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The timber shortage in the Pacific Northwest is forcing sawmill owners to improve the competitiveness of their harvesting and processing operations. A key leverage point in those operations is log bucking. A computer simulation and financial statement analysis were used to compare the processing efficiency and profitability of three bucking strategies: log cost minimization (traditional 40-foot preferred-length logs); hauling length maximization (55-foot preferred-length logs); and the Integrated Log Manufacturing system (ILM), a proposed computer-based strategy that acts as a harvest-site merchandiser which integrates harvest-site tree bucking and lumber manufacturing. Five days of sawmill operations were simulated for each strategy; the same second-growth Douglas-fir trees were processed each day to fill identical lumber orders. The sawmill produced 0.4 percent and 1.9 percent more cubic feet of targeted lumber with the 55-foot preferred-length strategy and ILM respectively, than with the 40-foot preferred-length strategy. Compared with the 40-foot preferred-length strategy, sawmill profits rose $2,262 (23%) per week in pay-as-scaled sales with the 55-foot preferred-length strategy, and $5,530 (57%) per week in lump sum sales with ILM.

Three Strategies for Tree Bucking at the Harvest Site: Consequences for the Sawmill

by

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CONTRIBUTION OF AUTHORS

Dr. Charles Brunner was involved in the experimental design, analysis, and writing of the manuscript. Dr. James Funck was involved in the experimental design and analysis. Dr. John Sessions assisted with the experiment by writing computer programs.

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INTRODUCTION

The timber shortage in the Pacific Northwest has inflated log prices to record levels and created a situation where the only sawmills that will survive are those that can pay the most for logs and still earn a profit. Sawmills have traditionally invested in new technology to gain a competitive advantage; some experts predict that the next innovations will occur in log manufacturing and delivery (12, 30, 46).

In bucking, a set of crosscuts unique for each tree will produce the logs that yield the most valuable lumber at the sawmill (17, 60). This relationship is recognized by logging managers and is also the basis for optimal log-bucking systems at sawmills (8, 14). Where trees can be hauled to the mill in one piece, sophisticated bucking systems can optimize tree value. Trees in the Pacific Northwest, however, generally grow too tall to be legally hauled on public highways in one piece. At least one bucking cut must be made at the harvest site. Because the location of any cut constrains subsequent processing, the optimal value of the lumber processed by even state-of-the-art sawmill log bucking systems is limited by an initial, and most likely suboptimal, cut at the harvest site (27, 60).

Sawmills currently manage tree bucking at the harvest site by having trees bucked into long logs of "preferred-length". Sawmills that use preferred-length logs minimize log costs by taking advantage of inconsistencies in the Scribner log scale (37) and retain manufacturing flexibility with logs that can be cut into a variety of standard lumber lengths. An implicit assumption of this strategy is that the harvesters' goal is to minimize log costs.

In this study, we examined whether sawmills could increase profitability by integrating tree bucking with the lumber manufacturing process and by focusing on maximizing lumber value rather than minimizing costs. In this paper, we propose a system of integration and compare the profitability of this integrated system with two common, preferred-length strategies.

OPTIMAL BUCKING

Mathematical formulas that optimize log value by guiding log manufacturing at the harvest site have evolved over the past 20 years. They have been used in training (28), auditing work (36, 53), cruising and appraising timber (32, 39), analyzing timber sale bids (39), developing stand specific bucking rules (26), and creating decision aids for manual and mechanized log-manufacturing (15, 20, 40, 51). These formulas are not based on lumber value, but on open-market log prices. Research has shown that open-market log prices are weakly related to actual mill lumber-order requirements (41, 49, 52, 60).

In Scandinavia, sawmills remotely control tree bucking at the harvest site through radio communications and computers on harvesting machines (1, 55). Log value is calculated as the total value of the lumber that will be sawn from a tree segment given prevailing market conditions. Trees are bucked directly into short logs at the harvest site. Weyerhaeuser has implemented this technology in the southeastern United States (2) and is currently experimenting with it in the Pacific Northwest (13). If we assume that timber stands less than 50 years old are uniformly distributed across all slope classes, then about 9 percent of the total cubic volume of timber harvested in western Oregon from 1991-2000 could be harvested with cut-to-length systems (4, 50). These machines cannot measure the geometry of the entire stem before bucking and rely on a guess-and-check method that precludes true optimization. These systems show, however, that real time management of tree bucking at the harvest site, with affordable process control and communications technology, is a possibility.

By comparison, sawmills have considerable experience with long-log bucking optimizers. These systems measure log dimensions and shape, and then calculate the short logs that will maximize lumber value (11, 54). Log bucking optimizers incorporate sawing patterns, edging methods, saw kerfs, sawing variations, planing allowances, product prices, and current lumber orders into log bucking decisions (23, 61). These systems have increased lumber value by 5 to 12 percent (10, 35) by exploiting critical diameter breakpoints along the stem, and minimizing the volume wasted as short ends called "lily pads" (45).

LOG COSTS

Westside scaling rules (37) require long logs nominally over 40-feet long to be segment scaled as two shorter segments nearly equal in length. Segment scaling tends to increase the scaled volume of a tree and to increase log costs. This has led to the popularity of the 40-foot preferred-length long log.

Log costs are also influenced by the terms of the timber sale agreement. In pay-as-scaled sales, the timber is paid for on a board-foot basis according to the scaled volume of the timber as it is removed from the tract. In addition, all stump-to-mill costs are traditionally paid on a contract rate multiplied by scaled volume. Thus, timber purchasers strive for 40-foot long logs and avoid segment scaling to minimize long log scale and log costs.

In lump-sum sales, however, the purchase price is paid in a single payment before the timber is cut. Since payment is not based on actual scaled volume, the purchaser does not suffer any scale-related costs for bucking long logs into lengths other than 40 feet. Furthermore, since any tract of timber contains a finite volume of wood, tree-length logging costs to fell, yard, buck, and haul the long logs of varying lengths are relatively constant.

INTEGRATED LOG MANUFACTURING

Integrated Log Manufacturing (ILM) is direct sawmill control of individual tree bucking at the harvest site. An ILM system mimics the sawmill's tree bucking optimizer by "pre-merchandizing" trees into long logs. Figure 1 illustrates this pre-merchandizing process.

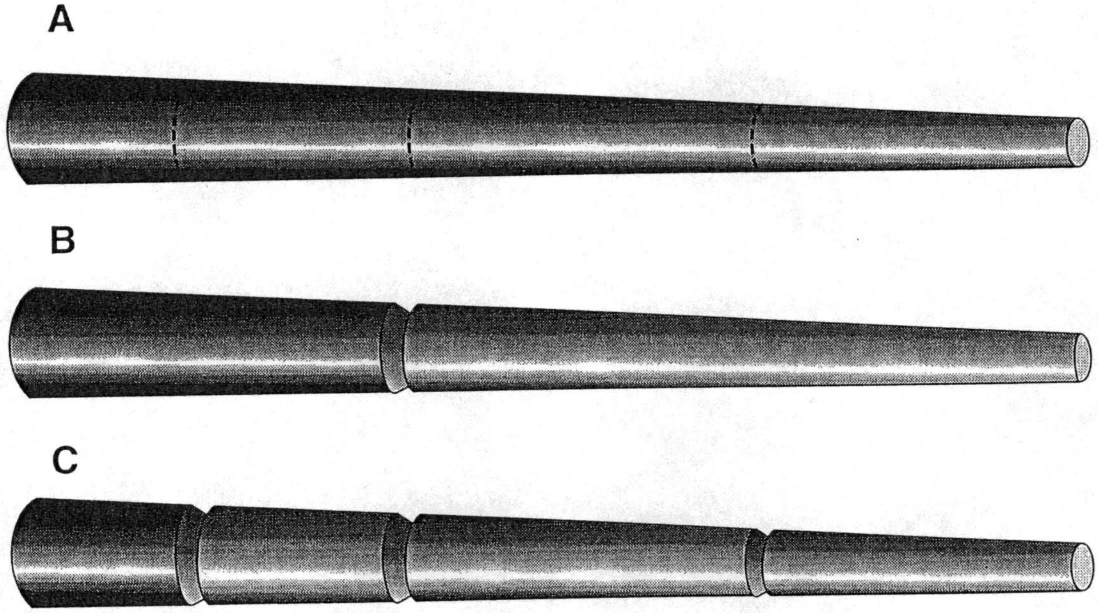

Figure 1.–Ideal tree bucking process: (A) tree merchandizer solution designating optimal bucking points; (B) long logs consistent with the optimal bucking solution; and (C) the optimal set of short logs bucked at the sawmill from the long logs.

Figure 1(A) shows the optimal bucking solution that would be calculated at the sawmill if it were possible to transport the whole tree in one piece. Figure 1(B) shows the tree pre-merchandised into two long logs that are of transportable lengths and that preserve the optimal bucking pattern. The resulting long logs are then hauled to the sawmill where they are bucked into the optimal set of short logs, as shown in Figure 1(C), and processed into lumber.

Young (60) demonstrated that when trees contain more than two long logs an additional optimization step may be desirable. This two-phase optimization consists of a tree bucking step identical to that illustrated by Figure 1(A), followed by a second optimization step which calculates where the bucking cuts should be made at the harvest site in order to both preserve the original optimal solution and minimize tree Scribner scale. By minimizing the Scribner scale of the tree, all Scribner-based costs (which may include cutting, yarding, hauling, and timber taxes) would also be minimized. Although Young proved that this two-phase optimization is possible, no attempt was made to include it in this study due to the additional computer programming required.

The capabilities required to implement ILM are:

- Log value must be calculated identically at both the sawmill and the harvest site.
- The tree bucking implementation platform at the harvest site must be able to rapidly measure tree diameter and length, assess surface quality, and be able to apply an optimization algorithm to determine tree bucking cuts and execute those cuts without decreasing production rates compared to current methods.
- The sawmill must be able to communicate in real time with the harvest site.

- The sawmill must be able to positively identify individual long logs so they can be processed into lumber under the same assumptions that were used in the original tree bucking optimization.

Log Value

The calculation of log value has proved a vexing problem for researchers in the field of tree bucking optimization. Garland et al. (20) found that sawmill imposed preferred-length constraints (for example, that 80% of the long log volume delivered to the sawmill must be in 36' to 40' lengths) reduced returns to timber owners by about 6 percent compared to the theoretical maximum when the requirements were met exactly. In practice, returns are depressed even further because long logs far in excess of the limit are usually made. For example, Olsen et al. (41) found that more than 90 percent of the long logs in several studies were in the preferred-lengths when only 80 percent were specified.

Furthermore, there is doubt about how well preferred-length specifications actually meet mill needs. The following passage from the discussion in Young (60) illustrates this skepticism. The speaker is Brent Sauder, Assistant Manager of MacMillan Bloedel Limited's Wood Harvesting Research Division in British Columbia.

> The key thing that Glen's (Young) work has pointed out is that we do not have the right information to put into this box (the tree bucking optimization computer). There is a key chunk of data that somebody does not want to give us and that is the relationship between log length and value. You go to a sawmiller who has three prime lengths and you ask him 'Would you rather have 33, 37, 41?' They say, 'We will pay you the same for all of them.' Then you ask, 'Does that mean if I give you a 39 I will not get anything?' 'Oh no! But I will not like them,' is the reply. "How much do you not like them?' 'I cannot tell you.' So when you have to have a solution and you run through the optimization with this

> information and you cut the biggest length possible in a given grade. Then you go to the sawmillers and they tell you it is the way to go broke quick.

The problem is rooted in the sawmill's inability or unwillingness to offer discrete prices for long logs of specific diameter, length, and grade; or in other words, to tell the market "how much do you not like them."

Brown (9) explains that sawmills have traditionally measured their profitability based on how much more lumber they make compared to what was predicted by log scale. He presents an analysis that shows how sawmills can cut the best combination of lumber products to maximize profits given specific market demand. In the context of ILM, Brown would consider the log's value as the sum value of the products manufactured from that log, and that the appropriate measure would be dollars per cubic foot of log volume.

Although Brown generally confines his analysis to short logs at the sawmill and only briefly touches on the utility of the dollars per cubic foot measure as the basis for long log bucking optimization at the sawmill, we propose extending the logic to the harvest site. This is accomplished by first calculating the dollar value of short logs in a given lumber market as the sum value of the lumber that will be sawn from them. These values would then be divided by the cubic volume of the short log to arrive at a dollars per cubic foot value for the short log. These discrete short log values would be the inputs into the tree bucking optimizer at the harvest site. Under this system long logs would not have a separate market value based on Scribner board-foot scale. Instead, the value of a long log would be explicitly the sum value of the lumber to be sawn from the short logs which comprise the long log.

Tree Bucking Implementation Platform at the Harvest Site

Several tree bucking configurations at the harvest site have been investigated. The first involved cutters using bucking optimization computers (ruggedized industrial handhelds) at the stump. Olsen, et al. (38) showed that length measurement errors were negligible; however, errors in diameter measurement resulted in open market long log value losses of 1.2 percent to 5.2 percent. In addition, data entry reduced cutter productivity 33 percent.

Olsen, et al. (42) recently reported on the results of a field trial in Oregon where a Log Quality Technician (called a Buckmaster) worked along with a cutter at the stump. The cutter felled and limbed the timber, and the Buckmaster input the data, communicated the optimal bucking solution to the cutter, and then tagged the resulting long logs with bar code labels. No results were reported concerning measurement accuracy, but cutter productivity was estimated to be 20 percent lower than unassisted bucking without a computer. Net long log value increases in this study were less than 3 percent after subtracting the added costs of the Buckmaster and reduced cutter productivity.

In addition to optimal tree bucking at the stump, several approaches have been used to buck tree-lengths at the landing or other central location. Olsen et al. (40) reported the results of a field trial involving a Hahn Harvester at a central sort yard in Oregon. This particular sort yard is located on the edge of a large industrial tree farm. Whole trees are trucked to this yard over private roads. The Hahn Harvester is a machine about the size of a tractor-trailer that consists of a loader arm, delimbing arms, a conveyor system, bucking saws, an encoder for measuring length, and a light curtain for measuring diameter. The operator is located in an elevated cab from which he controls all machine functions. The mode of operation is the operator loads a tree onto the conveyor butt-first. The conveyor draws the tree into the machine while the delimbing arms move in the opposite direction cutting off the limbs. Length and diameter measurements are made at locations designated by the operator for input into the optimization computer. The tree is then repositioned and the bucking saws activated to implement the optimal solution. The results showed productivity decreased 29 percent due to the extra positioning of the tree required to gather the necessary measurements and implement the optimal solution. Diameter and length measuring accuracy was found to be adequate, and a taper equation produced diameter estimates that would have been adequate 90 percent of the time. Inaccurate assessments of surface quality by the operator due to having a view of only about one-third of the tree caused 8 percent to 10 percent discrepancies between the value of logs actually cut and the optimal solution for the study trees. The researchers concluded that long log value increases of about 20 percent are achievable using the Hahn Harvester by modifying it with existing technology.

In New Zealand, Cossens (15) studied the Hahn Harvester as a tree bucking platform in Radiata pine (*Pinus radiata*). Log value recovery was 1.2% lower than manual tree bucking due primarily to the operator having difficulty accurately assessing surface quality and correctly locating the critical diameter breakpoints along the stem. Eighty-three percent of the logs cut were within the allowed length tolerance of 5cm. Machine damage resulted in volume and value losses of 0.45 percent and 0.41 percent respectively.

Macalister (31) recently reported on another tree bucking configuration: the New Zealand Forestry Corporation's Kaingaroa Processing Plant. This NZ$24 million central processing plant receives tree-length stems harvested from the adjacent 465,000-acre forest and hauled exclusively over company-owned roads on special heavy-duty trucks. The trees are debarked and tree information such as cutting and logging contractor identification, land compartment the tree is from, date and time of felling, and unique tree identifying number is taken from a bar code tag attached to the tree at felling. The tree is then conveyed to a grading station where it is automatically scanned for true shape geometry. While the stem is being scanned the station operator uses a joystick-guided laser to record the type, size, and location of various surface defects. With this information, an optimization computer calculates the locations of the bucking cuts which maximize the value of the stem given the current log order file. The tree is then conveyed to the bucking station where chop saws execute the optimal solution. The resulting logs are then labeled with bar code tags and sorted. The system is currently processing 36 trees per hour, and is expected to process 78 trees per hour at full production. Although this system is instructive regarding the feasibility of using high technology in tree bucking, its applicability is limited to situations where tree length stems can be transported to the facility over private roads, such as on large industrial forests.

In 1992, the Forest Engineering Research Institute of Canada (FERIC) (18) proposed developing a stroke-boom delimber merchandizer system for optimally bucking tree-length stems at the landing or roadside. A stroke-boom delimber is a machine consisting of hydraulically controlled grapples and delimbing knives which slide along a long rail. The rail is most commonly mounted horizontally, higher and to one side of the operator cab of a hydraulic excavator. In operation the stem is picked up by the grapple and drawn towards the machine. At the same time the delimbing knives are wrapped around the stem and it is lifted free of the ground in the horizontal position. The tree is held steady in the grapple while the delimbing knives are pushed out to the end of the rail, shearing off the branches as it goes. The grapple is then released and the delimbing knives reverse their direction of travel and pull the stem towards the machine. The grapple is reactivated and the knives travel away from the machine again, delimbing as they go. This process is repeated until the entire tree is delimbed up to the merchantable top diameter. The tree's direction of travel is then reversed and a bucking saw, usually mounted at the end of the rail furthermost from the machine, is activated at the desired points in order to buck the tree into logs. Unlike the Scandinavian harvesters, these delimbers can measure the entire stem before they make any bucking cuts (5). In addition, these machines are not limited by terrain because they operate on the landing, and are becoming commonplace in the Pacific Northwest (25, 44, 47, 48). As much as 64 percent of the total volume that will be harvested in western Oregon by the turn of the century could be processed by stroke-boom delimbers (4).

The proposed FERIC system was equipped with computer-aided tree measuring, optimizing, and processing devices which would buck trees relative to maximum lumber values, mill manufacturing requirements, and log hauling regulations. Subsequent development work tested two diameter measurement systems: ultrasonic and an infrared reflected/shadow approach. Both failed to produce the desired diameter measurement precision of 0.25-0.50 inches, and the project was suspended.

As the reader can see, optimal tree bucking at the harvest site has been plagued not by poor algorithms to do the optimization but by an inability to provide the algorithm with accurate stem geometry and surface characteristic data at acceptable production rates. Jamieson (24) recently reported that this may no longer be the case. Weyerhaeuser

Company's Coos Bay, Oregon, operation has successfully field tested a Denharco DM 3500 stroke-boom delimber equipped with the Control Plus II measuring and tree bucking optimization system. In regards to the quality of the optimization, Harvest Manager Bruce Davis was quoted as saying, "The system does exactly what you ask it to do, and if we wanted to change our preferred lengths overnight, we'd just go into the computer, choose new pre-sets, and away we'd go." The computer calculates bucking solutions in about one-half second. Audits showed that 98.7 percent of the resulting long logs were within one inch of target length. Denharco is confident a well-calibrated system can provide length precision within 0.125 inches. In addition, delimber production increased 33 percent using this system compared to a stroke-boom delimber without Control Plus II.

In summary, it appears that the stroke-boom delimber has evolved to the point where it can provide the required capabilities of accurately and rapidly measuring tree diameter and length. The ability to calculate the optimal solution and execute it has long been available. Assessment of surface quality characteristics from the cab of a stroke-boom delimber has not been reported in the literature. In this study we assumed that, as was the case for the Hahn Harvester (40), a stroke-boom delimber operator would be able to accurately delineate zones on the stem of homogeneous surface quality based primarily on the allowable knot sizes for various log grades. We further assumed that operators would be able to do this during the delimbing stroke; in other words, that there would be no loss in production attributable to this assessment. Lastly, we assumed that operators would also be able to designate points on the stem that must be bucked out due to rot, excessive sweep, or other unacceptable geometric incontinuity. If these assumptions hold true, then the tree bucking implementation platform requirements can be met using existing technology.

Real Time Communications

We assume that the sawmill is cutting to order, which means that only lumber that has been ordered by a customer is to be made. When the demand for lumber of a given dimension is satisfied, the production process shifts focus to the remaining portions of the order. The sawmill needs to be able to monitor what the harvest site is producing, assess the harvest site long log output in terms of lumber production, and then issue new instructions to the harvest site when specific lumber order requirements are satisfied.

The model for this feedback mechanism is found in Thomlinson's (56) description of a sawmill optimal bucking system. In addition to the typical scanner hardware and on-line process control computer, Thomlinson's system includes an off-line sawmill simulation computer to calculate log value tables that are used by the bucking process control computer. Changes in lumber target sizes, sawmill machine settings, product prices, and log diameter, length, and taper can be quickly evaluated and new price tables prepared.

We propose a similar system located at the sawmill that will monitor and adjust tree bucking at the harvest site on an ongoing basis. This system would consist of a sawmill simulation computer and either data radio or satellite communications hardware similar to that used by long haul trucking companies and the package delivery industry. The sawmill would periodically query each harvest site and would extract short log data describing what that site had produced since the last query. The short log data would be processed by the off-line sawmill simulation computer and the resulting lumber tallied. When a simulation indicated that an ordered lumber dimension requirement could be satisfied by the logs already produced, a zero lumber value would be assigned to that product and a separate simulation would be run to calculate updated log values. These new values would then be communicated to the harvest sites and would control subsequent tree bucking. This process would be repeated until the production schedule was satisfied or the work day was over.

This system enables the sawmill to exert timely control over the tree bucking process at remote sites by directly manipulating the log value inputs of the harvest site bucking optimization computer. The communications and simulation technology required by such a system is readily available, affordable, and field-proven in other industries.

Log Identification

Delivery of the right logs at the right time is for naught if they are subsequently processed at the sawmill using product price assumptions different from those used to buck the tree in the first place. Needed is a way to positively identify each long log at the sawmill prior to being bucked into short logs. This identification process could conceivably control short log bucking. The sawmill chop saw would simply implement the final bucking cuts as illustrated earlier in Figure 1(C).

Long log producers, log sort yard operators, and the regional log scaling bureaus have long used laminated paper bar code tags attached with standard metal staples to identify their products. According to Olsen, et al. (42), they are quite robust and have shown very good survivability in logging field trials. These tags are usually attached to logs while they are still in decks at the harvest site or once loaded on trucks. The data associated with the tag is captured at the scales where the logs are officially measured by scaling bureau personnel.

Under ILM, the bar code would have to be part of the long log data packet that is transmitted to the sawmill in order to facilitate accurate log identification. It would also be desirable to mechanically affix the tags to the logs while the tree is still in the grip of the stroke-boom delimber. This capability would greatly reduce the chance that a log would be misidentified later in the process.

No literature was found concerning mechanical attachment of bar code tags as an option on stroke-boom delimbers.

Summary

ILM is direct control by the sawmill of individual tree bucking at the harvest site. ILM is desirable for the same reasons optimal log bucking has proven worthwhile at sawmills: improved lumber volume recovery and improved recovery of the most valuable lumber.

ILM eliminates the communication barrier between timber harvesters and sawmillers by providing a common measure of log value: dollars per cubic foot based on lumber prices. ILM enables sawmillers to specify discrete values for logs of a given diameter, length, and grade in a timely and accurate manner. In short, ILM provides sawmillers with a means of describing "how much they like them."

For the most part, ILM can be implemented with existing, affordable technology. The stroke-boom delimber appears to be the platform of choice due to its reported capabilities for accurate log diameter and length measurement, and its ability to optimize the whole tree prior to making any bucking cuts. Existing equipment can provide real time data communications between the sawmill and the harvest site. Additional work will be necessary to develop a system for identifying individual long logs and matching those logs to the lumber prices used to calculate their optimal bucking solution.

If it can be assumed that ILM is a technically feasible alternative to traditional preferred-length tree bucking, two questions remain. First, will different tree bucking strategies at the harvest site result in different proportions of lumber, chips, sawdust, and shavings being produced at the sawmill? Second, what are the financial consequences of different tree bucking strategies to the whole sawmill business? This thesis is an investigation of those two questions.

METHODS

Sof$aw (3, 57), a log-breakdown simulation program based on Best Opening Face (BOF)(22), was used to model the production of a hypothetical green dimension sawmill. Research has shown that, because it assumes that logs are truncated cones with circular cross-sections, BOF tends to overestimate log value recovery on real logs with non-circular cross-sections and sweep (61). For the purposes of this study, BOF's shortcomings are irrelevant because they are applied equally to all scenarios being investigated. In this study it is the differences that matter, not the absolute values. In practice, the sawmill would use the log-breakdown model which best simulates their operation.

The mill operating characteristics used in this study, such as saw kerfs, sawing variation, and edging methods, were a composite of several western Oregon sawmills. One sawmill provided an order file, on the condition of anonymity, that formed the basis of a 5-day production schedule and that specified volume requirements by dimension, price, and shipping date.

BUCK-CF, an early prototype of the cubic-scale variant of Oregon State University's (OSU) optimal tree-bucking software was provided by Dr. John Sessions (19), and was used to simulate the sawmill's bucking optimizer and the ILM-configured stoke-boom delimber. BUCK-CF is based on the same network algorithm used in OSU's optimal tree bucking software. This algorithm solves the tree bucking problem by considering a tree to be a network of arcs where each arc represents a possible log length, and the arc length is equal to the value of the log. The program then calculates the optimal bucking solution by solving the network for the longest path, or in this case, the most value. BUCK-CF differs from OSU's optimal tree bucking software by using cubic feet to calculate volume instead of Scribner board-feet. Log cubic volume is approximated in BUCK-CF by calculating the volume of a cylinder with diameter equal to the log's small-end diameter and length equal to the log's length. A second difference between BUCK-CF and OSU's optimal tree bucking software is that BUCK-CF optimizes for value based on the dollars per cubic foot value of short logs as derived from lumber prices, as opposed to dollars per Scribner board-foot values of long logs derived from open market log prices. Optimizing for value based on short logs helps to minimize the inaccuracies inherent in approximating the volume of a tapered log using a cylinder because as a log gets shorter it approaches a cylinder for practical purposes.

Data for 500 second growth Douglas-fir *(Pseudotsuga menziesii)* trees from four western Oregon timber sales were used (Fig 2).

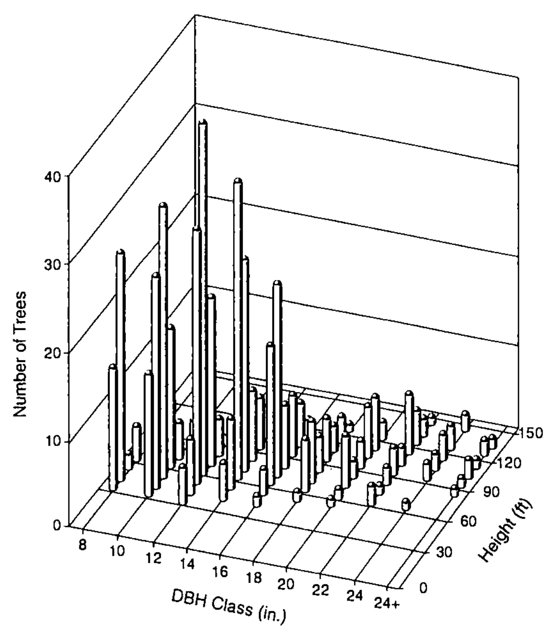

Figure 2. - Distribution of study tree population by d.b.h. and merchantable height.

Trees were assumed to be straight with circular cross sections, and the minimum small-end log diameter allowed by BUCK-CF was 6 inches. All long logs were assumed to have 2-Sawmill (2S) or 3-Sawmill (3S) surface quality characteristics, meaning maximum knot sizes of 2.5 and 3 inches respectively (37). Because it is difficult to predict the grade of a piece of lumber that will be produced from a given log (7, 21, 33, 34, 58), and because it is becoming common for sawmills to purchase second growth 2S and 3S long logs for the same price per thousand board foot (MBF)(6, 59), we assumed that all lumber produced was of 2 & Better grade.

Other assumptions of the simulation were that the manufacturing goal of the sawmill was to satisfy the daily production schedule and that the daily order file was based on the shipping dates of lumber orders. All lumber that was to be shipped on a given day was either pulled from the finished inventory or manufactured with the appropriate lead time so as to be available for shipping. The portions of the order file that could not be filled from finished inventory were organized into the daily production schedule.

Sof$aw maximized lumber value and therefore sawed the most valuable lumber first, when possible. As portions of the schedule were completed, the system re-focused on producing the next most valuable lumber. Once the 500 trees were processed, any lumber still required to satisfy the order file was purchased in complete bunk units on the open market at a price equal to the sawmill's lumber prices plus a freight charge. Any excess lumber was placed in finished inventory and was available to satisfy the order file for the next day.

In order to establish the log prices for BUCK-CF, a dummy set of short logs consisting of 684 diameter and length combinations was processed through Sof$aw with the order-file price table (see Appendix I for an example). These dummy logs ranged in small-end diameter from 6.0 to 24.8 inches (the largest butt diameter in the tree population). Each 1-inch diameter class was broken into intermediate diameters. For example, the 6-inch diameter class was represented by 6.0, 6.3, 6.5, and 6.8-inch logs; the 7-inch diameter class was represented by 7.0, 7.3, 7.5, and 7.8-inch logs. The large-end diameter of these logs was calculated from the small-end diameter and the average taper of the tree population (1 inch per 10 feet). Logs were between 8 to 24 feet long in 2-foot increments. A specimen of every possible diameter and length combination was processed. The cubic volume of each log was calculated with the 2-end conic rule used by the regional log-scaling bureaus (16,35). The value of any particular log was equal to the value of the lumber cut from it. Since BUCK-CF works in whole inch increments, the dollar per cubic foot ($\$/ft^3$) values for logs within a single length and diameter class were averaged in order to arrive at a single $\$/ft^3$ value for the entire class.

BUCK-CF was set to optimize short log value with these $\$/ft^3$ values and used to buck the tree population. The tree population was sorted by butt diameter into groups of 5 to 15 trees (the larger the diameter of the trees in a group, the fewer the number of trees in the group). After the group order was randomized, the trees were processed in the same order in each simulation. Long log lengths were determined by combining adjacent short logs to meet, but not exceed, the maximum long log length for the bucking strategy. Under the 40-foot bucking strategy, however, long logs were allowed to exceed the nominal 40-foot length in order to reduce the number of logs that were less than 24-feet long. The maximum long log length was 55 feet. Tree butt diameters were calculated by adding a random number between 0 and 1 to the nominal whole-inch diameter reported in the raw data. The tree-butt diameters were held constant for individual trees for the rest of the study. Twelve inches of trim was added to each long log. Long logs were scaled with standard rules and conventions (35).

We processed the resultant short logs with Sof$aw using the same price table employed to determine the value of the dummy logs. Small-end and large-end diameters of short logs were calculated to the nearest one-hundredth of an inch from the butt diameter and the taper of the tree segment of origin, as recorded in the raw data. Short log lengths were the nominal lumber lengths (8 to 24 feet in 2 feet intervals); log trim volume was tallied separately and recorded as lily pad chips. Sof$aw tallied other by-products (sawdust, planer shavings, and chips) and lumber pieces by dimension and value.

After Sof$aw processed each group of trees, the production schedule was filled with the resultant lumber. If all dimensions remained unsatisfied, the next group of trees was processed without any change in the simulation operating parameters. If any dimension was satisfied, the price for that dimension would be set to zero in the Sof$aw lumber-price table and short log values would be recalculated. The next group of trees was processed by BUCK-CF and Sof$aw with the new values until another dimension requirement was satisfied. This process was repeated until either the production schedule was satisfied or 500 trees were processed.

Pro-forma balance sheets and income statements were created for the sawmill through ratio analysis of the annual reports of three lumber companies. Log inventory was valued at cost by using stumpage and stump-to-mill costs provided by local procurement foresters and logging superintendents. Applicable tax rates were calculated from prevailing Oregon timber tax schedules (43). A detailed initial lumber inventory was taken from a sawmill and valued at cost from sawmill costs provided by the OSU Cooperative Extension Service and from the aforementioned stumpage costs. Unit prices for bark, chips, sawdust, and shavings were taken from Lewis (29).

Log costs were determined by scaling each long log individually with prevailing rules and conventions (37). Under the 40-foot preferred-length scenario, trees were bucked into as many 40-foot long logs as possible. Similarly, under the 55-foot preferred-length scenarios, trees were bucked into as many 55-foot long logs as possible. ILM permitted bucking standard-length long logs no longer than 55 feet.

Log costs in this study in pay-as-scaled scenarios were based on contract rates (stump-to-mill costs) multiplied by log scale, whereas log costs under lump-sum scenarios were equal to pay-as-scaled log costs for 40-foot long logs. Timber taxes were based on board-foot scale and were the only log-cost component in lump-sum scenarios that varied with long log scale. Integrated Log Manufacturing capital and operating costs were based on the estimates of equipment manufacturers and software developers. All costs and prices were current as of June, 1991 (see Appendix II).

RESULTS AND DISCUSSION

In the 40-foot bucking strategy, the 2,500 trees (500 trees per day over 5 days) were cut into 5,045 long logs scaling 633.33 MBF Scribner scale. The trees were cut into 4,150 long logs scaling 641.60 MBF in the 55-foot strategy, and 4,665 long logs scaling 665.64 MBF in ILM. The length distributions of the long logs in each bucking strategy are shown in Figure 3. These results confirm the conventional wisdom that cutting 40-foot long logs minimizes Scribner board-foot scale.

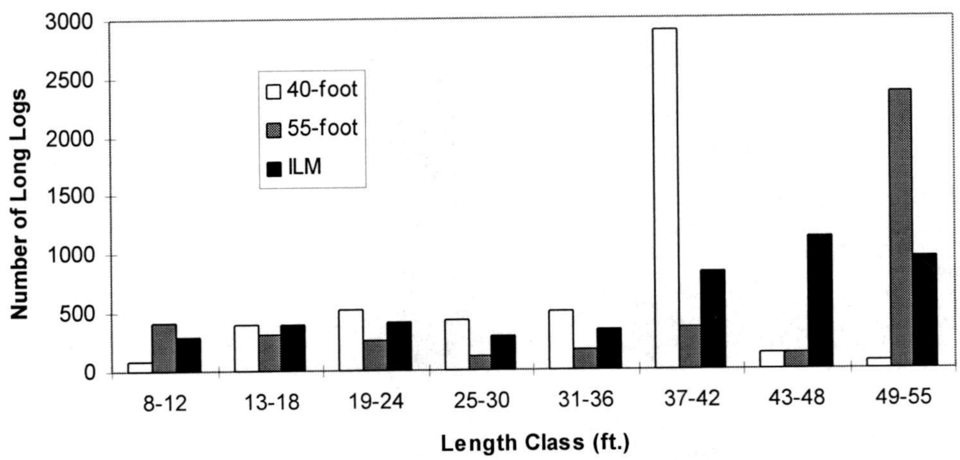

Figure 3. - Length distribution of long logs by bucking strategy.

The long logs were in turn bucked into their final lengths. In the 40-foot strategy, 10,953 short logs averaging 15.27 feet in length and 10.47 inches in small-end diameter were produced. In the 55-foot strategy, 10,850 short logs averaging 15.03 feet in length and 10.50 inches in small-end diameter were produced. In ILM, 11,095 short logs averaging 15.33 feet in length and 10.39 inches in small-end diameter were produced (Figs. 4 and 5).

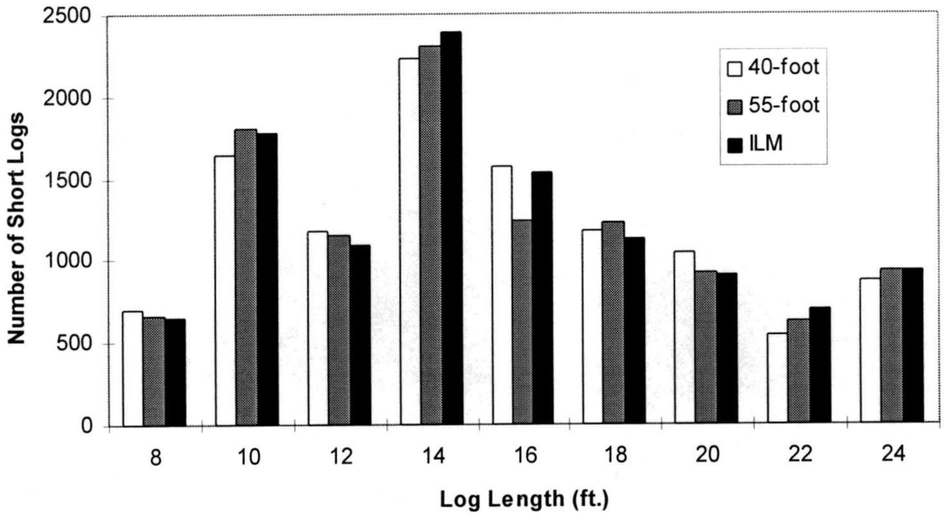

Figure 4. - Length distribution of short logs by bucking strategy.

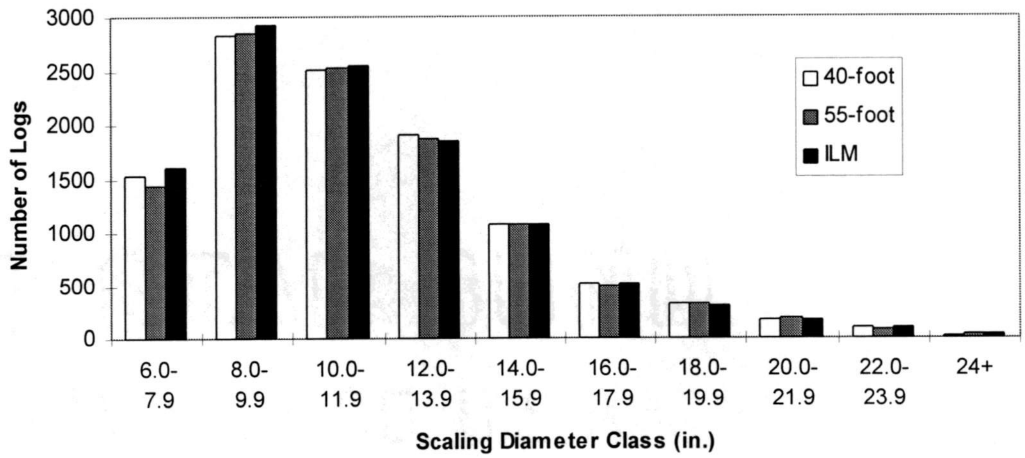

Figure 5. - Small-end diameter distribution of short logs by bucking strategy.

Figure 6 shows the percentage of tree volume converted into lumber and by-products in each bucking strategy.

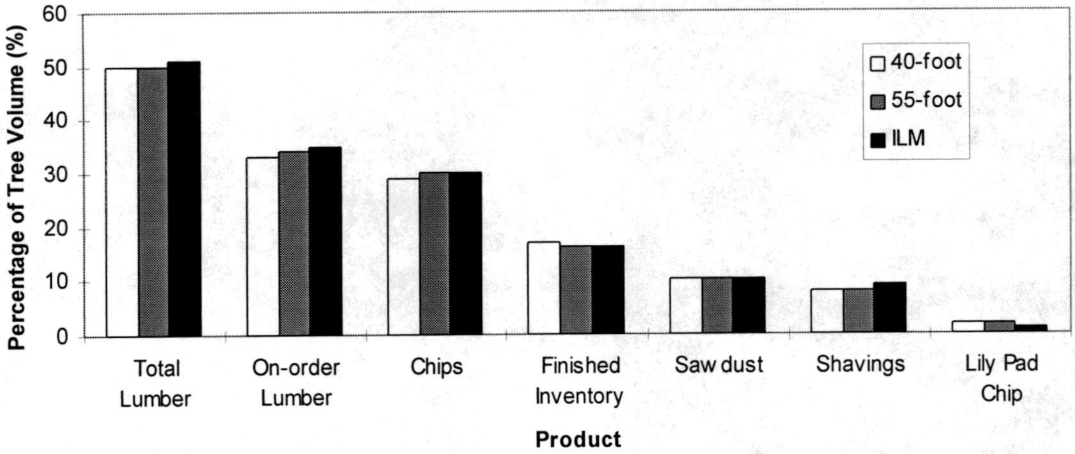

Figure 6. - Tree volume converted into lumber and by-products by bucking strategy.

ILM produced 1 percent more total lumber than either the 40-foot or 55-foot strategies. More importantly, ILM produced 1.9 percent more on-order lumber (lumber in the current production schedule) than the 40-foot strategy, and 1.5 percent more than the 55-foot strategy. As a result, the finished lumber inventory in ILM was 6.5 percent less than that of the 40-foot strategy and 4.8 percent less than that of the 55-foot strategy.

The superior wood-utilization efficiency of ILM was the result of the relatively small volume of production that was wasted as lily pad chips. Because ILM integrates short log bucking at the sawmill with long log bucking at the harvest site, it is able to minimize lily pad volume through two mechanisms.

First, ILM eliminates most lily pads by making the bucking cuts that coincide with those of the sawmill bucking optimizer. Second, the lily pads ILM produces occur towards the tree top. Since trees taper, lily pads of a given length from the tree tops contain less volume than lily pads of identical length from lower on the stem. The 40-foot preferred-length strategy produced the most long logs and hence, the most lily pad volume. These lily pads also occurred lower on the stem.

ILM produced only 40 percent and 42 percent of the lily pad volume of the 40-foot and 55-foot strategies respectively, by creating more lumber, more on-order lumber, and fewer chips. Thus, ILM improved the product-mix of the sawmill. Table I shows the financial consequences of the different bucking strategies. ILM earned $5,530 or 57 percent more profit in lump-sum sales for the week than the 40-foot strategy. The 55-foot strategy earned $3,767 (39%), more profit in the lump-sum sales and $2,264 (23%) more profit in pay-as-scaled sales than the 40-foot strategy. In pay-as-scaled sales, only ILM was less profitable than the 40-foot strategy, with $310 (3%) less profit than the base case.

Because all the bucking strategies filled the lumber orders, the differences in total sales were due to by-product sales. Although ILM had the highest cubic volume of by-products, the 40-foot strategy produced the most high value residues (chips and lily pad chips), and posted the highest net sales.

This simulation confirmed that the 40-foot strategy minimizes log costs. Log costs for the 55-foot strategy and ILM in pay-as-scaled sales are higher than those for the 40-foot strategy because of Scribner-scale related stumpage costs and timber taxes. Differences in log costs between the 40-foot strategy and the other strategies in lump-sum sales were due to scale-based timber taxes.

TABLE I. - Income statement for the sawmill by bucking strategy and timber purchase method.

	40-Foot (PAS/LS)[a, b]	55-Foot (PAS)[a]	ILM (PAS)[a]	55-Foot (LS)[b]	ILM (LS)[b]
Lumber sales	$395,202	$395,202	$395,202	$395,202	$395,202
Byproduct sales	$43,292	$43,241	$41,956	$43,241	$41,956
Gross sales[c]	$438,494	$438,443	$437,158	$438,443	$437,158
Cost of goods sold					
Stumpage	$171,770	$173,717	$179,134	$171,478	$170,439
Stump-to-mill	$62,868	$62,761	$65,265	$62,761	$65,265
Timber taxes	$13,089	$13,237	$13,650	$13,237	$13,650
Milling	$76,543	$76,413	$75,950	$76,413	$75,950
Purchased Lumber	$42,514	$37,457	$32,360	$37,457	$32,360
Freight	$1,679	$1,478	$1,277	$1,478	$1,277
Sales & admin.	$40,780	$40,711	$40,464	$40,711	$40,464
Total cost of goods sold[c]	$409,243	$405,774	$408,100	$403,535	$399,405
EBIT[d]	$29,251	$32,669	$29,058	$34,908	$37,753
Interest expense	$14,603	$14,623	$14,876	$14,604	$14,802
Taxable income	$14,648	$18,046	$14,182	$20,304	$22,951
Income tax (33.4%)	$4,892	$6,027	$4,737	$6,782	$7,666
Net profit[c]	$9,756	$12,019	$9,445	$13,522	$15,285

[a]PAS = Pay As Scaled.

[b]LS = Lump Sum.

[c]Subtotal.

[d]EBIT = Earnings Before Interest and Taxes

Despite the lower log costs of the 40-foot strategy, lower lumber recovery forced the sawmill to purchase 3.9 percent more lumber by volume than in the 55-foot strategy, and 18.3 percent more than in ILM, to fill orders. More importantly, in the 40-foot strategy, the sawmill spent 13.5 percent more for open market lumber than in the 55-foot strategy, and 31.4 percent more than in ILM. Although the 40-foot strategy did minimize log costs, it resulted in the highest total cost of goods sold.

Overall, lump-sum sales were more profitable for the sawmill than pay-as-scaled sales. Lump-sum sales are insensitive to costs based on the Scribner scale (except for timber taxes) and consequently log costs in lump-sum sales approach those of the 40-foot strategy. This allows more efficient wood utilization by a sawmill to accrue to the bottom line without being diluted by artificially inflated log costs.

In Table II, the balance sheet shows that log-inventory valuations followed the same pattern as log costs in the income statement because of their sensitivity to costs based on the Scribner scale. Finished inventory, however, showed the combined effects of log and milling costs spread over the lumber volume. At the end of the week, ILM and the 55-foot strategy resulted in 3.0 percent and 0.8 percent less finished lumber inventory on a cubic volume basis, respectively, than the 40-foot strategy. Inventory values followed similar patterns. ILM was the only strategy that posted a net shrinkage in the value of the inventory for the week, with 1.8 percent less ending inventory than beginning inventory. In contrast, inventory value for the 40-foot strategy increased by 1.1 percent and by 0.3 percent for the 55-foot strategy. In lump sum sales, the reduced costs for the sawmill due to lower finished inventories, however, were insignificant compared to the increased burden in log-inventory costs for all strategies except the 55-foot strategy in lump-sum sales. In this case, finished lumber inventory savings almost negated the increase in log inventory costs.

TABLE II. - Balance sheet for the sawmill by bucking strategy and timber-purchase method.

	40-Foot (PAS/LS)[a, b]	55-Foot (PAS)[a]	ILM (PAS)[a]	55-Foot (LS)[b]	ILM (LS)[b]
Logs	$913,389	$922,289	$958,876	$914,019	$926,566
Finished Inventory	$57,059	$56,962	$57,248	$56,615	$55,918
Cash	$31,776	$31,776	$31,776	$31,776	$31,776
Receivables	$29,422	$29,422	$29,422	$29,422	$29,422
Deposits	$48,305	$48,305	$48,305	$48,305	$48,305
Total Current Assets[c]	$1,079,951	$1,088,754	$1,125,627	$1,080,137	$1,091,987
Plant & Equipment	$10,800,000	$10,800,000	$10,879,080	$10,800,000	$10,879,080
Total Assets[c]	$11,879,951	$11,888,754	$12,004,707	$11,880,137	$11,971,067
Current Debt	$746,793	$746,793	$746,793	$746,793	$746,793
Long Term Debt (11.35%)	$6,690,514	$6,699,317	$6,815,270	$6,690,700	$6,781,630
Total Liabilities[c]	$7,437,307	$7,446,110	$7,562,063	$7,437,493	$7,528,423
Owners' Equity	$4,442,644	$4,442,644	$4,442,644	$4,442,644	$4,442,644
Liabilities & Owners' Equity[c]	$11,879,951	$11,888,754	$12,004,707	$11,880,137	$11,971,067

[a]PAS = Pay As Scaled.

[b]LS = Lump Sum.

[c]Subtotal.

If the sawmill directed all profits, except for a sum equal to the profit for the 40-foot strategy, into higher stumpage bids, the 55-foot strategy would result in a 1.9 percent higher bid in pay-as-scaled sales ($ 156,000 on a yearly basis) and a 3.3 percent higher bid in lump-sum sales ($259,000 on a yearly basis). ILM would result in a 4.8 percent increase in bid value in lump-sum sales ($383,000 on yearly basis), and would be noncompetitive in pay-as-scaled sales due to higher Scribner-related costs. Although this simulation used two ILM-configured stroke-boom delimbers to buck trees for a single sawmill, the ILM infrastructure is capable of coordinating more delimbers. As such, the results for ILM should be viewed as conservative.

CONCLUSIONS

Tree bucking strategies designed to minimize log costs do not always maximize sawmill profitability. In our simulation, alternative tree bucking strategies enabled the sawmill to produce more total and more on-order lumber than was possible under the current industry practice (40-foot). Relatively small increases in lumber volume recovery resulted in disproportionate increases in sawmill profitability.

Sawmill profits for the maximum haul-length strategy for both pay-as scaled and lump-sum timber sale scenarios were higher than those for the log cost minimization base case. The maximum haul-length strategy has the advantages of requiring no additional capital to implement, and of being less time sensitive in regards to when the sawmill processes the logs.

In contrast, ILM, which appears economically viable for lump-sum sales or cubic pay-as-scaled sales, requires a substantial investment in capital and operating costs, and depends on long logs being matched to their corresponding sawing solution at the sawmill in order to achieve optimization. Despite these obstacles, ILM merits consideration by sawmills in areas where lump-sum sales predominate, and by integrated firms that primarily process fee timber. If we assume a 5-year life and lump sum sales, ILM earned an internal rate of return of 65 percent and had a payback period of 17 months when compared to the 55-foot strategy.

Lump-sum sales were always more profitable for the sawmill than Scribner-based, pay-as-scaled sales. Because lump-sum sales avoid both the inconsistencies of the Scribner scale and the arbitrary bias of segment scaling, profit-maximization strategies based on cubic volume can work unconstrained. Alternatively, cubic-based, pay-as-scaled sales provide both the timber seller and buyer with the best of both worlds: payments based on the scale of the actual volume removed, and no Scribner-related costs. This study's results present compelling evidence that such sales would increase sawmill profitability, provide the government with higher tax receipts, and provide timber owners with potentially greater stumpage returns.

FURTHER RESEARCH

Several questions about tree bucking at the harvest site warrant further research. These questions involve the timber resource, the sawmill system, the tree bucking platform at the harvest site, and tree bucking strategy refinements.

This study used 500 trees that were processed in a specific order. There exists a remote chance that the tree order unintentionally favored one tree bucking strategy over the others, and that the results are not indicative of the system's behavior. It would be valuable if the results presented here could be verified or refuted using different sets of trees, or at least with different tree orders. In addition, the results presented here should be considered theoretical maximums from the standpoint that the trees were assumed to be straight with circular cross-sections. It is of practical importance to sawmillers to know if there is a threshold tree size, shape, and degree of crookedness beyond which the costs of alternative tree bucking strategies outweigh the benefits. It is also necessary to calibrate the simple bucking optimizers that utilize these simplifying assumptions against more accurate true three-dimensional models in order to assess the achievable benefits of alternative tree bucking strategies.

This study assumed that the hypothetical sawmill was able to process whatever we presented to it. In reality, increasing the physical piece throughput of a given sawmill may not be possible, and a more accurate simulation model would include material flows through machine centers, not the least of which would be in the log yard. Also, this study indicated that there may be consequences regarding finished inventory levels that may or may not be desirable. A simulation covering a longer time period would show whether the inventory behaviors reported here are characteristic tendencies of the respective tree bucking strategies or merely anomalies specific to this study.

Another important question left unanswered by this study is whether the current generation of stroke-boom delimbers can in fact operate as assumed under the ILM scenario. More needs to be known concerning the ability of operators to assess tree surface quality and defects, as well as the frequency and magnitude of measurement system errors and their impact on the optimal bucking solution. In addition, the feasibility of developing a means of mechanically attaching bar code tags to long logs, or some completely different solution to the log identification problem, warrants investigation.

Lastly, there are at least two refinements to ILM which may increase its value. The first is the aforementioned two-stage optimization presented by Young (60) which would optimize the long log bucking pattern to minimize Scribner-based costs. The second refinement is the development of a strategy to address the problem of cutting narrow lumber from large trees. This problem occurs when, as in this study, ILM is free to cut whatever lumber remains in the current production file from the next tree presented to it. For example, because ILM is driven by lumber value it makes the most valuable lumber still remaining in the production file out of the next tree presented to it that can physically produce that lumber dimension. Early in any given production day this is exactly what is desired, and ensures that costly stumpage is converted into the highest value lumber first. As the production day unfolds, the orders are filled from high value to low value, and eventually all the trees are being processed into relatively low value lumber. Historically, low value lumber has been the short, narrow dimension products that can be produced from relatively small trees. The problem is that trees yarded to the landing are random with respect to size, and ILM, as described in this study, will convert large trees into these low value products when that is all that is left in the production order. This is particularly wasteful of a scarce resource - large diameter timber - necessary for the production of the wider, longer, and more valuable lumber products. Required is a way to govern the tree bucking process so that the relatively few large trees are not cut into low value products.

Notwithstanding these questions, alternative in-woods tree bucking strategies designed to maximize sawmill profits by integrating harvesting and lumber manufacturing appear to have the potential of providing sawmills with a competitive advantage.

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APPENDICES

APPENDIX I. Example of a dummy set of short logs and log values.

SDIB (in.)[a]	LDIB (in.)[b]	Length (ft.)[c]	$ Value[d]	FT^3	$\$/FT^3$	AVG$\$/FT^3$[e]
11.0	12.5	14.3	$34.30	10.76	$3.19	
11.3	12.8	14.3	$34.30	11.34	$3.02	
11.5	13.0	14.3	$34.30	11.72	$2.93	$3.00
11.8	13.3	14.3	$35.00	12.30	$2.85	
11.0	12.7	16.3	$44.24	12.51	$3.54	
11.3	13.0	16.3	$44.24	13.15	$3.36	
11.5	13.2	16.3	$44.24	13.56	$3.26	$3.33
11.8	13.5	16.3	$45.00	14.25	$3.16	
11.0	13.0	18.3	$15.62	14.41	$1.08	
11.3	13.3	18.3	$15.62	15.13	$1.03	
11.5	13.5	18.3	$15.62	15.83	$0.99	$1.03
11.8	13.8	18.3	$16.50	16.39	$1.01	
11.0	13.2	20.3	$9.10	16.26	$0.56	
11.3	13.5	20.3	$9.10	17.07	$0.53	
11.5	13.7	20.3	$9.10	17.62	$0.52	$0.53
11.8	14.0	20.3	$9.75	18.47	$0.53	
11.0	13.4	22.3	$16.31	18.16	$0.90	
11.3	13.7	22.3	$16.31	19.06	$0.86	
11.5	13.9	22.3	$20.39	19.68	$1.04	$0.94
11.8	14.2	22.3	$20.39	20.61	$0.99	
11.0	13.6	24.3	$40.96	20.13	$2.03	
11.3	13.9	24.3	$40.96	21.12	$1.94	
11.5	14.1	24.3	$51.20	21.79	$2.35	$2.14
11.8	14.4	24.3	$51.20	22.82	$2.24	
12.0	13.9	8.3	$0.00	7.02	$0.00	
12.3	13.2	8.3	$0.00	7.36	$0.00	
12.5	13.4	8.3	$0.00	7.59	$0.00	$0.00
12.8	13.7	8.3	$0.00	7.95	$0.00	

[a] SDIB = Small-end diameter inside bark.

[b] LDIB = Large-end diameter inside bark.

[c] Length = Log length plus 0.3 feet trim.

[d] $ Value = Dollar value of the short log based on selling prices of the highest value lumber that could be sawn from it.

[e] AVG $/FT3 = Average dollar value per cubic foot for short logs of a given length and 1-inch diameter class.

APPENDIX II. ILM system costs and stump-to-mill costs.

Assumptions:

1. ILM system costs pertain to a satellite communications-configured system.
2. ILM system is to be retrofitted onto 2 existing stroke-boom delimbers.
3. The logging system production is yarder-constrained at 250 trees (126.66 mbf) per day per harvest site.
4. There are 240 working days per year in the woods; 8 machine hours per working day; 260 working days per year in the sawmill.

ILM System Capital Costs

One satellite communications transceiver per delimber @ $4,500 ea.	$9,000
One satellite base unit transceiver at the sawmill	$5,000
One off-line simulation PC at the sawmill	$5,000
One production tracking PC at the sawmill	$5,000
One bucking optimization PC per delimber @ $5,000 ea.	$10,000
One data logger per delimber plus spare @ $2,000 ea.	$6,000
One diameter measurement kit per delimber @ $10,000 ea.	$20,000
Software	$15,000
Training: 20 man-days total for delimber operators and raw material controller at the sawmill	$4,080
TOTAL CAPITAL COST	$79,080

APPENDIX II. (continued)

Total capital cost (P) =	\$79,080
Salvage (S) assumed at 10% of P =	\$ 7,908
Service life (N) =	5 years
Scheduled machine hours (SMH) =	1,920
Maintenance (M) assumed at 10% of P =	\$ 7,908
Average annual investment (AAI)[a] =	((P-S)x(N+1))/2N
	((\$79,080-\$7,908)x(5+1))/10
	\$42,703 per year
Property taxes (T)[a] =	0.145 x AAI
	0.145 x \$42,703
	\$619 per year
Insurance (I)[a] =	.00875 x AAI
	.00875 x \$42,703
	\$374 per year
Depreciation (D) =	(P-S)/N
	(\$79,080-\$7,908)/5
	\$14,234 per year

[a] from Bushman, S. P. and E. D. Olsen. 1988. Determining costs of logging-crew labor and equipment. Forest Research Laboratory, Oregon State University, Corvallis. Research Bulletin 63. 22 pp.

APPENDIX II. (continued)

Sawmill raw material controller wages and benefits (W) =	hourly wage x benefits factor x working hours per year
	$17 per hour x 1.5 x 2080 hours
	$53,040 per year
Communication fees (C) =	$420 per year base fee + $2,700 per year phone charge + $7.60 per day data transfer charge
	$420+$2,700+($7.60 x 240 work days per year)
	$4,944 per year

Interest charges are computed in the balance sheet (Table II).

Total owning costs per year =	T + I + D
	$619 + $374 + $14,234
	$15,227 or $7.93 per SMH
Total operating costs per year =	M + W + C
	$7,908 + $53,040 + $4,944
	$65,892 or $34.32 per SMH
Total cost per SMH =	Owning SMH + Operating SMH
	$7.93 + $34.32
	$42.25

APPENDIX II. (continued)

Typical total cost per SMH for a stroke-boom delimber (Lim-mit 2200)[b] =	\$97.32 per SMH
Total ILM system costs per SMH for a 2 delimber system =	(Typical delimber cost x 2)+ total ILM system cost
	(\$97.32 x 2) + \$42.25
	\$236.89
Processing cost per MBF =	(Total ILM system cost per SMH x 8 SMH per day)/253.32 MBF per day
	(\$236.89 per SMH x 8 SMH per day) divided by 253.32 MBF per day
	\$7.48 per MBF

[b] Peterson, J. T. 1988. Cost and productivity comparison of mechanized tree processors. Canadian Forest Industries, December 1988, pp. 33-38.

APPENDIX II. (continued)

Stump-to-Mill Component Costs ($ per MBF)

Cut	$ 8.50
Yard	$41.98
Process (40 and 55-foot)	$ 6.76
Process (ILM)	$ 7.48
Scaling	$ 3.41
Load & Haul	$30.85
TOTAL (40 and 55-foot)	**$91.50**
TOTAL (ILM)	**$92.22**