OPTIMIZING THE FOREST FOR SUSTAINABLE MANAGEMENT, IMPROVED MANUFACTURING PERFORMANCE, AND TOTAL PROFITABILITY

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ABSTRACT

Technology in modern, high-production, southern yellow pine sawmills provides data acquisition and analysis tools that can be beneficial for timber, operational, market planning, and decision making in integrated forest products companies. By utilizing scanned, three-dimensional, stem profile data gathered at the log bucking process of a mill operation, prediction equations can be developed for the specific mill processes to estimate lumber recovery factor (LRF), board volume, stem volume, and mill products' value in standing timber. Intensive plantation management combined with the application of a process model to predict sawmill performance based on standing timber attributes could promote ecological, operational, and economical benefits as well as improved lumber quality and increased market flexibility for integrated forest products companies. Data and research indicate that properly managed smaller diameter sawtimber could provide as high or higher LRF values, more volume per acre, and higher quality wood products than timber managed for larger diameters. A growth and yield projection and an economic analysis were performed to demonstrate the validity of these claims.

Keywords: forest management, LRF, modeling, plantations, sawmill, southern pine, sustainable, technology

INTRODUCTION

Southern pine forests are taking the lead as the commodity-grade timber basket for the United States. Gentile topography, favorable soil types, and relatively long growing seasons make many regions in the South ideal for growing timber; and silvicultural practices in the South have allowed the region to produce large volumes of timber in a sustainable manner. As increased market demand and ever-more stringent sustainable forestry guidelines face the region, opportunity exists for the South to emerge as a premier example of sustainability, innovation, and economic progress.

Sawmill, pulp and paper mill, and most other softwood conversion technologies are approaching maturity. That is to say that any future major conversion efficiency gains associated with new equipment in the most technologically advanced facilities will be restricted to advancements such as "kerf-less" sawing or engineered wood products processes and equipment that convert a higher percentage of the raw material into the most valuable products. However, substantial yield increases in the order of 10–20% are still attainable by managing and matching resources in the forestry management process for optimal performance in the mill conversion process.

The influx of computer technology into the forest products manufacturing industry has expanded the quantity and quality of data available for studying the relationships of raw material attributes to process efficiency. Careful management of this data could afford forest products companies new avenues for decision criteria throughout their integrated structure. Enhancements can be achieved in sustainable management, manufacturing processes, and total company profitability as a result of optimizing the forest for total process performance.

One area of total process performance that could be improved revolves around a large log paradigm that prevails in the forest products industry. Favoring increased bole diameters is evident in forest management practices, mill procurement strategies, and is most reflected in stumpage values. This paper proposes that the underlying principles of the large log paradigm might not be totally solid and that there are advantages to be gained by process and quality driven rather than diameter driven management decisions in the industry. The intent of this paper is not to propose a blanket solution to improve process performance in the South. Its true intent is to present one way that certain organizations can apply new technology to achieve specific objectives that are strategically aligned with the company's vision.

The number of trees per unit area and the spatial relationship of those trees to one another in a stand can affect the lumber quality, the lumber recovery factor (LRF), and the lumber value when the stems are processed at the mill. Initial planting densities and thinning are silvicultural tools that can be used to control the proportion of juvenile wood, size and number of knots and, thus, the quality of lumber produced from managed plantations (Clark 1994; McAlister 1997). The total volume produced from a stand generally decreases as initial spaces are widened and thinning intensity is increased. Tree diameters and conventional "sawlog" volumes generally increase with both wider spacing and more intense thinning (Oliver and Larson 1996; Baldwin 1998).

Total stem volume production from a stand is the greatest when the growing space is most efficiently utilized. To emphasize total stand growth, the stand must be managed such that large values of leaf-area-index are accumulated and maintained. Conversely, to emphasize individual tree growth, the stand must be managed to promote large crowns on individual trees. Both conditions are mutually exclusive (Dean 1996). Once the tree canopy is closed and the growing space is occupied, trees will continue height growth; and total stem volume production will be maximized on the site

If the large log paradigm were consistent, the attempt to take advantage of wood quality in smaller diameter stems could be over-ridden by the inherently lower LRF of small logs. If there were not an inherently lower LRF with small

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logs or if a manner existed to grow small logs with higher LRF values, there could be an opportunity to modify silvicultural practices and to produce higher-grade lumber.

Intensively managing timber for higher process performance could allow more products to be supplied from a given tract of land, thus reducing the total land base required to meet the timber demands of society. This progression of events could eventually free more forestland for non-timber uses.

SUSTAINABLE MANAGEMENT

Silvicultural systems are designed to deal with a whole complex of biological, physical and economic considerations. Formulation of a silvicultural system should start with analysis of the natural and socioeconomic factors of the situation (Smith 1997).

Intensively managed plantations offer a unique opportunity to reduce the area of land required to grow timber for the world's wood products demands while providing economic benefits for timber producers and environmental benefits for conservationists. Excluding fuel wood, it is estimated that intensively managed plantations could supply 90% of the world's demand for pulp and wood construction materials in the form of commodity-grade products. Specially managed natural forests could supply the remaining 10% of specialty products. With this model, the fraction of the total forested area of the globe devoted to timber production could conceivably be as little as 5% (Sedjo 1997).

Private timberland ownership accounts for 89.6% of all timberland in the southeastern United States with 18.4% owned by the forest industry and 71.2% owned by nonindustrial private landowners (Davis and Johnson 2001). Due to timber harvest restrictions on public lands, as much as 10 billion board feet of timber produced from public forests a decade ago (USDA 2001) is now either imported or supplied by private forests mainly in the South (Clark 1998). Softwoods account for at least 60% of the timber harvests in most regions of the South. In the past, softwood harvests were obtained mainly from natural pine; however, at present, planted pine contributes about a third of softwood harvests, and its share is predicted to rapidly increase in the future (Siry 2001).

Forest Allocation

A triad approach to forest allocation as proposed by Seymour and Hunter in 1992 and illustrated in Figure 1 basically divides land use allocation for forests into the three classifications below (Hunter 1996).

1. **Production:** Intensive commodity production areas
2. **Reserves:** Areas with little or no resource use by people except low-intensity recreation
3. **Multiple Use:** Areas in which resource use is allowed while ecological values are carefully protected.

Intensively managed production areas such as those represented by southern pine plantation silviculture provide the most economically efficient means to produce large volumes of quality fiber to meet consumer demands for timber products. Production forests are managed foremost for timber but other management objectives can be achieved through intensively managed forests. Although intensively managed plantations do not necessarily maintain a high degree of natural diversity, they do maintain most of the basic ecosystem equilibria such as high biological productivity, uptake of carbon dioxide, retention of nutrients, control of erosion, and regulation of hydrologic processes (Smith 1997).

Reserve areas serve an important role in protecting the ecological values associated with forests. Because we know so little about the distribution of species, notably insects, fungi and other poorly known taxa, concerns for biodiversity dictate that forest tracts be set aside simply because they are good examples of a particular type of ecosystem and are likely to encompass inconspicuous life forms (Hunter 1990).

Multiple-use forestry encompasses the forest use allocation area that falls between intensive production forests and non-timber use reserves. Multiple-use forests are managed for multiple objectives such as maintenance of biodiversity, protection of water resources, recreation, and less intense timber production.

All three types of forest allocation are important to conciliate the wide array of forest management ideologies present in society. In much the same manner as intensive agriculture allowed for the reforestation of abandoned farmlands in the United States at the turn of the 20th century, intensive plantation silviculture can concentrate timber production on smaller land areas and, in turn, promote other areas to be managed as multiple-use or reserve forests.

With current restrictions on timber harvesting from public lands and because of the large private timberland ownership in the southeastern region of the country, one might construe that the Triad allocation model could potentially

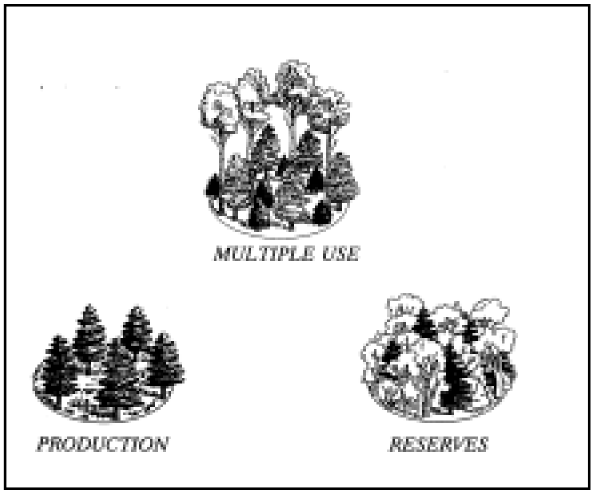


Figure 1.—Triad approach to forest allocation.
(From Seymour and Hunter 1992 in Szaro 1996).

shift a huge portion of the South's forests into intensive plantation management. The question could be asked; would such a scenario create an apparent national numeric balance among the three forest allocation types yet foster an imbalance of allocation in the South?

To understand the implications of forest allocation in the South, one must first consider the size of the timberland in the region. The grand total of the southern forests, changing daily as land is reclaimed to woodlands and being converted from timberlands to other uses, now approximates 235.5 million acres, or 368 thousand square miles. That is the equivalent of the gross area of the five New England states plus Michigan, Wisconsin, Minnesota, Indiana and another some two thousand square miles. The pre-Columbian forests of the South could have encompassed 400,000 square miles (Walker and Oswald, 2000). There are more than 60 forest-cover types in the South that have been recognized by the Society of American Foresters. The oak-hickory-pine type is the most widespread type but the four principal southern pines (longleaf [*P. palustris* Mill], slash [*P. elliottii* Engelm], shortleaf [*P. echinata* Mill], and loblolly [*P. taeda* L.]) are the primary native species on more than 69 million acres (Walker and Oswald 2000).

An example of how the Triad allocation model exists in the south can be illustrated with forest allocation in the southern state of Arkansas. Only 13% of the 18.4 million acres of timberland in Arkansas are currently allocated to pine plantation management. Multiple-use and reserve forests in the state include 14% natural pine forests, 17% oak-pine forests, 39% oak-hickory forests, and 17% bottomland hardwood forests (AFC 1995). Arkansas' forests not only supply raw materials for the largest manufacturer in the state, but they are home to two national forests (2.4 MM acres), twelve wilderness areas, many of the 51 state parks, one national park, and eight scenic and wild rivers.

Forest Certification

In the early 1990's, efforts were begun to implement forest certification programs around the world. Certification is advertised as a market-based instrument designed to encourage sustainable forestry; it is structured to provide proof to forest products consumers that their purchase is not supporting unsustainable or inequitable forest practices. Certification programs such as the internationally based Forest Stewards Council (FSC) along with industry developed domestic programs such as the American Forest and Paper Association's Sustainable Forestry Initiative (SFI) have been structured to provide third-party certification audits and a label for certified products. The American Tree Farm System that was established in 1941 is also positioned to provide certification services as efforts to certify wood products in the U.S. progress.

Chain-of-custody is currently an unresolved concept within forest certification designed to require businesses to establish systems that would create a paper trail demonstrating that certified materials were kept separate from non-certified, and could be accurately tracked to maintain their identity from grower to consumer. Predicting the outcome and ramifications of chain-of-custody debates at this stage would be highly speculative. However, if chain-of-custody regulations were implemented, an accurate accounting of the forestry management practices associated with processed timber would be necessary. The ability to produce more products from company-owned and managed timberland through improved silvicultural practices that would increase timber yields, or through better mill efficiencies, would offer integrated forest products companies more internal control over chain-of-custody issues.

IMPROVED MANUFACTURING PERFORMANCE

Overview

Laser-based scanning technology coupled with off-line sawmill computer simulation programs provides resource managers new opportunities for analyzing timber. The ability to three-dimensionally surface scan tree length stems and store the scanned images for later analysis and modeling is a powerful tool for relating the effects of forestry management practices on mill production and performance.

One of the key indicators for process efficiency is LRF that quantifies the ratio of lumber (BF) manufactured from every cubic foot (CF) of timber processed. LRF, stated in terms of board feet per cubic feet (BF/CF), is a reflection of the combined effects of raw material attributes, manufacturing technology, operation and management in the process, and the products being manufactured. An important goal for a manufacturing process is the conversion of an input into a product that makes money for the owners of the process. While high LRF numbers should not be the ultimate goal of a sawmill manufacturing process, Figure 2 shows that in a commodity type market, such as for softwood lumber, LRF is highly correlated to the value of products manufactured from timber.

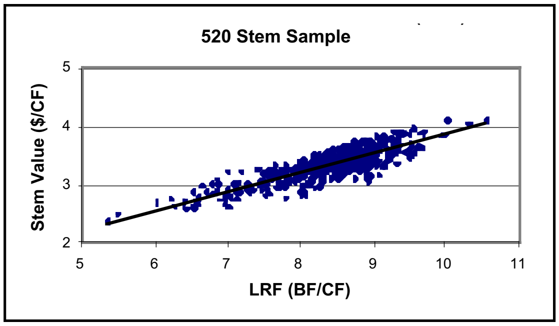


Figure 2.—Stem lumber yield verses realized value

The ability to accurately predict LRF, total timber volume, lumber volume, chip volume, sawdust volume, total product value, product distribution, and mill production rates for a stand of timber before it is harvested would be a valuable management tool for forest resource managers, mill managers, and marketing managers in an integrated forest products company. This tool could be used to more accurately valuate standing timber and to generate coefficients and constraints for linear programming harvest models.

A database containing up-to-date data on company owned stands could be managed to streamline company timber through the mill process. This would enable companies to fill large or special orders with the most efficient resource use while reducing inventories of stored timber and processed lumber. The tool might also be used to help resource managers design timber stands at various stages from regeneration to final harvest to increase growth yields and timber quality in the forest while optimizing LRF and value at the mill.

Although noted for relatively fast growth rates and suitability to intensive plantation management, the process of growing, harvesting, and manufacturing timber into lumber can span several decades in the southern pine belt region of the southeastern United States. Much speculation must be employed when establishing a stand of timber that may not be harvested for its highest value products for 25–30 years or more. In general, according to principles of forest economic analysis, a well-managed forest appreciates in value while the trees are growing up to the point at which net present value for the stand is maximized. When a tree is harvested its potential market value is fixed even though little may be known about the nature and value of the individual products that will eventually be sold in the market. After timber is harvested, it can spend months in round wood or lumber inventory before products from the timber are sold in the market. Above and beyond obvious major decisions such as retaining harvested land and planting trees rather than selling the land or planting an agricultural crop, or even to manage for sawtimber verses pulpwood, the first major product-based decision that is made for an individual tree is made at the log bucking step of the mill process. Figure 3 illustrates the major processes for growing, harvesting, and manufacturing timber into marketable products. The chart also shows major transition lines, time frames associated with each process, the influence of inventory, and the relative market predictability and flexibility at different stages of the process.

Utilizing scanned tree data, mill modeling software, and statistical data analysis, preliminary test data show that it is possible to predict with a high degree of accuracy (less than 1% error) several key attributes for tree length stems before they are processed. Opportunity exists to increase mill LRF values from an estimated 10 to 20% through refinement and implementation of this process within integrated forest products companies.

Results from data analysis also show that some of the assumptions regarding the large log paradigm should be revisited in the light of more rigorous data analysis for whole tree stems. LRF and more importantly, mill value, are not as dependent on large tree diameters as might be suggested by the large log paradigm. In fact, many smaller diameter stems can produce higher LRF and higher mill values than many larger diameter stems.

Dissecting the Large Log Paradigm

A common belief accepted by many in the wood products industry is that larger diameter sawtimber stems are superior to smaller diameter stems. This large log paradigm is based on the following assumptions regarding large diameter stems:

1. They are less expensive to harvest
2. They provide for increased mill production
3. They produce a wider range of more valuable lumber products
4. Larger diameters translate into higher LRF and value at the mill

Are large diameter stems less expensive to harvest?

Given the same topography and site conditions, larger diameter stems are indeed less expensive to harvest than smaller diameter stems. For example, logging costs for stems with average diameter at breast height (dbh) of 12 inch are approximately 10% less than stems with an average dbh of 9 inch (Duryea 1991).

Do large diameter stems provide for increased mill production?

Generally speaking, larger diameter stems do provide for increased mill production. However, the total impact of smaller diameters on the mill process requires a somewhat complex analysis.

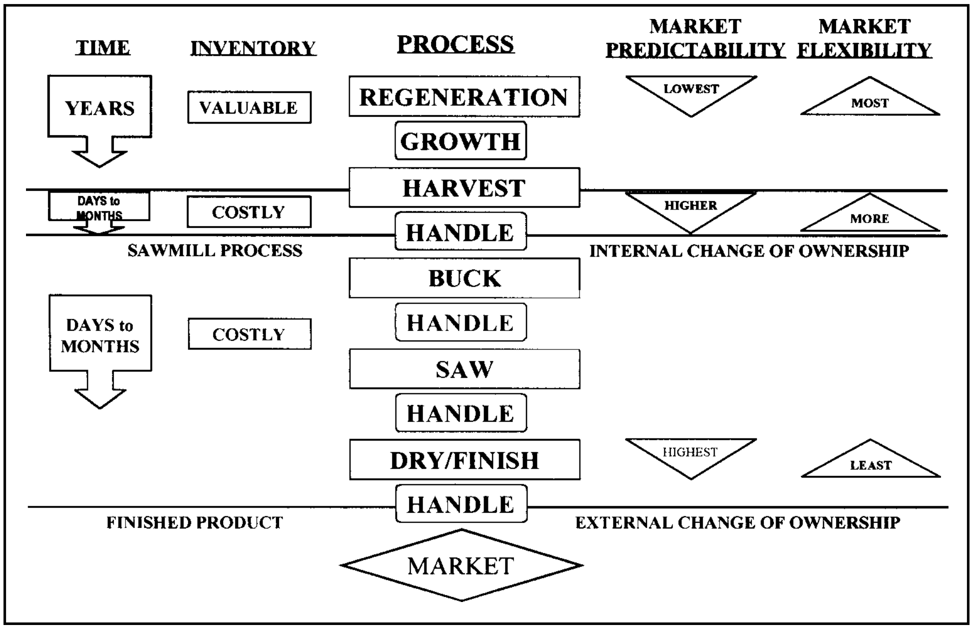


Figure 3.—Lumber production process flow for a single facility.

Log count and piece count are two critical indicators of mill productivity. With modern sawmill technology, log count can be increased as log diameter decreases mainly due to the ability to increase feed speed through chip heads and saws as the depth of cut decreases. Therefore, smaller diameter logs can be processed through the mill at a higher rate than larger diameter logs. A mix of smaller diameter stems also has less variation around the mean diameter of the mix. This translates into less distance that saws and chip heads must shift between sawlog sets which, in turn, can reduce set time on machines and facilitate smaller gaps between sawlogs resulting in higher linear throughput in the mill.

Because LRF is not solely dependent on diameter and since some small diameter sawlogs can have a higher LRF than some larger diameter sawlogs, it is possible that as log size (CF/Log) decreases, an increase in LRF can directly offset reductions in lumber production. For example, if a 6.0 CF log that has an LRF of 8.0 BF/CF was run through a mill then 48 BF of lumber would be produced. If a 5.45 CF log (10% smaller) with an LRF of 8.8 BF/CF (10% more) was run through the same mill, the net result would still be 48 BF of lumber. A nuance in the math is that log volume (CF) is a function of the square of the diameter and a 10% reduction in diameter translates into a 19% reduction in volume. To illustrate this point, consider the sawlogs in the above example. If both logs were 16 feet long, the average diameter of the 10% higher volume log would be 8.3 inches and the average diameter of the smaller volume log would be 7.9 inches (an approximately 5% decrease in diameter resulted in a 10% decrease in volume).

As average lumber width in a mill decreases, the average piece size (BF/Piece) also decreases and the mill has to handle more boards to produce the same total lumber volume. Since a greater number of smaller diameter logs are being processed in southern sawmills, improvements in computer, control, and machine technology have allowed new equipment to be designed that still has the flexibility to cut and process up to 12-inch wide lumber but at higher speeds with more precision. These changes have forced sawmill equipment to undergo major design speed improvements over the last decade as shown in Figure 4.

Machine Center	1991 Rates	2001 Rates
Primary Breakdown	8 logs/min	16 logs.min
Edger	25 boards.min	35 boards/min
Gang Saw	8 cants/min	16 cants/min
Trimmer/Sorter	80 boards/min	120 boards/min
Planermill	80 boards/min	130 boards/min

Figure 4.—Design Speed Improvements.

Generalizations regarding the net effects of decreased stem diameters on production can be misleading. Total production in modern southern pine sawmills usually is limited by air discharge permit capacity on dry kilns rather than on process speed. As existing mills are modernized and as new mills are being built, advances in sawmill technology are equipping mills to run at higher piece rates that will allow them to efficiently process smaller diameter stems and meet kiln limitations under normal operation.

Do large diameter stems produce a wider range of more valuable lumber products?

Up to the diameter increment that allows the production of 12-inch wide lumber, larger diameter sawlogs progressively allow more variety in the product mix. Whether or not a wider product mix adds more value to a mill process is dependent on the cost of the raw material, the quality of the finished products, and the particular market conditions when the products are sold.

To state that wide dimension (10- and 12-inch) lumber will eventually be phased out of production would be irrational at this point. To imply that all producers should focus all production efforts on narrow dimension lumber would suggest a tunnel vision view that fails to recognize the vast quantity of larger diameter standing timber and the existing markets for wide dimension lumber. However, price premiums that have historically been present for wide dimension have eroded over the past decade (Fig. 5) while production has dramatically increased for engineered wood products such as wooden I-joists (Fig. 6). Wooden I-joists are direct substitute products for wide dimension lumber in certain applications. If these trends continue then a wide product mix should no longer play as significant a role in the demand for larger diameter stems.

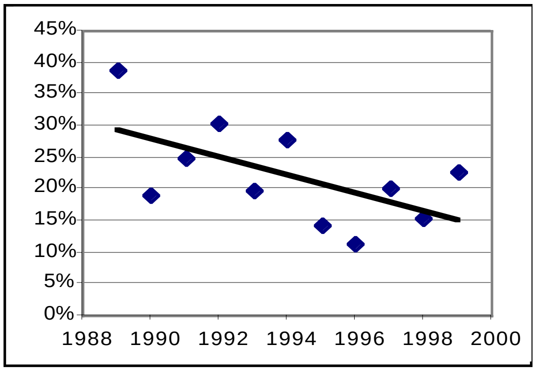


Figure 5.—Wide Lumber Price Premiums. Average yearly price premiums 10" and 12" widths over 4" and 6" widths grade #2 SYP. (Values from Random Lengths - 1999)

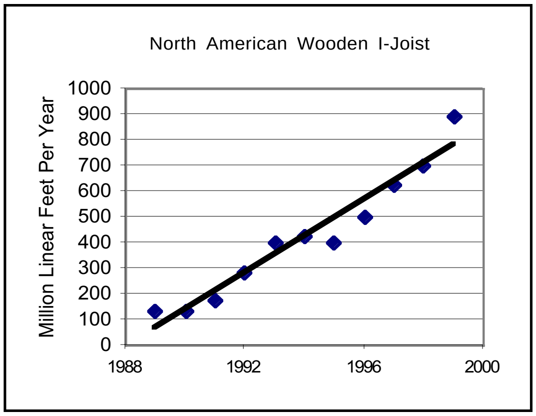


Figure 6.—Wide Lumber Substitutes

In order to produce larger diameter stems with higher stumpage values, forest managers have spaced southern pine wider at planting and have thinned heavier to allow the growing space needed for larger diameters. Both wood quantity and quality can be adversely affected by management decisions to increase bole size by planting at wider spacing when sawlog production is the objective (Baldwin 2000). Less dense stands lead to larger branches, more knotty timber, a bigger juvenile core and in some species, to wood of lower average density (Savall and Evans 1986).

Being able to predict the mill performance of standing timber would facilitate forest managers' ability to manage timber for quality products and increased stand volume rather than for larger diameters. Consequently, supplying quality timber with desirable process attributes could improve mill efficiency while producing more valuable products for the market.

Do large diameters translate into higher LRF at the mill?

With modern mill technology, it is relatively simple to track total cubic volume of sawlogs into the mill and total lumber leaving the mill. This technology allows for almost instantaneous reporting of mill LRF that can be compared with monthly inventories to check the mill's total fiber balance. This data is typically reported as mill averages and is seldom looked at on a log-by-log or on a stem-by-stem basis because of the complexity in monitoring the production from individual logs and stems.

A common practice is to report LRF for a group of sawlogs based on categorizing all sawlogs into 1-inch diameter classes and reporting the average LRF for each diameter class. Figure 7 shows such a table that was compiled for 1,513 sawlogs based on the small end diameter and LRF for each log. The graph depicts that as diameter increases from the 5-inch class to the 9-inch class, LRF steadily increases and then begins to level out for diameters greater than 9 inches. Please note that the high LRF for the 13-inch diameter class was based on only one sawlog in the mix that fell into the 13-inch class and there was no 14-inch class shown on the graph because there were no logs in that class in the sample. This trend corresponds well to the large log paradigm but it does not tell the entire story.

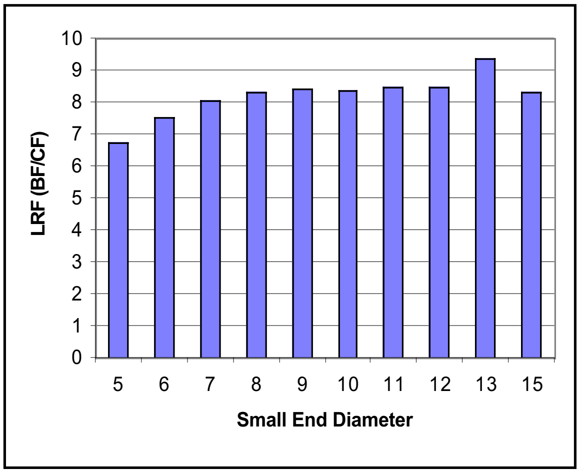


Figure 7.—LRF by small end diameter
(1,513 Sawlogs - 1" Increment Class)

Figure 8 shows the same 1,513-sawlog sample with the sawlogs divided into 0.1-inch diameter classes. Because only a few logs were represented in the 5-, 13-, and 15-inch classes, those classes were omitted from the graph for clarity. The heavy line in the center of the graph shows the average LRF for each 0.1-inch increment class. The vertical lines represent the range of LRF values for each class and the top and bottom lines represent the maximum and minimum boundaries for each class.

Figure 8 illustrates that although there was a general trend toward higher LRF as sawlog diameters increased, there were obviously some smaller diameter logs that had excellent LRF values while there were some larger diameter logs that had relatively poor LRF values.

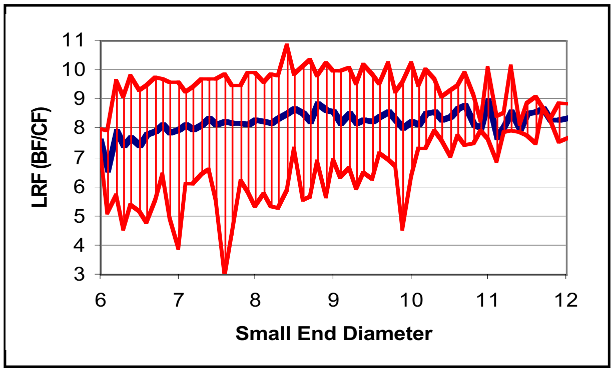


Figure 8.—LRF by small end diameter
(1,513 Sawlogs - 0.1" Increment Class)

The data represented in Figures 7 and 8 were based on individual 8- to 20-foot long sawlogs that were produced from a sample of 520 stems.

Both large and small diameter sawlogs are produced when tree length stems are bucked into sawlogs. The complexity of the diameter relationship to LRF becomes even greater when the entire stem is considered in the analysis.

Several factors other than diameter also affect LRF. The major contributing factors to LRF can be summarized as follows:

1. Diameter increment
2. Taper
3. Sweep
4. Geometrical shape of cross-sectional areas
5. Defects and damage

The diameter increment effect is related to the method that rectangular cross-sectional areas of lumber are fit into the somewhat circular cross-sectional area of a log. The fit is dependent on fixed dimensional increments for lumber thickness and width, saw kerf, sawing variation, and wane allowances. A "tight" fit with a high LRF is one in which the edges of the lumber touch the outer surface of the log with a high percentage of the log area occupied by the combined area of the individual lumber pieces. The excess fiber loss due to log diameter increments between the smallest diameter for a solution and the largest diameter for a solution can result in LRF decreases that are highly variable but in the magnitude of 10%.

The taper effect on LRF is related to unutilized log volume that results from the conical shape of a log caused by varying diameters from one end to the other. Manufacturing processes such as split-taper and full-taper sawing, and slewing and skewing infeeds, have been developed to reduce the negative effects of taper; but all negative taper effects cannot be alleviated in the manufacturing process. Taper effects are also highly variable in the degree of reduction of LRF. An analysis performed with sawmill simulation software projected the lumber volume in an 8.5-inch diameter cylinder verses the lumber volume in truncated cones. Varying degrees of taper were analyzed but one end diameter was held constant at 8.5 inches. The results showed that LRF factors could decrease by a few percentage points up to 25% depending on the amount of taper in the truncated cones.

The sweep effect on recovery is the result of curvature in logs. Sweep is generally defined as the maximum distance, in inches, that the centerline of a log varies from a straight line drawn from the center of both ends of the log. Sweep can be in one direction and in one plane or it can be in multiple directions in multiple planes. A straight log has a sweep value of zero. Curve sawing technology has greatly improved the LRF values for logs with sweep. However, since curve sawing is only performed on the cant, loss in LRF from sideboard lumber is still present in logs with sweep. The sweep effect on reduced LRF is also highly variable. A simulation trial for sweep, similar to the trial for taper, using an 8.5-inch diameter cylinder showed that LRF reduction could be as high as 14% for 2 inches of single-direction sweep in a 14-foot sawlog in a mill that utilizes curve sawing technology. The loss was due to sideboards on each side being processed as 2x4s rather than 2x6s in the cylinder with sweep.

The geometrical shape of cross-sectional areas down the length of a log can also reduce LRF where irregularities create volumes that cannot be utilized for lumber. In a similar manner, timber defects and timber damage also create volumes of wood that cannot be converted into solid lumber.

Diameter increment, taper, sweep, cross-sectional area and irregularities combine to form an immense number of ways that LRF can be reduced on a log-to-log basis in a sawmill. On a stem-to-stem basis, the combinations become even greater.

In a typical southern pine sawmill, tree length stems are bucked into nominal 8- to 20-foot long sawlogs and non-sawlog fiber sections are removed and chipped. The sawlogs often are mixed together between the bucking process and the sawmill's primary breakdown process. Inside the sawmill, several different machine centers constantly mix the lumber together making it virtually impossible to trace an individual piece of lumber back to the stem where it was produced. Add to the complexity the possibility of allocating chips and sawdust back to the stem where they originated and the task becomes enormous. Trying to accurately ascribe lumber production and total product value to individual stems while a mill was operating would be an overwhelming as well as an unsafe endeavor.

Over the past two decades, the influx of computer scanning, optimization, and control technology has been tremendous in modernized sawmills. The refinement of lumber optimization computer software has led to the development of "off-line" computer simulation programs that utilize the same software and configuration parameters that are used in the mill process. This technology has allowed operators to model "what-if" scenarios inside the mill as well as providing a means for calculating the potential benefits of capital-intensive modernization projects. Since the parameters used in the software can be configured the same as what is used during actual mill production, the simulation model can predict very accurately how an individual stem will be processed inside the mill that is being simulated.

In early 2000, a portable, laser based, scanner was constructed that can be used to accurately scan tree length stems before they are processed at the sawmill. The three-dimensional, stem profile computer images that are acquired with the scanner are used in the simulation software to model how the actual stems would be processed in the sawmill. The simulation model not only calculates and records every piece of lumber produced from individual stems but it also tracks the total fiber that would be converted to chips and sawdust during the process. Several stem studies were commissioned for sawmills across the southeastern United States after the portable scanning device was constructed. Stem characteristics and mill configurations were observed to be significantly different in each of the studies. Although the main purpose for the studies was to analyze the benefits of future capital-intensive mill modernization projects, the data was also useful for examining individual stem attributes.

A comparison of large-end stem diameter verses LRF for a 520-stem sample obtained with the portable scanning device and simulated in the mill simulation software is shown in Figure 9. The sawlog data shown in Figures 7 and 8 were combined to produce the data for Figure 9. The chart shows that there is a general upward trend in LRF as stem diameter increases but the overall correlation of diameter to LRF is weak. The average large end diameter for the sample of stems was 10.96 inches and the average green LRF for the sample was 8.48 BF/CF. The average lumber value from the stems was $371 per MBF. This mix of stems would be classified as sawlogs and the delivered cost of the stems would be approximately $45–$55 per ton.

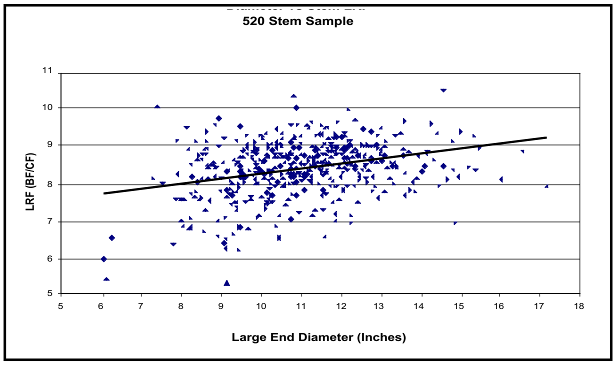


Figure 9.—Diameter vs. Stem LRF

Figure 10 shows the same 520-stem sample but the stems have been arranged according to LRF class. The chart shows the distribution of stems by diameter for each of the ten LRF classes. The box on the chart outlines all stems that had less than or equal to 11-inch large end diameter and had an LRF greater than or equal to 8.00 BF/CF. One hundred eighty-nine out of 520 stems (36%) were included in the box. The average green LRF for the stems in the box was 8.67 BF/CF and the average lumber value was $376/MBF. This mix of sawtimber would be classified as Chip-n-Saw and the average delivered cost of the stems would be approximately $30 to $35 per ton using current timber pricing guidelines. Compared to the total mix, the smaller diameter, higher recovery stems would produce 2.2% more lumber per CF of timber with a $5/MBF premium at 32% less log cost.

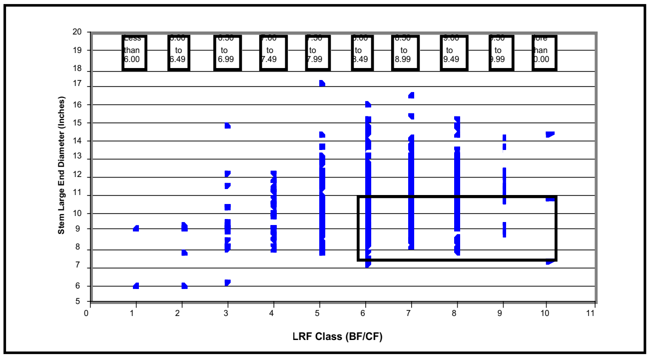


Figure 10.— LRF and Diameter distributions for 520-stems.

Preliminary Analysis of Predicting Mill Performance in Standing Timber

Using the data from the 520-stem sample above, an analysis was preformed to determine the statistical relationship between various measurable tree attributes such as diameter, length, sweep, and taper to mill performance parameters such as LRF, lumber volume, and lumber value. The data for the 520-stem sample was generated using actual scanned images of tree-length stems in a mill simulation software package. When configured to simulate a mill operation, the simulation software can be tweaked to produce results that are within +/-1% of the actual mill process.

The 520-stem sample was randomly split in half to provide two, 260-stem samples. One set of data was used for statistical analysis to generate prediction equations for LRF. The other set of data was used to assess the accuracy of the prediction equations. SAS® software was used to analyze the data.

The first prediction equation was based on a linear regression model using large diameter, small diameter, length, and sweep rate as the explanatory variables to predict LRF. The resultant prediction equation from the first half of the data was as follows:

$$LRF = 0.151d+0.051D+0.032L - 4.784S + 6.190$$

d = stem small end diameter (inches)
D = stem large end diameter (inches)
L = stem length (feet)
S = sweep rate (inches per foot)

When the above equation was applied to all 260 stems in the second half of the data, the average green LRF predicted for the 260-stem sample was 8.371BF/CF verses the actual LRF for the sample of 8.419BF/CF. The predicted LRF value was 0.58% less than the actual value. To analyze the effects of sample size on the prediction equation, a series of sub-sampling was performed on sample sizes of 50, 20, 10, and 5 stems. As part of the sub-sampling test, random numbers were used to select samples from the 260-stem data set. Five trials were performed for each sample size and the average LRF from the five trials was compared to the actual LRF of the complete data set. Table 1 shows the results of the data analysis. The results of the accuracy analysis suggest that the prediction equation would provide an acceptable means to predict mill LRF with relatively small sample sizes. One drawback to this equation might be that accurate field measurements for the required explanatory variables would be difficult to obtain without felling the tree. Additional work may be required to generate an error coefficient to correlate hand-measured data to scanned data.

An additional regression analysis was performed in a similar manner but the only explanatory variable used was large end diameter. The resulting prediction equation was as follows:

$$LRF= 0.142D + 6.813$$

The LRF prediction based on large end diameter only was 8.370BF/CF verses 8.419BF/CF for the sample data set. Unexpectedly, the prediction was only 0.59% lower than the actual value. A possible explanation for this result is that the degree of accuracy of the diameter measurements and the quantity of data measured are sufficient to accurately estimate average LRF when the individual stem LRF values are averaged. Summarized results from the prediction equation accuracy analysis for predictions based on large end diameter only are shown in Table 2.

An area of concern in the preliminary data analysis was that the coefficient of determination (R-squared) values for the regression equations were low. The R-squared values for the multiple parameter equation and the diameter only equation were 0.34 and 0.11, respectively. However, when parameters such as BF per stem, CF per stem, and dollar value per stem were estimated, the R-squared values were approximately 0.90. Even though the R-squared values were low for predicting LRF, the prediction equations appeared to have high prediction precision as shown in Tables 1 and 2. Although the coefficient of determination is often thought of as a measure of "usefulness" or "goodness of fit" for a regression equation, it actually only partially measures the usefulness and goodness of fit of a regression equation (Barrett 1974). When the slope of a regression line is shallow, it can have a low coefficient of determination but maintain a high degree of predictive precision (Barrett 1974). Further examination of the prediction equations above show that the arctangent of the regression coefficients equate to slopes in the 2–12° range. These shallow slopes for the regression lines could explain the low R-squared values yet high predictive precision. Conversely, the slopes of the prediction coefficients for the equations for BF per stem and CF per stem were of the order of 80°.

Table 1.—Prediction equation accuracy analysis for various sample sizes.(Prediction equation based on small diameter, large diameter, length, and sweep rate.)

Sample Size	Actual LRF	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Predicted LRF	Predicted Accuracy	Margin of Error +/-
260	8.419	8.371	8.371	8.371	8.371	8.371	8.371	-0.58%	0.00%
50	8.419	8.519	.274	8.484	8.426	8.314	8.403	-0.19%	1.55%
20	8.419	8.475	8.303	8.560	8.344	8.623	8.461	0.49%	1.98%
10	8.419	8.294	8.366	8.393	8.571	8.461	8.417	-0.03%	1.53%
5	8.419	8.395	8.404	8.121	8.790	8.416	8.425	0.07%	3.48%

Table 2.—Prediction equation accuracy analysis for various sample sizes.(Prediction equation based on large diameter only.)

Sample Size	Actual LRF	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Predicted LRF	Predicted Accuracy	Margin of Error +/-
260	8.419	8.370	8.370	8.370	8.370	8.370	8.370	-0.59%	0.00%
50	8.419	8.341	8.413	8.306	8.381	8.370	8.362	-0.68%	0.60%
20	8.419	8.340	8.307	8.338	8.372	8.397	8.351-	0.82%	0.51%
10	8.419	8.337	8.344	8.410	8.299	8.275	8.333	-1.02%	0.76%
5	8.419	8.466	8.241	8.343	8.341	8.268	8.332	-1.04%	1.29%

Figure 11 illustrates the effects of data rotation to increase the angle of the data while maintaining a constant mean squared error (MSE). The coefficient of determination for the 520-stem data set increased to 0.99 as the data was rotated. This would explain the high predictive precision of the regression equation.

The impact of low R-squared values will need to be thoroughly reviewed in future analysis for LRF predictions. If low R-squared values prove to be limiting factors for prediction accuracy then model design might need to be based on parameters such as total BF per stand or total finished product value per stand rather than LRF.

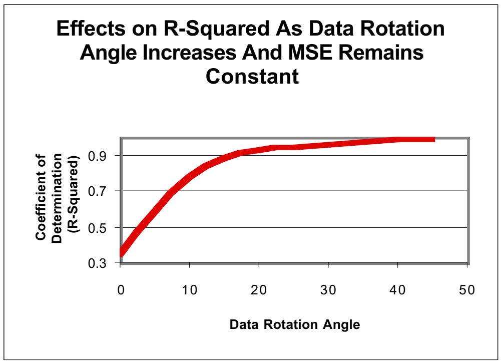


Figure 11.—Data Rotation Effects on R^2

Future Analysis and Implementation

Basis for future analysis

Substantial improvements in management flexibility and economic benefits are potentially available by more accurately predicting mill performance for standing timber and utilizing the timber to its fullest value. These benefits merit future efforts for implementing further testing and eventually establishing a market driven, congruously integrated forest management plan.

A congruously integrated forest management plan would optimize timber supply and balance mill production with market demand in a manner that maximized the economic and social utility of the integrated owner. Because of unique timber production, mechanical processes, and markets associated with each mill, specific management plans would need to be tailored to individual forests and mills. However, the individual plans could be focused to serve common markets and optimize resources for a multiple-facility corporation. The major process components and the major decision points of a single facility management plan are illustrated in Figure 3. A multiple-facility, congruously integrated forest management plan would consist of several individual plans with unique forests and mills connected to a common market. The size of the market would increase as additional programs were added; and market diversity would increase as a result of more products and suppliers. Figure 13 is a simple model that represents how multiple, congruously integrated management plans might be visualized.

The model, as illustrated in Figure 3, has been condensed for clarity in Figure 12 to show how multiple forests and mill processes would focus on a common market.

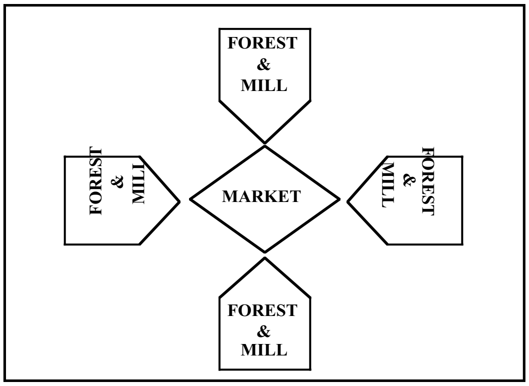


Figure 12.—Multiple forests and mills visualization model.

Subject of Study

The ideal forest and mill combination for future study would include an integrated system with a relatively large supply of company-owned (fee) timber sourcing a modernized sawmill. A key component of the sawmill process would be a tree-length scanning system in the log processing area. The initial analysis and implementation would be made on a single-facility plan but would be structured so that the process of developing a plan could be replicated at additional facilities.

Key Participants

The future analysis and testing would require cooperation between forest, mill, and marketing managers in an integrated forest products company. In addition to management cooperation, key participants from each area would be needed to perform legwork and to develop the mechanics of the plan. Technical support and cooperation from computer information systems personnel would be needed to fully implement the management plan.

Methods

The study team would develop a clear and concise set of guidelines before any fieldwork was done. These guidelines would detail the specific goals of the study as well as a process for achieving the goals.

The main objectives for the study would include:

1. Calibrating a model for the mill process based on a sample of timber
2. Correlating field gathered data with the electrically/mechanically acquired data at the sawmill
3. Testing the model on an additional sample of timber
4. Expanding the model to meet specific forest, mill, and marketing objectives
5. Limited implementation of the plan with monitoring, feedback and refinement
6. Recommendations, cost, and benefits for full implementation

More specifically, the study would include sampling, felling, hand measuring, processing, and tracking test samples of stems through the harvesting and milling processes. Data would be collected throughout the study and rigorous modeling and statistical analysis would be performed with the data.

Conclusions regarding manufacturing performance

Modeling and statistical analysis of data generated from modern scanning and optimization sawmill technology can be useful for predicting the mill performance of standing timber based on measurable attributes of the timber.

Application of this tool could aide in developing a more congruous management process for integrated forest products companies. A better understanding of the relationship of the actual geometric profiles of stems that perform best in a particular mill, to the management practices and growth characteristics of trees growing in the mill's timber basket, has potential to greatly increase the mill's performance, generate higher quality lumber and promote a more sustainable and efficient use of the natural resource. More specifically, accurately predicting the mill performance of a stand of timber before harvest can afford managers the following opportunities:

1. More accurate timber valuation.
2. Accurate assessments of timber value to a specific mill for non-fee wood timber purchases.
3. A unique ability to channel stands of timber through the manufacturing process to meet specific market demands that better utilize certain stands.
4. Market driven information for stand management from regeneration to harvest with more market predictability at harvest.
5. Ability to reduce timber and lumber inventory by streamlining timber through the process.
6. Serve as a basis for managing stands for optimum stand volume, mill value and improved lumber quality rather than for large diameter targets.

TOTAL PROFITABILITY

As described above, several opportunities exist for economic benefits to the integrated forest products company by being able to accurately predict mill performance in standing timber. The following analysis is an elaboration of item 6 above. It examines the economic benefits of managing loblolly pine (*Pinus taeda* L.) at higher densities, for smaller diameters and increased sawtimber volume, in an intensively managed plantation system. The ability to monitor stands so that they could be harvested at their optimum value and performance levels would be crucial to such a management plan. The analysis only examines the benefits of higher timber volumes and improved mill performance. The analysis does not ascribe additional value to the management plan for increased lumber grade, which in itself, might be enough reason to manage contrary to the large log paradigm. The analysis also does not attempt to include any external benefits such as those associated with chain-of-custody issues or for the reduction in timberland required to source a mill. However, from the analysis, it appears that a congruously integrated management plan targeted at smaller diameters could require approximately 39% less land base to furnish a 120MBF/year sawmill currently using intensive plantations managed according to the large log paradigm. The analysis also does not consider any benefits of increased pulp mill yield due to less juvenile wood or better fiber strength from pulpwood produced from a higher tree density management regime. The analysis also does not address any increases in high-grade veneer production if the timberland were to be used for both sawtimber and veneer logs.

Before delving into the economic analysis case study, an elaboration on lumber quality benefits for managing at higher tree densities in southern yellow pine is included.

Benefits of Higher Tree Densities

Advantages of maintaining higher tree densities by planting at closer spacing and by thinning less to achieve higher quality lumber from the sawtimber include:

Benefits of closer initial spacing:

1. Less juvenile wood forms in the stem.
2. More growing space is utilized.
3. Natural pruning occurs at a higher rate since the lower branches are shaded more.
4. Higher form factors can be achieved by reduced taper in the lower bole after thinning.
5. Lumber grade and strength are higher due to less juvenile wood.

Benefits of less thinning:

1. Promotes smaller individual tree crowns reducing branch size and number of branches.
2. Smaller gaps are created in the growing space that allows the site to maintain higher productivity.
3. The net volume of sawtimber produced from the stand over a given time period can be increased.
4. Lumber grade and strength are higher due to fewer and smaller knots.

Reduction in juvenile wood and increased form factor in individual trees

Juvenile wood is a cylinder of wood surrounding the pith where xylem cells are formed by immature cambium. The prolonged influence of the apical meristem in the active crown is thought to be responsible for juvenile wood formation since, regardless of tree age, juvenile wood is formed in that portion of the stem that contains young live crown (Clark 1994). In general, juvenile wood, core wood, or crown wood as referred to by some, implies the initial vertical growth in a tree in each year of the tree's life along with the subsequent years of radial growth as the live crown moves upward until the base of the crown passes the point where the vertical growth originated. Core wood is typically referred to as the first 10 years of growth in SYP but it could be more or less, depending on the rate of rise of the crown. From a lumber quality standpoint, lumber produced from crown wood, which includes the core of the lower bole, typically has more knots, fewer grains per inch and a higher ratio of springwood to summerwood than lumber produced from the outer layers of the lower bole. The larger ring thickness in crown wood is attributed to the higher radial growth rate in the crown, and particularly at the base of the crown, where the most productive branches are located. Figure 13 illustrates the diameter growth pattern down the length of a tree grown at close spacing verses a tree grown at wider spacing.

The sum of all the annual sheaths of wood determines the form of the stem of the tree. Open-grown trees have ring widths increasing from top to bottom, so when they are added together the stem tapers all the way from top to bottom. Forest-grown trees, where ring width decreases below the crown, have stems that taper within the crown, but they may be almost cylindrical below the crown (Wilson 1984). A general spacing effect is that form factors increase and taper rates decrease in denser crops (Savall and Evans 1986).

A significant issue in plantation management of coniferous species is the proportion of juvenile wood. The increase in the amount of juvenile wood formed in plantations is largely due to the wider spacing associated with plantation management compared to the close spacing of naturally regenerated stands. The length of time between plantation establishment and canopy closure will have a large impact on the proportion of juvenile wood formed in the stand (Dean 1996). The faster growth of individual trees at wider spacing, especially among many plantation conifers, causes an increase in the size of the core of juvenile wood (Savall and Evans 1986).

In 1994, a study was conducted to determine the effects of initial spacing and thinning on lumber grade, yield, and strength of loblolly pine (*Pinus taeda* L.). In the study, plots were planted at spacings of 6 by 6, 8 by 8, 10 by 10, and 12 by 12-feet and were thinned to residual basal areas of 60, 80, 100, and 120 ft^2/acre at age 18 and at 5-year intervals through age 38. Trees thinned from the plots at age 38 were processed into lumber. The lumber was visually graded and machine rated. Plots planted at spacings of 6 by 6-feet and thinned to 100 ft^2/acre produced 60% grade #2 and better lumber while plots planted at 12 by 12-feet spacing and thinned to the same basal area yielded only 42% grade #2 and better. Plots planted at 6 by 6-feet and 8 by 8-feet yielded the highest proportion of lumber classified as 1650 Fb to 2100 Fb while plots planted at 12 by 12-feet yielded the lowest proportion of lumber in the 1650 Fb to 2100 Fb

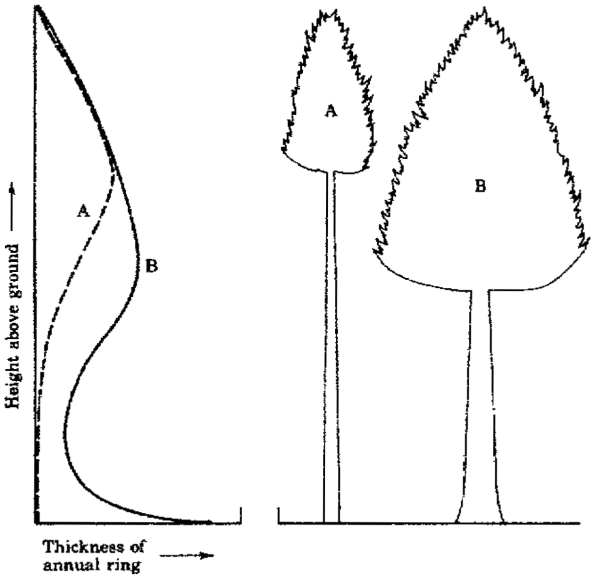


Figure 13.—Tree ring width for trees grown at closer spacing (**A**) and trees grown at wider spacing (**B**). (From Smith 1997)

strength classification. The lumber value per MBF was about 10% higher for the 6 by 6-feet plots thinned to 100 ft^2/acre than for the 12 by 12-feet plots thinned to the same residual basal area. On a per-acre basis, plots thinned to leave the highest residual basal area produced the highest volume and value per acre. The study also showed that at dbh values less than approximately 12 inches, the percent grade of #2 lumber was higher than the percent grade of #3 and #4 but for dbh values greater than 12 inches, the percent grade of #3 and #4 was higher than the percent grade of #2 (Clark 1994).

In 1997, a similar study was conducted to determine the effects of initial spacing on mechanical properties of lumber sawn from unthinned slash pine (*Pinus elliottii* Engelm. var *elliottii*). The study examined the lumber produced from replicated stands representing tree spacing of 6 by 8, 8 by 8, 10 by 10, and 15 by 15-feet (McAlister 1997). The study reported that wider spacings produced larger juvenile cores. In an earlier study in 1989, Clark and Saucier reported that the slash pine from the same test plots produced juvenile wood for the first 10 rings at all planting densities. Analysis of collected increment cores showed that the diameter of the juvenile core was proportional to the initial tree spacing and averaged 4 inches for the trees spaced 6 by 8-feet; 4.6 inches for the trees spaced 8 by 8-feet; 5.5 inches for the trees spaced 10 by 10-feet; and 6.3 inches for the trees spaced 15 by 15-feet (McAlister 1997). Although all of the lumber tested exceeded Southern Pine Inspection Bureau (SPIB) #2 grade rules, both the average modulus of elasticity (MOE) and the average modulus of rigidity (MOR) in the tested lumber generally decreased when tree spacing increased from 6 by 8-feet (908 trees per acre) to 15 by 15-feet (194 trees per acre).

Another study done in east Texas in 1990 looked at lumber characteristics of 20-year old slash planted at 12 by 12-feet spacing and thinned to 250 trees per acre. The study found that nearly 55% of the stem volume was made up of core wood verses 16% for a similar size dbh sample of 50-year old trees initially planted at 6 by 6-feet spacing and thinned to 245 trees per acre. All of the lumber from the more closely spaced trees passed both Fb and MOE requirements for all grades produced. The lumber sawn from the 20-year old trees had much lower pass rates especially for MOE as only 8% of grade #2 and 9% of grade #3 2x4 lumber was acceptable and only 19% of grade #2 and #3 2x6 lumber was acceptable (MacPeak 1990).

Fewer and smaller knots

SYP lumber grading rules go into great detail describing the form, size, quantity, and occurrence of knots for various lumber grades (SPIB 1991). In general, the grading rules require more sound, smaller, fewer, and wider spaced knots as lumber grade increases. Knots, the most common defect of wood grown in managed forests, are simply the result of a sawn surface produced on the lumber in a location that a branch at one time occupied. Knots produced while branches are still alive are known as live or intergrown knots, and knots that are formed after branches die are called dead, or encased knots (Smith 1997). The number and size of branches on sawtimber stems directly affects the grade of lumber that can be produced from the stems. In a spacing and thinning study for 38-year old loblolly pine it was reported that heavier thinning significantly increased both foliage and branch biomass of individual trees as well as the number of branches per tree, mean and maximum branch diameter and mean and maximum branch length. Crown length was significantly longer as thinning increased and there were consistently larger ratios of crown biomass to total above ground tree biomass as thinning intensity increased (Baldwin 2000). Spacing generally had less impact on branch and crown size than thinning had in the study.

An added benefit of higher stand density is the natural pruning effect that proceeds from the ground upward and starts with the killing of branches by the shade of those above (Smith 1997).

Potential for increased sawtimber volume

An old adage of density management is “room to grow no room to spare.” While a valid concept, it provides no basis for implementation nor any indication of achievement. Although foresters often speak of maximizing productivity, the relation between growing stock and growth is one of the most poorly understood concepts across the natural resource profession (Dean 1996). Simply stated, the relation between growth and growing stock is this: for a given combination of species, age, and site, as a greater percentage of the growing space is utilized, total net primary productivity and gross-volume increment increase and average tree growth decreases (Dean 1996). This concept can lead to complicated evaluations in management plans that must consider planting cost, thinning cost, market demands, rotation cycles, mortality rates, and growth rates to mention a few. Many of these factors must be estimated at the time of stand establishment even though they might not come into play for several years into the business cycle of the management plan. An idealized scenario in which tree density would be high to allow early canopy closure and high leaf-area-index, and competition was such that no restriction in height growth would occur across the stand, would more fully utilize the site and produce the most volume from the stand; but it might have very few trees that would be of sawtimber quality by even the least restrictive of definitions. At the other end of the spectrum, in an idealized scenario where trees were open grown or spaced in a manner to allow maximum size crowns on individual trees, the average tree diameters would be much larger; but the overall production of the stand would be less due to insufficient utilization of the site.

In a study of the growth expectations from alternative thinning regimes and prescribed burning in naturally regenerated loblolly-shortleaf pine stands through age 20 (Cain 1996), it was reported that the total volume production at age 20 was greatest on the unthinned control plots but more sawtimber volume (dbh > 24cm) was obtained from plots where the heaviest pre-commercial and commercial thinning occurred.

In a report on pre-commercial thinning in longleaf pine (Kush 1998) it was reported that thinning treatments in longleaf pine had the following effects by age 34: number of trees, stand density, and [stand] volume generally declined and tree dbh generally increased as prescribed stand density declined.

In the aforementioned study on the effects of spacing and thinning on stand and tree characteristics of 38-year-old loblolly pine (Baldwin, 2000), slight thinning increased total bole volume and total bole biomass per unit area over the bole volume and biomass from unthinned stands. However, as would be expected, as thinning intensity increased from less thinning (120 ft^2/acre residual basal area) to heavier thinning (60 ft^2/acre residual basal area), the total bole volume and biomass per unit area decreased. These results were observed from all five initial spacing designs that were studied. As expected from the study, both initial planting density and thinning intensity affected the quadratic mean diameter. The widest spacing and the heaviest thinning combination produced the largest diameter trees.

By planting at higher densities to reduce juvenile wood and by thinning just enough to produce acceptable tree diameters while maintaining fewer and smaller branches, a management plan could conceivably be structured to forgo larger tree diameters for more total volume and better quality lumber from a sawtimber stand. Using modeling and sampling techniques to monitor the mill performance of the stand would allow managers more flexibility to strategically harvest the stand to meet production and marketing objectives. The net results could be increased lumber volume from the stand with a higher unit value in the market.

Case Study

The following case study compares two management regimes for loblolly pine on industrial timberland in east Texas. The two regimes are as follows:

CASE 1: Model growth and yield, evaluate mill performance and perform financial analysis for timber managed for "sawlog" size (11 inches and larger) target diameters at breast height. This type management regime would be employed to produce larger diameters in a short rotation cycle and would conform to the large log paradigm. However, some sawlog management regimes are much more aggressive than this scenario in trying to achieve larger diameters earlier. A more aggressive management plan would involve wider initial spacing and heavier thinning.

CASE 2: Model growth and yield, evaluate mill performance and perform financial analysis for a forest management regime to optimize financial returns to the integrated timberland owner based on "Chip-n-Saw (CNS)" size target diameters at breast height. The goal of this management plan would be to maximize sawtimber volume in the CNS size class while improving fiber quality. Since the range of diameter distributions from this management regime would be much narrower than the diameter distribution from a sawlog management regime, there would be less variation within the stand.

The growth and yield modeling for both cases was accomplished using the Cutover Loblolly Plantation Model (c-loblolly) developed by Thomas G. Matney at Mississippi State University.

Site conditions used in the model and the analysis were as follows:

* Site index (Base 25) - 64 feet. Site preparation, competition control, and fertilization treatment were estimated to increase site index to 72 feet for the analysis
* Soil and subsoil texture - fine sandy loam
* Drainage - somewhat poorly drained (dom. Gray 20–30 inches)
* Beginning site conditions were assumed to be just after harvest

Stand regeneration and improvement costs were estimated as follows:

* Shear and subsoil (one pass) - $135/Acre
* Planted seedlings - $0.635/tree
* Herbicide competition control at establishment - $65/Acre
* Mid-rotation herbicide competition control - $85/Acre
* Fertilization (Dap & Urea) - $80/Acre per application

Additional management parameters and values used in the economic analysis were as follows.

* Sawlog - 11 inches and up large diameter to 6 inches small diameter - $42.58/ton stumpage
* CNS Log - 7.5 inches to 11 inches large diameter to 5 inches small diameter - $18.26/ton stumpage
* Pulpwood - 3 inches minimum diameter - $4.89/ton stumpage
* A $75 per acre management cost was added to the CNS management regime in year 27 to account for the cost of additional sampling and monitoring in the final years before harvest
* Minimum acceptable rate of return (MARR) - 4% real
* Annual tax expenses were estimated at $3 per acre an no annual income such as that from hunting leases was included

All stumpage prices used in the analysis were statewide weighted average values for November and December 2000 obtained from the Texas Forest Service's Timber Price Trends in Texas publication Volume 18, No.6. This particular reporting period indicated lower timber prices for sawlogs, CNS logs, and pulpwood than for previous years.

The CASE 1 sawlog management regime was outlined as follows:

* Manage for 23 - 30 year rotation with high volume of sawlog stems (11 inches and up) at final harvest
* Shear and subsoil, plant 756 TPA, competition control at establishment, apply two mid-rotation fertilization treatments (one after each thinning), employ one mid-rotation competition control
* First thin between 11 and 15 years, target 20% row removal and 75 SF residual basal area
* Second thin between 17 and 21 years, target 75 SF residual basal area

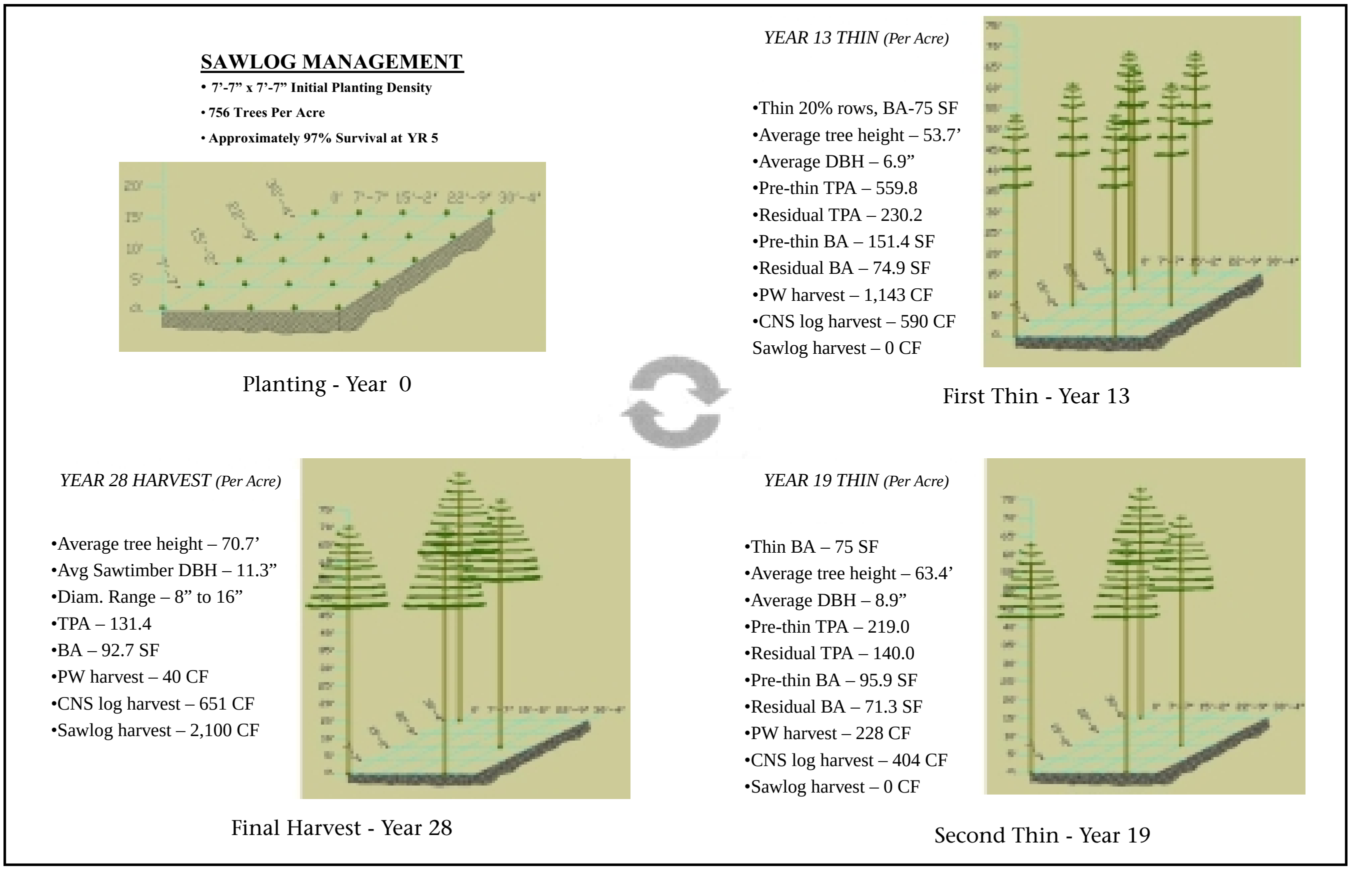
The CASE 2 CNS management regime was outlined as follows:

* Manage for 23 - 30 year rotation with high volume of CNS stems (7.5–11 inches) at final harvest. Manage to reduce juvenile wood and knots to improve lumber quality
* Maximize stand volume and value in the high-yield plantation and the mill process.
* Shear and subsoil, plant 1210 TPA, competition

control at establishment, apply one mid-rotation fertilization treatment after thinning, employ one mid-rotation competition control, row thin 50% of rows at 12 to 17 years.

Using c-loblolly, the growth and yield of the two management regimes were modeled. Figures 14 and 16 below depict management cycles for the two regimes while Figures 15 and 17 show growth and yield for the two cases. Net present value (NPV) calculations were performed to determine the optimal harvest age for the two regimes. The maximum NPV for the sawlog regime was at year 28 and the maximum NPV for the CNS regime was at year 30.

Based on the results of the growth and yield models, an economic evaluation was performed for each of the management regimes. Figure 18 shows the forest economic benefits of the sawlog management regime as depicted in Figures 14 and 15. Figure 19 shows the economic benefits of the CNS management regime as depicted in Figures 16 and 17. Because the stumpage price for sawlog class sawtimber was over $24 per ton more than CNS class sawtimber, it was no surprise that the $875/acre NPV for the sawlog management regime was nearly 21% higher than the $726/acre NPV for CNS management even though the CNS regime produced 38% more sawtimber (CNS logs and sawlogs) than the sawlog regime. Figures 18 and 19 recap the net effects of the two management regimes on the economics of the forest management cases.



SAWLOG MANAGEMENT

- 7'-7" x 7'-7" Initial Planting Density
- 756 Trees Per Acre
- Approximately 97% Survival at YR 5

Planting - Year 0

YEAR 13 THIN (Per Acre)

- Thin 20% rows, BA-75 SF
- Average tree height – 53.7'
- Average DBH – 6.9"
- Pre-thin TPA – 559.8
- Residual TPA – 230.2
- Pre-thin BA – 151.4 SF
- Residual BA – 74.9 SF
- PW harvest – 1,143 CF
- CNS log harvest – 590 CF
- Sawlog harvest – 0 CF

First Thin - Year 13

YEAR 28 HARVEST (Per Acre)

- Average tree height – 70.7'
- Avg Sawtimber DBH – 11.3"
- Diam. Range – 8" to 16"
- TPA – 131.4
- BA – 92.7 SF
- PW harvest – 40 CF
- CNS log harvest – 651 CF
- Sawlog harvest – 2,100 CF

Final Harvest - Year 28

YEAR 19 THIN (Per Acre)

- Thin BA – 75 SF
- Average tree height – 63.4'
- Average DBH – 8.9"
- Pre-thin TPA – 219.0
- Residual TPA – 140.0
- Pre-thin BA – 95.9 SF
- Residual BA – 71.3 SF
- PW harvest – 228 CF
- CNS log harvest – 404 CF
- Sawlog harvest – 0 CF

Second Thin - Year 19

Figure 14.—CASE 1: Sawlog manaagement forest cycle.

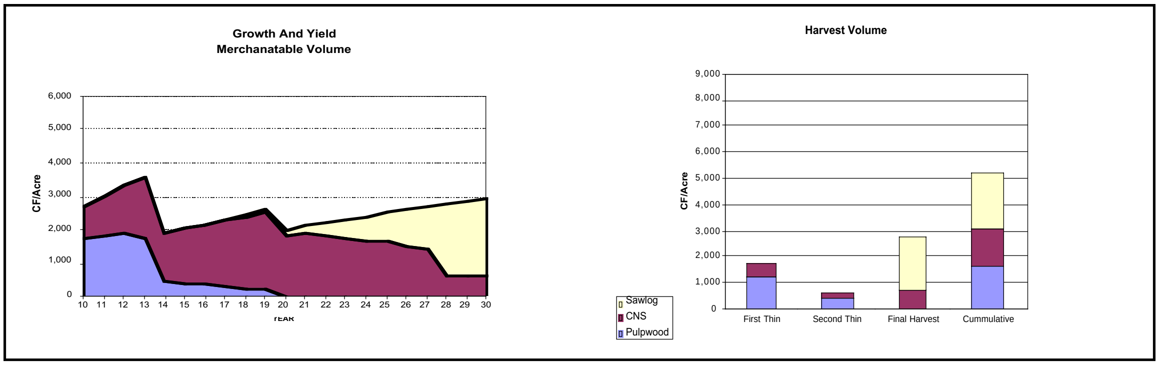
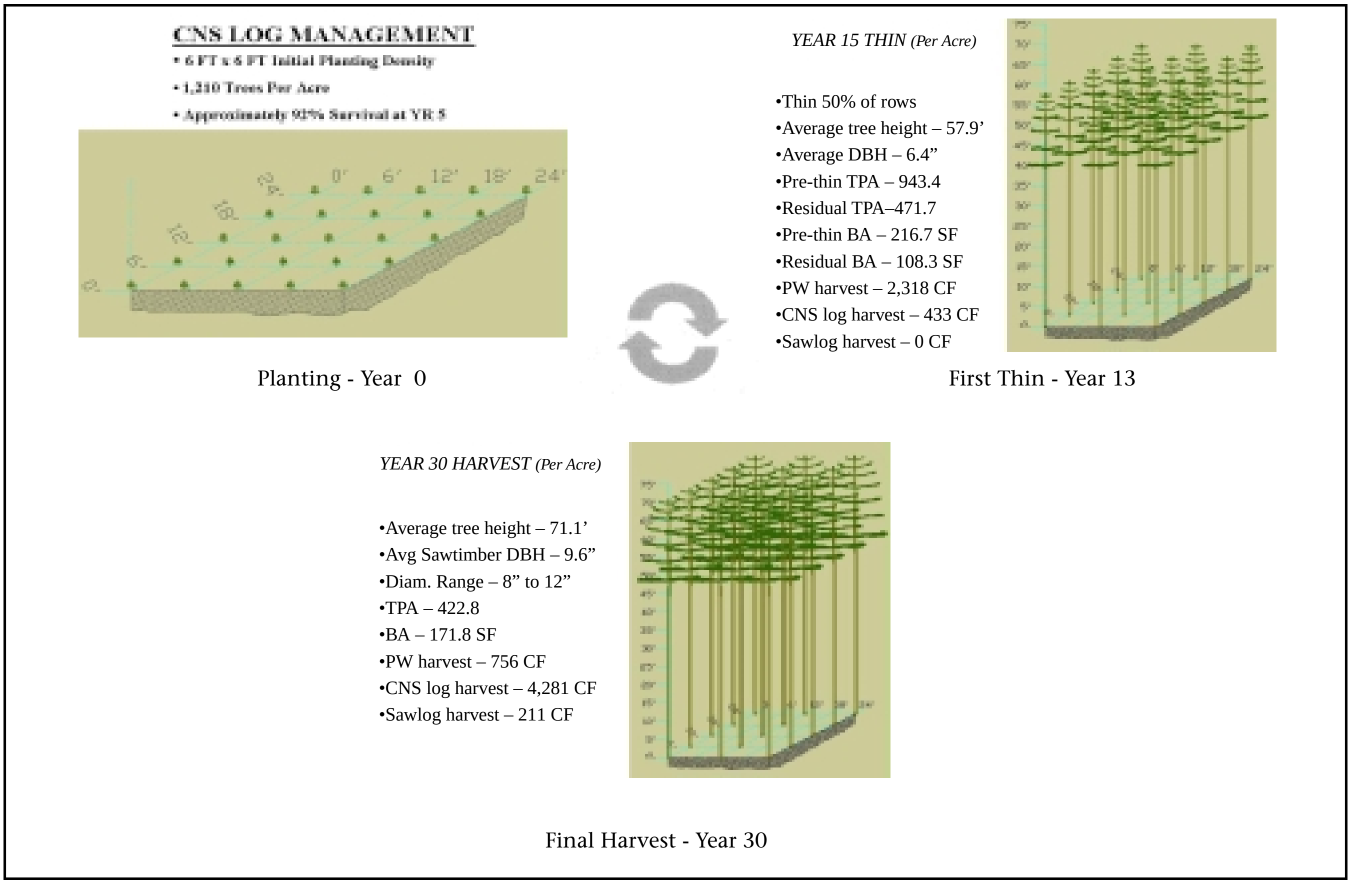


Figure 15.—CASE 1: Sawlog management growth and yield.



CNS LOG MANAGEMENT

- 6 FT x 6 FT Initial Planting Density
- 1,210 Trees Per Acre
- Approximately 92% Survival at YR 5

Planting - Year 0

YEAR 15 THIN (Per Acre)

- •Thin 50% of rows
- •Average tree height – 57.9’
- •Average DBH – 6.4”
- •Pre-thin TPA – 943.4
- •Residual TPA–471.7
- •Pre-thin BA – 216.7 SF
- •Residual BA – 108.3 SF
- •PW harvest – 2,318 CF
- •CNS log harvest – 433 CF
- •Sawlog harvest – 0 CF

First Thin - Year 13

YEAR 30 HARVEST (Per Acre)

- •Average tree height – 71.1’
- •Avg Sawtimber DBH – 9.6”
- •Diam. Range – 8” to 12”
- •TPA – 422.8
- •BA – 171.8 SF
- •PW harvest – 756 CF
- •CNS log harvest – 4,281 CF
- •Sawlog harvest – 211 CF

Final Harvest - Year 30

Figure 16.—CASE 2: CNS management forest cycle.

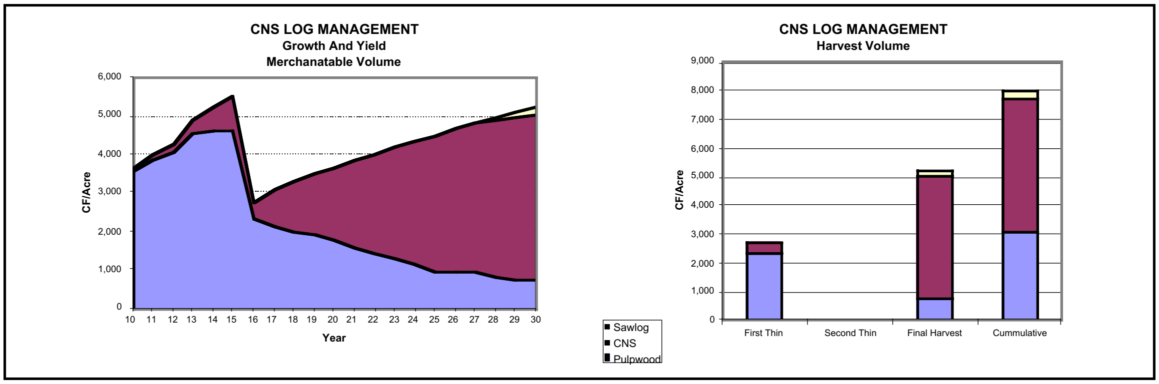


Figure 17.—CASE 2: CNS management growth and yield

Annual Income: $0.00 Per Acre
Annual Expense: $3.00 Per Acre
MARR: 4.00% real
Inflation: 3.00% per year
Interest: 7.12% nominal
Rotation: 28 Years
Ht: 3,045 $/Acre
Lt: 300 $/Acre
PW Stumpage: 0.147 $/CF
CNS Stumpage: 0.548 $/CF
Sawlog Stumpage: 1.277$/CF
NPV (WPL1): 875 $/Acre
IRR: 10.1%

Management Actions		$/Acre	
Description	Year	Value	NPV
1) Site Prep	0	(135.00)	(135.00)
2) Plant	0	(48.00)	(48.00)
3) Comp. Control	0	(65.00)	(65.00)
4) Fertilize	13	(80.00)	(48.05)
5) First Thin	13	254.44	152.81
6) Fertilize	19	(80.00)	(37.97)
7) Comp. Control	19	(65.00)	(30.85)
8) Second Thin	19	255.34	121.19

Costs: (365)
Benefits: 1,149
B/C Ratio: 3.1

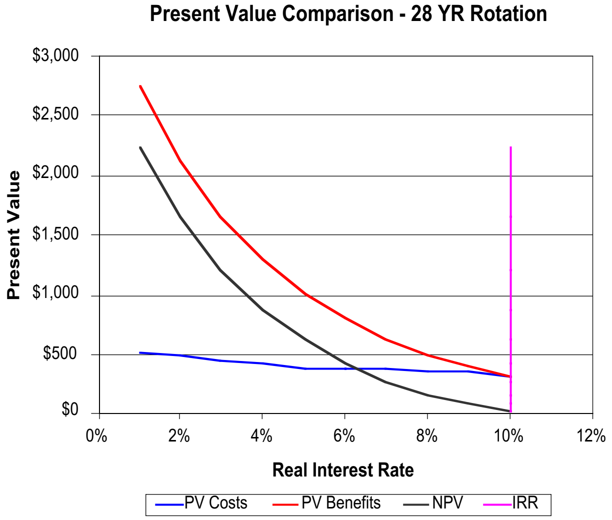


Figure 18.—CASE 1: Sawlog management regime forest economics summary. (All values are in year zero dollars)

Annual Income:	$0.00 Per Acre
Annual Expense:	$3.00 Per Acre
MARR:	4.00% real
Inflation:	3.00% per year
Interest:	7.12% nominal
Rotation:	30 Years
Ht:	2,725 $/Acre
Lt:	300 $/Acre
PW Stumpage:	0.146 $/CF
CNS Stumpage:	0.547 $/CF
Sawlog Stumpage:	1.277 $/CF
NPV (WPL1):	726 $/Acre
IRR:	9.2%

Management Actions		$/Acre	
Description	Year	Value	NPV
1) Site Prep	0	(135.00)	(135.00)
2) Plant	0	(76.83)	(76.83)
3) Comp. Control	0	(65.00)	(65.00)
4) Thin	15	577.50	320.67
5) Fertilize	15	(80.00)	(44.42)
6) Comp. Control	15	(65.00)	(36.09)
7) Sampling	27	(65.00)	(26.01)

Costs:	(383)
Benefits:	1,046
B/C Ratio:	2.7

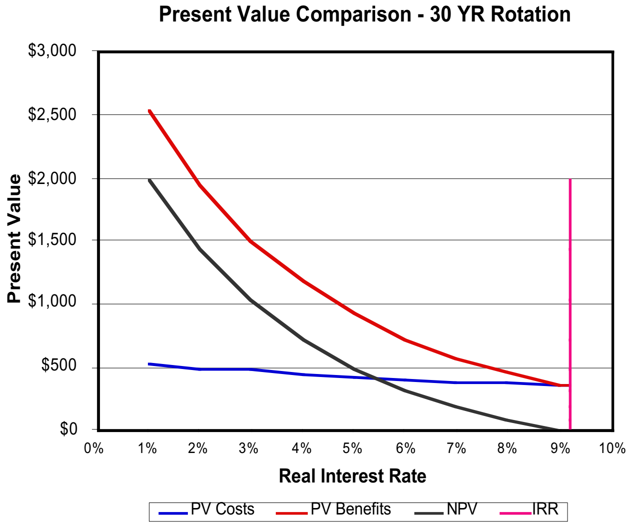


Figure 19.—CASE 2: CNS management regime forest economics summary. (All values in year zero dollars)

Because fee timber is bought and sold in a competitive market, there usually exist an internal change of ownership between forest and mill operations within integrated forest products companies as was shown in Figure 3. Based on the economic data from the two forest management regimes presented, one might conclude that the sawlog management regime would be the most profitable for a forestry division as well as an entire company. However, since the CNS management regime would produce superior sawtim ime, there would be a discrepancy in the timber pricing. If a congruously integrated management plan were implemented, important decisions would have to be made regarding the market value of premium CNS logs and whether to account for increased company profits in the forestry division, the operations division, or a combination of the two. For purposes of this analysis the following sawmill economic comparisons will be based on the assumption that the price for premium CNS sawtimber would remain the same as the standard price for CNS sawtimber; and any additional company profits would be accounted for at the mill operation.

Looking back at the 520-stem sample represented in Figure 10, the mill analysis assumed that the entire sample represented a mixture of stems produced from a plantation sawlog management regime. The stems included in the box in Figure 10 would represent the mixture of stems that would be produced from a plantation CNS management regime. A recap of the key numbers from the sample data is shown in Table 3.

Table 3.—Key parameters from 520-stem sample data.

Parameter	Sawlog Regime	CNS Regime
Sawtimber Diameter Range	7.5 to 17 inch	7.5s to 11.0 inch
LRF	8.48 BF/CF	8.67 BF/CF
Lumber Value	371 $/MBF	376 $/MBF
Stumpage	42.58 $/Ton	18.26 $/Ton

Five stems in the sample failed to meet the minimum 7.5-inch diameter to qualify as CNS sawtimber by the definition used in the growth and yield model. All five stems were included in the analysis for the sawlog regime and two of the five were included in the CNS regime. Also, the growth and yield model projected a small volume of timber in the CNS analysis that would be over the 11- inch minimum to be classified as a sawlog. The sawlog stumpage prices were used in the analysis for all sawlogs projected by the growth and yield model. However, since the growth and yield model projected only a small volume of over 11.0 inch diameter stems, the larger diameters were not used in the analysis when calculating the average LRF and lumber value for the CNS regime. Based on the simulation data, had the effects of the larger diameters been included, the CNS LRF would have been 8.70BF/CF and the average lumber price would have been 373$/MBF.

Financial calculations building from the forest economics calculations and carrying through the entire mill process were performed for the two management regimes. Table 4 lists the calculations for the net stumpage prices per the individual timber products.

Table 4.—Net stumage prices.

	Sawlog Regime	CNS Log Regime
Tons/Acre Pulpwood	51.65	99.92
Tons/Acre CNS	47.72	153.20
Tons/Acre Sawlog	68.26	6.85
Tons/Acre CNS & Sawlog	115.98	160.05
Total Tons/Acre	167.62	259.97
$/Ton - Pulpwood	4.89	4.89
$/Ton - CNS Stumpage	18.26	18.26
$/Ton - Sawlog Stumpage	42.58	42.58
CF/Acre - CNS & Sawlog	3,569	4,925
Avg. Sawtimber Stumpage	32.57	19.30

Table 5 lists the harvesting costs used to calculate net delivered timber prices.

Table 5.—Net delivered timber prices.

	Sawlog Regime	CNS Log Regime
CNS Logging - $/Ton	13.92	13.92
Sawlog Logging - $/Ton	11.63	11.63
CNS Logging - $/Acre	664	2,132
Sawlog Logging - $/Acre	794	80
Net Logging Cost - $/Ton	12.57	13.82
Net Logging Cost - $/Acre	1,458	2,212
Delivered CNS Log Cost	(32.18)	(32.18)
Delivered Sawlog Log Cost	(54.21)	(54.21)
Delivered Combined Cost	(45.15)	(33.12)

Table 6 shows the calculations for the sawmill operation based on the mill simulation data for the 520-stem sample weighted accordingly with the stem mix for each management regime.

Table 6.—Sawmill performance.

MILL TOTALS	Sawlog Management	CNS Log Management
Green Production - BF/YR	126,315,789	126,315,789
Shipped Lumber - BF/YR	120,000,000	120,000,000
Lumber Sales - $/YR	44,551,835	45,070,073
Bark Sales - $/YR	280,208	335,017
Sawdust Sales - $/YR	59,285	52,598
Chip Sales - $/YR	3,780,719	3,354,247
Shavings Sales - $/YR	6,359	6,359
Total Sales - $/YR	**48,678,406**	**48,818,293**
Log Usage - Ton/YR	560,416	558,361
Log Cost - $/YR	(25,300,231)	(18,492,394)
Manufacturing Cost - $/YR	(12,631,579)	(12,631,579)
Total Costs - $/YR	**(37,931,810)**	**(31,123,973)**
Before Tax Profit - $/YR	**10,746,596**	**17,694,320**
Depreciation - $/MBF	(40)	(40)
Depreciation - $/YR	(4,800,000)	(4,800,000)
Taxable Income - $/YR	5,946,596	12,894,320
Tax Rate	38%	38%
Tax	(2,259,706)	(4,899,842)
After Tax Profit - $/YR	**8,486,890**	**12,794,479**

Finally, Table 7 shows the calculations for the net economic impact to the integrated company based on NPV for both the forestry and mill operations. The mill financial analysis in Table 6 shows a substantial premium for the CNS regime. When the mill premiums were discounted and added to the forest economics values, the company-wide NPV for the CNS regime was still higher than the sawlog regime but not as dramatic. Figure 20 graphically depicts the total NPV to the integrated forest products company for the two management regimes based on the number of acres that would be used to produce fee wood for the process facility. The CNS regime would require 3,489 acres per year for the mill to operate at 100% fee wood and the sawlog regime would require 4,832 acres per year (39% more land base) for 100% resource sufficiency. Assuming that the integrated company would not have enough land base to be 100% self-sufficient for sawtimber, the NPV curves could be followed to the point on the graph that represented the available land base at which point the lines would parallel each other. The graph also assumes that any excess land under the CNS management regime would be managed for sawlogs to recognize the increased NPV for sawlogs when selling timber on the open market. A brief sensitivity analysis performed on the model indicated that an across-the-board timber price increase of 10% would change the NPV return to land values for the sawlog regime and the CNS regime to 1,511 and 1,615 $/Acre, respectively.

Table 7.—Total profitability.

	Sawlog Management	CNS Log Management
Rotation Length - YR	28	30
ARR - %	4.0%	4.0%
NPV of Forestry - $/Acre	875	726
NPV of Forestry - $/YR	4,226,858	3,506,326
NPV of Mill - $/YR	2,830,186	3,944,777
Total NPV - $/YR	7,057,044	7,451,102
NPV Return To Land - $/Acre	1,460	1,542

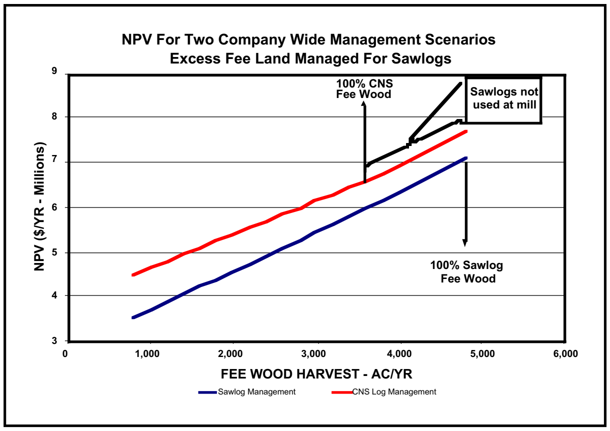


Figure 20.—Land base vs. Total NPV

CONCLUSIONS

Preliminary data analysis of a 520-stem data set indicated that modeling and statistical analysis could be used to accurately predict the mill performance of timber before the timber is processed. The analysis suggested that prediction equations could be developed to estimate LRF, lumber volume, stem volume, and product dollar value of standing timber with a relatively high degree of accuracy.

Additional testing and analysis would need to be performed with the forestry, operations, and marketing divisions of an integrated forest products company to develop a model for a specific forest and mill and to refine and implement the model. This pilot study would be used to access the benefits of the model and to estimate the cost of implementing a full-scale model.

A growth and yield and economic analysis case study examining two types of forest management regimes showed that because of price premiums for large diameters, traditional large diameter sawlog management provides higher net present value for forest management activities when timber is sold in a competitive market. However, when looking at the company-wide effects of forestry management practices, the case study showed that higher total company-wide NPV could be achieved by managing for timber that was higher quality in terms of stand volume and mill performance, yet lower in market price due to smaller average diameters. Economic benefits related to higher lumber grades were discussed but were not included in the calculations for the economic analysis.

Full development of the model could lead to new methods of managing for sawtimber that would focus more on quality and performance rather than certain diameter targets in the forests of the South. Biological, physical, and economical benefits could be realized through combining the model with a more congruous management approach. These benefits could be realized among the forestry, operations, and marketing groups of an integrated forest products company who had vision to produce more volume, higher quality forest products, and more income from their land base, in a manner that promoted sustainability and biodiversity.

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