

Dimension yields from Factory Grade 2 and 3 red oak logs

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Abstract

With rising timber costs and a decreasing supply of high-grade timber resources, manufacturers of solid wood products need to adopt more efficient processing methods that better utilize existing timber resources. To address this need, this study explores the potential of converting hardwood logs directly into dimension parts. The specific objective of this study was to estimate the potential cutting yield of dimension parts and potential value recovery obtainable from Factory Grade 2 and 3 red oak sawlogs under various processing configurations and cutting bills. A combination method of sawing logs into flitches and then cutting flitches into dimension parts was used. Two log sawing patterns (live sawing and five-part sawing) combined with two cutting sequences (rip first and crosscut first) and three cutting bills were tested. The results indicated that Grade 2 logs produced higher dimension yield than Grade 3 logs. However, Grade 2 logs resulted in much less value recovery per dollar log input than Grade 3 logs because of the notably higher price of Grade 2 logs. These results suggest that direct processing systems offer a very promising method for converting low-grade timber resources into high-value solid wood products. Other results of the study show how different processing configurations and cutting orders can affect yield and value recovery.

The conversion of logs into dimension parts in a conventional processing system usually takes place in two steps. In the first step (Fig. 1), logs are sawn into lumber and the lumber is marketed according to standard grades specified by the National Hardwood Lumber Association (8). In the second step, the lumber is dried and processed into dimension parts in a dimension mill or a rough mill associated with a furniture or cabinet plant. In this conventional system, some usable solid wood material from the log

flitches is edged and trimmed off at the sawmill and put into chips to "up-grade" the board and maximize the market value of the boards. In a previous study (6), it was found that the resulting volume of furniture cuttings could be increased by 25 percent by eliminating edging and trimming of hardwood flitches at the sawmill. This large increase calls attention to a more efficient and economical use of hardwood resources that would have otherwise been converted to a less valuable product.

As the price of timber resources increases and as environmental constraints limit the volume of logs that can be harvested, the processing concept of directly converting logs into dimension parts needs to be explored. This direct processing concept can be defined as a manufacturing system that converts hardwood logs directly into rough green dimension parts without the intermediate steps of lumber manufacturing, grading, trading, shipping, drying, and storage. In the direct processing system (Fig. 1), logs are sawn into flitches that may or may not be rectangular pieces, depending on the sawing patterns used. These flitches are immediately cut into green rough dimension parts. The green rough dimension parts are then dried and shipped to furniture makers, cabinet makers, and other users of solid wood parts. The main advantage of the direct processing system is that it can use lower grade logs to produce high-value dimension products. Therefore, the direct processing system will

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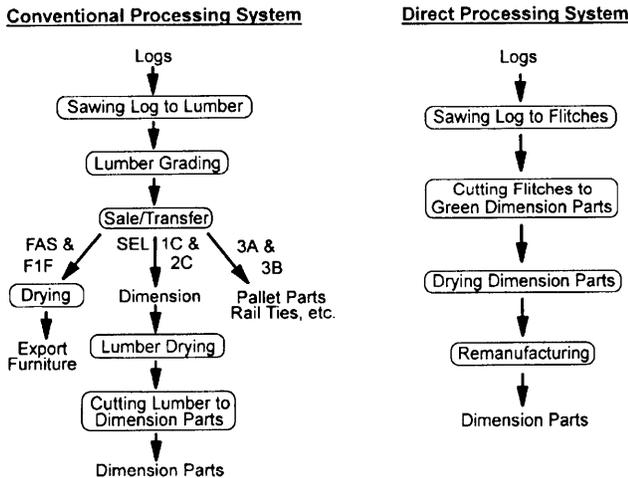


Figure 1. — Comparison of the conventional processing system and the direct processing system.

provide a greater value added opportunity for the U.S. hardwood dimension industry with its abundance of lower grade hardwood logs.

The direct processing system has been used in Japan and Europe (2) and there has been a recent trend to process dimension parts from logs in the United States (5, 10). However, little comprehensive research in evaluating the direct processing system has been reported. Many areas concerning cutting yield, value recovery, productivity, production costs, profitability, and economic feasibility of a direct processing system remain unanswered. To address the first two of these areas, the objective of this study was to determine the potential cutting yield and value recovery of dimension products that can be attained directly from logs. In particular, this study focused on estimating yield and value recovery from both Grade 2 and 3 red oak logs. The effect of various processing configurations and cutting bills on yield and value recovery was also investigated in this study.

Materials and methods

The methods used in this study were devised to investigate the potential yield and value recovery of a direct processing system that cuts logs directly to green dimension. Many factors can influence the yield and value recovery of such a system. The factors considered in this study include input log grade (Grade 2 vs. Grade 3), log sawing pattern (live vs. five-part), log flitch cutting sequence (rip-first vs. crosscut-first), and cutting bill requirements (short, long, and mixed). The following section describes the methods, materials, and assumptions used in the study.

Direct processing system configuration

The proposed direct processing system that cuts logs directly to green dimension products combines sawmill operations with rough mill operations. Many different direct processing options can be considered including various combinations of headsaw break-

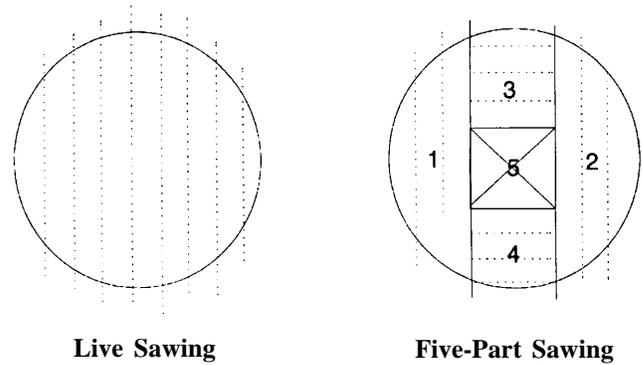


Figure 2. — Diagram of live sawing and five-part sawing.

down patterns and rough mill cutting sequences. In general, logs enter the mill and are debarked and broken down as typically done in a hardwood sawmill. The flitches that result in this primary breakdown then go through a dimension rough mill process to be cut into green dimension blanks. Consequently, the selection of the primary sawing pattern and rough mill cutting sequences have a substantial effect on the yield and quality of the dimension parts produced.

TWO sawing patterns for sawing logs to flitches (live and five-part sawing (Fig. 2)) were considered in this study. These two sawing patterns are currently used in many hardwood sawmills. Five-part sawing has been widely used for sawing low-grade hardwood logs into lumber and cants. In five-part sawing, parts 1 and 2 are usually sawn on a headrig saw, parts 3 and 4 are sawn on a gang resaw, and part 5 (a cant) is removed from the center of each log. The cant can be used for making pallet parts rather than dimension parts. The size of the center cant produced in this study for the five-part sawing method was assumed to be a 4- by 4-inch cant. In this study, the two principal cutting sequences currently used in rough mills, rip-first and crosscut-first, were considered for cutting flitches into rough dimension parts.

Data preparation

A total of 11 Factory Grade 2 and 10 Factory Grade 3 red oak logs were used in obtaining the yields of green rough dimension parts. The logs were 8 to 12 feet long. The small-end diameter of the logs ranged from 12 to 16 inches for the Grade 2 logs and 10 to 15 inches for the Grade 3 logs. The log scaling board footage was measured by the International 1/4-inch Rule. All logs were graded in a sawmill by a log grader and were then re-graded by an expert before sawing in accordance with USDA Forest Service Factory Grade log Rules (9). After the logs were sawn, the grades of these logs were further verified to be accurate by comparing the actual lumber grade distributions obtained with published lumber grade yields for factory logs (4).

To provide data to estimate yields for live-sawing patterns, all logs were live sawn into 1-1/8-inch flitches using a circular headrig saw with a kerf of 0.28

TABLE 1. — Cutting bills tested.

Cutting bill	Length category	Cutting length (in.)	Cutting width*
1	Mixture	15, 18, 21, 25, 29, 33, 38, 45, 50, 60, 75	Random
2	Shorter	15, 18, 21, 25, 29, 33	Random
3	Longer	38, 45, 50, 60, 75	Random

*Widths ranged from a minimum of 1.0 inch to a maximum of 5.0 inches.

inch. The first opening face of each log was randomly selected. After the logs were sawn into flitches, each flitch image, including the shape and all defects on it, was traced onto a transparent sheet. Defects included wane, sound and unsound knots, stain, decay, pith, holes, checks, and splits. From the image on each transparent sheet, data of each flitch, including internal defects and outline, were digitized and entered into a computer. Using 1/4-inch resolution, the coordinates of the lower left and upper right corners of the rectangle enclosing each defect and the type of defect were recorded. Several smaller contiguous rectangles were used for large and irregular defects, in particular wane, to better approximate their true shape.

With some additional sawing, the same live-sawn flitches were used to provide the data to estimate yields for five-part sawing patterns. Assuming that the position of the first opening face on a log for five-part sawing was identical to the first opening face used in the live sawing, the flitch data of parts 1 and 2 in five-part sawing were obtained directly from the live-sawn flitches. For a given log, the flitch data of parts 3 and 4 in five-part sawing was obtained by ripping the three central live-sawn flitches into 1-1/8-inch strips. The adjacent strips from the three central live-sawn flitches were used to reconstruct the board faces resulting from parts 3 and 4. Shape and defect data were traced from the reconstructed board faces and digitized in the same manner as described earlier.

Estimation of dimension yield

After data preparation, four groups of actual flitch data were available (two log sawing patterns for each of the two log grades). CORY (3), a computer-based cut-up program, was then used to estimate the cutting yield from each of the four groups of flitch data. The two-stage version of CORY was used to optimize the sawing of random-width, fixed-length cuttings. One stage in this two-stage process is defined as either a rip or a crosscutting operation. A sawing process enters a new stage when the operation changes from crosscut to rip or vice versa. The computed "optimal" cutting yields from a two-stage processing sequence are conservative because no salvage cutting operations are considered.

To test the effect of different dimension cutting system configurations, both the rip-first and crosscut-first models of CORY were used. A random-width cutting was specified ranging from a minimum of 1.0 inch to a maximum of 5.0 inches. A 1/4-inch kerf was assumed for crosscutting and a 3/16-inch kerf for ripping. All cuttings were clear-two-face (i.e., no defects were allowed on either face of each cutting).

Just as the direct processing mill configuration influences the yield of dimension parts, so does the specification of the cutting lengths required during a production run. To investigate the effect of different cutting lengths required, three cutting bill requirements were used in CORY and are listed in Table 1. These cutting lengths were adopted from the standard sizes recommended by Araman et al. (1). The first cutting bill contains a mixture of both longer (≥ 38 in.) and shorter cuttings (≤ 33 in.), the second cutting bill includes only shorter cuttings (≤ 33 in.), and the third cutting bill includes only longer cuttings (≥ 38 in.).

In CORY, the cutting priorities for different cutting lengths are determined by the relative value of each cutting length to others in a cutting bill. By assigning an exponential weighting factor (*wf*) to cutting length, the relative value of each cutting is determined based on the value of $Width \times Length^{wf}$. A weighting factor of 1.1 was used in all CORY analyses used in this study. This weighting factor reflects a higher priority placed on longer cuttings.

CORY output provides information on the board footage of dimension parts produced, percentage recovery of individual part lengths, average length of parts produced from given input, and cutting solutions of each flitch. In this study, total yield is defined as the ratio of board footage of rough dimension parts produced to the scaling board footage of the input logs. For five-part sawing, the yield of the 4- by 4-inch cants is similarly defined as the ratio of the board footage of cants produced to the scaling board footage of the input logs. Scaling yield instead of actual volumetric yield was used for comparisons in this study because sawlogs are priced and marketed according to a log scale. Logs were scaled using the International 1/4-inch Rule (9).

Estimation of value recovery

Because longer parts are usually more difficult to obtain than shorter parts for the given raw material input, especially for lower quality logs, longer parts have more value than shorter parts. Therefore, yield and value are not necessarily the same. In addition, the cants produced by five-part sawing were not taken into account in dimension yield, however, these cants are a part of the value recovered from input logs and need to be considered in value recovery. Estimating product value is a complex task. First, price is a sensitive issue to product manufacturers: the majority of them are not willing to reveal their price information to others. Second, the price for the same product

varies between companies and can change significantly over time.

One important issue in estimating the value of dimension parts is how to determine the relative value of different cutting lengths. An exponential relationship between part value and cutting length was used in previous studies (11,12). This relationship can be expressed as:

$$Value = A \times Width \times Length^f \quad [1]$$

In Equation [1], the exponent f can be determined by exponential regression using actual price data (7,12). The constant A is the base price of dimension and can also be determined using actual price data.

If both sides of Equation [1] are divided by $Width \times Length$, the value per board footage parts, $Price$, will be obtained:

$$Price = A \times Length^{f-1} \quad [2]$$

The parameter A in this study was based on the price of 33-inch parts. Given the price of 33-inch parts, $Price_{33}$, and substituting in Equation [2], A is found to be $Price_{33}/33^{f-1}$. Hence, the price per board foot (BF) for a part of a particular length, $Price_L$, can be determined:

$$Price_L = Price_{33} \times (Length / 33)^{f-1} \quad [3]$$

Based on actual price data obtained through a survey (7), exponential regression was used to determine $f = 1.3$. The average price, $Price_{33}$, for 33-inch-long clear-two-face 4/4 red oak dimension parts was found to be \$2,200 per thousand BF (MBF).

Since the yield of dimension parts obtained from CORY was green dimension yield, some assumptions were made to convert green yields to dry yields. Dry dimension yield considering volume losses from both shrinkage and drying degrade was assumed to be 79 percent of the green dimension yield. This reduction considers a 7 percent volume loss due to shrinkage from green to a final moisture content of 6 percent and a 15 percent volume loss due to post-drying remanufacturing necessary to remove the presence of any drying defects such as end split and warp. The value of dimension parts of each individual length was calculated by multiplying the board footage of dry parts of each length by the corresponding price obtained from Equation [3]. For five-part sawing, the value of 4-by 4-inch cants was added to the value recovery. The price for 4- by 4-inch pallet cants was assumed to be \$190 per MBF, based on information obtained from pallet manufacturers.

TABLE 2. — Overall scaling yield ^a of rough green dimension parts from Grade 2 and 3 red oak sawlogs for four processing methods. ^b

Cutting bill	L-X		L-R		F-X		F-R	
	Grade 2	Grade 3	Grade 2	Grade 3	Grade 2	Grade 3	Grade 2	Grade 3
	----- (%) -----							
1	77.9	76.2	76.4	73.3	71.8 ^c	65.6 ^d	69.7 ^c	62.3 ^d
2	78.5	76.7	77.1	75.3	72.7 ^c	66.8 ^d	70.5 ^c	63.5 ^d
3	61.5	57.1	62.3	58.6	57.8 ^c	52.5 ^d	57.8 ^c	52.3 ^d

^aScaling yield is defined as the ratio of board footage of rough green dimension parts to the International 1/4-inch scaling board footage of the input logs.

^bL-X = live-sawing followed by crosscut-first cutting; L-R = live-sawing followed by rip-first cutting; F-X = five-part sawing followed by crosscut-first cutting and F-R = five-part sawing followed by rip-first cutting.

^cA 15.4 percent scaling yield of 4- by 4-inch cants from five-part-sawn Grade 2 logs was not included in the data shown in this table.

^dA 22.7 percent scaling yield of 4- by 4-inch cants from five-part-sawn Grade 3 logs was not included in the data shown in this table.

TABLE 3. — Dollar value recovery per board foot of log input by log grade for four processing methods. ^a

Cutting bill	L-X		L-R		F-X		F-R	
	Grade 2	Grade 3	Grade 2	Grade 3	Grade 2	Grade 3	Grade 2	Grade 3
	----- (\$) -----							
1	1.46	1.18	1.65	1.37	1.44	1.14	1.55	1.20
2	1.40	1.15	1.46	1.23	1.35	1.08	1.37	1.09
3	1.38	1.09	1.43	1.17	1.34	1.06	1.35	1.08

^aL-X = live-sawing followed by crosscut-first cutting; L-R = live-sawing followed by rip-first cutting; F-X = five-part sawing followed by crosscut-first cutting; and F-R = five-part sawing followed by rip-first cutting.

TABLE 4. — Dollar value recovery per dollar of log input by log grade for four processing methods. ^a

Cutting bill	L-X		L-R		F-X		F-R	
	Grade 2	Grade 3	Grade 2	Grade 3	Grade 2	Grade 3	Grade 2	Grade 3
	----- (\$) -----							
1	3.94	9.86	4.45	11.39	3.89	9.48	4.18	10.02
2	3.77	9.59	3.95	10.25	3.64	8.99	3.71	9.06
3	3.73	9.05	3.86	9.73	3.62	8.82	3.66	9.02

^aL-X = live-sawing followed by crosscut-first cutting; L-R = live-sawing followed by rip-first cutting; F-X = five-part sawing followed by crosscut-first cutting; and F-R = five-part sawing followed by rip-first cutting.

TABLE 5. — Number of cutting operations required to obtain 1 board foot of rough green parts by log grade for four processing methods. ^a

Cutting bill	L-X		L-R		F-X		F-R	
	Grade 2	Grade 3						
1	3.4	4.5	3.2	4.2	2.8	3.8	2.8	3.7
2	3.6	4.6	3.9	4.9	3.1	4.1	3.6	4.4
3	2.0	2.7	2.5	3.0	1.8	2.4	2.3	2.6

^aL-X = live-sawing followed by crosscut-first cutting; L-R = live-sawing followed by rip-first cutting; F-X = five-part sawing followed by crosscut-first cutting; and F-R = five-part-sawing followed by rip-first cutting.

TABLE 6. — Average cutting lengths of dimension parts by log grade, processing method, and cutting bill. ^a

Cutting bill	L-X		L-R		F-X		F-R	
	Grade 2	Grade 3						
	(in.)							
1	24.1	22.1	36.2	35.1	29.8			
2	21.4	20.4	25.9	25.3	23.3	22.5	26.3	26.2
3	47.8	45.2	50.7	50.6	49.4	48.0	50.7	50.7

^aL-X = live-sawing followed by crosscut-first cutting; L-R = live-sawing followed by rip-first cutting; F-X = five-part sawing followed by crosscut-first cutting; and F-R = five-part sawing followed by rip-first cutting.

Results and discussion

Dimension yield and value recovery from red oak logs

The overall yields of rough green dimension parts produced from Grade 2 and 3 red oak logs are tabulated for the three cutting bills and four combinations of the sawing patterns and cutting sequences are presented in Table 2. Varying from processing system configuration and cutting bill used, the average scaling yield of rough green dimension parts ranged from 57.8 to 78.5 percent for Grade 2 red oak logs and from 52.3 to 76.7 percent for Grade 3 red oak logs. Overall, 7 percent more dimension yield can be realized from Grade 2 logs over Grade 3 logs.

The value recoveries from Grade 2 and 3 red oak logs are shown in Tables 3 and 4. On the basis of per scaling BF (International 1/4-in.) log input, the value recovery from processing logs directly into dimension parts ranges from \$1.34 to \$1.65 for Grade 2 red oak logs and from \$1.06 to \$1.37 for Grade 3 red oak logs (Table 3). On the basis of log value, \$1 of log input can produce a range from \$3.62 to \$4.45 value of products output for Grade 2 red oak logs and from \$8.82 to \$11.39 value of products output for Grade 3 red oak logs (Table 4). Although Grade 2 logs average 24 percent greater value recovery than Grade 3 logs on a log volume basis, Grade 2 logs average 60 percent less value recovery than Grade 3 logs on a log value basis.

These dimension yield and value figures give only an overall range of gains in dimension parts from given logs. These figures vary from input log grades, processing system configurations, and cutting bills. The following discussion will provide further analysis on the effect of these factors on dimension yield and value recovery.

The effect of log grade on dimension yield and value recovery

Compared to Grade 3 logs, Grade 2 logs resulted in an average of 7 percent greater dimension yields. This greater yield of Grade 2 over Grade 3 logs is more pronounced for five-part sawing (from 8.8% to 11.9%)

than for live sawing (from 2.2% to 7.7%). Although Grade 2 logs can produce higher dimension yield than Grade 3 logs, the value recovery from Grade 3 logs, on the basis of log value, is over twice as much as that from Grade 2 logs. The simple reason is that the price of Grade 2 logs is much higher than the price of Grade 3 logs. In fact, the price of the Grade 2 red oak logs can be more than triple the price of the Grade 3 red oak logs. For Grade 3 logs, the effect of lower prices on the value recovery far surpasses the effect of lower yields.

In discussing the value recovery from Grade 2 and 3 logs, the possible difference in processing costs was not considered. Because Grade 3 logs contain more defects than Grade 2 logs, more cutting operations are needed for processing Grade 3 logs, and more cutting operations will result in higher machining and labor costs. Therefore, the operating cost of processing Grade 3 logs can be more than that of processing Grade 2 logs. Table 5 gives information on the average number of cutting operations (i.e., the number of passes through both the rip and crosscut saws) required to produce 1 BF of rough green dimension by log grades, which was obtained from CORY output. As shown in Table 5, Grade 3 red oak logs require about 30 percent more cuttings than Grade 2 red oak logs to obtain the same volume of dimension output.

Although the operating cost of processing Grade 2 logs can be less than that of processing Grade 3 logs, the large difference in the value recovery from per dollar log input between the two log grades may not be offset by the difference in their operating cost. Hence, it may be more economical for the direct processing system to process Grade 3 logs than to process Grade 2 logs. In other words, the direct processing system is more suitable for processing lower grade logs than for processing higher grade logs. To fully evaluate the economic performance of the direct processing system for processing different grades of logs, future work is being undertaken to explore in more detail the overall profitability of the direct processing system considering operating costs as well as value recovery.

The effect of processing configuration on dimension yield and value recovery

In this study, the two sawing patterns and two cutting sequences produced four combinations of sawing pattern and cutting sequence. How the different processing configurations affect dimension yield and value recovery is another concern of this study.

Compared to live sawing, five-part sawing resulted in 3.7 to 6.7 percent less dimension yield for the Grade 2 logs and 4.6 to 11.8 percent less dimension yield for the Grade 3 logs. This reduction in yield was expected because five-part sawing produced 4-by 4-inch cants that were not cut into dimension parts. Five-part sawing produced an additional 15.4 and 22.7 percent scaling yield from Grade 2 and 3 red oak logs, respectively, when considering the 4- by 4-inch center cants. The reduction in dimension yield resulting from producing cants is much less significant for the cutting bill that contains only longer cuttings (lengths ≥ 38 in.) than for the cutting bill that contains shorter cuttings (lengths ≤ 33 in.). Therefore, as cutting requirements shift toward increasingly longer cuttings the contribution of the center portion of the log to dimension yield decreases.

The difference in dimension yield between rip-first and crosscut-first was small ($\leq 3.3\%$). However, rip-first cutting resulted in substantially longer cutting lengths than crosscut-first cuttings for both Grade 2 and 3 logs (Table 6). The effect of rip-first cutting had an especially large increase in average cutting length with a cutting bill of mixed lengths (cutting bill 1).

For both Grade 2 and 3 red oak logs, on both bases of per BF log input and per dollar log input, the combination of live sawing and rip-first gained the highest value recovery among the four combinations of sawing pattern and cutting sequence. Although the combination of live sawing and crosscut-first produced much higher dimension yield than the combination of five-part sawing and rip-first, the difference in value recovery between these two processing configurations appears to be very small. This is partially because the combination of five-part sawing and rip-first produced much longer cuttings than the combination of live sawing and crosscut-first, and partially because the value of cants produced in five-part sawing was taken into account in the calculation of value recovery.

The effects of cutting bill on dimension yield and value recovery

It is a general trend that the longer the required cuttings, the lower the cutting yield. It was found that cutting bills with longer cuttings (cutting bill 3) resulted in 10 to 19.6 percent less part yield when compared to cutting bills with shorter cuttings (cutting bill 2). The cutting bill with both longer and shorter cuttings (cutting bill 1) resulted in highest value recovery. Compared to cutting bill 2, bill 1 resulted in an average of \$0.35 and \$0.72 more value recovery from per dollar log input for Grade 2 and 3 logs, respectively. Compared to cutting bill 3, bill 1 resulted

in an average of \$0.40 and \$1.03 more value recovery from per dollar log input for Grade 2 and 3 logs, respectively. These results suggest that a mill processing hardwood logs directly into rough dimension parts should try to include both longer and shorter cuttings in its cutting bills to gain the maximum value recovery. From these results, it also can be seen that the difference in value recovery caused by cutting bill is larger for Grade 3 logs than for Grade 2 logs.

The yield data presented in this paper were obtained under "optimal" cutting conditions. Issues that can significantly affect these results such as defect variability within log grades, drying degrade, worker performance, material handling, and other practical constraints of the process have not been investigated. Future studies will look more closely at some of these practical constraints and how they can affect the overall performance of a direct processing system. However, the results of this study do show that there can be a large potential for increasing cutting yields and value recovery from our abundant low-grade timber resources and calls attention to more efficient processing techniques.

Summary

The results showed that the overall scaling yield of rough green dimension parts ranges from 57.8 to 78.5 percent for Grade 2 red oak logs and from 52.3 to 76.7 percent for Grade 3 red oak logs. On the basis of log value, \$1 of log input can produce an output value ranging from \$3.62 to \$4.45 for Grade 2 red oak logs and from \$8.82 to \$11.39 for Grade 3 logs. Based on per dollar log input, Grade 3 logs have a higher value recovery than Grade 2 logs because of the notably higher price of Grade 2 logs. This result indicates that the direct processing system is more suitable for processing Grade 3 logs than for processing Grade 2 logs.

In considering processing configurations, the results of this study show that the combination of live sawing and rip-first can provide the highest value recovery among the four combinations of sawing patterns and cutting sequences tested. The combination of longer cuttings and shorter cuttings in a cutting bill can offer higher value recovery than only having shorter or longer cuttings in a cutting bill. This result suggests that shorter cuttings and longer cuttings should be combined in a production run, whenever possible, to recover the maximum value from given logs. Combining shorter cuttings and longer cuttings in one cutting bill is particularly important for recovering the maximum value from Grade 3 logs. With proper processing technology and management techniques, a processing system that produces dimension products directly from logs can offer a promising alternative in value added processing of lower grade timber resources.

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