Economics of cutting wood parts with a laser under optical image analyzer control

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Abstract

A financial analysis using discounted cash-flow techniques was used to determine the economic feasibility of a new laser lumber processing system for use in a furniture rough mill. The projected cost of the system was $790,000 which would replace conventional crosscut and ripsaws costing $256,856. A financial analysis was made assuming only a 5 percent yield increase resulting from saw kerf elimination in a mill cutting 32 MBF (thousand board feet) per day. Other potential laser savings were ignored in this initial study. With this conservative approach, calculated savings for a furniture plant using red oak lumber were $1,210 per day and $1,198 per day when using sap gum.

The net present value of the laser investment was $408,024 and the internal rate of return after tax was 22.5 percent. Both values would be considered an excellent investment opportunity in the financial community.

Current laser technology, optical analyzers, and computer systems can be used to design a laser lumber cutting system. While the economic feasibility is positive, additional work is required to optimize equipment and develop software control systems needed for a working unit.

Hardwood lumber is produced in different grades having defects randomly located throughout the board. In a furniture rough mill, the lumber is remanufactured into smaller parts and the defects removed — a process that produces considerable waste. Additionally, it is likely that both lumber and labor costs will continue to rise. These factors indicate the need for a new system that can reduce overall costs by improving lumber yield and by automating the rough mill process.

During the last 15 years, the space program and military research have provided exciting new industrial equipment with unique capabilities. Three pieces of such hardware are of special interest to this study. First is the high speed digital computer with its ability to rapidly acquire and process large quantities of data.

Second is the laser — an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers have been used by the wood industry to cut hard maple die boards (2) and route complicated furniture and veneer parts (6). Current equipment can cut 3/4-inch-thick oak boards at a speed of approximately 12 feet per minute (fpm) with a 3-kW machine. Equipment is also available with cutting speeds in the range of 100 fpm. Laser cutting of wood has numerous advantages. Most important to this study is the small kerf (approximately 0.015 in. wide) and the ability to start and stop cutting at any location. The ability to cut multisize pieces located anywhere on the board makes it correspond to a punch press with infinitely variable die sizes. Other advantages include reduced noise, clean cut, no tool wear, low energy consumption, and adaptability to computer control.

The third and most recent piece of key equipment is the optical image analyzer. Recently, digital image processing techniques have been extended to the point that image analyzers can recognize patterns and textures. In effect, thinking machines that can see are now available. It seems possible that this technology

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can be used to sense the size and location of defects in surfaced lumber.

Central to the system are computer programs to control and give direction to these three key pieces of equipment. The computer program for determining optimum yield of specified size pieces from a variable size board having randomly located defects has been written, tested, and used (Huber 1969). The image analysis programs for identifying and locating lumber defects are not available but similar sophisticated programs have been used in other inspection applications. Research at the Southern Forest Experiment Station is underway to provide the image analysis programs and fast processor hardware needed for practical real time applications.

The objective of this study was to determine the economic feasibility of using a laser cutting device under control of an optical image analyzer to replace conventional processing methods in a furniture dimension rough mill.

TABLE 1. — *Plant costs for lumber and processing.*

Grade	4/4 Lumber costs: Southern red oak	Sap gum
	($/MBF)	
FAS	610[a]	380[a]
1C	325	285[a]
2C	155	157
Processing costs (both species)		
Process	($/MBF or computer entry)	
Delivery	50	
Drying[b]	75 (-7.0% shrinkage)	
Interest	18% for 90 inventory days	
Stacking and handling	10	
Gluing	50	
Rough mill processing costs (both species)		
Grade	($/MBF)	
FAS	85	
1C	105	
2C	115	
Value of salvage pieces	50 at 5% usage	

[a]Includes premium of $100.00 (a cost added to values published in Hardwood Market Rept. (1).

[b]Includes additional processing charge added to values published in Hardwood Market Rept. (1).

Materials and methods

Two plants cutting different types of furniture parts and having the same production capacity were analyzed. Conventional plant processing costs were compared to new system costs in areas related to lumber raw material, machinery, energy, and labor.

In the cost analysis, the following assumptions were made:

1) The plant will cut 32,000 board feet of southern red oak or sap gum graded lumber per day using an optimum lumber grade mixture. (Sap gum is a category of lumber as defined by the National Hardwood Lumber Assoc. and is wood of the species *Liquidambar styraciflua* L. Southern red oak is *Quercus falcata* Michx. var *falcata*.) This would be an 8 MM board foot plant when operating for 250 days per year or a 16 MM board foot plant operating two shifts. The difference in kerf loss between cutting with a saw and a laser will amount to a yield increase of 5 percent per day. Location sensitivity of the laser system will produce longer parts and will increase yield the equivalent of 9.6 percent. The combination of effects would amount to 14.6 percent (4).

2) Plant costs for lumber and processing were derived from values in the Hardwood Market Report (1) and are given in Table 1.

A sample financial analysis was also computed based on two currently used criteria in the financial community to evaluate investment potential — net present value and internal rate of return. The analysis was based on the conservative assumptions given in Table 2.

TABLE 2. — *Assumptions used in the financial analysis.*

New laser system installed	
Primary laser and optics	$545,000
Machinery and conveying equipment	125,000
Optical Image Analyzer Computer	120,000
Total cost	$790,000
Old system (current new price)	$256,856
Tax rate	50%
Investment tax credit	10%
Salvage value and current book value of old system	$25,685
5% yield difference (old vs. new) using optimum mix of oak at $1,210/day × 250 days (Table 3)	$302,500/year
Depreciation — 10 years, straight line	$79,000
Debt rate (cost of borrowing funds)	20%

Net present value (NPV_i) was calculated as described by Schall and Haley (9) where:

$$NPV_i = -I_i + \sum_{t=1}^{10} \frac{X_t}{(1+r)^t}$$

and

I_i = initial investment of project i
X_t = cash flow in the t^{th} period or a year
t = time in years
r = discount factor (after tax cost of debt)

Steps involved in the computation are as follows:

1) I_i = cost of new equipment − (salvage value of replaced equipment + investment tax credit)
2) X_t = (savings, old vs. new) (1 − tax rate) + tax (new depreciation − old depreciation)
3) PV_{X_t} = (present value of an annuity received over 10 years at 10% (or 6.1446 from tables)) (X_t). (10% was used as a discount rate; it is half of 20% the debt rate which represents the after tax cost of debt given a tax rate of 50%.)
4) $NPV_i = PV_{X_t} - I_i$

Internal rate of return is calculated from the equation

$$NPV_i = -I_i + \sum_{t=1}^{10} \frac{X_i}{(1+IRR_i)^t}$$

where IRR_i is the rate that would yield a net present value of zero for project i. I_i and X_i are determined from

TABLE 3. — *Lumber costs and savings per day for solid wood household furniture as yield is increased using different lumber grades.*[a]

Lumber grade and yield improvement	Southern red oak		Sap gum	
	Cost	Savings	Cost	Savings
(%)	($)		($)	
Optimum mix[b]	16,328		18,314	
5	15,118	1,210	17,116	1,198
9.6	14,190	2,138	16,065	2,249
14.6	12,980	3,348	14,867	3,447
All FAS	22,287		19,270	
5	21,017	1,270	18,009	1,261
9.6	19,891	2,396	17,205	2,065
14.6	18,621	3,660	15,944	3,326
All 1C	16,876		18,797	
5	15,765	1,111	17,568	1,229
9.6	14,928	1,948	16,489	2,308
14.6	13,817	3,059	15,260	3,537

[a]The Optimum Furniture Cutting Program (TELPLAN 62) (5) was used to make dollar calculations for a 32 MBF per day plant.
[b]26% No. 1C and 74% No. 2C for red oak; 48% FAS, 46% No. 2C, and 6% No. 1C for sap gum.

TABLE 4. — *Lumber costs and savings per day for kitchen parts as yield is increased using different lumber grades.*[a]

Lumber grade and yield improvement	Southern red oak		Sap gum	
	Cost		Cost	Savings
(%)			($)	
Optimum mix[b]	15,639		15,402	
5	14,481	1,158	14,261	1,141
9.6	13,599	2,040	13,343	2,059
14.6	12,441	3,198	12,202	3,200
All FAS	23,699		17,028	
5	22,148	1,551	15,914	1,114
9.6	21,160	2,539	15,203	1,825
14.6	19,609	4,090	14,089	2,939
All 1C	17,638		16,365	
5	16,484	1,154	15,295	1,070
9.6	15,472	2,166	14,355	2,010
14.6	14,318	3,320	13,285	3,080

[a]The Optimum Furniture Cutting Program (TELPLAN 62) (5) was used to make dollar calculations for a 32 MBF per day plant.
[b]20% No. 1C and 80% No. 2C for red oak; 20% No. 1C and 80% No. 2C for sap gum.

the previous net present value calculation and the *IRR* is determined from compound interest tables for 10 years.

Results

Plant processing costs

Initial net rough mill costs. — Table 3 gives initial net cost values for a typical plant cutting parts for household furniture. A standard lumber cutting bill with a range of lengths from 15 to 76 inches was developed to produce 1 day's cutting requirements. The net cost for the rough mill was generated using the Optimum Furniture Cutting Program, Telplan No. 62 (5). Telplan No. 62 is a computer program using furniture dimension yields from Englerth and Schumann (3) and other data. For red oak, the net initial cost was $16,328 with an optimum grade mix of 26 percent No. 1 Common and 74 percent No. 2 Common. For sap gum, the net cost was $18,314 with an optimum grade mix of 48 percent First and Seconds (FAS), 6 percent No. 1 Common, and 46 percent No. 2 Common. The same net cost series was run using all FAS and all No. 1 Common grade to produce the same set of parts. Costs other than lumber were kept constant. The results for all FAS and all No. 1 Common are presented mainly for comparison to the optimum mix.

In Table 4, the same series of calculations are produced except a cutting bill duplicating requirements for kitchen cabinet construction was used. The lengths range up to 80 inches but the majority of parts are below 40 inches and were narrower. The results in terms of initial net costs are approximately the same for both plants.

Saw kerf and longer parts. — Circular saws produce wood loss as sawdust removed by the saw. With conventional sawing, it is necessary to cut completely across a piece of rough lumber in order to remove defects. This causes further loss of usable material by making short pieces from potentially long ones. The process of sawing thus decreases yield by loss through saw kerf and loss of clear sections joining the defects removed.

One of the considerable advantages of the laser cutting system is the very narrow kerf; 0.015 inch versus the 1/8 to 1/4 inch removed with circular saws. By eliminating saw kerf, additional yields can be achieved. Schumann and Englerth (10) found that saw kerf elimination could account for between 5.2 and 9.0 percent depending upon lumber grade. Huber (4), using two different cutting bills for a conventional and a punch press type of rough mill, found yield increases due to kerf reduction of between 9.2 and 11.2 percent, depending upon grade and type of cutting bill. In the present analyses, a kerf resulting in a 5 percent yield increase was chosen since a laser system would not entirely eliminate the kerf.

The Optimum Cutting Computer Program (5) was used to calculate the daily savings for lumber. The program computed a daily cost and the only change made in the program was to increase yield. The computer was allowed to select the lowest cost grades of lumber for the optimum mix.

From Table 3, the savings in lumber resulting from only a 5 percent yield increase using the optimum mix amounted to $1,210 per day for red oak. For a plant using 32 MBF per day for 250 days, this would amount to $302,500 per year. The savings for sap gum was $1,198 per day or $299,500 per year.

The laser system has location selectivity type cutting where long available parts in a rough board will not be cut into two or more pieces. The ability to produce longer parts without buying the next higher lumber grade was assumed to increase value by the equivalent of 9.6 percent yield.

Savings associated with production of longer parts for the optimum mix amounted to $2,138 and $2,249 per day for oak and gum, respectively. Combined kerf and longer parts' savings were $3,348 per day ($837,000 per year) for red oak and $3,447 per day ($861,750 per year) for sap gum. Savings using other lumber grades (FAS and No. 1 Common) are also tabulated. A similar savings from reduced kerf and longer parts is shown in Table 4 for the plant cutting kitchen cabinet parts.

Lower lumber grades. — There is a possibility of substituting lower grades of lumber to produce the same products using a laser system because of location selectivity. Clear areas cut by laser will yield longer parts not sawn in two by initial crosscutting, thereby permitting use of lower grades. Since the primary purpose of purchasing higher grades of lumber is the production of longer parts, there is an economic advantage in using a lower grade in laser cutting.

The price structure of lumber is usually not based entirely on yield achieved from the higher grade but also on the production of the longer parts. The user with a laser system could purchase a lower grade and still achieve the same results as would be possible through buying the higher grade and sawing it conventionally. A number of variables must be considered. Several examples have shown that savings from 9 to 11 percent (4) should be possible.

Product quality and machinery. — Quality of the product may be somewhat reduced by laser cutting. Lasers slightly burn wood surfaces (7) and such surfaces may require machining prior to gluing. However, the cost of this machinery would be small in comparison to previously discussed advantages.

Additionally, the laser cutting system can cut profiled (curved) parts. Such production could eliminate bandsawing of some solid parts, thereby improving yield. The cost advantage of this feature was not calculated but should prove positive.

A laser with a multiple cutting head could probably eliminate from 6 to 12 crosscut saws and ripsaws. Computations for the 32 MBF processing plant assumed three cutoff saws and nine ripsaws. There is a possibility that some of this conventional equipment may be kept to process thicker lumber unsuitable for laser cutting.

Energy, labor, and safety. — Hourly costs for electricity and carbon dioxide to operate a 250-watt laser were estimated at $0.90 in Grand Rapids, Mich. (6). A 9-kW laser might consume 100 kW per hour costing about $7.50 per hour of use. Saws and blower motors necessary to evacuate sawdust would use significantly more energy.

While sawdust is eliminated with laser cutting, some smoke is produced. However, the quantities released to the atmosphere can be well controlled with existing technology. There would be a slight disadvantage to elimination of sawdust if it were used as fuel. However, there would probably be sufficient waste from the cut lumber without using sawdust and tradeoff costs favor solid wood parts.

Since the laser system is a single unit replacing 6 to 12 other pieces of equipment, less space would be needed. The reduced cost of supplying, reheating, and cleaning replacement air needed to evacuate sawdust in the conventional rough mill is an additional advantage of the laser system.

The laser system would be operated with less but more highly skilled labor. The old system with crosscut and ripsaws required 20 or more employees whereas the laser system could probably be operated with 3 to 5 workers.

Studies have shown (8) that employees without supervision will often produce 5 to 15 percent lower yield of parts due to inattention and boredom. This loss would not occur in the laser system since cutting decisions and operations are automatic. The laser system should be safe, quiet, and dust-free.

Financial analysis

A sample financial analysis of a furniture rough mill is now provided using net present value and internal rate of return methods. Based on the data in

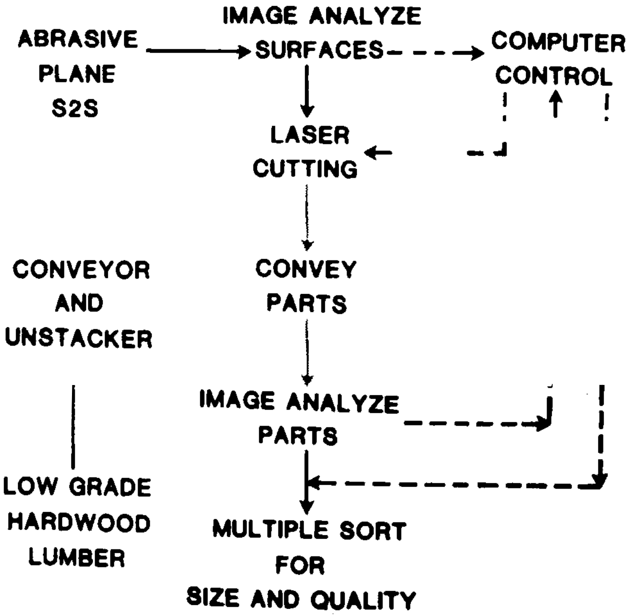

Figure 1. — Rough mill process flow chart.

Table 2, the net present value computations are as follows:

$$I_i = \$790{,}000 - (\$25{,}685 + \$79{,}000) = \$685{,}315$$
$$X_i = (\$302{,}500)\,(1 - 0.5) + 0.5\,(\$79{,}000 - \$25{,}685)$$
$$= \$151{,}250 + \$26{,}685 = \$177{,}935$$
$$PV_{X_i} = 6.1446\,(X_i) = 6.1446\,(\$177{,}935)$$
$$= \$1{,}093{,}339$$
$$NPV_i = PV_{X_i} - I_i = \$1{,}093{,}339 - \$685{,}315$$
$$NPV_i = \$408{,}024$$

Based on the given assumptions, the net present value was $408,024. Any positive value of NPV_i would yield a net increase in the company's total value. The decision rule is to accept projects with positive NPVs.

These calculations are based on a 4-million-board-foot output plant. A plant of greater capacity could be achieved economically by working more than one shift. For additional shifts, there would be no new capital investment — only labor, utilities, and material costs would increase. The projected savings for larger capacities could, therefore, be much greater.

Internal rate of return was calculated using the same assumptions as net present value except proceeds of the project could be reinvested at the same rate of return as that of the project.

The computation is as follows:

$$\left.\begin{array}{l} I_i = \$685{,}315 \\ X_i = \$177{,}935 \end{array}\right\} \text{from net present value computation}$$
$$PV = \text{present value} = \frac{I_i}{X_i} = \frac{685{,}315}{177{,}935} = 3.8514$$
$$IRR = 22.6\%\ \text{(determined from compound interest tables for 10 years).}$$

The internal rate of return of 22.6 percent (45.2% before tax) would be considered an exceptional return in the financial community.

Since the financial analysis was based on very conservative assumptions and has shown an excellent return by the discounted cash-flow method, it was unnecessary to repeat the calculations based on additional yield improvements available through other savings. However, such computations would demonstrate additional positive economic advantages for the laser system.

Discussion

Figure 1 shows a flow diagram of the proposed defect analysis and laser lumber cutting system. Low grade hardwood lumber enters the process stream and is unstacked and conveyed to an abrasive planer where it is surfaced on both faces. The boards then pass through an image analyzer where they are optically scanned. Using texture analysis algorithms and fast processor hardware currently under development, the nature and

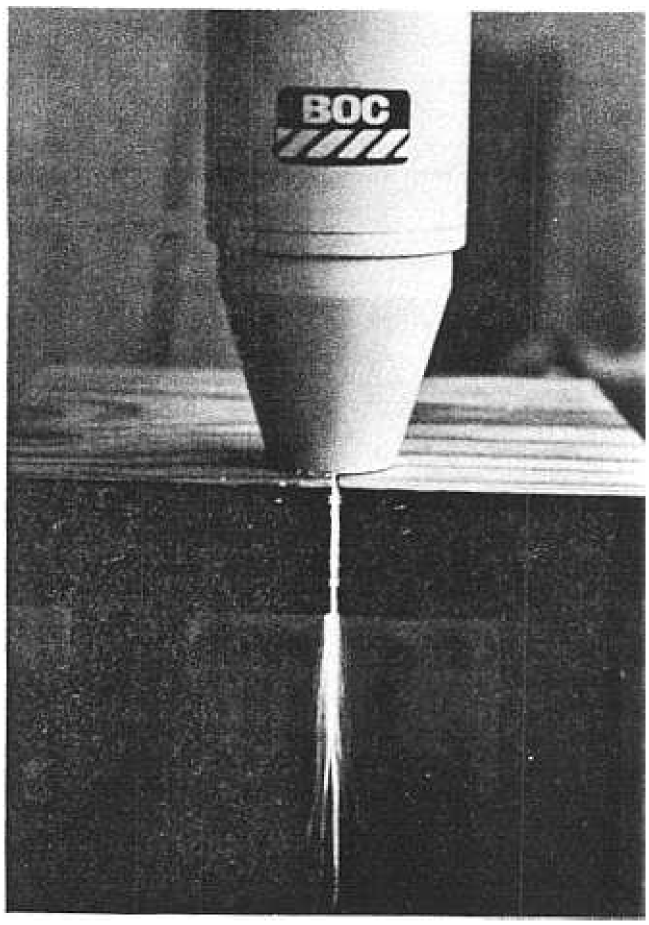

Figure 2. — Photograph of a continuous carbon dioxide laser cutting a 1-inch-thick board in a direction across the grain. (Photo courtesy of British Oxygen Co.)

location of defects are established. Defect data are then computer processed to yield the optimum cutting pattern for each board based on a given cutting bill.

Boards are then directed to the laser cutting device also operated under computer control (Fig. 2). The system might consist of multiple laser beams driven across boards as the lumber is continuously fed through the system. Individual laser cutters would move back and forth a relatively short distance corresponding to the maximum width of boards. Cutting along the grain could be accomplished as boards pass longitudinally under other laser beams. Cut parts are then scanned in a separate analyzer and automatically sorted by size and quality.

Projections from an earlier study indicate approximately 5,254 lineal feet of cutting is necessary to process 1,000 board feet of rough lumber. Assuming a full 8-hour shift and a steady cutting cycle, the laser must cut 350 lineal feet per minute to process 32 MBF of lumber per shift. The capability of current high power laser equipment is in the range of 50 to 100 lineal feet per minute. There are several possibilities such as two or three shift operations and using multiple laser cutting heads controlled by one computer.

With high technology systems, such as those described here, a higher level of training would be needed for key personnel. The proposed system has a greater degree of automation, uses less total labor, and is safer. The system must be kept clean, mechanically stable, and possibly climate controlled. It is a radical departure from current practice but the future competitive nature of the wood furniture industry may depend on innovations such as this.

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