NONDESTRUCTIVE EVALUATION FOR DETECTION OF HONEYCOMB IN THE SAWMILL: AN ECONOMIC ANALYSIS

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ABSTRACT

The technical feasibility of using ultrasonics-based nondestructive evaluation (NDE) for detecting non-visible defects such as honeycomb and closed surface checks has been established. The economic feasibility of using ultrasonics-based NDE in the sawmill is established in this study of red oak scanning. Three different-sized sawmill configurations for processing dry lumber through an ultrasonic NDE scanner are analyzed. Sensitivity analyses show that a decrease in revenues or a decrease in capacity utilization has the greatest impact on the potential profitability of the investment. Results indicate that the economic benefits of scanning red oak lumber to identify the occurrence of honeycomb or closed surface checks will, in the majority of cases, outweigh the cost of implementing this new technology in the sawmill.

Nondestructive evaluation (NDE) of wood using ultrasonics has been under development at the USDA Forest Products Laboratory, Madison, Wis., for 3 years (4,5,14,15). Ultrasonics-based sensing holds potential for detecting non-visible defects such as honeycomb, closed surface checks, and encased pith. Honeycomb and closed surface checks in kiln-dried lumber, if undetected at the start of remanufacturing, can be a source of value loss because the value added to the wood during remanufacture will be wasted.

In this study, we investigate the economic feasibility of introducing ultrasonics-based NDE into a sawmill following kiln-drying to detect honeycomb and closed surface checks. We examine three investment-processing scenarios that cover a range of capital investment and mill productivity alternatives. Using a discounted cash-flow approach, we calculate the net present value and internal rate of return for each investment-processing scenario. Also, we discuss some general issues in investment analysis that affect results.

We focus on red oak lumber in this analysis because of its commercial importance and because red oak lumber is prone to drying-related defects, i.e., honeycomb and closed surface checks. An estimated 27 percent of lumber consumed in the manufacture of wood household, upholstered, and wood office furniture is red oak (11). In addition, red oak is currently the highest volume species used in the production of dimension stock, accounting for 33 percent of all species used (12). Wengert (16) notes that in drying the commercially important hardwoods of North America, the oaks are the most prone to degrade from deep surface checking or honeycomb.

STUDY DESIGN

APPLICATION ALTERNATIVES

Where might the ultrasonics-based technology be applied? There are several distinct application alternatives or scenarios that can be considered: 1) in a hardwood sawmill with dry-kiln facilities; 2) in the distnbution/remanufacturing operation of an inter-media-y in the hardwood lumber distribution channel; and 3) in the dry unstacker or roughmill areas of a secondary wood processor.

In this analysis, we focus on the first of these alternatives—application of NDE sensing post-drying in a hardwood sawmill complex. Sawmills with kilns either dry and then ship their dry lumber essentially as is after unstacking or they perform certain remanufacturing or value-adding activities such as regrading, sorting for different markets/customers, or edging and trimming the lumber to increase its value. NDE sensing for the detection of honeycomb, used in inspection, would provide a measure of quality assurance heretofore unachievable. Based on the NDE results, separation of "good" and "bad" lumber will take place

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TABLE 1. — Variable and fixed operating costs for three sawmill-based ultrasonics NDE production alternatives, years 1 to 10.

Cost item	Small (5 MMBF/yr.)	Medium (10 MMBF/yr.)	Large (25 MMBF/yr.)
	($)		
Variable costs			
Labor	22,100	44,200	110,500
Utilities	7,500	15,000	37,500
Fixed costs			
Other fixed costs	7,500	15,000	37,500
Total	37,100	74,200	185,500

to increase quality of lumber delivered to the customer. While the NDE scanning cannot guarantee 100 percent defect detection, the lumber could decertified as having no more than a certain percentage of internal defects. Sawmills would undertake NDE scanning only if they can obtain a premium for lumber that is so certified,

In this study we investigate the feasibility of implementing NDE scanning of kiln-dried lumber for three different size-based sawmill configurations. The small configuration assumes a daily production rate of 20 thousand board feet (MBF) of kiln-dried lumber through the sensor. Assuming the production facility operates 250 days per year. this would be equivalent to a mill producing about 5 million board feet (MMBF) of lumber per year. The medium configuration is based on a production rate of 40 MBF per day or a total of 10 MMBF per year. The large configuration is based on a production rate of 100 MBF per day through the NDE sensing operation, or a total of 25 MMBF per year.

Methods of analysis

The economic feasibility of the NDE technology applied to the small, medium, and large mill configurations is assessed using a discounted cash flow (DCF) approach to obtain the net present value (NPV) and the internal rate of return (IRR). The relationship between initial investment requirements and anticipated future after-tax cash flows is best captured using these DCF evaluation measures.

Investment parameters

Initial costs

Investment requirements for a single NDE scanner, installed and running, are estimated to be approximately $50,000 per unit. However, we believe that an additional amount should be added to this initial investment to cover contingencies such as freight, sales tax, and engineering changes in the production line. This amount is estimated to be 25 percent of the cost of the equipment investment, or an additional $12,500, making the total investment in scanning and materials handling equipment equal $62,500. No salvage value is assumed for the NDE equipment at the end of the investment period.

Variable operating costs

We assume the variable costs associated with lumber scanning are the labor cost for the NDE scanner operator and the direct electrical and other miscellaneous utility costs associated with operating the equipment **(Table 1).** Assuming a direct hourly wage rate of $8.50 plus mandatory fringe benefits (30%) of $2.55 per hour, the one-shift cost per year for the NDE scanner operator is calculated to be $22,100. Utility costs, including direct electrical costs, are estimated at $30 per 8-hour shift for a one-shift cost per year of $7,500. All these costs are based on a similar analysis by Harpole and McDonald (10) and have been adjusted to reflect current unpublished wage/benefit profiles and utility rates experienced by hardwood lumber processors.

Other variable costs such as supply costs, selling expenses, and raw material costs are not factored into this analysis. We have assumed that introducing the NDE technology would have only a limited effect on supply costs, thus, incremental supply costs are set at zero. Selling expenses associated with establishing salvage markets for the honeycombed lumber and obtaining premiums for the honeycomb-free lumber are difficult to estimate. Therefore, selling expenses are not individually addressed but instead are captured in the variable cost adjustments made in the sensitivity analysis. The cost of the raw material (lumber) is considered later for purposes of estimating processing costs on the NDE equipment.

Fixed operating costs

Fixed costs are generally composed of management and administrative costs, insurance costs, and maintenance expenses. For purposes of simplification, these costs are combined into a single value, referred to as factory overhead. Unpublished data obtained from hardwood lumber processors indicate that factory overhead, expressed as a percent of sales, is about 15 percent on an annual basis. In the absence of more quantitative data, the fixed operating cost in this analysis is 15 percent of the cost of the installed NDE equipment. This amounts to $7,500 per one-shift year **(Table 1).**

Revenues

Unlike other investment analyses where revenue estimates are obtained from estimates of sales of a final product on the open market, this analysis deals with changes in lumber value as it is inspected with the ultrasonic NDE scanner. For sawmills with dry-kiln facilities, we assume lumber is either dried and shipped as is (without NDE sensing) or remanufactured into value-added, proprietary grades (after NDE sensing).

In combination, the price obtained for lumber certified as "inspected for honeycomb and closed surface checks" and any salvage value that can be realized from the lumber culled out during certification must exceed the going market rate for "uncertified" lumber—otherwise there is no financial incentive for adopting this technology. Indications of the willingness of softwood lumber buyers to pay a premium for high quality lumber were detected by Reddy and Bush (13). There is reason to expect the same willingness to pay a premium exists among hardwood lumber buyers. Bush et al. (1), using determinant attribute analysis, concluded that grading accuracy is critical for hardwood lumber users and provides an opportunity for hardwood lumber producers to employ a differentiation or focus strategy to tailor their products to increase customer satisfaction. They note the following, "In the case of grade hardwood lumber, differentiation could be based on lumber grading and may result in price differentials or increased customer loyalty."

There also must be a market for the lumber separated out in the inspection process. This lumber can be sold to lum-

TABLE 2. — Price of Appalachian Region kiln-dried red oak lumber, by grade, January 1996.[a]

Lumber grade	Dollars/MBF
FAS	1,455
SEL	1,435
No. 1 Common	965
No. 2 Common	635

[a] Source: Hardwood Market Report, Memphis, Tenn. (9).

TABLE 3. — Total revenues, by lumber grade, from sale of salvage lumber, for three mill size alternatives, years 1 to 10.

Lumber grade	Small (5 MMBF/yr.)	Medium (10 MMBF/yr.)	Large (25 MMBF/yr.)
	($)		
FAS	6,600	13,200	32,999
SEL	8,197	16,393	40,984
No. 1 Common	28,964	57,929	144,822
No. 2 Common	20,725	41,449	103,623
Total	64,486	128,971	322,428

ber buyers who are not as concerned with the presence of the internal defects and are willing to purchase this lumber at some price that reflects the salvage value of the lumber. Selling these new products may require (at least initially) considerable sales effort. This effort will have a cost associated with it that may be significant but is difficult to estimate. This variable cost is addressed via our sensitivity analysis. Entry of competitors will likely decrease price premiums for certified lumber and will increase supply to markets that purchase the salvage lumber. The overall result will be a reduction in profits and in the measures of investment worth. While this effect is not directly quantifiable in the DCF analysis, the conservative nature of the investment parameters allows for considerable change in the price premium without adverse effect on the measures of investment worth. The impact of the revenue assumptions on the DCF analysis results is part of the sensitivity analysis.

In this analysis, the increase in value, or premium, for the certified lumber is equated to the prevailing market price of lumber separated out in the inspection process. The mill then realizes an increase in revenue equal to the salvage value for the lumber separated out in the inspection process when that lumber is sold. Therefore, as some buyer's desire for cost avoidance of honeycombed lumber translates into additional revenues for the sawmill, these revenues can be used to measure the performance of the investment.

Estimating these revenues requires that we first estimate the following parameters: 1) the species, volume, and distribution of lumber grades being processed; 2) the frequency of occurrence of the relevant defects for each lumber grade processed; and 3) the current market price for kiln-dried lumber. The current market price used in this analysis comes from the January 6, 1996, Hardwood Market Report (9).

The species, volume, and distribution of the lumber grades going through the scanner at a sawmill depend on the log and lumber markets of the individual mill. For purposes of this analysis, certain simplifying assumptions about species, volume, and distribution of lumber grades are made. For reasons noted earlier, we have chosen to limit the species in the analysis to red oak.

We recognize that considerable variation exists in the species and grades of lumber produced from one sawmill to another. Because there is a lack of published statistics on sawmill production, we use the distribution of lumber recovered from grade 2 sawlogs as an approximation of actual lumber production from sawmills. A distribution, by grade, of red oak lumber recovered from grade 2 sawlogs was obtained from Hanks (6). The expected grade distribution from No. 2 grade red oak sawlogs is: 10.8 percent FAS, 11.2 percent Selects, 34.5 percent No. 1 Common, 25.3 percent No. 2 Common, and 18.2 percent 3A and lower.

Our estimation of the frequency of occurrence of the relevant defects for each lumber grade is based on results presented by Wiedenbeck (18). These results give the mean cumulative areas of various visible defects for Appalachian red oak lumber by grade. We assume the area of non-visible defects related to splits, pith, and pith-related defects, i.e., honeycomb and closed surface checks, equals the area of the visible defects. This assumption is supported by Wengert (17), who observed, "In 99 percent of the cases of internal checking, the internal check is an extension of a surface check or end check." The results presented by Wiedenbeck provide a conservative estimate of the amount of wood affected by honeycomb and closed surface checks. The volume-based percentage of lumber affected by honeycomb or closed surface checks is estimated to equal 0.14 percent for FAS grade red oak lumber, 0.28 percent for Selects grade red oak lumber, 1.96 percent for No. 1 Common grade red oak lumber, and 3.04 percent for No. 2 Common grade red oak lumber.

In the sawmill scenario posed in this analysis, a premium is obtained for lumber certified as "inspected for honeycomb and closed surface checking." If this premium equals the value of lumber separated out in the inspection process, the revenue received from selling certified lumber is the same as the previous revenue from selling all lumber uninspected. However, the lumber separated out in the inspection process is sold for some salvage price. Therefore, the mill realizes an increase in revenue equal to the salvage price obtained for the lumber separated out by inspection when it is sold.

In order to calculate this increase in revenue. we must first estimate the number of boards separated out in the inspection process. If we assume that drying practices minimize the occurrence of honeycomb. the results of Cech and Pfaff (2) can be used to estimate the number of boards containing honeycomb. Cech and Pfaff found 2.9 percent of No. 1C red oak boards and 4.3 percent of No. 2C red oak boards contained honeycomb when dried to 8 percent moisture content using a mild kiln schedule. Based on the percentage of boards with defects found by Wiedenbeck (18), these estimates are extended to include FAS and Selects grades at 1.4 and 1.7 percent, respectively. The number of boards separated out in the inspection process is obtained by multiplying the total number of boards processed in each grade by the percent of boards just given that were estimated to contain honeycomb. The total number of boards processed in each grade is estimated by dividing the board foot

volume of lumber production in each grade by an average volume per board reported by Wiedenbeck (18).

The salvage value of the boards separated out by inspection is assumed to be no more than 60 percent of the current market price for lumber in each grade **(Table 2).** This is a conservative estimate of the salvage value, given that the volume of material affected in each board was shown earlier to range from less than 1 percent for FAS and Select lumber to just over 3 percent for No.2C lumber.

The revenue from the salvage lumber in each grade is calculated by multiplying the number of boards separated out in the inspection process by the average volume per board and by the salvage price per board foot. Summed across all grades, this yields the daily salvage value for boards separated out by inspection. These daily values are converted to yearly values by multiplying the salvage value by the number of operating days, assumed to be 250 days per year **(Table 3).**

OTHER FACTORS AFFECTING INVESTMENT

In addition to the initial capital expenditure, operating costs, and revenues, other less obvious factors also influence the economic feasibility of ultrasonic-based scanning of hardwoods. These include: the time period or useful life of the investment, inflation, depreciation, sources and costs of funds, tax rates and tax credits, and the time required to reach full production (8).

In our analysis, we assume a 10-year period for evaluation of the investment. This period is fairly standard and can be justified on the basis that: 1) discounted values after 10 years at current interest rates make up a relatively small percentage of the total revenue resulting from the investment; 2) equipment can become outmoded by advancing technology so that obsolescence must be considered for investments longer than 10 years; and 3) when longer periods are forecast for investment, the degree of uncertainty concerning investment assumptions greatly increases (8).

The rate of inflation and its effects on the various revenue and cost factors is difficult to predict. Underestimating or overestimating changes in inflation rates has consequences that can seriously affect predicted performance. Given that we cannot accurately predict these changes, we have chosen to disregard inflation and assume constant net revenues over the life of the investment.

Depreciation, as used in DCF analyses, provides a shield from taxation for a portion of income equal to the amount of investment in building and equipment. Several methods are available for writing off depreciation. We have chosen the most conservative approach, i.e., straight line depreciation over 10 years. Therefore, for this analysis we have apportioned equipment costs equally over the 10-year period of the investment.

The interest cost of debt capital and the desired return (profit) earned by equity capital for this investment analysis are set at 12 and 15 percent, respectively. We assume that the proportion of the total investment financed by debt capital is 40 percent. Because we are mixing debt and equity in a 40/60 ratio and debt reflects its after-tax cost, the true hurdle rate (that which will return 15% to investors) for this investment is 11.88 percent. While individual investors will have different sets of financial arrangements, we believe that these estimates of the source and cost of funds are in line with current rates and financing options available to investors in the industry (3).

The effective tax rate for this investment is set at 40 percent of taxable income. This rate is a composite rate including federal, state, and local taxes. Individual investors may experience higher or lower effective tax rates, but this rate will be close to the actual rate experienced by the majority of investors.

In our DCF analysis of an ultrasonics-based NDE investment, we do not consider start-up or learning curve rates of production to be significantly less than full production. Because the new equipment will be placed in an existing production stream, full production is expected to be reached almost immediately. The equipment, when installed and running, is designed to process all of the raw material going through the manufacturing operation. Our initial assumption is that lumber can be processed at a rate of 72 lineal feet per minute through the ultrasonic NDE equipment. This is a con-

TABLE 4. — Small sawmill (5 MMBF per year) cash flow summary for one scanner, one shift per day production.

Year	Equipment investment	Revenues	Operating costs	Depreciation	Net after-tax cash flows
	($)				
0	62,500				- 62,500
1		64,486	37,100	6,250	18,931[a]
2		64,486	37,100	6,250	18,931
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--		--	--	--	--
--		--	--	--	--
10		64,486	37,100	6,250	18,931

[a] Calculated as follows: $64,486 – $37,100 = $27,836 (before-tax revenue); $27,836 – $6,250 = $21,136 (taxable income); $21,136 – $8,454 (taxes) = $12,681 (after-tax profit); $12,681 + $6,250 = $18,931 (after-tax net cash flow).

TABLE 5. — Medium sawmill (10 MMBF per year) cash flow summary, for two scanners, one shift per day production.

Year	Equipment investment	Revenues	Operating costs	Depreciation	Net after-tax cash flows
	($)				
0	125,00				- 125,000
1		128,971	74,200	12,500	37,863[a]
2		128,971	74,200	12,500	37,863
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--		--	--	--	--
10		128,971	74,200	12,500	37,863

[a] Calculated as follows: $128,971 – $74,200 = $54,771 (before-tax revenue); $54,771 – $12,500 = $42,271 (taxable income); $42,271 – $16,908 (taxes) = $25,363 (after-tax profit); $25,363 + $12,500 = $37,863 (after-tax net cash flow).

servative estimate of the throughput rate for the scanner since it has been suggested that the scanner may be capable of throughput rates in excess of 100 lineal feet per minute. At the rate of 72 lineal feet per minute, 20 MBF of lumber can be processed in a single 8-hour shift.

Comparative cash flow summaries

The net after-tax cash flows are calculated by subtracting operating costs and depreciation from revenues, computing taxes, and then returning depreciation to the after-tax income. For medium and large configuration mills with throughput of 40 and 100 MBF per day, respectively, certain changes are required that affect the net after-tax cash flows. In the case of the medium configuration, a second ultrasonics sensor is required to process the lumber through the mill in a single shift. For the large configuration, an investment in a third scanner with two of the scanners operating at two shifts per day would be required to enable the requisite lineal feet of lumber to pass through the mill. Cash flow summaries showing net after-tax cash flows for the three different-sized mills are included in **Tables 4** to **6.** These net after-tax cash flows, used to calculate the DCF measures and the non-discounted payback period, are generated using a simplified cash flow analysis program. JEFFI, developed by Hansen and Palmer (7),

TABLE 6. — Large sawmill (25 MMBF per year) cash flow summary for three scanners, two shifts per day production.

Year	Equipment investment	Revenues	Operating costs	Depreciation	Net after-tax cash flows
	($)				
0	187,500				- 187,500
1		322,428	185,500	18,750	89,656[a]
2		322,428	185,500	18,750	89,656
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--		--	--	--	--
10		322,428	185,500	18,750	89,656

[a] Calculated as follows: $322,428 – $185,500 = $136,928 (before-tax revenue); $136,928 – $18,750 = $118,178 (taxable income); $118,178 – $47,272 (taxes) = $70,906 (after-tax profit); $70,906 + $18,750 = $89,656 (after-tax net cash flow).

TABLE 7. — Economic performance of ultrasonics-based NDE scanner for the three sawmill-based production alternatives.

Sawmill size	NPV	IRR	Payback period (non-discounted)
	($)	(%)	(yr.)
Small	44,992	27.4	3.3
Medium	89,989	27.4	3.3
Large	321,574	46.8	2.1

TABLE 8. — Sensitivity of IRR to 10 percent shifts in initial assumptions for a small mill (5 MMBF per year) with one scanner and one shift per day production.

	-20%	-10%	0%	+10%	+20%
	(IRR (%))				
Operating days	14.8	21.1	27.4	33.5	39.6
Revenue	13.0	20.2	27.4	34.3	41.2
Variable cost	33.8	30.6	27.4	24.2	21.0
Fixed cost	29.2	28.3	27.4	26.6	25.8
Initial investment	34.0	30.7	27.4	24.8	22.2

Results and discussion

Discounted cash flow performance

The results of the DCF analyses for the small, medium, and large mill configurations indicate that ultrasonics-based nondestructive evaluation for detection of internal checks in hardwoods is economically feasible. As shown in **Table 7,** the NPV was positive for all three mill configurations, ranging from $44,992 for the small mill to $321,574 for the large mill. Positive NPVs indicate that these investments will earn a return greater than the firm's cost of capital, noted earlier as 11.88 percent. Likewise, the IRR ranged from 27 percent for the small configuration to nearly 47 percent for the large configuration. Although the small mill and medium mill configurations had the same IRR value, the NPV for the medium mill was twice as large as the NPV for the small mill. Non-discounted payback periods ranged from 3.3 years for the small configuration to 2.1 years for the large configuration. Given the stated assumptions about grade mix and lumber price, equipment cost, and operating costs, there appears to be a direct relationship between size and performance. Although the larger configurations are potentially more profitable, a single NDE scanner, processing 20 MBF of dry lumber per day, can be a commercially viable addition to the manufacturing operation.

Of more importance, perhaps, is how sensitive the performance measures for the three configurations are to changes in the initial assumptions. We evaluated how sensitive the IRR results were to changes in the key assumptions related to initial investment, revenues, and operating costs. We did this by imposing a 10 percent change in each of the assumptions while holding the other assumptions constant. Our results indicate that decreases in the number of operating days per year or in the revenues received have the most significant negative impact on IRR. Likewise, increases in investment and operating costs also have a negative impact on IRR, but these impacts are less than those relating to decreases in number of operating days or in revenues received. Because of the uncertainty regarding the precise amount of the initial investment, it is reassuring to note the relative insensitivity of the performance measures to changes in the initial investment cost assumption. Major additions to the initial investment cost assumption, that is, additional costs associated with alterations in the flow of material through the sawmill, should not be expected to significantly alter the conclusions regarding the investment's profitability. **Tables 8** to **10** show the changes

TABLE 9. — Sensitivity of IRR to 10 percent shifts in initial assumptions for a medium mill (10 MMBF per year) with two scanners and one shift per day production.

	-20%	-10%	0%	+10%	+20%
	(IRR (%))				
Operating days	14.8	21.1	27.4	33.5	39.6
Revenue	13.0	20.2	27.4	34.3	41.2
Variable cost	33.8	30.6	27.4	24.2	21.0
Fixed cost	29.2	28.3	27.4	26.6	25.8
Initial investment	34.0	30.7	27.4	24.8	22.2

TABLE 10. — Sensitivity of IRR to 10 percent shifts in initial assumptions for a large mill (25 MMBF per year) with three scanners and two shifts per day production.

	-20%	-10%	0%	+10%	+20%
	(IRR (%))				
Operating days	26.6	36.7	46.8	55.9	65.0
Revenue	24.0	35.4	46.8	57.1	67.4
Variable cost	56.0	51.4	46.8	41.4	36.0
Fixed cost	48.6	47.7	46.8	45.2	43.6
Initial investment	56.2	51.5	46.8	42.3	37.8

in IRR associated with 10 percent shifts in the number of operating days, revenue, variable costs, fixed costs, and the cost of the initial investment for the three configurations.

For the small (5 MMBF per year production) and medium (10 MMBF per year production) mill configurations **(Tables 8** and **9),** IRR was most sensitive to decreased revenues and reduced operating schedules (i.e., number of operating days). The IRR fell below 15 percent when either of these assumptions was reduced by 20 percent. Twenty percent increases in variable costs and 20 percent increases in the initial investment cost also resulted in decreases in IRR; but, the investments still had a return of over 15 percent in both cases.

Similar IRR sensitivity analysis for the large (annual production of 25 MMBF per year) mill configuration **(Table 10)** shows that 20 percent changes in the levels of the initial assumptions do not cause the IRR to fall below 20 percent. In the case of a 20 percent decrease in the revenue assumption, the IRR decreases to 24.0 percent.

It is important to note that we did not measure compound effects. As stated earlier, only one of the initial assumptions was changed at a time while all others were held constant. If there were increases in several of the cost items along with a decline in revenues, the compound effect could be much greater.

Revenue from Changes in Lumber Grade Mix

Because revenue changes impact IRR more than changes to other assumptions, the effect of changes in lumber grade mix on revenue (or internal cost savings) must be considered. The volume of lumber produced from grade 2 sawlogs includes 18.2 percent No. 3A Common and below lumber. Therefore, a mill sawing grade 2 sawlogs and producing 20 MBF of lumber per 8-hour shift will produce an average of 3.64 MBF of No. 3A and below grade lumber each shift. If we assume that this material would not be processed through the NDE scanner because of the limited market for this material, the revenue estimates for the three production alternatives are then based on 16.36 MBF of FAS, Select, No. 1C, and No. 2C lumber going through the NDE scanner per 8-hour shift. Increasing the throughput of these four grades of lumber to 20 MBF per shift (keeping the same relative distribution for these four grades) will increase the per shift revenue from $257.94 to $315.33 and the yearly revenue from $64,486 to $78,834. Obviously, an increase in revenue will result in an increase in DCF measures, all other costs being held constant. In fact, the 22 percent increase in revenue from $64,486 to $78,834 increased the IRR from 27.4 percent to 42.4 percent.

The effects on revenue of processing only one grade of lumber through the scanner are considerably different. In the case where a daily input of 20 MBF of only FAS lumber is processed through a single NDE scanner, the revenues are reduced to $61,110 and return an NPV of 23.4 percent. Processing only Select lumber increases revenues to $73,185 and returns an NPV of 36.9 percent. Likewise, processing only No. 1C or No. 2C lumber (20 MBF per 8-hr. shift) through the NDE scanner results in increased revenues of 30 and 27 percent, respectively, of the revenue generated in the grade 2 sawlog example. A key point to remember is that the assumptions we made regarding the percent of lumber volume affected by honeycomb or closed surface checks were conservative.

Conclusion

We have chosen to focus on dry versus green lumber inspection in this analysis. Honeycomb and closed surface checks (drying-related defects) are more reliably detected using ultrasonics-based NDE scanning than is wetwood, in green lumber. For producers who serve customer segments that place higher value on check and honeycomb-free material, NDE scanning for detection may enhance customer loyalty and/or bring price premiums. As Bush et al. (1) point out, lumber producers wishing to optimize their marketing mix for a particular segment should consider determinant attribute differences among the segments, Because accurately graded lumber is identified as the most important attribute across several sectors. the implementation of ultrasonics-based NDE scanning can provide a means for product differentiation.

Each of the three different-sized production configurations for processing lumber through an ultrasonic NDE scanner seems economically feasible, In developing an economic analysis for these alternatives, we have tended toward conservative estimates of revenues and costs. We have shown that a decrease in revenues or a decrease in capacity utilization has the greatest impact on the potential profitability of the investment. Our results and sensitivity analyses indicate that the economic benefits of scanning red oak lumber to identify the occurrence of honeycomb or closed surface checks will, in the majority of cases, outweigh the cost of implementing this new technology.

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