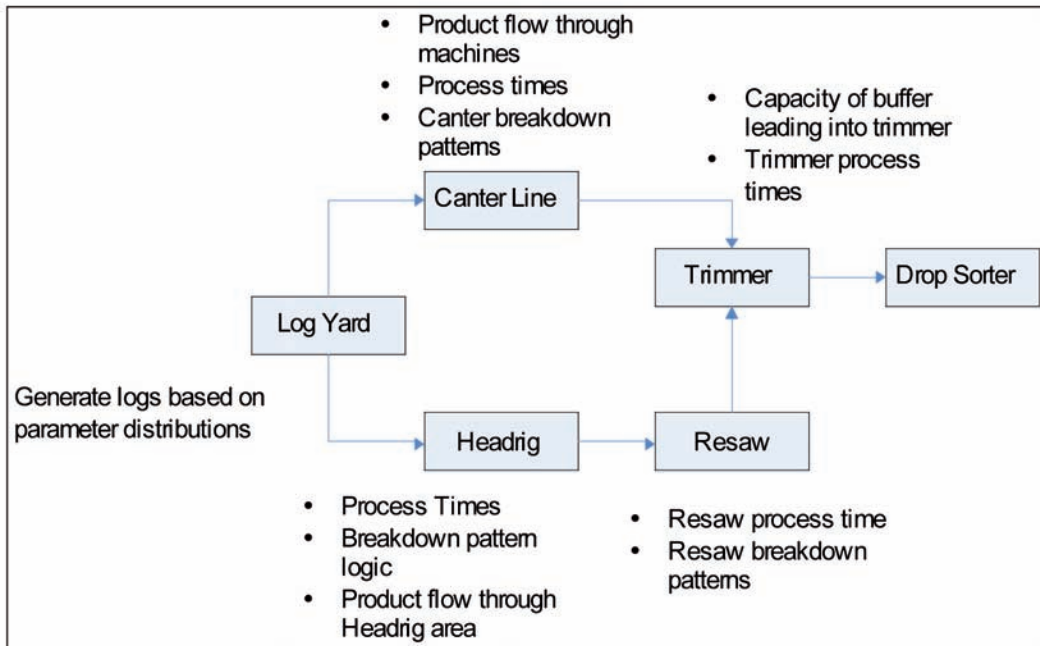

Figure 2: Information required for the conceptual simulation model

The simulation model was programmed using an academic license of the commercial software Arena 8.0 from Rockwell Software (Kelton *et al*. 2003). For the basic flow of products throughout the mill we connected machine centers and conveyors, entered conveyor speeds and lengths, introduced basic information for machine process times and product breakdowns that were expanded upon later, and concurrently developed the animation of the mill flow. Next, we used the Arena Input Analyzer to generate distributions for the machine process times and log parameters, and this information was added into the model in place of the basic information. We created sub-models for the detailed logic required, by programming a) the log breakdown logic used at the headrig for lumber, timber products, and Japanese square products, b) the log breakdown logic used at the canter, c) the breakdown logic required at the re-saw for the cants from the headrig, and d) the logic used to determine the queue order when boards climb up the waterfall simulator prior to entering the trimmer. All sub-models were then connected into the main model. We created statistical counters for board counts, logs processed, and other key indicators.

Arena's Input Analyzer was also used to generate probability density functions for the length and diameter parameters for each of the log species, as well as the time and motion studies used to determine the variable machine set up and process times. The program ranked the fitted distributions based on the smallest square error calculated, and also provides a p-value from the chi-square goodness of fit test or Kolmogorov-Smirnov (KS) test. Details of this analysis are given in Thoews (2008). The estimated white pine diameter was the only distribution that modeled well the observed data ($p > 0.15$). Since the other proposed probability functions did not statistically represent the observed data, continuous empi-

rical distributions generated from Arena Input Analyzer were used in the simulation model instead. It is important to note that a change in actual raw material inputs, such as a shift to processing larger logs of a specific species, would invalidate the use of the empirical data in the model. New data would have to be collected and either a new empirical distribution used, or if possible, a valid probability function.

In order to define machine process times within the simulation, actual process times from the saw-mill were collected. The process times of a machine center are often equal to the rate of the conveyor speed, and variability occurs when there are manual set up or align times within that process. Although some machines are set to process at specific feed speed rates, variability occurs as work pieces are aligned prior to entering the machine. We conducted time and motion studies at machine centers that had process variability either from setup times or because of the natural variation within the process. In each time study, at least 30 times were measured for each time element, at various machine processes, as described in Thoews (2008).

Once developed, the model was both verified and validated. For model verification, we constantly debugged the model by testing it to ensure that the code compiled at every step, and we also tested various sections to ensure that the model logic performed as expected. This was done throughout the entire model development process. In model validation we needed to ensure that the model was a rea-listic representation of the real system. This was achieved through face validation tests and statistical validation tests. In one face validation test we compared the number of boards per shift processed by the simulation model with the actual expected output of the real system. After examining the data from the model, the mill management determined that the model was face valid for lumber count throughput. In order to determine if the breakdown logic developed for the headrig was representative of the mill, we performed another face validation test by calculating the lumber recovery factor (LRF; the volume of lumber cut from a log measured in board feet, divided by the volume of the log measured in cubic meters) at the headrig machine center, and compared the results of the model with the actual mill mea-surements. The minimum and maximum averages from the model contained the point estimate. As a result we determined that the LRF from the model was representative of the mill for the lumber patterns for fir-larch and white pine species. However, the LRF point estimate was substantially different from the model estimates for LRF for the lodgepole pine species, and therefore did not accurately measure the breakdown of lumber for that species. Consequently, further testing was only performed with the fir-larch and white pine species. The number and volume of boards processed at the canter machine center were also analyzed to determine if the breakdown patterns developed for the model were re-presentative of the mill. It was found that the fir-larch and pine species were representative of actual production from the mill (Thoews, 2008).

In order to validate the number of logs processed at both the headrig and canter lines, the number of logs processed per minute was compared between the model output and mill data. The log per minute parameter was selected instead of logs per shift due to the random run schedule of the canter line. Mill data, containing 25 random shift reports from the headrig and 30 random shift reports from the canter, were used to compare against the model results. In the model, a total of 40 replications were run for the headrig. These consisted of 10 fir-larch lumber replications, 10 white pine lumber replications, 10 lodgepole pine lumber replications, and 10 Japanese square timber replications. Thirty canter-only replications were run, consisting of 15 lodgepole pine replications and 15 fir-larch replications. Appro-priate statistical tests were selected based on the data characteristics, following the hypothesis test flow chart as described by Chung (2004).

The four sets of data were tested to determine whether they are well modeled by a Normal (Gaus-sian) probability distribution or not, using the Kolmogorov-Smirnov test (Chung, 2004). The null hypo-thesis was that the data set was normally distributed, and test results summaries are shown in Table 1.

Table 1: Summary results for normality tests, mill and model data

Data Set	Replications	p-value
Headrig – Mill data	25	0.148
Canter – Mill data	30	>0.150
Headrig – Model data	40	0.088
Canter – Model data	30	0.014

For both the headrig mill data and canter mill data, we failed to reject the null hypothesis, and we concluded that the two data sets were normally distributed (p = 0.148 and p > 0.15, respectively). However, for the Arena output data, we rejected the null hypothesis for both the headrig and canter (p = 0.088 and p = 0.014, respectively), and we concluded that the respective data sets were not well modeled by a Normal probability distribution. As these data sets were not normally distributed, a non-parametric Wilcoxon rank-sum test was used to test for a statistically significant difference between the mill and the model data sets. We failed to reject the null hypothesis that headrig data sets for the model and mill are significantly different (Z-test = -0.102; Z-crit = -1.645; α = 0.05). The same test was used to compare the canter data sets, and again we failed to reject the null hypothesis that canter data sets for the model and mill are significantly different (Z-test = -0.355; Z-crit = -1.645; α = 0.05). Based on this analysis, we established that the actual (mill) and model results were not significantly different statistically.

In conclusion, through various validation tests, we determined that the simulation model that we developed was in fact an appropriate representation of the actual sawmill manufacturing process.

Scenario Analyses
Based on the information obtained from the simulation model while performing the verification and validation tests, it became apparent that the trimmer was the bottleneck in the sawmill when both the headrig and canter were being run concomitantly. This coincided with our basic observations at the sawmill. The model was then tested with either only the canter or only the headrig running, to determine what impact this would have on the trimmer bottleneck. Under these conditions, it was observed that the trimmer was no longer a system bottleneck, as the buffer was no longer at its maximum capacity; the mill was only constrained by how fast logs were processed at the primary breakdown (canter or headrig). Since the sawmill typically runs both lines during a shift, this situation was the one analyzed by the simulation model, specifically focused on how the bottleneck capacity would respond to different trimmer parameters. For this analysis, five different scenarios were considered. These scenarios, the rationale for the selection of these scenarios, and the selected parameters and their respective range values, are detailed below.

Scenario 1.   base case – trimmer lug speed set to 0.20 m/s (40 ft/min);
Scenario 2.   trimmer lug speed set to 0.25 m/s (50 ft/min);
Scenario 3.   trimmer lug speed set to 0.25 m/s (50 ft/min) and a 10% reduction in trimmer downtime;
Scenario 4.   trimmer lug speed set to 0.41 m/s (80 ft/min) and a 10% reduction in trimmer downtime;
Scenario 5.   trimmer lug speed set 0.41 m/s (80 ft/min), a 10% reduction in trimmer downtime, and BAE edger feed times reduced by 50%.

In the sawmill, the trimmer machine center (and its corresponding lug conveyor) was typically

operating at a speed of 0.20 m/s (40 ft/min, scenario 1). The machine had the capability of operating at speeds of up to 0.25 m/s (50 ft/min), however, this was the maximum speed that the trimmer operator could physically operate the machine (scenario 2). Due to the high amount of downtime, both short and extended, observed at the trimmer, it was estimated that the mill could implement measures to decrease downtime by 10% - this was also confirmed by the management (scenario 3). The speed of 0.41 m/s (80 ft/min) was selected for analysis because we also wanted to investigate the impact of implementing a brand new trimmer system, which was capable of running at twice the current operating speed, in order to determine the overall impact on the lumber throughput - boards produced in a shift by the mill (scenario 4). Scenario 5 was selected to reduce in half the BAE edger feed times (i.e., to speed up the edger), due to the observed shift in the bottleneck that occurred in the alternative scenarios. Each scenario was tested as one shift run, with 30 replications each. Both the headrig and BAE edger were set to operate for the entire shift duration.

RESULTS AND DISCUSSION

Under scenario 1 (base case), the average number of boards produced ('boards out') was 13,148 pieces. The trimmer operator was busy on average 97.56% of the time. A busy trimmer operator was defined as the time period when the operator was physically taking a board and placing it into the trimmer lug loader. The average volume occupied by material in the large buffer leading into the trimmer area was 5.72 m^3 (2422 board feet measure, fbm). The trimmer lug loader conveyor was utilized 92.59% on average. Lug loader utilization was defined as the percentage of "full" lugs (containing a board) from the total number of lugs of the lug loader conveyor, throughout one shift. The BAE edger was utilized on average 96% of the time. BAE edger utilization was defined as the percentage of time when the BAE edger had a board or cant in process.

Similarly, these parameters were analyzed for scenarios 2 through 5 and the summary results are reported in Table 2.

Table 2: Summary results for the five scenarios analyzed

	Average Boards Out	Trimmer Operator Utilization	Large Buffer Volume	Trimmer Conveyor Utilization	BAE Edger Utilization
	(pieces)		(m^3)		
Scenario 1	13,148	98%	5.72	93%	96%
Scenario 2	14,019	94%	3.93	89%	92%
Scenario 3	14,280	84%	0.97	81%	91%
Scenario 4	14,693	66%	0.66	66%	92%
Scenario 5	17,294	88%	3.19	85%	86%

To test if the scenarios are statistically different from each other, the Welch Confidence interval method was used, as described in Chung (2004). This method was selected because it assumes the worst case scenario where both data sets have non-equal variance, and is based on the Smith-Satterthwaite t-test. If the confidence interval includes the value 0 (zero), then it is said that there is no significant difference between the two data sets tested. The results of the Welch Confidence interval are shown in Table 3 for α=0.05, and are presented as [min value, max value].

Table 3: Welch Confidence Interval results for the alternative scenario comparison tests

Comparison	Scenario	Degrees of Freedom	t-value	Confidence Interval
A	Scenario 1 vs. Scenario 2	41	2.0195	[-1356, -385]
B	Scenario 2 vs. Scenario 3	57	2.0025	[-935, 412]
C	Scenario 3 vs. Scenario 4	58	2.0017	[-1120, 294]
D	Scenario 4 vs. Scenario 5	50	2.0086	[-3491, -1710]

Based on the results from the Welch confidence interval method, we concluded that there was a significant difference in comparison A, between scenario 1 (base case) and scenario 2 when the trimmer lug loader conveyor was increased to 0.25 m/s (50 ft/min). Based on the average output, we determined that, when the feed speed is increased from 40 to 50 lugs per minute, there is an increase of 6.6% in the average total board output. While it is within the ability of the machinery to achieve this feed speed rate, due to the manual labour involved at this station a second employee would be required to ensure that there is a smooth flow of boards for the trimmer operator to place onto the trimmer lug loader. The trimmer operator has only a few seconds to flip the board onto the trimmer lug conveyor, to visually evaluate what needs to be trimmed off, and to set up the trimmer machine. Experienced trimmer operators can manage speeds of about 0.20 m/s (40 ft/min); however increasing the speed to 0.25 m/s (50 ft/min) will result in additional operator errors, missed boards, and increased machine center downtime due to boards crossing up and blocking the conveyor as they reach the operator.

There was no significant difference between the average total lumber output in comparisons B and C, as the confidence interval included the value zero. However, there was a significant difference in comparison D when the additional BAE edger adjustment was made. These results are shown in Figure 3.
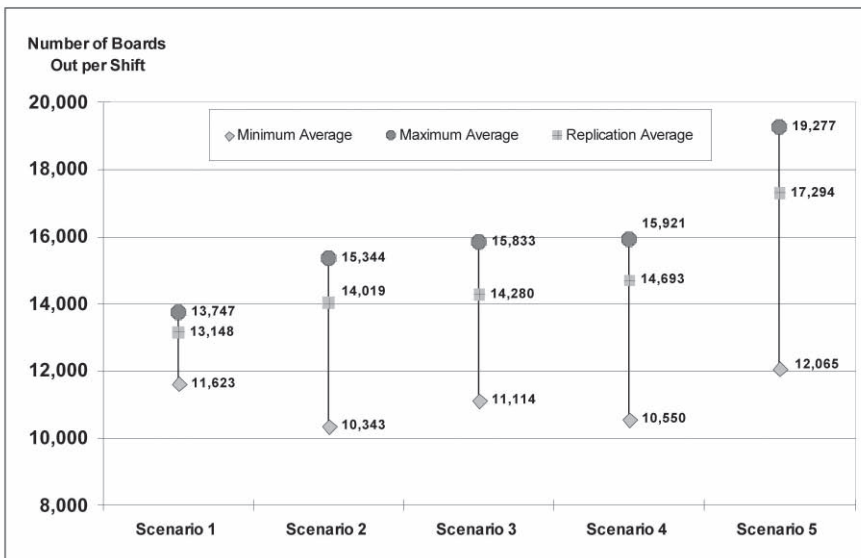

Figure 3: Average board output from each scenario

On subsequent analysis we determined that the reason for comparison test B and C to not be significantly different – even though lug speed is increased with a reduction in downtime - is that the bottleneck of the entire system shifts from the trimmer back to the BAE edger. As we increased the feed speed and reduced the downtime gradually from scenario 1 to scenario 5, we expected to see an increase in the maximum average and replication average in the board output values. This was confirmed by the scenario results shown in Figure 3, showing a general trend of increased variation in board output from scenario 1 to scenario 5. We investigated further the volume throughput of each scenario (in fbm), as well as the trimmer and BAE edger utilizations, and the results are shown in Figure 4.
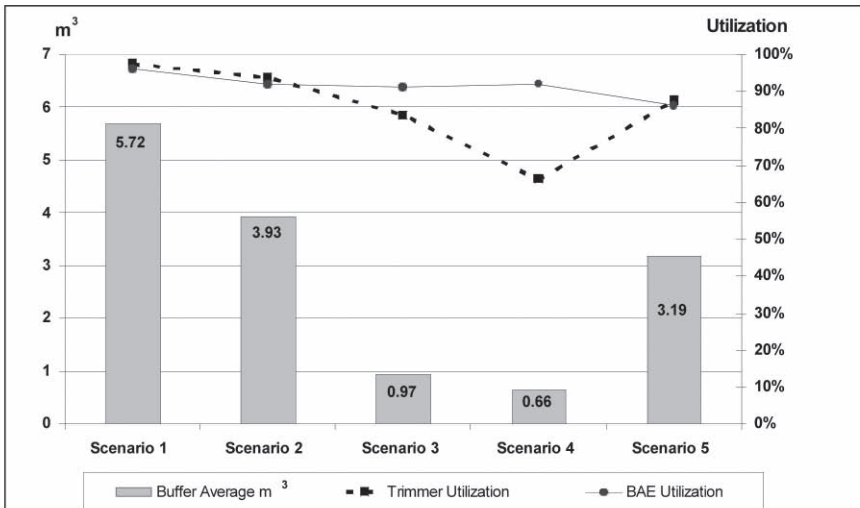

Figure 4: The change in model attributes under alternative scenario run conditions

In scenario 2, the increase in lug speed to 0.25 m/s (50 ft/min) resulted in a noticeable decrease in the average volume of boards in the large buffer prior to the trimmer. There was also a slight decrease in the average trimmer utilization. In scenario 3, the further reduced trimmer downtime considerably reduced the volume of lumber in the buffer and also caused a noticeable decrease in the trimmer utilization. Under these conditions, the buffer is full 14% of the time on average because the trimmer is able to reduce the number of boards that are waiting. In scenario 4, when the trimmer speed was increased to 0.41 m/s (80 ft/min), the reduction of boards waiting in the buffer became even more evident. The buffer was 9% full on average, and the trimmer utilization was at 66% on average. However, the BAE edger utilization was still 92% under scenario 4, indicating that the bottleneck had shifted to this machine center.

The shift in the bottleneck location is also illustrated in scenario 5 when the process time at the BAE edger was halved. With the increased process speed, the BAE edger was able to feed lumber into the main buffer at an increased rate. The volume of boards in the main buffer increased to an average value of 3.19 m³ (1353 fbm). The trimmer was busy 88% of the time as there were extra boards to supply the lug loader. As a result, the bottleneck had shifted from the BAE edger machine back to the trimmer machine center.

The analysis of the five scenarios described above indicated that an increase in only the trimmer lug loader speed, even when coupled with reduced trimmer downtime, would not eliminate the production bottleneck – as evident by the observed work in process in the queue leading into the trimmer. The scenarios results pointed out that, in order to balance out the production flow between machine centers, and thereby enabling an increase of boards produced from the entire system, improvements to both the BAE edger and the trimmer must be made at the same time.

The results of scenario 2 suggest that increasing the trimmer lug loader conveyor speed to 50 lugs per minute can lead to improvements of about 7% in the total board output. This would, however, require an additional worker to assist the trimmer operator. Also, scenario 4 results indicate that an increase in the BAE edger speed to 0.41 m/s (80 ft/min) – which would be equivalent to replacing the current machine with a higher productivity one – can lead to an average increase in total board output of about 30%.

Using OptQuest for Analysis

The shift of the bottleneck from the trimmer to the BAE edger was explored in more detail using OptQuest for Arena – a program combined with the Arena software that uses metaheuristics to search for optimal solutions within the simulation model (Rockwell Software, 2004). Based on the scenario analysis in the previous section, the main bottleneck of the system is at the trimmer machine center, under normal operating conditions. However, if a substantial increase in the trimmer speed is applied, the bottleneck then shifts to the BAE edger machine center. OptQuest was set up in such a way to determine the optimal combination of trimmer lug speed and BAE edger feed speed in order to maximize the system's total board output. For this simulation optimization the trimmer downtime was reduced by 10%, as in the previous scenario analyses.

At the BAE edger, two separate process streams are possible, depending on if the entity is either a cant or a board, and each process stream has two components associated with this machine's process time. The first component is the time that it takes to feed a piece, either lumber or cant, into the edger, and to align it properly. The second component is the feed speed of processing either a board or a cant into and through the machine. Based on the characteristics of these two components, three scenario analyses were performed:

Scenario I.   basic simulation case, as shown in Figure 5;
Scenario II.   variable process board and process cant times;
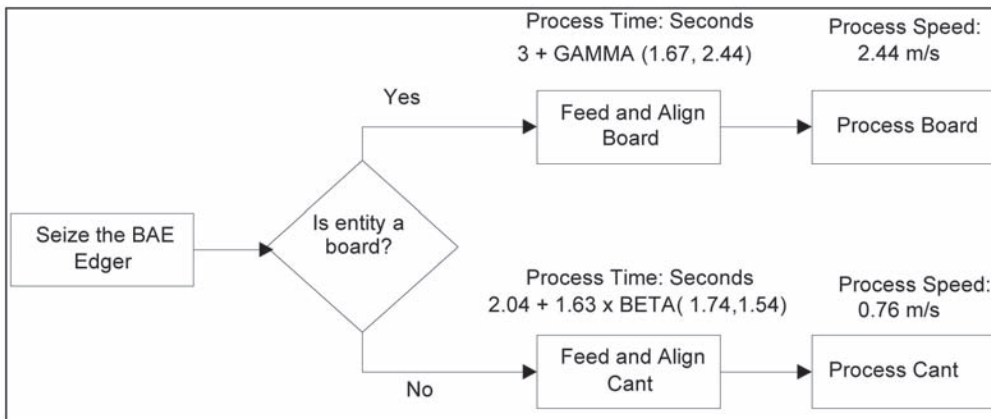Scenario III.   no feed and align process time, variable process board and process cant time.

Figure 5: BAE edger process time logic for basic simulation case I

The process times for feeding and aligning pieces were measured through a time and motion study, and the probability distributions were generated from the Arena Input Analyzer. The process times were obtained from the BAE edger operator. In scenario II, the same process times for feed and align were input into the simulation. OptQuest was set to change only the process board and process cant times. In scenario III, it was assumed that there were no feed and align process times. This assumption was made on the basis that a new BAE edger machine will most likely have a different time associated with

the set up and alignment of boards and cants. Therefore, in this scenario the feed and align times were considered to be part of the total process time. Thus, OptQuest was set up to manipulate only the total process time.

In order to setup OptQuest to run with the sawmill model, initial input was required in several steps. Four control variables were selected to be manipulated by the optimizer: 1) BAE edger –process board speed; 2) BAE edger – process cant speed; 3) Trimmer lug loader conveyor speed; and, 4) Waterfall conveyor speed. The BAE edger was controlled by the two processing times for cants and boards, while the trimmer speed was determined by the trimmer lug loader conveyor and the waterfall conveyor. The waterfall conveyor leads into the lug loader conveyor in front of the trim saw. The two conveyors control the speed of boards entering the trimmer.

Once the control variables were established, their ranges were selected. The minimum settings chosen were the current simulation process times and conveyor speeds, as shown in Table 4, and the maximum settings were set to a level equal to two times the minimum level. The step value, indicating the minimum incremental value that the optimizer can select for changing the control variable, was set to a value of 1 (one).

Table 4. Ranges for control variables

Control Variable	Minimum	Maximum	Step Value
BAE board process speed (m/s)	2.44	4.88	1
BAE cant process speed (m/s)	0.76	1.52	1
Waterfall conveyor speed (lugs/min)	40	80	1
Trimmer lug loader speed (lugs/min)	40	80	1

A process requirement constraint settings was used for the test, which stipulated that the trimmer utilization could not drop below 80%. This constraint was selected because in the scenario analysis, increases to trimmer lug conveyor speeds resulted in decreasing trimmer utilization.

Finally, the run time requirements for the optimizer were set. The simulation optimization can be set to run for: a) a number of simulations; b) a number of minutes; c) a future date; or, d) a number of non-improving solutions. Further options allowed for setting a fixed or variable number of replications, or stopping when the 95% confidence interval half width was within a specific value of the mean. For this test, the run requirements were set to 100 simulations with 30 replications, as we did not have a specific value to set the confidence intervals half width, and this provided a trade off between accuracy and processing time.

OptQuest Results

Results of the simulation/optimization run for all three scenarios are presented in Table 5.

Table 5. Simulation results for scenarios I - III

Variable	Basic Simulation Case – Scenario I	Opt-Quest Scenario II	Opt-Quest Scenario III
Average boards out (# boards/shift)	13,147	16,708	17,996
BAE board process speed (m/s)	2.44	4.75	2.47
BAE cant process speed (m/s)	0.76	1.52	1.31
Trimmer conveyor speed (lugs/min)	40	70	78
Waterfall conveyor speed (lugs/min)	40	40	67
Trimmer Utilization (%)	98%	85%	94%

The results from the OptQuest analysis confirmed our previous observations made by the manual scenario analysis. It was found that the BAE edger limits the total number of boards out of the sawmill when the trimmer conveyor speeds are increased. This is particularly evident with the set up times required for loading boards and cants into the BAE edger. In order to obtain a maximum board output for scenario III (with setup times removed and keeping trimmer utilization at 80% or more) the OptQuest simulation optimization found that the BAE edger feed speed must be increased by 0.03 m/s (7 ft/min), while the cant process time must be increased by 0.55 m/s (107 ft/min).

CONCLUSIONS

A discrete event simulation model was developed in order to study where productivity improvements could be made in an existing sawmill. This was achieved by analyzing the flow of lumber products throughout the manufacturing process, determining where the existing production bottlenecks occurred, and the impact of the amount of boards produced in a shift when these bottlenecks are removed. Simulation was selected to analyze this problem for a number of reasons. The model was able to deal with complex random elements that exist in a sawmill and could quickly determine the effects of different manufacturing decisions without interrupting actual production of the mill. The use of animation integrated with the simulation software helped to convey the results of the model to the mill management who were able to see the impact of various process decisions on mill flow as lumber pieces were routed to the various machine centers in the mill.

We discovered that when running only either the headrig line, or the canter line, the sawmill production capacity was constrained by these primary breakdown machine centers. However, when both machine centers were used concomitantly, the trimmer became the sawmill bottleneck. When the trimmer speed was increased from 0.20 m/s (40 ft/min, base case) to 0.25 m/s (50 ft/min) combined with a 10% reduction in downtime, we determined that the bottleneck had shifted from the trimmer to the BAE edger. This was evident by the 83% decrease in lumber volume of the buffer leading into the trimmer, and the decrease in trimmer utilization from 98% to 84% when compared to the base case. Under these conditions, the average board output only increased by 8.6% over the base case. When the speed of the trimmer was increased to a theoretical 0.41 m/s (80 ft/min) – consistent with replacing the trimmer machine with one that would run at double the speed – with a 10% reduction in downtime and 50% reduction in BAE edger feed speeds, the average board output per shift increased by 31.5%.

These results were confirmed by the OptQuest analysis, which used metaheuristics to derive an optimal solution. Under Scenario II, where the current feed and align times were considered at the BAE edger, OptQuest found a process solution that produced on average 16,708 boards per shift. This was an increase of 27% over the base case scenario. Under Scenario III, where the feed and align time was assumed to be part of the manufacturing process for the BAE edger, OptQuest found a process solution that produced an average of 17,996 boards per shift. This is an increase of 37% over the base case scenario.

The mill management was presented with the findings from this study, and based on these results some improvements were made to the flow of products in the trimmer area. The mill management increased the feed speed of the trimmer lug loader to 0.25 m/s (50 ft/min), and reduced some of the downtime experienced at the trimmer. These changes resulted in an actual increase of 10% to the mill output, slightly more than the 8.6% increase that the simulation model predicted under similar conditions.

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