DESIGN AND EVALUATION OF LOG-TO-DIMENSION MANUFACTURING SYSTEMS USING SYSTEM SIMULATION

WENJIE LIN
D. EARL KLINE
PHILIP A. ARAMAN
JANICE K. WIEDENBECK

ABSTRACT

In a recent study of alternative dimension manufacturing systems that produce green hardwood dimension directly from logs, it was observed that for Grade 2 and 3 red oak logs, up to 78 and 76 percent of the log scale volume could be converted into clear dimension parts. The potential high yields suggest that this processing system can be a promising technique for dimension manufacturing. To further explore the potential of this processing system, this study tests different mill designs and examines the effect of mill configurations, log grade, and cutting bill on dimension production rate. System simulation techniques are employed to aid in the design and evaluation of the proposed dimension mills. The results of this study show that the dimension production rates in mills configured for live-sawing average 22 percent higher than those configured for five-part (cant) sawing. The part production rates in mills processing Factory Grade 2 logs averaged 41 percent higher than those processing Factory Grade 3 logs. Other results show how different cutting-length specifications can impact production rate. The application of system simulation as a tool for identifying resource bottlenecks and improving overall mill efficiency is also illustrated.

As timber prices increase and as environmental constraints limit the volume of logs that can be harvested, new technologies that can more efficiently convert logs into value added products need to be explored. By eliminating the intermediate steps of lumber manufacturing, grading, and trading, producing hardwood dimension parts directly from logs has potential to increase conversion efficiency from logs to dimension. A previous study investigating the yield potential of converting logs directly into dimension parts revealed that up to 78 and 76 percent of the log scale volume (International 1/4-in. scale) could be converted into clear green dimension parts for Grade 2 and 3 red oak logs (9). The potential high yields suggest that this processing system can be a promising method for value added processing of hardwood sawtimber. The capability of using lower grade timber to produce dimension products by this processing system provides a potential opportunity to reduce the demand for high grade lumber by dimension, furniture, and cabinet manufacturers. However, many questions regarding the operational and economic performance of direct-processing systems are still unanswered. How should a direct-processing mill be designed so as to be productive and profitable? To gain a full understanding of the performance of the direct-processing system, different mill designs need to be thoroughly investigated. Furthermore, a direct-processing mill will need to process various qualities of logs and produce various lengths of dimension parts. Information on how the mill performance responds to changes in log input and the cutting lengths of dimension parts will add more understanding to the direct-processing system.

The ideal way to investigate the operational performance of a manufacturing system is to experiment with a real manufacturing plant. However, since actual dimension plants that process hardwood logs directly into dimension parts are not available for comprehensive testing, system simulation provides an alternative way to experiment with a direct-processing system. With system simulation modeling, alternative designs can be thorough] y studied before their costly introduction into a real manufacturing system (7). System simulation modeling has been successfully used in sawmill design, modification, and evaluation (1,2,12) and in rough mill design and evaluation (3,4,7,13). However, existing simulation models have either simulated the operations for a sawmill only (from logs to lumber) or for a rough mill only (from lumber to furniture parts). Further work

is needed to develop valid simulation models that integrate both sawmill and rough mill operations.

The focus of this study was to investigate the operational characteristics of
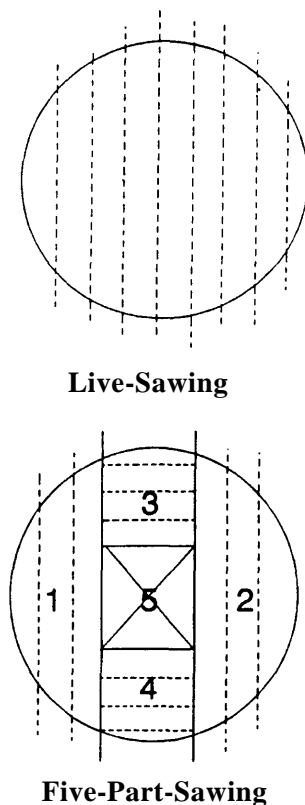

Live-Sawing

Five-Part-Sawing

Figure 1. — Log breakdown patterns.

direct-processing systems by evaluating different mill designs. The specific objectives of this study were: 1) to predict the production rates of direct-processing systems for various mill designs; and 2) to investigate the impact of changes in mill configuration, input log grade, and cutting lengths on the production rate of direct-processing systems. To address these objectives, appropriate simulation models will be developed and used to assist in the design and evaluation of direct-processing systems.

METHODOLOGY

The proposed manufacturing system (refereed to herein as the direct-processing system), which processes hardwood logs directly into rough green dimension parts, consists of two elemental components: 1) a sawmill component; and 2) a rough mill component. The sawmill component saws logs into flitches (or boards), and the rough mill component saws flitches into rough green dimension parts. This study evaluated direct-processing systems for two primary log-breakdown patterns at the sawmill, live-sawing and five-part sawing **(Fig. 1)** and for two rough mill cutting sequences, gang-rip-first and crosscut-first. The following four mill layouts were designed to study combinations of these log-breakdown and cutting sequences.

Design 1 **(Fig. 2)** was configured to use live-sawing and gang-rip-first cutting. Each log in design 1 is debarked and then live-sawn into flitches on a circular headrig saw. These flitches arc then slightly edged, planed, and then cut into rough green dimension parts using one gang-ripsaw and six chop saws. The rough green parts are sorted by length by six sorting workers.

Design 2 **(Fig. 3)** was configured to use live-sawing and crosscut-first cutting. Live-sawn flitches are planed and then cut into green dimension parts using three crosscut saws and five straight-line ripsaws. No part-sorting workers are involved in this design.

Design 3 **(Fig. 4)** was configured to use five-part sawing and gang-rip-first cutting. After a number of flitches arc cut from the two opposite faces of each log (parts 1 and 2 in **Fig. 1**), the remainder of this log then proceeds to the gang-resaw and there it is cut into a number of flitches (parts 3 and 4,4 in. wide) and a 4 by 4-inch cant (part 5). All flitches then go through the edging saw and the planer, and are cut into rough green dimension parts using one gang-ripsaw and six chop saws.

Design 4 **(Fig. 5)** was configured to use the combination of five-part sawing and crosscut-first. In design 4, the flitches coming out from the headrig and
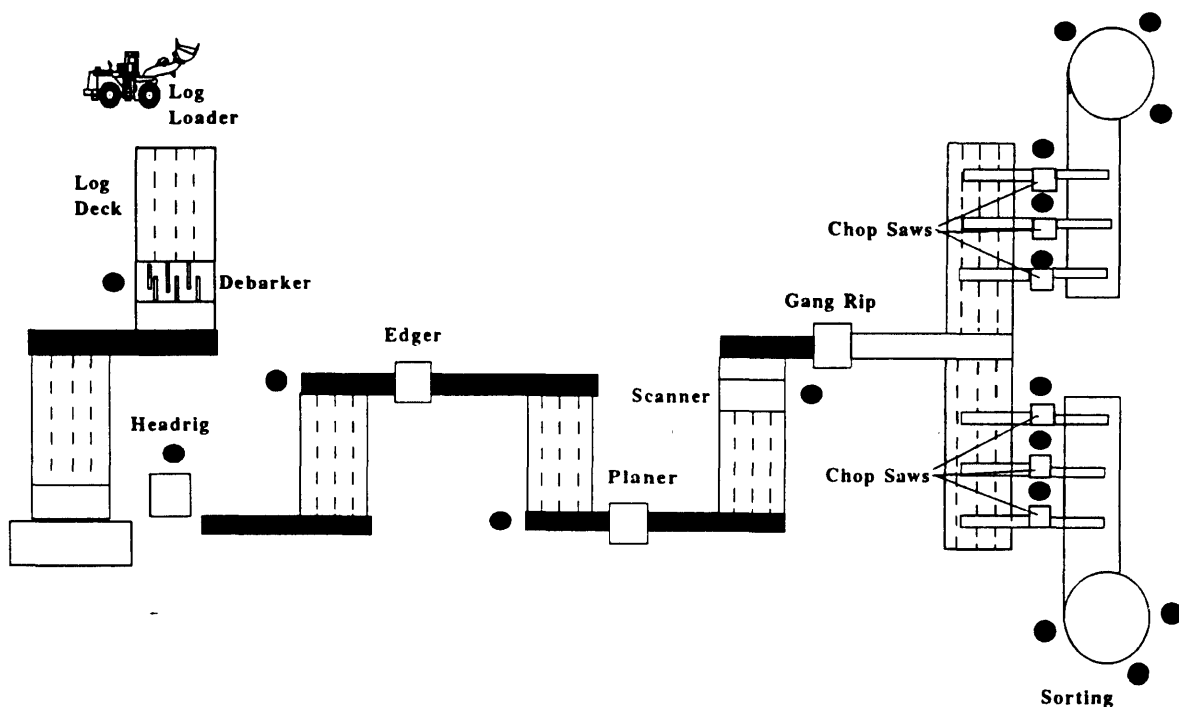

Figure 2. — Layout of mill design 1.

gang-resaw are planed and then cut into rough green dimension parts using three crosscut saws and five straight-line rip-saws.

Ideally, the best way to test and compare these four mill designs is to experiment with actual systems. Since the proposed mill designs for converting logs directly into rough dimension parts do not exist, such direct experimentation is not possible. Even if an actual plant did exist, the experimental time and ex-pense involved would severely limit what could be tested. System simulation provides an alternative way to perform limitless experimentation. The following methods describe how representative models for the four mill designs were developed.

MODEL BUILDING

SIMAN IV (10), a FORTRAN-based simulation language, was used in building the simulation models for the four mill designs shown in **Figures 2 through 5.** The process of building a simulation model involves an abstraction of the real system into mathematical/logical relationships. In this process, the mill layout and how material flows through each of the pieces of equipment are transformed into mathematical/logical representations through SIMAN IV. Since the transformation from logs into rough green dimension parts involves both sawmill and rough mill operations.
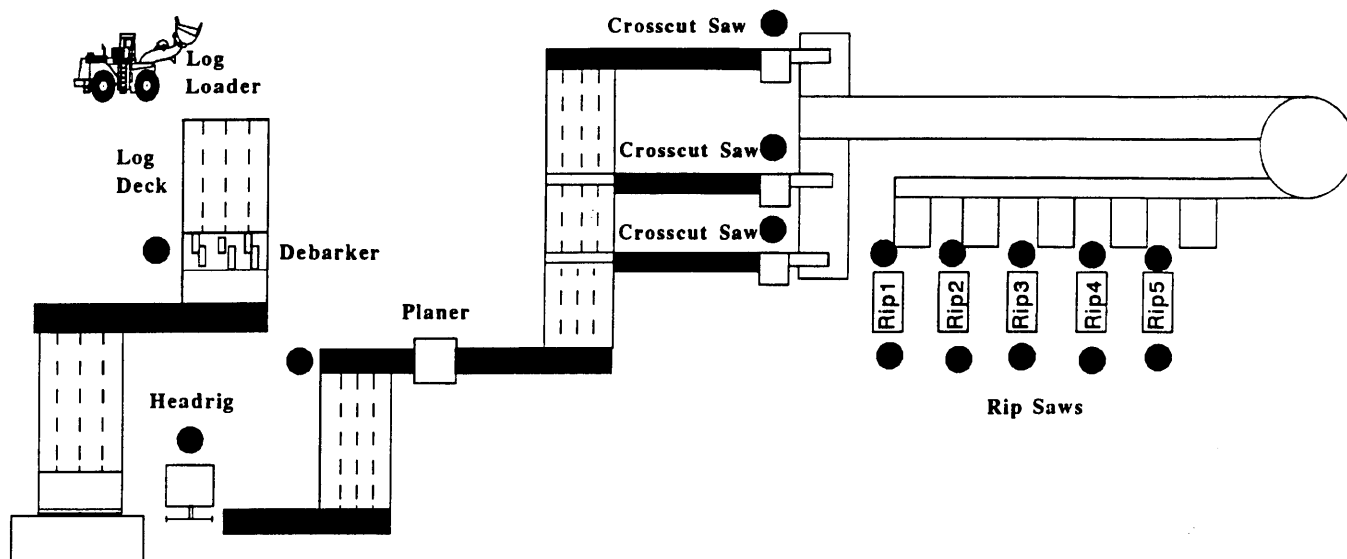

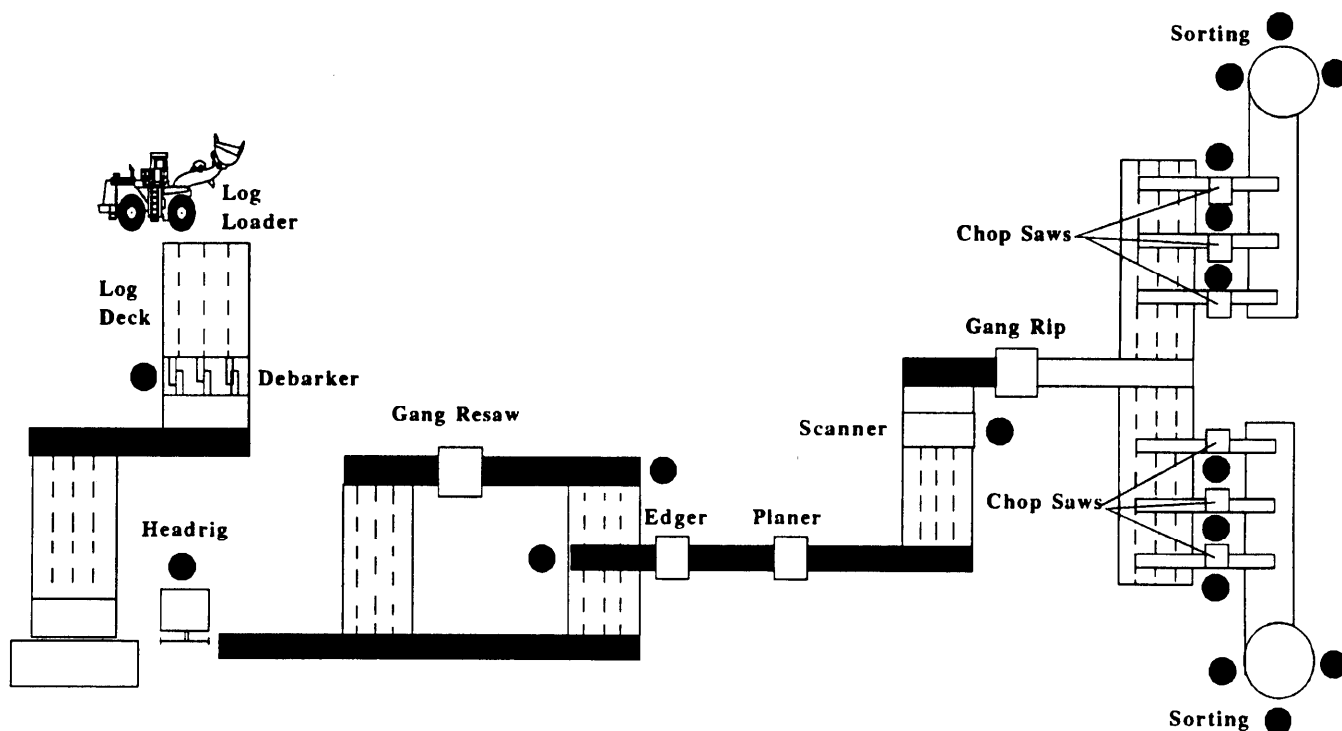Figure 3. — Layout of mill design 2.

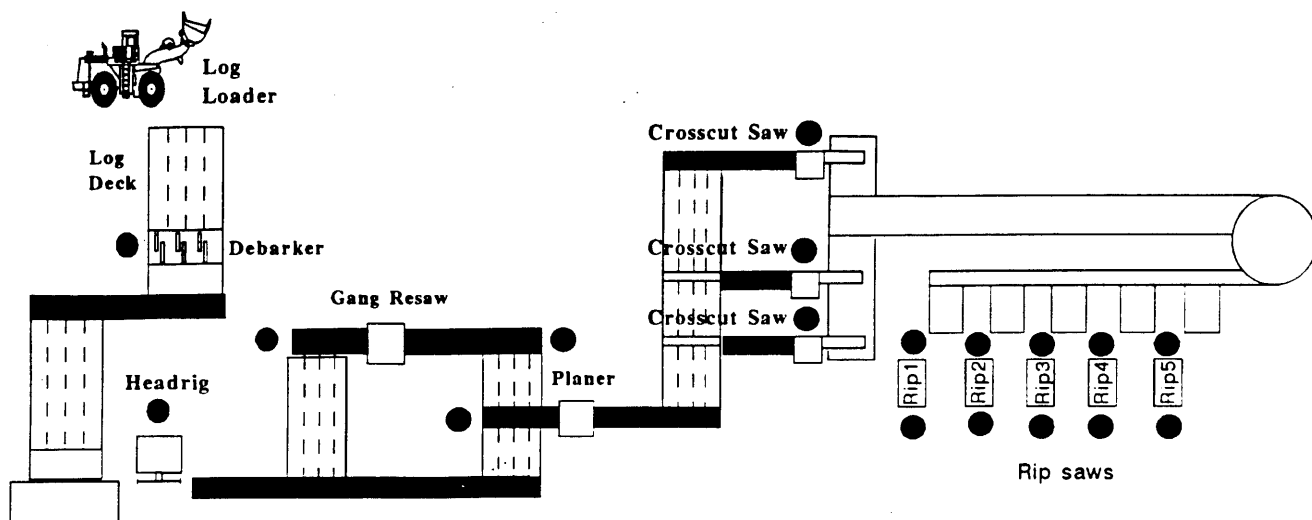
Figure 4. — Layout of mill design 3.

Figure 5. — Layout of mill design 4.

the modeling of the direct-processing system consists of two elemental components, a sawmill component and a rough mill component. The modeling of the sawmill component simulates how a log is broken down into flitches and the modeling of the rough mill component simulates how a flitch is cut into rough green dimension parts. These two model components are then linked together to constitute the simulation model for the direct-processing system.

DATA ACQUISITION AND INPUT PARAMETER MODELING

To attain a representative estimate of a particular direct-processing mill's performance, an accurate description of input parameters and their fictional relationships is needed. The data required as input to these simulation models include: 1) log and flitch sawing data; 2) machine processing rates and capacities; 3) workers' material-handling rates; and 4) conveyor and transporter capacities.

Log-sawing data required for breaking down logs into flitches was calculated based on log diameter and log length. Log data used in estimating dimension yields and dollar value recovery in the previous study (9) were used in this study. The small-end diameter of Grade 2 logs ranges from 10 to 17 inches, with length from 10 to 12 feet. The small-end diameter of Grade 3 logs ranges from 10 to 15 inches, with length from 8 to 10 feet. At the headrig, all logs were sawn into 1-l/8-inch flitches using a circular headrig saw with a kerf of 0.28 inch. For five-part sawing, cants were sawn into 1-1/8-inch side

boards and a 4- by 4-inch center cant with a kerf of 3/1 6 inch. The log input volumes were scaled by the International 1/4-inch rule.

The required cut-up operations for cutting flitches into rough green dimension parts were obtained by using CORY (6), a computer-based cut-up program. This program provides complete information on the number of sawlines and the location of each sawline for each individual flitch. In fact, these sawlines represent the required cut-up operations to achieve the predicted yields in the previous study (9).

Machine-processing rates and capacities, material-handling rates, and conveyor and transporter capacities were collected through in-mill timing studies. These timing studies were conducted in a hardwood sawmill and two rough mills (one gang-rip-first and the other crosscut-first). Data for the log loader, debarker, carriage, headrig saw, gang-resaw, edging saw, and associated operators with these machines were obtained from the sawmill. Data for crosscut-saws, straight-line ripsaws, and associated operators were obtained from the crosscut-first rough mill. Data for gang-ripsaw, gang-rip laser scanner, chop saws, and associated operators were obtained from the gang-rip-first rough mill. The data for crosscut saws, chop saws, and straight-line ripsaw operators were gathered on multiple machine/operators. The data were collected when the mills were processing red oak logs (in the sawmill) or 4/4 red oak lumber (in the rough mills).

Most of the input parameters associated with machine processing and material-handling rates were considered as random variables. Probability distributions of random input parameters were characterized by using the following procedures recommended by Law and Kelton (8). First, a family of distributions was selected based on frequency histograms and probability plots. Then, the parameters of each distribution were estimated using the maximum-likelihood method. Finally, these probability distributions were tested for goodness-of-fit using Chi-square tests. For those variables that had insufficient observations, triangular distributions were used. For certain discrete variables, such as the number of crosscuts and rippings per board, discrete distributions were empirically defined using original data.

MODEL VERIFICATION AND VALIDATION

The verification process consisted of isolating and correcting unintentional errors in the models. The computer program of each model was debugged in two subprograms, one represented the operations from logs to flitches and the other represented the operations from flitches to rough dimension parts. Then, the interface between the two subprograms was checked and corrected. Model verification was carried out in parallel with model development by testing the models stage by stage. Entity trace and interactive debugger facilities were used in the process of model verification.

Animation models were developed by using CINEMA IV (11) for each of

TABLE 1. — *Cutting bills.*

Cutting bill no.	Length catergory	Cutting Lengths	Cutting width[a]
		(in.)	
1	Mixed	15,18,21,25,29,33,38,45,50,60,75	Random width
2	Short	15,18,21,25,29,33	Random width
3	Long	38,45,50,60,75	Random width

TABLE 2. — *Production rates of the four mill designs.* [a]

Log grade	Cutting bill no.	Volume of logs processed				Volume of green part output			
		D1	D2	D3	D4	D1	D2	D3	D4
		- - - - - - - - -(MBF/shift)[b]- - - - - - - - -				- - - - - - - - -(MBF/shift)[c]- - - - - - - - -			
	1	27.7	27.9	21.0	25.7	21.2	21.7	14.6	18.5
Grade 2	2	25.4	27.5	21.0	23.2	19,6	22.0	14.8	16.9
	3	27.8	29.5	20.9	30.6	17.3	18.1	12.1	17.7
	1	19.5	19.5	17.9	20.6	14.3	14.8	11.2	13.5
Grade 3	2	19.5	19.4	17.7	19.5	14.7	14.9	11.2	13.1
	3	19.4	19.4	18.0	23.1	11.4	11.1	9.4	12.2
Overall average production rate[d]		23.2 A	23.9 B	19.4 *C*	23.8 D	16.4 A	17.1 B	12.2 *C*	15.3 D
Overall yield recovery (%)						70.7	71.6	62.9	64.4
Yield recovery when processing Grade 2 logs (%)						71.8	72.8	66.0	66.8
Yield recovery when processing Grade 3 logs (%)						69.2	70.0	59.3	61.4

[a]D1 = design 1 (live-saw/gang-rip/chop) ;D2 = design 2 (live-saw/crosscut/rip); D3 = design 3 (five-part-saw/gang-rip/chop); D4 = design 4 (five-part-saw/crosscut/rip).

[b]Thousand scaling board feet (International l/4-in. scale) per 8-hour shift.

[c]Thousand board feet of rough green dimension per 8-hour shift.

[d]Means with the same capital letter are not significantly different at $\alpha = 0.05$ under Duncan's multiple comparison test.

the simulation models and these were used in the model verification process, Animation displays information of all model components simultaneously. The simultaneous display makes it easier to follow the complex interactions occurring within a system, to check material flow, and to identify blockages and deadlocks in the system. Model refinement was earned out in conjunction with model verification work. These two interactive procedures were repeated until an acceptable model was obtained.

Since the proposed designs of the direct-processing system have yet to be built, no direct experimentation could be performed to validate these models. In cases like this, only the face validity (8) of the models can be checked. With the aid of animation, the reasonableness of the models and their behavior were checked by persons knowledgeable about sawmill and rough mill operations. A similar number of logs were processed in the simulated system and in the sawmill where data collection took place. A similar volume of boards were processed in the simulated system and the actual rough mills.

EXPERIMENTATION AND ANALYSIS

Twenty-four processing scenarios were simulated to evaluate the direct-processing system. Two log grades (Factory Grade 2 and 3) and three cutting bills **(Table 1)** were tested for the four mill layouts described in **Figures 2** through **5.** The cutting lengths in **Table 1** were adopted from the standard sizes recommended by Araman et al. (5). The first cutting bill contains a mixture of both longer and shorter cuttings; the second cutting bill represents shorter cuttings (lengths ≤ 33 in.); and the third cutting bill represents longer cuttings (lengths ≥ 38 in.).

Observations on the total volume of logs processed, the volume of rough green dimension parts produced, and machine and labor utilization data were collected in each simulation run and reported in the simulation output. Each simulation run simulated an 8-hour production shift with two 10-minute breaks and a 10-minute final clean up. Since

many of the input parameters of the simulation model are random variables. the output observations are also random variables. To statistically evaluate and compare the production rate and operational performance of the various scenarios, 10 replications of each processing scenario were simulated. Duncan's multiple-comparison procedures were used to test the difference between production rates of the various mill designs and cutting bills.

RESULTS AND DISCUSSION

PRODUCTION RATES OF THE VARIOUS MILL DESIGNS

The mean production rates of the four mill designs obtained from simulation are presented in **Table 2.** The production rate is measured in both the volume of logs processed (thousand board feet (MBF) based on International l/4-in. scale) and the volume of rough green parts produced per 8-hour shift. These results show that the production rate of the direct-processing system varies for different mill designs, different grades of input logs, and different lengths of dimension to be cut. Depending on mill design and part lengths, a direct-processing mill with one headrig saw can produce 12.1 to 22.0 MBF rough green dimension from Grade 2 red oak logs and 9.4 to 14.9 MBF rough green dimension from Grade 3 red oak logs per 8-hour shift. The simulation results in **Table 2** indicate that the part production rates of mills configured for live sawing (designs 1 and 2) average 22 percent higher than those configured for five-part sawing (designs 3 and 4). Mill designs 1 and 2 produced more parts in all cases except in the cases where design 4 processed cutting bill no. 3 (longer cuttings). In these cases, design 4 had the best part production rate for Grade 3 logs and the second best rate for Grade 2 logs.

Designs 3 and 4 have lower overall production rates because the log breakdown process generates a greater number of smaller boards that need to be processed through the rough mill. Therefore, extra rough mill capacity for these two mill designs are needed to process the greater number of boards generated for five-part sawing. This is especially evident in rip-first rough mills as illustrated in design 3, which generated the smallest volume of part output in all cases. The poor perform-

ante of design 3 was found to be caused by inadequate gang-ripsaw capacity and this will be addressed in a later section of this paper.

From a production point of view, the results in **Table 2** indicate that design 2 has the best overall part production rate. From a value point of view, the results in a previous study (9) indicate that live-sawing or five-part sawing followed by a rip-first dimension mill (equivalent to designs 1 and 3 in this study) have the best overall value recovery of parts. A comprehensive financial analysis that includes the investment cost and operating costs of the various designs is needed to determine which of these designs are best from an economic point of view.

THE EFFECTS OF INPUT LOG GRADE ON PRODUCTION RATE

The simulation results indicate that for the four mill designs tested the production rates when processing Grade 2 logs are substantially higher than when processing Grade 3 logs **(Table 2).** Processing Grade 2 logs results in 30 to 64 percent more rough dimension production rate than processing Grade 3 logs. These volume differences can be attributed to the differences in log quality and sizes between the two log grades. Because fewer defects exist in Grade 2 logs than in Grade 3 logs, fewer cuttings are needed to produce a given quantity of parts when processing Grade 2 logs. Because Grade 2 logs are usually larger in size than Grade 3 logs, the headrig saw can process more volume of Grade 2 logs than Grade 3 logs in a given amount of time.

Production rate is an important factor that can have substantial effect on the profitability of a direct-processing mill. However, the higher production rate in processing Grade 2 logs does not necessarily imply that processing Grade 2 logs will be more profitable than processing Grade 3 logs in a direct-processing system. This is because there are other factors that have significant impact on the profitability of the direct-processing system, such as the cost of logs and cutting yield in addition to production rate.

THE EFFECTS OF CUTTING LENGTHS ON PRODUCTION RATE

Because of the obvious difference in yield between processing various cutting lengths, it is better to use the volume

TABLE 3. — *Summary of the effect of cutting lengths on production rate.* [a]

Log grade	Mill design	Cutting bill no.	Volume of logs processed[b]		Bottleneck
			(MBF/shift)[c]		
Grade 2	Design 1	1	27.7	A	Headrig
		2	25.4	B	Chop saws
		3	27.8	A	Headrig
Grade 2	Design 2	1	27.9	A	Crosscut
		2	27.5	B	Crosscut
		3	29.5	C	Headrig
Grade 2	Design 3	1	21.0	A	Gang-rip
		2	21.0	A	Gang-rip
		3	20.9	A	Gang-rip
Grade 2	Design 4	1	25.7	A	Crosscut
		2	23.2	B	Crosscut
		3	30.6	C	Crosscut
Grade 3	Design 1	1	19.5	A	Headrig
		2	19.5	A	Headrig
		3	19.4	A	Headrig
Grade 3	Design 2	1	19.5	A	Headrig
		2	19.4	A	Headrig
		3	19.4	A	Headrig
Grade 3	Design 3	1	17.9	A	Gang-rip
		2	17.7	A	Gang-rip
		3	18.0	A	Gang-rip
Grade 3	Design 4	1	20.6	A	Crosscut
		2	19.5	B	Crosscut
		3	23.1	C	Headrig

[a] Design 1 = live-saw/gang-rip/chop; design 2 = live-saw/crosscut/rip); design 3 = five-part-saw/gang-rip/chop; design 4 = five-part-saw/crosscut/rip.
[b] For the given mill design and log grade, means followed by the same capital letter are not significantly different at $\alpha = 0.05$ under Duncan's multiple comparison test.
[c] Thousand scaling board feet (in International l/4-in. scale) per 8-hour shift.

of logs processed rather than the volume of green part output in determining the effects of cutting lengths on production rate. Multiple-comparison tests indicate that the effect of cutting lengths on production rate depends on mill design and input log grade **(Table 3).** For example, when processing Grade 3 logs, the volume of logs processed per shift by design 1 is minimally affected by changes in cutting bill. In contrast, when processing Grade 2 logs through design 2, different cutting bills affect production rate significantly. One possible explanation to these variations is that bottlenecks shift as mill design, log grade, and cutting lengths change.

In a direct-processing mill, production rate is largely determined by the busiest element in the system, or the bottleneck. The results in **Table 3** show that if the bottleneck lies in any location other than the chop saws or the crosscut saws, the log processing rate of the given mill will not change significantly when cutting lengths are changed. Attaining a

cutting bill with smaller cuttings requires more rough mill sawing operations than a cutting bill with larger cuttings. The more sawing operations required, the greater the workload on the chop saws (in gang-rip-first mills) or the crosscut saws (in the crosscut-first mills). If these two sawing operations have enough capacity to absorb the variation in workload resulting from cutting bill changes, the mill production rate (in volume of logs processed) will not change significantly as cutting lengths change. Otherwise, they become bottlenecks and can result in lower production rates for cutting bills with shorter lengths.

IDENTIFYING BOTTLENECKS AND IMPROVING MILL EFFICIENCY

Machine and labor utilization rates obtained from the simulation experiments provide important information that can help aid in the mill design process. **Tables 4** and 5 list the machine and labor utilization results for the four mill designs when processing two log grades

and three cutting bills, Usually, the machine or operator with the highest utilization rate is the bottleneck. For example, when design 1 processes Grade 3 logs for any one of the three cutting bills, the headrig saw utilization exceeds 99. Since the utilization of all other machinery in this example is well below 99 percent, it is obvious that the bottleneck is the headrig.

To constrain production, the utilization of a bottleneck machine or operator resource does not always have to be close to 100 percent. When processing Grade 2 logs in design 3, for example, no machine or labor resources are utilized over 70 percent. These utilization numbers suggest that there remains substantial machinery and labor capacity to produce more dimension, when in fact there is not, due to a bottleneck at the gang-ripsaw. At the ripsaw, the laser scanner operator has to wait until the previous board is completely out of the gang-ripsaw before the operator can drop another board onto the gang-ripsaw. Hence, the idle time of the ripsaw is due to a sequence-dependent delay and cannot be recovered unless a more sophisticated board-queuing mechanism is employed to eliminate this delay.

The bottlenecks identified based on the machine and labor utilization rates of individual processing scenario arc listed in **Table 3.** After the bottleneck in a mill design is identified, various options to remove the bottleneck can be considered. The improvements in mill design will come with improved production rate and overall mill efficiency. As shown previously, the production rate for design 3 was found to be particularly lower than the other mill designs. Also, it was concluded that design 3 was the only mill in which production was constrained by the gang-rip process. It was hypothesized that if this mill were modified by adding another gang-rip line, the productivity of the mill would increase and become more comparable with the productivity of the other mill designs. The effect of this change was investigated with additional simulation experiments.

If another laser scanner and gang-ripsaw are added to design 3 in parallel with the existing laser scanner and gang-ripsaw, simulation results show that the modified design with two gang-ripsaws has 26.7 to 47.8 percent higher production rate than its initial counterpart (**Table 6).** The overall average part production rate of 16.4 MBF per shift in the modified mill was found to be comparable with the other mill designs. Nonetheless, these improvements come at an added cost. The economic rationale of this modification option needs to be further determined.

If increasing production rate is not desired for design 3, another option of improving mill eficiency could be considered. **Tables 4** and 5 show that the utilization of chop saws and part sorters in design 3 is very low (i.e., less than 50% in many cases); therefore, there is a

TABLE 4. — *Machine utilization for different mill designs.* [a]

Machines	Processing Grade 2 logs				Processing Grade 3 logs			
	D1	D2	D3	D4	D1	D2	D3	D4
	-(%)-							
Log loader	25.4	26.1	21.9	25.3	24.0	23.6	22.2	25.0
Debarker	28.4	30.0	22.8	28.3	27.5	27.7	25.5	29.8
Headrig saw	91.7	95.8	60.5	77.0	99.5	99.5	76.3	90.0
Gang resaw	--	--	13.1	16.4	--	--	18.3	21.3
Planer	52.7	54.5	57.8	69.6	57.1	57.3	72.1	79.8
Edging saw	62.7	--	68.3	--	68.6	--	85.3	--
Laser scanner	54.7	--	51.5	--	60.4	--	63.7	--
Gang-ripsaw	62.5	--	69.8	--	68.3	--	86.7	--
Chop saws	63.7	--	45.7	--	55.9	--	43.4	--
Crosscut saws	--	74.0	--	73.2	--	74.2	--	71.4
Straight-line-ripsaws	--	71.8	--	69.3	--	54.7	--	64.1

[a] Averages for processing the three cutting bills listed in Table 1. D1 = design 1 (live-saw/gang-rip/chop); D2 = design 2 (live-saw/crosscut/rip); D3 = design 3 (five-part-saw/gang-rip/chop); D4 = design 4 (five-part-saw/crosscut/rip).

TABLE 5. — *Labor utilization for different mill designs.* [a]

Operator	Processing Grade 2 logs				Processing Grade 3 logs			
	D1	D2	D3	D4	D1	D2	D3	D4
	-(%)-							
Log loader op.	25.4	25.9	21.9	25.9	24.0	23.6	22.3	25.0
Debarker op.	28.4	29.7	22.8	28.3	27.5	27.7	25.5	29.8
Headrig op.	91.7	95.1	60.5	77.0	99.5	99.5	76.3	90.0
Gang resaw op.	--	--	4.4	5.6	--	--	6.1	6.7
Cant stacker	--	--	9.3	10.9	--	--	12.2	13.0
Planer op.	52.5	21.8	--	21.2	57.0	22.9	--	28.0
Edging saw op.	41.8	--	34.0	--	45.7	--	43.9	--
Laser scan. op.	54.7	--	51.4	--	60.4	--	63.7	--
Chop saw op.	70.6	--	50.7	--	62.8	--	48.7	--
Crosscut op.	--	90.8	--	91.2	--	86.2	--	91.0
Ripsaw op.(in)	--	61.4	--	63.8	--	52.6	--	61.0
Ripsaw op.(out)	--	59.1	--	69.4	--	45.9	--	55.8
Part sorters	61.1	--	43.7	--	55.2	--	42.9	--

[a] Average for processing the three cutting bills listed in Table 1, D1 = design 1 (live-saw/gang-rip/chop); D2 = design 2 (live-saw/crosscut/rip); D3 = design 3 (five-part-saw/gang-rip/chop); D4 = design 4 (five-part-saw/crosscut/rip).

TABLE 6. — *Production rate of the modified design with two gang-ripsaws.*

Log grade	Cutting bill no.	Log volume processed	Green part output	Production rate Increase	Bottleneck
		(MBF/shift)[a]	(MBF/shift)[b]	(%)	
	1	30.8	21.4	46.7	Headrig
Grade 2	2	26.7	18.8	27.1	Chop saws
	3	30.9	17.8	47.8	Headrig
	1	22.8	14.3	27.4	Headrig
Grade 3	2	22.8	14.4	28.8	Headrig
	3	22.8	11.9	26.7	Headrig
Overall average		26.1	16.4	34.1	

[a] Thousand scaling board feet (International l/4-in. scale) per 8-hour shift.
[b] Thousand board feet per 8-hour shift.

potential to reduce the numbers of chop saws and part sorters. After two chop saws were inactivated and two part sorters were removed, the simulation results indicated that the production rate of mill design 3 did not change significantly in most cases (except for a 12°/0 decline when processing Grade 2 logs for the short cutting bill). This reduction in capacity illustrates that simulation can be used to properly downsize underutilized resources.

The mill designs presented in this paper represent only a small subset of the many possible design alternatives for a direct-processing system. For example, the headrig saw could be a scragg mill headrig or chipper canter to increase log processing rate. The methodology presented in this paper can also be used to investigate these alternative mill designs.

SUMMARY

A previous study (9) found a large potential for increasing dimension yield from logs by converting hardwood logs directly into dimension parts. This study further investigated this processing option by evaluating the operational characteristics of dimension manufacturing systems that process logs into rough green dimension products. System simulation techniques were used to assist in the design and evaluation of four different direct-processing mills. The impact of changes in mill configuration, log grade input, and cutting bill on dimension production rate was investigated.

The simulation results for the four mill designs tested show that a direct-processing mill with one headrig saw can produce up to 22.0 MBF rough green dimension from Grade 2 red oak logs and up to 14.9 MBF rough green dimension from Grade 3 red oak logs per 8-hour shift. The dimension production rate in mills configured for live-sawing averaged 22 percent higher than those configured for five-part (cant) sawing with the same rough mill capacity. By increasing the capacity of certain rough mill machinery resources, the production rates of five-part sawing mills were increased to the levels of the live-sawing mills. Depending on the mill designs and cutting bill, processing Grade 2 logs resulted in 30 to 64 percent more rough green dimension production rate compared to processing Grade 3 logs. A cutting bill that includes many shorter lengths increased the load on the rough mill component of all designs studied. Lower production rates for cutting bills with shorter lengths were observed in some mill designs without spare rough mill capacity.

The potentially high production rates indicated in this study and the potentially high yields found in a previous study (9) indicate that directly producing dimension parts from logs may be a feasible value added log processing system. The results of this study not only add a thorough understanding of the direct-processing system but also provide essential information for a detailed economic analysis of this processing system. Work is continuing to assess the merits of direct-processing systems from an economic point of view.

LITERATURE CITED

1. Adams, E.L. 1984. DESIM: a system for designing and simulating hardwood sawmill systems. Gen. Tech. Rept. NE-89. USDA Forest Serv., Northeastern Forest Expt. Sta., Broomall, Pa. 10 pp.

2. _____. 1984. DESIM user's manual: a procedural guide for designing and simulating hardwood sawmill systems. Gen. Tech. Rept. NE-94. USDA Forest Serv., Northeastern Forest Expt. Sta., Broomall, Pa. 58 pp.

3. Anderson, R.B. 1983. Furniture rough mill costs evaluated by computer simulation. Res. Pap. NE-518. USDA Forest Serv., Northeastern Forest Expt. Sta., Princeton. W.Va. 11 pp.

4. Araman. P.A. 1977. Use of computer simulation in designing and evaluating a proposed rough mill for furniture interior parts. Res. Pap. NE-361. USDA Forest Serv., Northeastern Forest Expt. Sta.. Upper Darby, Pa.

5. _____, C.J. Gatchell, and H.W. Reynolds. 1982. Meeting the solid wood needs of the furniture and cabinet industries: Standard-size hardwood blanks. Res. Pap. NE-494. Northeastern Forest Expt. Sta.. Broomall, Pa. 27 pp.

6. Brunner, C. C., M.S. White. F.M. Lamb, and J.G. Schroeder. 1989. CORY: A computer program for determining dimension stock yields. Forest Prod. J. 39(2):23-24.

7. Kline, D. E., J.K. Wiedenbeck, and P.A. Araman. 1992. Management of wood products manufacturing using simulation/animation. Forest Prod. J. 42(2):45-52.

8. Law, A.M. and W.D. Kelton. 1991. Simulation Modeling and Analysis. 2nd ed. McGraw-Hill Book Co., New York. 759 pp.

9. Lin, W., D.E. Kline, and P.A. Araman. 1994. Dimension yield from Factory Grade 2 and 3 red oak logs. Forest Prod. J. 44(9):19-25.

10. Pegden, C. D., R.E. Shannon, and R.p. Sadowski. 1990. Introduction to Simulation Using SIMAN. McGraw-Hill, Inc., New York. 615 pp.

11. Systems Modeling Corp. (SMC). 1990. CINEMA IV Reference Guide. Sewickley, Pa. 155 pp.

12. Wagner, Jr., F.G. and F.W. Taylor. 1983. SPSM-A Southern Pine Sawmill Model. Forest Prod. J. 33(4):37-42.

13. Wiedenbeck, J.K. 1992. The potential for short length lumber in the furniture and cabinet industries. Ph.D diss. Virginia Tech, Blacksburg, Va. 260 pp.