ROUGH MILL SIMULATIONS REVEAL THAT PRODUCTIVITY WHEN PROCESSING SHORT LUMBER CAN BE HIGH

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ABSTRACT

Handling rates and costs associated with using short-length lumber (less than 8 ft. long) in furniture and cabinet industry rough mills have been assumed to be prohibitive. Discrete-event systems simulation models of both a crosscut-first and gang-rip-first rough mill were built to measure the effect of lumber length on equipment utilization and the volume and value of the rough parts produced. In the crosscut-first mill model, the volume and value of parts produced from short-length lumber compared favorably with the volume and value of parts produced from the medium- (8 to 13 ft. long) and long- (14 to 16 ft. long) length lumber. A "conservative case" short-lumber scenario was also simulated in which the distribution of cutting lengths was varied. The short-lumber volume and value yields for this model version were somewhat lower than the medium- and long-lumber yields. In the gang-rip-first mill model, the volume and value of parts produced from short lumber were equal to approximately 60 percent of the production from the medium and long lumber. The unstacker andplaner were unable to provide sufficient material to the ripsaws which, in turn, were unable to process the short lumber fast enough to keep the chop saws busy.

Before the furniture and cabinet industries will accept short-length (< 8 t?.) hardwood lumber, several obstacles must be overcome. These obstacles include: uncertainties about cutting yield (6,7), handling problems and costs, and the furniture industry's lack of experience with short lumber (5). If short-length lumber processing rate and cost estimates were available, the value of short-length lumber to the furniture and cabinet industries could be evaluated.

The number of problems associated with handling short lumber in any operation depends on the number of processing steps that the lumber goes through, the degree of system automation, and the level of specialization of the system's equipment for longer lumber. In a gang-rip-first furniture or cabinet rough mill, the length of the lumber remains an issue until the lumber reaches the chop saw. In a crosscut-first rough mill, all operations that follow the crosscut operation are adapted to handling short, cut-to-length boards; lumber length distinctions are lost as soon as the crosscut operation has been performed.

Visits to several rough mill operations have suggested that the following equipment limitations may be commonplace:

1. Planer/surfacer hold down systems that are not designed for short material lead to board skewing and stalling in the machine and may represent a safety hazard to operators in some cases.

2. Stacking and unstacking hoists have supports (knees) that are spaced to handle lumber longer than 8 feet.

3. Stick guides on the automatic stacker may not be optimally spaced to allow placement of sticks near the ends of short boards.

4. Limit switches (electronic eyes) on some pieces of equipment are unable to detect short lumber that can lead to misfeeds and handling problems.

5. Widely-spaced stops on accumulating conveyors can cause short boards to skew when pressure, resulting from accumulation, is applied.

Industry process control experts who have studied the feasibility of short-length-lumber utilization generally agree that, in most cases, these equipment problems could be readily fixed (2,4).

In assessing the feasibility of using short lumber in the rough mill, production rates and costs should be regarded as a much more important factor than equipment modification costs. When processing short lumber, more boards must be handled to obtain a given volume of parts, which increases produc-

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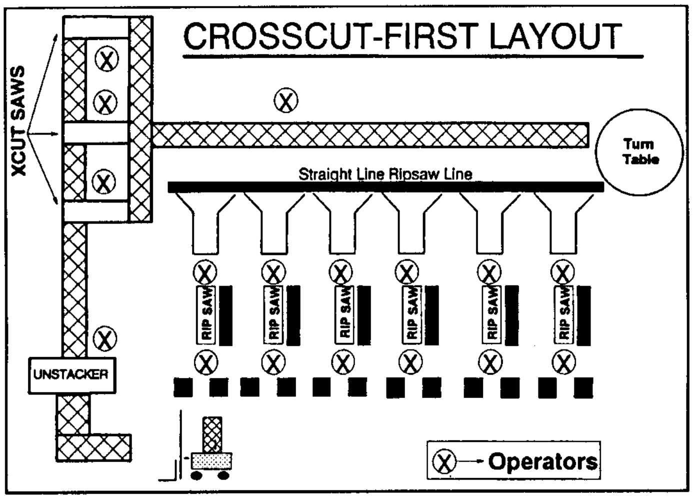

Figure 1. ---- Crosscut-first rough mill layout used in the simulation model.

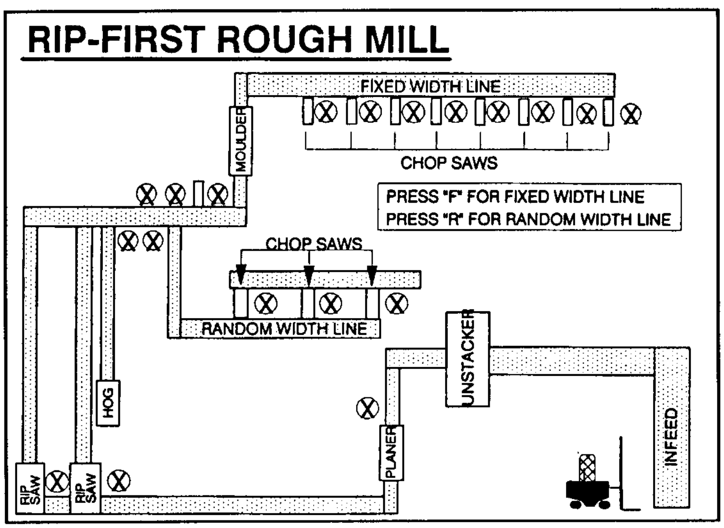

Figure 2. ---- Gang-rip-first rough mill layout used in the simulation model.

tion costs per unit of output volume (1,5).

One offsetting factor to consider when evaluating handling rates and costs is that the manual handling of short pieces can be performed more quickly and with less fatigue and strain than manual handling of long lumber (1). Another factor that maybe hard to assess but that could be very valuable in high production rough mills is the potential for using short-length lumber at times when long-length lumber is causing material to back up at various machine centers. For example, inserting a pack of 4- or 5-foot lumber when the ripsaws in a crosscut-first rough mill are backing up the system could smooth production flow.

In this study, we used discrete-event systems simulation modeling to investigate the major objections of furniture and cabinet manufacturers to using short lumber. We modeled a crosscut-first furniture part dimension rough mill and a gang-rip-first cabinet part dimension rough mill to determine the volume produced in these mills when using short- (4 to 7 ft.), medium- (8 to 13 ft.), and long- (14 to 16 ft.) length hardwood lumber. We also were interested in identifying production bottlenecks.

Systems simulation modeling

Opportunities to observe the processing of short lumber in furniture/cabinet rough mills are limited. Rough mill experiments designed to collect throughput and part value data would be very disruptive to rough mill operations. In addition, short-length lumber handling problems that might exist in a rough mill would complicate the experimental procedure and bias the results.

Systems simulation modeling provides a means of experimenting with a system that cannot be directly manipulated. The systems simulation modeling solution technique offers a powerful tool for evaluating the effect of lumber length on furniture rough mill volume and value yields. In a simulation model, resolution of handling problems can be assumed, and the potential production rates of short-length lumber can be obtained. Moreover, with simulation modeling, new production methods can be analyzed for their effects on production, alternative systems can be compared, bottlenecks can be isolated so possibilities for their removal can be studied, and sensitivity analysis can be performed.

Methodology

Because the furniture and cabinet industry's aversion to working with short-length lumber is predominantly associated with material handling, flow, and productivity issues, applying systems simulation modeling to this problem is appropriate. A PC- based simulation software programming language, SIMAN, was chosen as the development tool. An important feature is the program's animation facility (CINEMA) that provides a means of verifying and validating the model. Wiedenbeck and Kline (8) provide a detailed discussion of the computer simulation model development life cycle. A brief description of the modeling process follows.

System definition

The first step in the system definition phase was to identify crosscut-first and gang-rip-first rough mill cooperators who specialized in producing red oak parts. Red oak was selected for this study because it is the species used most often in the eastern U.S. furniture industry. A crosscut-first case goods dimension plant and a gang-rip-first cabinet parts plant agreed to become involved in this modeling project. These cooperators gave access and information throughout the year-long modeling process. Other elements of the system definition phase included: drawing the mill layouts **(Figs. 1** and **2),** measuring conveyor distances, talking with production management personnel about lumber length-based issues, and observing the systems in operation.

Data collection

After completing the system definition phase, exploratory timing studies on various operations were conducted, and it soon became clear which operations were most affectedly lumber length and piece counts. These operations became the focus of subsequent timing studies. An attempt was made to capture between-operator variability by gathering data on multiple operators for every operation.

The cutting bills used in the mill studies were selected by the rough mill supervisors who attempted to choose cutting bills that would match up well with the short-length lumber input **(Table 1).** However, simulated crosscut test results (6) indicated that the distribution of part lengths obtainable from short lumber is often comparable to that from longer lumber for longer cutting bills. The same cutting bill was used throughout the simulation; no limit was imposed on the number of parts of a given length that could be produced. The piece rates and cutting length distributions associated with these cutting bills were a critical part of the simulation models.

Model programming

Different versions of both the crosscut-first mill model and the gang-rip-first mill model were assembled for each of three lumber-length (nominal measure) groupings: short (4 to 7 ft.), medium (8 to 13 ft.), and long (14 to 16 ft.). These versions were differentiated by the distribution parameters for the various service rates and lumber attributes. However, the differences between the distributions sometimes created queuing problems in one model that were nonexistent in the other models. In these cases, additional programming was required to establish a realistic form of flow control.

To simplify and shorten the models, several assumptions were made during the modeling process. For example, in the crosscut-first model, it was assumed that no lumber-length-based differences in throughput rates and part yields existed for like-sized pieces in the straight-line ripping operation. In the gang-rip-first model, it was assumed that back-ups caused by insufficient rough part inspection and sorting capacity would never shut down the system; the rough mill supervisor would shit? personnel rather than stop production. Downtime was not modeled for either mill configuration.

TABLE 1. — Cutting bill specifications and cutting length-based value relationships used in the simulation models.

Cutting length	Cutting width	Cutting quality[a]	Value 1	Value 2	Value 3
---------(in.)---------			-------------($/BF)-------------		
		Crosscut-first cutting sizes and values			
14	R/W[b]	C1F	2.00	1.64	0.93
22	R/W	C1F	2.00	1.95	1.86
28	R/W	C1F	2.00	2.18	2.55
30.375	R/W	C1F	2.00	2.28	2.82
34	R/W	C1F	2.00	2.42	3.24
40.375	R/W	C1F	2.00	2.67	3.98
		Gang-rip-first cutting sizes and values			
8.25	2.50	C2F	2.00	1.41	0.27
13.25	2.50	C2F	2.00	1.61	0.85
15.75	2.50	C2F	2.00	1.70	1.14
22.25	2.50	C2F	2.00	1.96	1.88
25.875	2.50	C2F	2.00	2.10	2.30
14	R/W[c]	S2F	1.54	1.09	0.72
17	R/W	S2F	1.54	1.35	0.99
23	R/W	S2F	1.54	1.53	1.97
35	R/W	S2F	1.54	1.90	3.35

[a] C1F = clear one-face cutting, C2F = clear two-face cutting; S2F = sound two-face cutting.
[b] R/W= random-width cuttings.
[c] The random-width cuttings in the gang-rip-first rough mill model varied between .75 and 2.4375 inches.

System observation and discussions with mill management supported these simplifying assumptions.

Distribution determination

The next step involved determining the appropriate distributions to associate with the different service rates and material parameters. Timing study and board data collected at the cooperating mills were plotted in histogram form and candidate distributions were visually identified. An analysis of variance was conducted on those data sets that displayed lumber length-based tendencies. This was done in order to determine if different distributions were required when simulating the processing of different length lumber through the mill. The data were grouped into three length categories for these analyses.

The data were then analyzed with the Graphic Distribution Analysis (GDA) program (9). The GDA analyses were sometimes inconclusive in that the data for one of the length groups demonstrated one type of distribution while the data for another length group indicated a different candidate distribution was more appropriate. In these cases and in cases where the amount of data collected was thought to be insufficient, a triangular distribution was also considered. The minimum and maximum points for the triangular distribution were chosen from pooled mill study and timing study data. The “most likely” parameter estimate was based on histograms of the timing study data.

A critical distribution in both models is the number of parts and distribution of part lengths generated at the crosscut or chop saws. These distributions were estimated for the three lumber length classes using the two-stage version of the lumber cut-up program CORY (3). Red oak board data files that were assembled in the U.S. Forest Service’s Forestry Sciences Laboratory in Princeton, W. Vs., were segregated into short-, medium-, and long-length groups for processing by CORY.

For both the crosscut- and gang-rip-first models, two cutting length distributions were incorporated into the short lumber versions of the simulation models. One distribution represents the “most likely” estimation of the cutting distributions (based on the mill studies) and the other is a more conservative

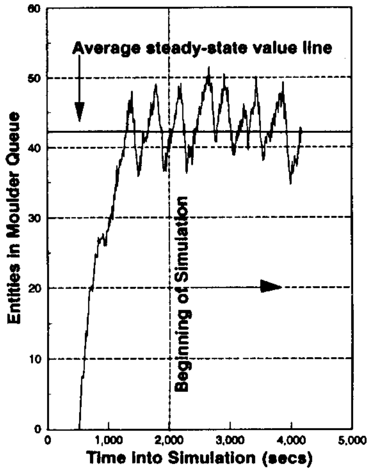

Figure 3. ---- Gang-rip-first model steady-state determination graph; entities accumulated in moulder queue.

estimate of these same cutting distributions (shorter mean part lengths). The alternate distributions were included to estimate the variability that might be expected given a slightly different cutting bill or a slightly different cutting length demand schedule. The distributions used in the final crosscut-first simulation model are detailed in Wiedenbeck (6).

For five of the more critical and less precise gang-rip-first parameter estimates, the simulation model was run successively with first one and then another of the distributions under consideration. Ten replications of each of these distribution-check runs were executed. T-tests ($\propto = .05$) were conducted to see if model output was significantly impacted by the choice of distribution. None of the output volume and yield variables varied between runs. Triangular distributions were selected for the final experimental runs for each of these five parameters. The distributions associated with the most critical parameters in the gang-rip-first experimental model are detailed in Wiedenbeck (6).

MODEL VERIFICATION AND VALIDATION

Model animations, built in parallel with the simulation models, proved valuable in model debugging and verification activities. For purposes of structural validation, the models were shown to the cooperators using the animation feature. Results from the simulation runs were discussed and questions concerning various flow relationships were posed. The crosscut-first simulation model was found to be acceptable by mill personnel. For the gang-rip-first model, several suggestions for improving the model were received that resulted in program changes.

STEADY-STATE DETERMINATION

The gang-rip-first system is a nonterminating system that requires steady-state treatment. When cutting bill changes are made, they frequently occur in a piecemeal fashion and they seldom affect any of the operations preceding the chop saws. The gang-rip-first system is rarely emptied to the point where operators begin a shift or a cutting bill in the idle state with empty buffers.

The beginning of steady-state was determined for the gang-rip-first model by collecting data on queue sizes and the length of time entities (e.g., lumber, strips, pieces, cuttings) resided in the system. Data collection on these variables began at time zero and proceeded for several thousand seconds.

In the gang-rip-first model, the long-length lumber group produced so many cuttings/strips at the first breakdown operation that the second stage cut-up operation's queues backed up steadily until a control mechanism within the model was triggered. The control mechanism shut down the ripsaws when more than 50 entities were in the moulder queue. Steady-state was reached in the model after the flow control mechanism was activated.

Figure 3 demonstrates the type of information used to determine steady-state for the gang-rip-first rough mill. Time T_{2000} was chosen as the beginning of the steady-state period through visual inspection of this and similar graphs produced from other replications of the model. The "average steady-state value line" shown on the graph is the mean value for "entities in moulder queue" for a "steady-state" simulation run that begins at T_{2000} . Because the selected steady-state starting point chronologically falls after the first several intersections of the mean value line and the plotted value line, the steady-state choice is substantiated. The same evaluation process was used to determine the end-point of the initial transient phase for each of the lumber-length-based versions of the gang-rip-first model. The bottlenecks in this system were the unstacker and planer for short lumber and the moulder for medium and long lumber. Because lumber reached these high volume pieces of equipment quickly, steady-state was achieved quickly.

The crosscut-first model was represented better by a terminating model. At the crosscut-first rough mill, represented by this model, several wholesale cutting bill changes are made daily. During the new cutting bill set-up period, the crosscut saws are shut down for several minutes while the operators change the jig positions on the front gauges. In almost all cases, the ripsaw operators manage to clear their infeed buffers during this set-up period. This, in essence, creates a terminating system with a fixed starting condition (ripsaws and sorting system idle and empty).

EXPERIMENTAL DESIGN

Ten replications of each version of the crosscut-first and gang-rip-first models were run. The average length of time spent working on a given cutting bill at the crosscut-first rough mill was approximately 1.5 hours. Therefore, statistics on the crosscut-first simulation runs were collected for 5,400 seconds. Statistics on the gang-rip-first model were collected for 1,800 seconds (1/2 hr.) beginning at the predetermined transient phase truncation point. Test runs of a longer duration were conducted to determine whether 1,800-second simulation runs were long enough. The output from the longer runs did not differ significantly from the output of the 1,800-second runs.

EVALUATION PROCEDURES

Mean values for the simulation output variables were calculated from the 10 replications of each model version. Ninety-five percent confidence intervals for the means were also calculated. An analysis of variance was performed on each of the output variables to determine if differences existed between the four length groups in each model (short, short-alternate, medium, long; $\alpha = .05$). Output variables exhibiting length-group-based differences were analyzed further using the Tukey multiple-comparison test (family error rate = 0.05).

TABLE 2. — *Crosscut-first rough mill simulation results: average values for 10 simulation runs of each lumber length group.*

Simulation output variable	Short lumber (4 to 7 ft.)	Short-alternate[a] (4 to 7 ft.)	Medium lumber (8 to 13 ft.)	Long lumber (14 to16 ft.)
Time in system (sec.)	485	527	853	1,072
Input volume (BF/hr.)	2,226	2,100	2,200	2,240
Production volume (BF/hr.)	1,709	1,567	1,686	1,716
Part value 1 ($/hr.)	3,418	3,133	3,371	3,431
Part value 2 ($/hr.)	4,139	3,599	3,876	3,948
Part value 3 ($/hr.)	5,555	4,512	4,870	4,939
Unstacker operator utilization (%)	23.1	22.6	15.3	11.7
Crosscut saw utilization (%)	93.2	93.7	93.3	94.1
Ripsaw utilization (%)	60.7	61.8	66.1	68.1
Rip queue entities	9	24	61	73

[a]Short-alternate simulation runs used a more conservative estimate of the distribution of cutting lengths obtainable from short lumber.

TABLE 3. — *Crosscut-first rough mill simulation results: confidence intervals and multiple comparison groupings for several important output variables.*

Simulation output variable	Lumber length processed in simulation	Mean ± 95% CI[a]	Grouping[b]
Output volume (BF/hr.)			
Low	Short-alternate[c]	1,567 ± 20	A
	Medium	1,686 ± 34	B
	Short	1,709 ± 15	B
High	Long	1,716 ± 24	B
Part value 1 ($/hr.)			
Low	Short-alternate	3,133 ± 41	A
	Medium	3,371 ± 69	B
	Short	3,418 ± 30	B
High	Long	3,431 ± 49	B
Part value 2 ($/hr.)			
Low	Short-alternate	3,599 ± 53	A
	Medium	3,876 ± 84	B
	Long	3,948 ± 57	B
High	Short	4,139 ± 40	C
Part value 3 ($/hr.)			
Low	Short-alternate	4,512 ± 79	A
	Medium	4,870 ± 115	B
	Long	4,939 ± 72	B
High	Short	5,555 ± 52	C
Ripsaw utilization (%)			
Low	Short	60.7 ± 0.6	A
	Short-alternate	61.8 ± 0.7	A
	Medium	66.1 ± 1.1	B
High	Long	68.1 ± 0.9	C

[a]CI = confidence interval.
[b]Groupings are from Tukey's multiple-comparison tests using a family error rate of .05.
[c]Short-alternate simulation runs used a more conservative estimate of the distribution of cutting lengths obtainable from short lumber.

RESULTS AND DISCUSSION

CROSSCUT-FIRST MODEL SIMULATION RESULTS

For the crosscut-first simulation model, the productivity (board foot per hour of cuttings) of the rough mill when processing short lumber was not statistically different than when medium and long lumber was processed through the rough mill **(Tables 2** and **3).** The short lumber generated high part volumes by producing an abundance of longer parts. The distribution of part lengths used in this model was empirically derived in a mill study conducted at the cooperating rough mill. The simulation runs that incorporate this cutting length distribution are referred to as the "short" version of the model. The "short-alternate" version of the model incorporates a more conservative estimate of the cutting length distribution.

The value of the parts produced in the short lumber simulations did not differ from the value of the parts produced in the medium lumber simulations for the value relationship where all parts are valued equally per board foot **(Tables 2** and **3).** However, the value of the parts produced from the short lumber was higher than the value of the parts from the medium and long lumber for the two value relationships where longer parts are more highly valued per board foot.

The average straight-line ripsaw utilization calculated from the 10 short lumber simulation runs was 60.7 percent **(Table 2).** The average values for the medium and long lumber simulation runs were 66.1 and 68.1 percent, respectively. The differences among these three utilization rates were statistically significant **(Table 3).**

Crosscut saw utilization was not significantly different for the different lumber length groups. Overall, crosscut saw utilization averaged 93.5 percent. **Table 2** shows average crosscut saw utilization for each lumber-length-based version of the crosscut-first rough mill model.

The mean hourly production volume for the more conservative short lumber simulation runs (short-alternate) was lower than the mean volumes for each of the other sets of runs **(Tables 2** and **3).** Similarly, the mean values in these conservative short lumber runs were lower than the mean values for the short, medium, and long runs. The mean ripsaw utilization percentages for the two short lumber simulations were not significantly different from each other but were lower than the medium and long utilization rates. These short-alternate runs incorporated a more conservative estimate of the size of the cuttings obtained from short lumber.

Average values for several other simulation output variables are also shown in **Table 2.**

RIP-FIRST MODEL SIMULATION RESULTS

For the gang-rip-first models (steady-state), the mean hourly production rates for both the "best estimate"

TABLE 4. — Gang-rip-first rough mill simulation results: average values for 10 steady-state simulation runs.

Simulation output variable	Short lumber (4 to 7 ft.)	Short-alternate[a] (4 to 7 ft.)	Medium lumber (8 to 13 ft.)	Long lumber (14 to 16 ft.)
Time in system (sec.)	262	261	539	916
Unstacker reload utilization (%)	15.0	12.9	8.4	5.9
Forklift utilization (%)	16.1	14.2	8.7	6.3
Input volume (BF/hr.)	3,023	2,995	5,142	4,894
Production volume (BF/hr.)	1,648	1,677	2,802	2,668
Part value 1 ($/hr.)	3,153	3,214	5,398	5,147
Part value 2 ($/hr.)	2,999	3,114	5,347	5,105
Part value 3 ($/hr.)	2,835	3,083	5,509	5,281
Ripsaw utilization (%)	84.1	85.1	97.2	90.5
Rip queue entities	13	13	28	31
Planer outfeed entities	7	7	13	15
Fixed width strip percent	74.9	74.8	77.5	79.9
R/W chop saw utilization (%)	55.7	56.9	46.2	41.9
F/W chop saw utilization (%)	68.7	69.5	83.7	86.3
Moulder queue entities	5	5	38	42
Fixed chop line entities	35	37	37	103

[a] Short-alternate simulation runs used a more conservative estimate of the distribution of cutting lengths obtainable from short lumber.

TABLE 5. — Gang-rip-first rough mill simulation results: confidence intervals and multiple comparison groupings for several important output variables.

Simulation output variable	Lumber length processed in simulation	Mean ± 95% CI[a]	Grouping[b]
Output volume (BF/hr.)			
Low	Short-altemate[c]	1,648 ± 67	A
	Short	1,677 ± 63	A
	Long	2,668 ± 47	B
High	Medium	2,802 ± 33	C
Part value 1 ($/hr.)			
Low	Short-altemate	3,153 ± 127	A
	Short	3,214 ± 121	A
	Long	5,147 ± 85	B
High	Medium	5,398 ± 58	C
Part value 2 ($/hr.)			
Low	Short-alternate	2,999 ± 123	A
	Short	3,114 ± 120	A
	Long	5,105 ± 90	B
High	Medium	5,347 ± 60	C
Part value 3 ($/hr.)			
Low	Short-alternate	2,835 ± 119	A
	Short	3,083 ± 122	B
	Long	5,281 ± 114	C
High	Medium	5,509 ± 96	D
Random chop utilization (%)			
Low	Long	37.3 ± 1.9	A
	Medium	46.2 ± 1.8	B
	Short	55.7 ± 2.1	C
High	Short-alternate	56.9 ± 2.8	C
Moulder queue (no. of entities)			
Low	Short-alternate	4.9 ± 0.2	A
	Short	5.0 ± 0.1	A
	Medium	38.6 ± 1.0	B
High	Long	42.4 ± 0.6	C
Fixed chop saw utilization (%)			
Low	Short-alternate	68.7 ± 2.6	A
	Short	69.5 ± 2.2	A
	Medium	83.7 ± 0.7	B
High	Long	86.3 ± 0.9	B

[a] CI = confidence interval

[b] Groupings are from Tukey's multiple-comparison tests using a family error rate of .05.

[c] Short-alternate simulation runs used a more conservative estimate of the distribution of cutting lengths obtainable from short lumber.

and "conservative" short lumber simulations were lower than the means of the medium and long simulation runs **(Tables 4** and **5).** The hourly production rates for the short lumber iterations were about 60 percent of the medium and long lumber production rates. The mean hourly production rates for the two short lumber simulations were not significantly different from one another.

In a gang-rip-first system, short lumber maintains its identity throughout most of the processing steps. In a crosscut-first system, the lumber length distinction is lost early when the crosscut saws cut the lumber in shorter parts. Any gang-rip-first rough mill operation where pieces move in a linear fashion and gaps between the pieces exist will demonstrate lower throughput rates for shorter lumber. In the gang-rip-first model, the planer, ripsaws, and, to a lesser extent, the moulder rates (a push-through moulder is modeled) are affected by lumber length. In addition, any operation requiring a loading and setup time for each piece (e.g., the chop saws and the ripsaw laser scan station) will have lower volume-based throughput rates when short lumber is processed.

A gang-rip-first rough mill model that did not include an in-line planer and moulder would probably show less variation between the short and medium lumber production figures. Using a fixed-arbor gang-ripsaw would reduce setup time per piece and the variance between the short and medium lumber production figures.

The mean part values calculated using the Value 1 and Value 2 relationships did not differ significantly between the two short lumber versions of the gang-rip-first model. The mean values for both short lumber model iterations were lower than the mean hourly part values recorded for the medium and long lumber simulations **(Table 4).** Multiple comparison test results indicate that a significant difference exists between each length group when part length is more highly valued (Value 3 relationship in **Table 5).**

The mean values of other simulation output variables are listed in **Table 4.** Of particular note are the mean values for fixed-width chop saw utilization (the fixed-width strip line processes approximately 80 percent of the strip volume).

In the short lumber simulations, the average utilization of the fixed-width chop saws was approximately 69 percent while the medium model's average was about 84 percent. In contrast, the random-width chop saw utilization rates are highest for the short lumber models. The moulder queue length data help to explain these seemingly contrasting results. The moulder queue length is quite short for the short lumber simulation runs but increases significantly for the medium and long lumber models. When the moulder queue gets above 50 entities, the ripsaws shutdown for at least 90 seconds. Because strips never back up at the moulder in the short-length lumber models, the ripsaws never pause and the supply of strips to the random-width chop saw line can continue uninterrupted.

A comparison of the machine utilization rates listed in **Table 4** for the two short iterations of the gang-rip-first model indicates that a small change in the chop saw distributions has essentially no effect on the production flow of the system. Because the difference in utilization rates is relatively unaffected by the change in cutting length distribution, the utilization rates also should be relatively unaffected by changes in the cutting bill. The gang-rip-first steady-state model seems to be robust in its prediction of short lumber throughput rates.

SUMMARY

Until recently, furniture and cabinet manufacturers have resisted using short hardwood lumber. Logs were bigger and they produced adequate amounts of medium and long lumber for the production of parts. Sawmill operators lacked the interest or need that would lead to producing and selling short lumber. Two things have changed this situation: 1) the average size of logs is now smaller and 2) as log prices increase, sawmills need to utilize their solid wood resource better to increase revenues. Increased use of short lumber will improve log yields.

In the crosscut-first rough mill, lumber length distinction is lost when the lumber is crosscut to specific length pieces in the first processing operation. We also found that the crosscut operators could produce specific length pieces at similar rates regardless of lumber length. Our simulation results showed no lumber length-based processing differences in the crosscut-first rough mill. The productivity of a crosscut-first rough mill processing short lumber into dimension can be high.

Our results indicate that lumber length can impact productivity in an automated gang-rip-first rough mill similar to the one we modeled in this study. When using short lumber, we could not match the production volume or part value of medium and long lumber. In a gang-rip-first process, lumber length is an issue until the material reaches the chop saws. We discovered that the linear movement and processing through the planer, ripsaws, and moulder produced much less throughput of parts processed from short lumber. Because the gang-rip-first rough mill modeled had many linear operations, it represents a worst-case scenario for processing short lumber. Remove the moulder and change the ripsaw to a fixed-arbor machine and productivity could be improved.

Finally, the straight-line ripsaw and crosscut saw utilization figures support our hypothesis that introducing short lumber into a rough mill system can smooth production flow when the straight-line ripsaw buffers are backing up. The slower crosscut saw rate per cutting and the redistribution of cuttings into different length classes could be used to regulate material flow.

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