USE OF COMPUTER SIMULATION IN MANAGING MANUFACTURING SYSTEMS: AN APPLICATION OF A SAWMILL-FLOW SIMULATOR TEMPLATE IN LUMBER MANUFACTURING.

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ABSTRACT

The study compared two policies on mill-wane allowance, i.e. the current mill's wane allowance and the maximum wane allowance allowed by the Western Wood Products Association (WWPA) stud-grade rules. Different levels of wane-allowance may have different impacts on lumber recovery, grade recovery, production, machine utilization, profit, and flow of lumber. Increasing the allowable proportion of wane on lumber should increase lumber recovery and production. However, increased proportions of wane on lumber lower its grade and thus its price. The question is, would this gain in recovery and production be large enough to offset lower prices for high-waned lumber? The sawmill-flow simulator template (SFST) was used to model the study mill and investigate the impact of changing the mill-wane policy. Employing the maximum wane allowance allowed by WWPA grade rules, lumber production increased from the current 393.55 m^3 to 416.54 m^3. Also, with more wane, the recovery rate and lumber recovery factor increased by 5.9% and 5.7%, respectively. However, regardless of the increases, it was found that there was no need to change the wane allowance, because with the current wane allowance the mill generated $2,364 more per shift than did with the maximum WWPA wane allowance. In addition, the model identified the debarker machine as a bottleneck in lumber production at the study mill. By increasing the debarker speed by 10%, and maintain the current wane allowance, an average of $4,279 per shift more profit and a more synchronised mill-flow could be achieved. Managers need timely and comprehensive information on which to base important decisions. Simulation provides a method to rapidly conduct experiments that predict results of alternative manufacturing decisions. In deciding which wane allowance to use, no raw materials, no machine times, no human resources, and no production time were utilized to reach the decision. That is the real power of simulation as a decision tool.

Keywords*:* Simulation-decision making-wane-grade rules-resources-utilization.

INTRODUCTION

Simulation is defined as the imitation of the operations of a real or proposed world-process or system over time. Simulation involves the generation of an artificial history of a system using a model and the observation of that artificial history to make decisions concerning the operating characteristics of the real system (Banks *et al.* 1996). Computer simulation makes use of computerized models to gain a better understanding of the system (Kelton *et al.* 2002). A sawmill system simulation model for example, can be defined as a collection of processing machine centres, raw material, work in progress, conveyors or transporters, surge decks, and people that act and interact to meet company's set goals.

Simulation was selected for this study because of the dynamics and modelling complexity of sawmills. Other techniques such as linear programming and dynamic programming, queuing theory, etc do not have the capability of modelling these dynamic and complex systems. In addition, simulation is the most common method for constructing models that include random behaviour of a large number and a wide variety of components (Askin and Standridge, 1993). Sawmill managers and designers face a multitude of decisions each day. They must be skilled at balancing inter-dependent variables including raw materials, personnel, equipment, product mix, product quality, orders and money. Changing any of these variables in one part of the mill can have unforeseen and sometimes detrimental impact upon other parts of the mill. Studying only one component of such a broad system in isolation from other components may not produce the best overall results (Kline *et al.* 1992). Furthermore, a full understanding of sawmill operations requires attention not only to the variables mentioned above but also to other sawmill variables. Other sawmill variables that need attention include plant layout, material flow, scheduling priorities, in-process inventory, labour and machine costs, alternative routings, interaction among machines, changes in products and value over time, and changes in technologies. Extreme heterogeneity in raw materials adds significantly to the complexity of sawmill systems. Instead of experimenting with the actual system to determine the impact of the decision, a simulation model can be built to assess the possible changes brought about by the decision.

This study was done at a small-log sawmill in the Northwest US, hereafter referred to as the study mill. The study compared two mill-wane allowance policies, i.e. the current mill wane-policy was compared to the maximum wane allowance allowed by the Western Wood Products Association (WWPA) stud-grade rules (1998). Wane is defined as the presence of bark or lack of wood from any cause on the edge or corner of a piece of wood. Different levels of wane-allowance may have different impacts on lumber recovery, grade recovery, production, machine utilization, surge decks, profit, and flow of lumber. The study mill produces lumber studs and the current stud mill grade distribution is 45, 50, and 5% premium stud, stud, and economy stud, respectively. The study mill products include a high proportion of high-grade finished studs with wane as low as 0 to 33% of the stud face widths. A decision to produce high-grade (premium studs) was made by the mill management to meet the demand of a "specific market". The motivation behind the decision was that this "specific market" would pay a $50/MBF premium for studs with little wane. The Western Wood Products Association (WWPA) (1998) stud-grade rules allow wane up to 50% of lumber face width and 30% of thickness. The study mill, however, allows wane up to only 33% of width and 30% of thickness in their sawing solutions.

A shift to greater wane allowance would likely prompt the mill to quit the premium stud market, since far fewer pieces of this grade would be produced. Therefore, the stud-grade distribution with maximum WWPA wane allowance was estimated to be 0, 95, and 5% premium stud, stud and economy stud, respectively. Increasing the allowable proportion of wane should increase lumber recovery and production. However, increased proportions of wane on lumber lower its grade and thus its price. Would this gain in recovery and production be large enough to offset lower prices for studs? This constituted the main question for this study.

Mill description

The layout of the study mill is presented in Figure 1. The machines at the study mill include a debarker, a log cut-off saw, a gang chipping headrig, a sorter, an unscrambler, and a lumber stacker. The study mill operates two eight-hour shifts per day

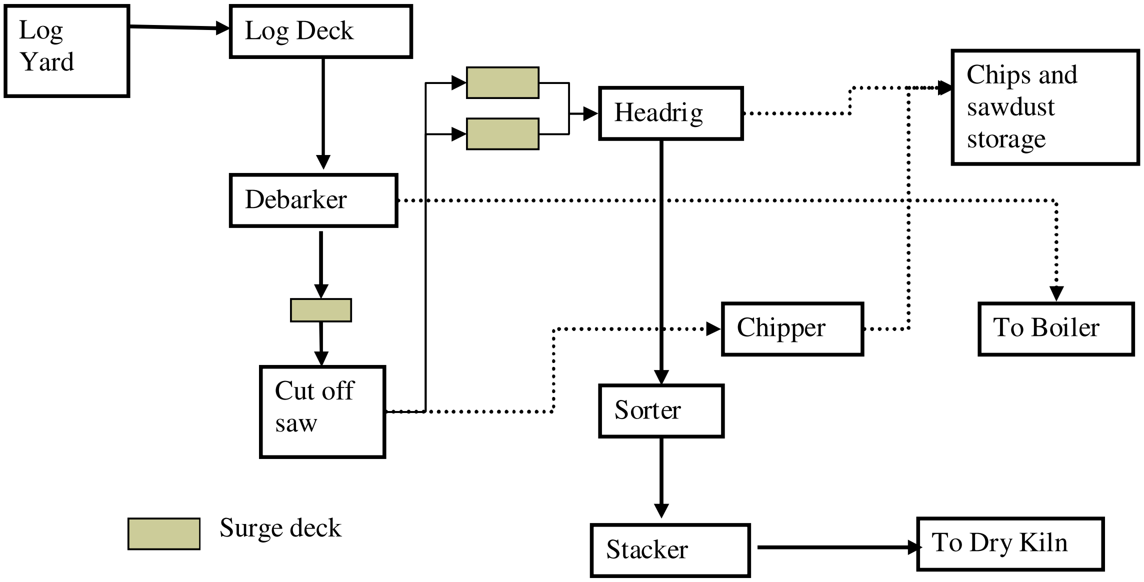

Figure 1 Study sawmill process flowchart

In Figure 1, sawlogs from the log yard are transported to a log-deck using front-end wheel loaders. From the log-deck a conveyor is used to convey logs to a debarker machine centre where bark is removed from sawlogs. Sawlogs are then conveyed to a cut-off saw. At the cut-off saw, the ends of short logs (i.e. logs already cut to lumber lengths) are just cleaned up and proceed to the headrig machine centre. All multiple-segment sawlogs are cross-cut to lumber-lengths plus trim allowance. Off-cuts from the cut-off saw are sent to a chipper. Between the cut-off saw and the headrig of this sawmill, two parallel queues or surge decks store sawlogs for the headrig. Log diameter determines the queue to which a particular log will proceed. At the headrig, sawlogs are processed into lumber, chips, and sawdust. Lumber is conveyed to a J-bar lumber sorter. At the sorter, lumber is then sorted by dimension and placed into batches of 248 to 527 pieces depending on the lumber sizes within the batch. Batches are then conveyed to an unscrambler where they are singulated. Lumber is then stick-stacked at a lumber stacker. Wheel loaders move lumber stacks either to a green lumber yard or directly to kiln carts to form kiln charges. The dotted line from the debarker represents movement of barks to the mill boiler whereas dotted lines from the chipper and headring represent movement of chips and sawdust to storage facilities. A dotted line from the cut-off saw represents flow of off-cuts to the chipper machine.

The study mill products include a high proportion of high-grade finished studs with wane as low as 0 to 15% of the stud face widths. A decision to produce high-grade (premium studs) was made by the mill management to meet the demand of a “specific market”. The motivation behind the decision was that this “specific market” would pay a $50/MBF premium for studs with little wane. The Western Wood Products Association (WWPA) (1998) stud-grade rules allow wane up to 50% of width and 30% of thickness. The study mill, however, allows wane up to only 33% of width and 30% of thickness in their sawing solutions.

METHODS

The sawmill-flow simulator template (SFST) used in this study is a unique and simple simulation package developed by the author for predicting results of changes at small-log sawmills. It belongs to the family of stochastic and discrete event simulation models. The SFST is appropriate to be used in lumber manufacturing because of the stochastic and discrete characteristics observed in sawmill operations. For example in sawmills, each log fed into the sawmill, each log processed, and each piece of lumber produced, change the system state at narrow windows of time (discrete) as the lumber manufacturing process continues. Examples of stochastic variables in sawmills include machine processing times, material inter-arrival times, machine down and up times, queue lengths, repair times, and material throughput times.

The sawmill-flow simulator template (SFST) is made up of two main components: 1) the log–sawing logic, and 2) the sawmill-flow logic. The log-sawing logic, also known as log breakdown, is a key to predicting lumber recovery. The sawmill-flow logic analyzes machine utilization and processing times, material flow in sawmills, and production. Sawmill systems often include the sawmills (green end), kilns, and planers (dry end).

All machines involved in processing of lumber were described in the SFST. Small-log sawmill data were collected at the study mill to allow model building and testing. The types of data collected included log descriptions, log size distribution, log-sawing solutions, lumber sizes and prices, equipment types and configurations, machine-material processing times, types of material handling mechanisms and speed, log arrival rates (inter-arrival times), failure patterns of machines, working schedules, i.e. number of shifts and break-lengths.

Of the data collected at the study mill, material processing times, log arrival rates, and machine-failure patterns were random variables. These variables are better represented by probability distributions than by their mean values (Law and Kelton 2000, Biller and Nelson 2002, Kelton *et al.* 2002). Simulation models rely on the accurate specification of these distributions and their associated parameters that serve as inputs to the models (Henderson 2003). Therefore, raw data on these variables were collected and fit with probability distributions. The *"Input Analyzer for Arena®" software* was used to fit continuous theoretical distributions to observed raw data, estimates their parameters, and measures how well they fit the data. Continuous theoretical distributions were chosen because they better represent randomness than do empirical distributions (Law and Kelton 2000). The following debarker sawlog process times (in seconds) were collected at the study mill and illustrate how distribution functions were fit to various sets of empirical data. The debarker processing time empirical data is presented in Table1.

However, due resources limitations, the scope of the SFST was limited to the green end of the sawmill, i.e. everything from the log yard to green lumber-sorting. Decisions made at the green end of the sawmill influence the overall performance of the sawmill system. Also, the green end sets the production, lumber sizes, lumber grade recovery, lumber volume recovery, and many other sawmill performance parameters, therefore it was logical within the limited resources of the author to model the green end than any other part of the sawmill system

Table 1 A set of raw data to be converted into a distribution function using the *Input-Analyzer* for Arena®

6.67	6.67	6.67	6.67	7.50
6.00	7.50	6.00	6.00	5.45
6.00	6.00	6.67	7.5	5.45
5.45	6.00	5.45	5.45	6.00
5.45	6.00	6.00	6.00	6.67
5.00	8.57	8.57	10.00	10.00
10.00	6.67	7.50	6.00	6.67
6.00	10.00	10.00	8.57	8.57
12.00	12.00	10.00	7.50	7.50
8.57	8.57	6.00	6.67	8.57
6.00	6.67	8.57	6.67	7.50
12.00	6.67	5.45	5.45	5.45
6.00	5.00	6.00	6.67	5.00
6.67	5.45	6.67	5.45	7.50

These data were keyed into an Excel spreadsheet and saved as a text (delimited) file. Uploading the file into the *Input Analyzer* produced a histogram of the data shown in Figure 2. In this case, the best fit distribution was a Weibull distribution. The *Input Analyzer* also generated a distribution expression together with the distribution parameters (5 + WEIB (2.18, 1.12). A summary of all possible distributions and squared error values associated with each distribution starting from the smallest to largest were also generated. Two criteria were used to select the best fit distribution (Kelton *et al.* 2002): 1) the mean squared error which measures quality of the distribution's match to the empirical data (the smaller the better fit), and 2) *p-values* from the chi-square and Kolmogorov-Smirnov (K-S) goodness-of-fit hypothesis tests.

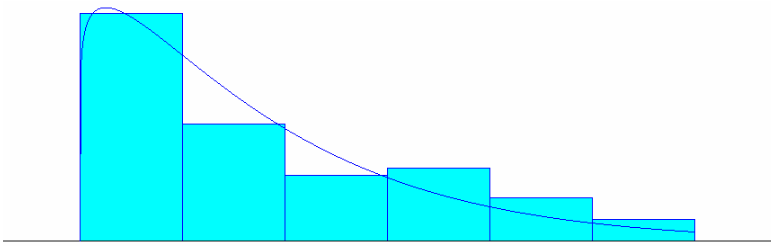

Figure 2 A function density distribution fitted to the empirical data

Distribution: Weibull
Expression: 5 + WEIB (2.18, 1.12)
Chi Square Test
Corresponding *p*-value < 0.005
Kolmogorov-Smirnov Test
Corresponding *p*-value = 0.1481

Fit All Summary

Function	Square Error
Weibull	0.0739
Gamma	0.081
Erlang	0.0877
Exponential	0.0877

The SFST has an Excel user interface. Therefore, data on machine processing speeds, conveyor lengths and speeds, log specifications and distributions, surge deck capacities, stud-grade distribution, lumber and residual prices, log costs, and fixed costs were described in Excel spreadsheets and read into the SFST. Fixed costs were assumed to be \$2000 per hour and log costs were assumed to be \$55 per ton. Lumber prices were quoted from the Random Lengths Yardstick (January, 2005). Prices for residual materials were collected at the study mill and included \$45 per bone-dry ton of chips and \$10 per ton of sawdust.

Running the SFST

Since the starting and ending conditions of the simulation were known (i.e. after eight hours of operation), the SFST simulation was treated as a terminating simulation (i.e. a simulation in which there is a "natural" event E that specifies the length of each run(replication) (Law and Kelton 2000). Statistics on number and volume of logs processed, lumber and residue production, machine utilization, lumber recovery, and values of both lumber and by-products were generated.

Because the SFST embeds stochastic parameters in it (e.g. processing times, log interarrival times, etc), comparing the two wane allowances based on a single run of each scenario would be an unreliable approach (Law and Kelton, 2000). Therefore, the comparison was improved by running ten dependent SFST replications of 8-hour lengths (the shift length time) for both scenarios. The data generated by the SFST were then compared on the basis of their average values across replications. However, since the profit realized from each scenario was crucial in deciding which wane allowance to use, it was subject to further analysis. The analysis involved constructing a confidence interval for the difference in profit for the two scenarios. By constructing a confidence interval, the observed profit difference was tested as to whether it was significantly different from zero. The profit difference was also quantified. Therefore a paired-*t* confidence level ($\alpha = 0.1$) was constructed using the following expressions as suggested by Law and Kelton (2000):

$$Z = X_{1j} - X_{2j} \qquad (1)$$

Where;

1, 2 = Current little wane and more wane scenarios, respectively

X_{1j} = Profit generated by the current little wane scenario in the *j-th* replication

X_{2j} = Profit generated by the more wane scenario in the *j-th* replication

Z = the observed difference between the two profit values

$$\bar{Z}(n) = \frac{\sum_{j=1}^{n} Z_j}{n} \qquad (2)$$

Where;

$\bar{Z}(n)$ = average profit difference

$$\hat{Var}[\bar{Z}(n)] = \frac{\sum_{j=1}^{n}[Z_j - \bar{Z}(n)]^2}{n(n-1)}$$

Where;

$\hat{Var}[\bar{Z}(n)]$ = the profit difference variance

$n_1 = n_2 = 10$ - number of replications and equation (4) was used to determine the confidence interval

$$\bar{Z}(n) \pm t_{(n-1),1-\alpha/2}\sqrt{\hat{Var}[\bar{Z}n)]} \qquad (4)$$

RESULTS AND DISCUSSION

Machine utilization

Table 2 contains simulated mean machine utilization values for the four primary machines in the study mill. Although there was no real difference in machine utilization between scenarios for the debarker, cut-off saw, and headring, the sorter showed increased utilization for the maximum WWPA wane scenario. The increased utilization observed was expected, because more wane allowance produced more lumber (Table 4) than did the current high-standard wane scenario. The additional pieces sent to the sorter lead to an increase in sorter utilization.

Table 2 Simulated means of machine utilization (%) for 10 replications

	Machine utilization	
	Current high-standard wane	Maximum WWPA wane
Debarker	99.94	99.92
Cut -off saw	68.37	68.30
Chipping headrig	89.95	89.41
Sorter	81.52	84.74

Number and volumes of log processed

Results on the number and volumes of logs processed are shown in Table 3. The number of log pieces and volumes were similar in both scenarios. This may be explained by looking at the machine utilization summary (Table 2). The debarker machine (the first machine from log inlet) was utilized almost 100% of the time and therefore was the determinant of how many logs could be processed in a run regardless of the available capacities at down stream machines in either case.

Table 3 Simulated means of logs processed for 10 replications

	Logs processed	
	Current high-standard wane	Maximum WWPA wane
Number of logs (pcs)	8,040	8018
Volume of logs (m^3)	598.3	597
Weight of logs Kg	624,800	623,500

Lumber production

Lumber production increased from 393.64 m^3 (166,903 bf) produced with the current high-standard wane scenario to 416.62 m^3 (176,648 bf) produced with the maximum WWPA wane scenario (Table 4). This was an increase in lumber production of 5.8% and was expected. Less wood was converted into residuals in the maximum WWPA wane scenario than in the current high-standard wane scenario. Consequently, less chips and sawdusts were produced by maximum WWPA wane scenario (Table 4).

Table 4 Simulated means of lumber and residual production for 10 replications

	Lumber and residual production	
	Current high-standard wane	Maximum WWPA wane
Lumber, m^3	393.64	416.62
Chips, BDT	218	169
Sawdust, BDT	110	91

Lumber recovery

Table 5 contains summary data for lumber recovery. Cubic recovery (recovery rate) and Lumber recovery factor (LRF) increased with increased wane allowance. These results were expected as more lumber per cubic foot of logs was produced in the maximum WWPA wane scenario than in the current high-standard wane scenario.

Table 5 Simulated means of lumber recovery for 10 replications

	Lumber recovery	
	Current high-standard wane	Maximum WWPA wane
Cubic recovery (%)	43.88	46.77
LRF	7.88	8.36

Product values and operating costs

Table 6 summarizes the product values and operating costs from both scenarios. The current high-standard wane scenario generated an average of $2,364 more profit per 8-hour shift than did the maximum WWPA wane scenario. The profit difference analysis showed there was a significant mean profit difference of $ 2,513 ± 296 at 90% confidence level. Since this interval does not contain a zero, suggests that no change should be made to the current wane policy. Of the $2,364 average difference in profit between scenarios, 93% was contributed by the difference in chip value. It is evident that the amount of chips can make a real difference in deciding which wane allowances to use at a particular mill.

Table 6 Product values, log costs, and fixed costs

	Current high-standard wane	Maximum WWPA wane
Lumber value	63,656	63,516
Chips value	9,816	7,621
Sawdust value	1,114	913
Total Product value	74,586	72,050
Log costs	34,464	34,292
Fixed costs	16,000	16,000
Profit	24,122	21,758
The confidence interval of profit difference	$ 2,513 ± 296	

The simulation output identified the debarker machine as a bottleneck (i.e. the most critical machine(s) that limits a system from achieving higher production (Goldratt and Cox 2004) in lumber production at the study mill. The bottleneck machine is expected to occur at the most expensive machine (Kempthorne 1978). At the study mill though, the most expensive machine is the chipping headrig not the debarker. Mill management should find a way to increase capacity at the debarker. Debarker capacity improvement could lead to an increase in lumber production. For example, ten replications of the SFST were run when the debarker processing speed was increased by 10% over the current debarker speed. Results presented in Tables 7 through 10 indicate that an increase in debarker speed was not only beneficial to production and profit of the mill, but also a more synchronized mill-flow was achieved. The increase in debarker speed pushed more logs through the mill (Table 8) and exploited the capacity of the headrig (Table 9). By increasing the debarker speed, an average of $4,279 per shift more profit could be achieved (Table 10).

Table 7 Simulated means of logs processed for 10 replications

	Logs processed	
	Current debarker speed	Higher debarker speed
Number of logs (pcs)	8,040	8,894
Volume of logs (m^3)	598.3	659.77
Weight of logs Kg	624,800	687,200

Table 8 Simulated means of machines utilization (%) for 10 replications

	Machine utilization	
	Current debarker speed	Higher debarked speed
Debarker	99.94	99.51
Cut -off saw	68.37	77.37
Chipping headrig	89.95	99.51
Sorter	81.52	88.92

Table 9 Simulated means of lumber and residual production for 10 replications

	Lumber and residual production	
	Current debarker speed	Higher debarker speed
Lumber, m^3	393.56	433.90
Chips, BDT	218	240
Sawdust, BDT	110	117

Table 10 Product values, log costs, and fixed costs

	Current debarker speed	Higher debarker speed
Lumber value	63,656	70,170
Chips value	9,816	10,829
Sawdust value	1,114	1197
Total Product value	**74,586**	**82,196**
Log costs	34,464	37,795
Fixed costs	16,000	16,000
Profit	**24,122**	**28,401**

CONCLUSION

The study results indicated that there was no need to change the wane allowance, because the current high-standard wane scenario generated $2,364 more per shift than did the maximum WWPA wane scenario. It was also noted that the debarker and not the headrig was the bottleneck machine at the study mill. If the mill management could find a way to increase capacity of the debarker, the SFST showed that both production and profit would increase.

This study demonstrated how computer simulation could be used as a tool in the decision- making process. By applying the SFST/simulation to investigate the effect of use of different wane-allowances, resources were saved. No raw materials, no machine times, no human resources, and no production time were utilized. Also, no lumber was produced in reaching the decision. Prior to making a decision, a broad picture of the would-be performance of the system could be brought to the manager. The evaluation of mill performance as demonstrated in this case study shows the real power of simulation as a decision tool.

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