USE OF THE DOMINANCE CONCEPT FOR MATCHING RAW MATERIAL GRADES OF DOUGLAS-FIR TO LUMBER PRODUCTION OBJECTIVES[1]

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ABSTRACT

The concept of dominance, adopted from game theory, was applied to the problem of determining the most feasible Douglas-fir log grades for producing a given lumber product mix. Three sets of multiple objectives, representing three different broad categories of mills, were analyzed to assess how changes in the primary product mix affected the log buying and trading decisions. The mill categories examined were integrated mills producing both structural and nonstructural lumber, cutting mills producing nonstructural specialty lumber, and dimension mills producing structural lumber. In general, peeler log grades were most suitable for nonstructural lumber, while sawlogs were most suitable for structural lumber. Feasible log grades for the integrated mills included both peeler logs and sawlogs, but were predominantly second growth. Repeating the analyses with 1960 data indicated little change in log grade selections over time.

Keywords: Product line planning, value added, technology assessment, multiple objectives, product policy.

INTRODUCTION

In the Pacific Northwest, competition for old growth, high quality timber has reduced its abundance and caused increases in log prices that are far greater than increases in end product prices. Given the shift from old growth timber to second growth timber in this region, the trend of rising log cost differentials between log grades is likely to continue, implying that timber management and procurement as well as timber processing and conversion will remain the major concerns of the wood products industry (Rich 1980).

A key factor of survival under such economic conditions is careful product policy formation and product line planning. In forming a product policy, a wood products firm defines the scope of its product line in a way that best relates the firm's productive capacity and capabilities to consumer demand. Product line planning facilitates the implementation of product policy and includes a careful appraisal of the firm's strengths and weaknesses with respect to raw material resources, production facilities, and competitive position. A carefully formulated product policy becomes the foundation on which business and strategic decisions are made (Rich 1970).

Careful matching of resource and product and of product and market are especially important in the face of increasing resource scarcity. As the value added in converting logs into commodity lumber declines, producers face declining

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returns unless they adopt one or more of the following alternatives for increasing the value extracted from the logs:

1. Alter the product mix to include more custom, higher-margin, noncommodity products.
2. Incorporate technologies that improve yield and productivity.
3. Adopt technologies that enable substitute products to be made from a less expensive resource.

For large firms having their own timber supply and sufficient capital, integrated utilization has been a successfully used technique for accomplishing the above alternatives. Development of an integrated forest products complex enables logs of varying grades to be sorted and routed from the forest into the conversion process that will provide the maximum value added. The result is maximum fiber utilization from each log and a diversified product line (Rich 1970, 1977b). Well-developed operations research techniques are available to such firms for assistance in the routing and sorting decisions (Smith and Harrell 1961; Jackson and Smith 1961; Dane 1967; Holmes 1976).

Such an option is not always available to the small- to medium-sized firm lacking both an extensive resource base and sufficient capital. The problems faced by these mills usually stem from a tight timber supply and fluctuating product markets. Successful mills in this category have relied on the identification of the best types of logs for their operations, the acquisition of these logs through astute bidding and trading, and the maximum utilization of the raw material (Rich 1976).

Furthermore, these mills have a clearly defined concept of the type of business in which they are engaged. Generally, they follow the strategies of either a dimension mill or a cutting mill. Although both types of mills seek to maximize recovery from the logs, they differ with respect to the raw material type utilized, the product produced, and the basis of yield recovery (Rich 1977a).

Dimension mills produce narrow dimension, commodity lumber in high volumes. Second growth timber is generally used, and emphasis is placed on volume recovery. The marketing process is often handled by regular broad-line wholesalers. Cutting mills, on the other hand, produce a multiproduct specialty line, utilize old growth timber, and concentrate on grade recovery. Log trading is a common practice in such mills as the coordination of log supply and product line is of particular importance. Additionally, cutting mills often retain greater control over the marketing process (Rich 1970, 1977a).

Both types of mills must identify, from the available resource quality spectrum, the log grades that best suit their production facilities and their product lines. For dimension mills with a fairly narrow product line, a variety of grades may be suitable. A cutting mill having a multiproduct specialty line may also find a variety of suitable grades, but a further matching of log grade to specific product may be necessary. Additionally, the grades of logs suitable for each type of mill are likely to be different. Realistically, these decisions must often be based on multiple objectives. While maximum value added is generally desired, maximum recovery of desired products and minimum recovery of undesired products may also be important considerations. This is particularly true of mills that do not have the marketing and distribution channels necessary to handle large quantities of both commodity and specialty products.

DOMINANCE

The concept of dominance is proposed as a means of targeting feasible log grades for a particular product or product class. Dominance is often applied in game theory and is simply a commonsense method of eliminating from consideration any alternatives that are not desirable under any circumstances (Morris 1977). In game theory, a strategy is said to be dominated if another strategy exists that is at least as good regardless of what alternative action the opponent takes (Hillier and Lieberman 1974).

A variation of the dominance concept was applied by de Kluyver et al. (1980) to a two-stage, multiple objective thinning and harvesting problem. Stage one involved the use of multiple objective dynamic programming (MODP) to find feasible thinning and clearcutting regimes for different types of forest stands. The number of feasible regimes was reduced by determining which of them were "efficient." A multiple objective, efficient regime was nondominated; i.e., no other regime existed that was superior on at least one objective criterion. The efficient regimes were then combined in a multiple objective linear programming (MOLP) model to generate optimal management policies for multi-stand forests. Elimination of nonefficient regimes in stage one significantly reduced the quantity of input for the MOLP model employed in the second stage.

An analogy of dominance also occurs in the field of industrial product management. A dominant product design is one that has distinct advantages over all other designs in almost every application. Once accepted, this design is incrementally improved over time to enhance its performance and reduce its cost. During the period in which the design dominates, few radical design innovations are observed (Pessemier 1982).

APPLICATION TO THE WOOD INDUSTRY

In this analysis, a feasible log grade is defined as one that is not dominated by any other log grade. In other words, there is no log grade that more closely meets at least one of the firm's objectives and is no worse for any other objective. Feasible logs, then, are the ones most desirable, given the firm's objectives, product mix, and level of technology. The ability of a log grade to remain nondominated will depend on the price performance of both the logs and the resulting products, and the ability of the firm to respond to these price changes. Like the analogy of the dominant product design, the firm may reduce costs by employing incremental technological improvements during the period of feasibility. If changing conditions make a log grade or grades no longer feasible, the firm must switch to a different grade or, if that is not possible, make major changes in its technology and/or its product policy.

METHODOLOGY

While this approach could be used to analyze any mill producing multiple lumber grades and product types from multiple raw material grades, the analysis was limited to Douglas-fir lumber mills because of the availability of sufficiently detailed, nonproprietary yield and price information. Various hypothetical log selection decisions were made, using the concept of dominance, for these mills. Decision criteria involved both the yields of various lumber grades from different log grades and the value added realized from the log conversion process. Data

TABLE 1. *Percentage yields of Douglas-fir lumber product classes, by log grades.*[1]

Log grade	Selects	Moulding	Factory Selects	Shop Lumber	Structural lumber
Old growth					
No. 1 peeler	60.7	2.6	3.0	6.8	26.9
No. 2 peeler	48.0	1.8	5.9	9.2	35.1
No. 3 peeler	37.8	5.3	2.6	6.4	47.9
Special Mill peeler	14.3	2.9	0.2	2.1	80.5
No. 2 sawlog	16.3	3.0	1.6	8.1	71.0
No. 3 sawlog	3.7	1.2	0.6	8.3	86.4
Second growth					
No. 3 peeler	65.4	—	—	—	34.6
No. 2 sawlog	2.9	—	—	—	97.1
No. 3 sawlog	1.0	—	—	—	99.0

[1] Totals may not sum to 100 because of rounding.

were derived from the results of a study by Ringe (1983) in which value added trends for different log grades and conversion technologies were simulated to evaluate the utility of value added as a technology assessment tool. This was accomplished by using log cost and product price projections, based on historical data, in conjunction with the necessary product yield information to simulate value added in future years. The lumber yield information used, both here and in Ringe (1983), was obtained from Lane et al. (1973) and Fahey and Martin (1974).

Value added, instead of profit, was chosen as a decision criterion for two reasons. First, profit is an accounting concept that can be determined and interpreted in different ways by different individuals. Second, estimation of profit requires data that are normally available only on a proprietary basis. While profit could certainly be used as a decision criterion, use of value added will serve to demonstrate the operation and utility of the analysis.

In this analysis, the basic data used from Ringe (1983) were the percent values added in cutting a specific grade of lumber from a particular log grade. If we let

LMV_j = the value of lumber of grade j cut from all logs of a given grade
LGV_j = the value of the percent of the total log scale used to manufacture the lumber of grade j

then

$$\text{percent value added} = [(LMV_j - LGV_j)/LGV_j]100 \quad (1)$$

This expresses value added as a percent of log value to facilitate comparisons.

This procedure relies on the assumption that the percent overrun (or underrun) and the rate of residue generation are the same for each grade of lumber cut. While there is some validity to this, given the direct physical relationship between log and lumber, it is suspected that overrun (underrun) and the amount of residue produced vary with both the grade and size of the lumber cut. To incorporate this level of realism into the analysis, however, would require more detailed yield studies than were available. The decision criteria employed in this analysis, then, serve to demonstrate industry trends and the application of the dominance concept

TABLE 2. *Expected percent value added in cutting Douglas-fir lumber, by log grade, in 1984.*

Log grade	Selects	Moulding	Factory Selects	Shop Lumber	Structural lumber	Total
Old growth						
No. 1 peeler	18.0	1.1	0.9	0.2	−13.3	6.9
No. 2 peeler	21.9	1.1	2.8	1.7	−14.7	12.8
No. 3 peeler	31.2	5.7	2.3	3.2	−11.4	31.0
Special Mill peeler	12.7	4.0	0.2	1.3	−1.8	16.4
No. 2 sawlog	18.9	4.7	2.2	7.0	−4.4	28.4
No. 3 sawlog	7.0	3.2	1.3	13.2	8.8	33.5
Second growth						
No. 3 peeler	50.6	—	—	—	−1.4	49.2
No. 2 sawlog	3.8	—	—	—	11.8	15.6
No. 3 sawlog	2.1	—	—	—	53.5	55.6

to log selection. Because of the underlying assumptions made in formulating these criteria, care must be exercised in drawing rigid conclusions from the results produced.

The decision criteria based on value added were actually the expected value added in cutting a product or class of products from a given log grade.

Let

YD_j = the percent yield of lumber grade j cut from a given log grade (from Ringe 1983)

VA_j = the percent value added in cutting lumber grade j from a given log grade (also from Ringe 1983)

EVA_j = the expected value added in cutting lumber grade j from a given log grade (this was employed as a decision criterion)

then

$$EVA_j = (YD_j)(VA_j) \qquad (2)$$

Expected value added for a given log grade or for a class of products cut from a given log grade was obtained by summing the pertinent EVA_j values. This is analogous to the procedure employed by Raiffa (1970) in his use of expected payoffs in decision trees. The basic yield data and expected value added data used to formulate the decision criteria can be found in Tables 1 and 2, respectively.

The lumber cut from these logs falls into two broad categories: structural and nonstructural. Structural lumber includes the Select Structural, No. 1, No. 2, No. 3, and Economy grades of Structural Light Framing Lumber, Structural Joists and Planks, Beams and Stringers, and Posts and Timbers. With the exceptions of all Economy grade lumber, No. 2 and No. 3 grade Beams and Stringers, and No. 3 grade Posts and Timbers, this lumber is assigned stress ratings (WWPA 1980). The value imputed to these grades depends on the magnitude of these ratings. The various grades of Selects, Moulding, Factory Selects, and Shop Lumber make up the nonstructural category. This lumber is used in applications where appearance is important and is graded on its appearance and lack of cosmetic defects.

To determine the nondominated logs for a given set of objectives, an i X j matrix of the following form was constructed:

$$\begin{matrix} S_{11} & S_{12} \ldots S_{1j} \\ S_{21} & S_{22} \ldots S_{2j} \\ \cdot & \cdot \ \cdot\cdot\cdot\cdot \\ \cdot & \cdot \ \cdot\cdot\cdot\cdot \\ \cdot & \cdot \ \cdot\cdot\cdot\cdot \\ S_{i1} & S_{i2} \ldots S_{ij} \end{matrix}$$

where

S_{ij} = the decision criteria value involved with using log grade i according to objective j.

If there were two log grades g and h such that S_{gj} either equaled S_{hj} or more closely met objective j than S_{hj} for all j, then log grade g was said to dominate log grade h.

Simulated value added figures for 1984 were used, in conjunction with lumber yield information, to determine the feasible log grades for three different hypothetical sets of mill owner objectives. These objective sets were assumed to be representative of three broad categories of sawmills: integrated mills, cutting mills, and dimension mills. The analysis was then repeated using simulated value added figures for 1960. In this way changes in log grade selections, necessitated by cost pressures over the past two decades, could be assessed.

RESULTS

The first situation analyzed was that of a firm having sufficient facilities and distribution channels to produce and market both structural and nonstructural lumber. The hypothetical set of simultaneous objectives (Objective Set 1) was:

1. Maximize the expected value added from nonstructural lumber.
2. Maximize the expected value added from structural lumber.

The decision criteria matrix for this set of objectives is presented in Table 3.

In this case, four of the nine log grades analyzed were feasible—old growth No. 3 sawlogs and all three grades of second growth logs. This group of feasible log grades includes the three having the highest total expected value added (see Table 2). Hence, if the firm's sole objective was to maximize total value added, three of the grades selected in the dominance test (all but second growth No. 3 peelers) would still be the three most desired grades.

When more than one nondominated log grade results from the dominance test, further manipulations are required if the determination of the optimal log grade is desired. Two possible methods outlined by de Kluyver et al. (1980) are the MINSUM and MINMAX solutions. The MINSUM selects as optimal the feasible log grade having the lowest weighted sum of percentage deviations from target objective values, while the MINMAX solution selects the log grade for which the maximum percentage deviation from any target objective is minimized. Target values are the optimum values for each individual criterion; in this case 50.6 for nonstructural lumber and 53.5 for structural lumber (Table 3). Assuming equal weights for all decision criteria, the optimal (most preferred) logs are second growth

TABLE 3. *Expected percent value added in cutting Douglas-fir nonstructural and structural lumber, by log grade, in 1984.*

Log grade	Nonstructural	Structural
Old growth		
No. 1 peeler	20.2	−13.3
No. 2 peeler	27.5	−14.7
No. 3 peeler	42.3	−11.4
Special Mill peeler	18.3	−1.8
No. 2 sawlog	32.8	−4.4
No. 3 sawlog[1]	24.8	8.8
Second growth		
No. 3 peeler[1]	50.6	−1.4
No. 2 sawlog[1]	3.8	11.8
No. 3 sawlog[1]	2.1	53.5

[1] Nondominated log grades for Objective Set 1.

No. 3 sawlogs by the MINSUM solution and old growth No. 3 sawlogs by the MINMAX solution.

In considering nonintegrated mills that concentrate on producing specialty lumber or dimension lumber, it was assumed that a major objective, in addition to maximizing yield and return of the desired product, would be minimizing the yield of undesired lumber grades. For a cutting mill producing high quality Select lumber, the following set of hypothetical objectives (Objective Set 2) was used:

1. Maximize the expected value added in producing Select grade lumber.
2. Maximize the percentage yield of Select grade lumber.
3. Minimize the percentage yield of structural lumber.

Table 4 contains the decision criteria matrix for this objective set.

The feasible log grades were old growth No. 1 peeler logs and second growth No. 3 peeler logs. Of the nine log grades, these two yield the highest percentage of Select grade lumber and the lowest percentage of structural lumber. Additionally, the second growth log grade chosen had the highest percent value added for Select grade lumber. The old growth No. 1 peeler logs, however, did not result in the second highest percent value added for this lumber grade.

Although use of the dominance concept resulted in two feasible log grades, a mill may or may not be able to obtain sufficient quantities of these through log buying and/or trading to satisfy their production needs. An iterative procedure can be employed that allows priorities, based on feasibility, to be assigned to individual log grades or groups of log grades. The two nondominated log grades in Table 4 would be the most desirable. However, if they are removed from the analysis, i.e., if their rows of decision criteria are removed from the table, the log grades that would be feasible choices if old growth No. 1 and second growth No. 3 peeler logs were not available can be identified by performing the dominance test again. Doing this reveals that old growth No. 2 and No. 3 peeler logs become the new nondominated log grades. Should additional logs be required to satisfy production needs, a further iteration indicates that old growth No. 2 sawlogs would become feasible.

The final analysis was for a dimension mill primarily concerned with the pro-

TABLE 4. *Expected percent value added in sawing Select lumber in 1984 and percent yields of Select and structural lumber for Douglas-fir.*

	Value added	Yield	
Log grade	Selects	Selects	Structural
Old growth			
No. 1 peeler[1]	18.0	60.7	26.9
No. 2 peeler	21.9	48.0	35.1
No. 3 peeler	31.2	37.8	47.9
Special Mill peeler	12.7	14.3	80.5
No. 2 sawlog	18.9	16.3	71.0
No. 3 sawlog	7.0	3.7	86.4
Second growth			
No. 3 peeler[1]	50.6	65.4	34.6
No. 2 sawlog	3.8	2.9	97.1
No. 3 sawlog	2.1	1.0	99.0

[1] Nondominated log grades for Objective Set 2.

duction of structural lumber. Specifically, the hypothetical objectives used (Objective Set 3) were as follows:

1. Maximize the expected value added in producing structural lumber.
2. Maximize the percentage yield of structural lumber.
3. Minimize the percentage yield of nonstructural lumber.

The decision criteria matrix for this objective set can be found in Table 5.

In this case, the results of the dominance test were very clearcut. The second growth No. 3 sawlog was superior to all other grades for all criteria and was, therefore, the only nondominated log grade. As in the case of the cutting mill, "next best choices" for buying and trading had to be determined to avoid reliance on a single log grade. Removing the row for the second growth No. 3 sawlogs from Table 5 and testing again for dominance indicates that second growth No. 2 sawlogs would become the feasible choice. An additional iteration reveals that old growth No. 3 sawlogs would be the third best choice.

TABLE 5. *Expected percent value added in sawing structural lumber in 1984 and percent yields of structural and nonstructural lumber for Douglas-fir.*

	Value added	Yield	
Log grade	Structural	Structural	Nonstructural
Old growth			
No. 1 peeler	−13.3	26.9	73.1
No. 2 peeler	−14.7	35.1	64.9
No. 3 peeler	−11.4	47.9	52.1
Special Mill peeler	−1.8	80.5	19.5
No. 2 sawlog	−4.4	71.0	29.0
No. 3 sawlog	8.8	86.4	13.7
Second growth			
No. 3 peeler	−1.4	34.6	65.4
No. 2 sawlog	11.8	97.1	2.9
No. 3 sawlog[1]	53.5	99.0	1.0

[1] Nondominated log grades for Objective Set 3.

TABLE 6. *Expected percent value added in cutting Douglas-fir lumber, by log grade, in 1960.*

Log grade	Selects	Moulding	Factory Selects	Shop Lumber	Structural lumber	Total
Old growth						
No. 1 peeler	33.3	2.2	2.1	1.7	2.0	41.3
No. 2 peeler	24.4	1.5	3.9	2.3	2.6	34.7
No. 3 peeler	28.5	6.2	2.6	2.9	14.8	55.0
Special Mill peeler	13.6	4.7	0.3	1.4	63.3	83.3
No. 2 sawlog	28.8	7.7	3.6	11.3	80.8	132.2
No. 3 sawlog	9.0	4.4	1.8	17.0	108.0	140.2
Second growth						
No. 3 peeler	48.5	—	—	—	18.4	66.9
No. 2 sawlog	5.9	—	—	—	135.9	141.8
No. 3 sawlog	2.7	—	—	—	200.9	203.6

CHANGES OVER TIME

In repeating the analysis for 1960, the same three hypothetical objective sets were used. Decision criteria matrices were formulated using the same yield data and the value added figures in Table 6. In 1960, feasible log grades for the integrated mill (Objective Set 1) were old growth No. 2 and No. 3 sawlogs and second growth No. 2 and No. 3 sawlogs. Note that by 1984, old growth No. 2 sawlogs were no longer feasible and had been replaced by second growth No. 3 peelers. Only the lowest grade of old growth logs remained feasible. During this period, the total value added for all grades of sawlogs declined dramatically (between 73 and 89%) while total value added for second growth No. 3 peelers declined only 26%.

The situation for cutting mills (Objective Set 2) changed very little from 1960 to 1984. As in 1984, old growth No. 1 peelers and second growth No. 3 peelers were the feasible log grades in 1960 for satisfying this set of objectives. A change was observed in the second iteration of the dominance test to determine "next best choices." In 1960, old growth No. 2 and No. 3 peelers and No. 2 sawlogs were all feasible in the second iteration. In 1984, the old growth No. 2 sawlogs did not become feasible until the third iteration. For the dimension mill (Objective Set 3), no changes in feasible log choices were observed from 1960 to 1984.

CONCLUSIONS

A major advantage of dominance is its conceptual simplicity. It is a workable, easy to apply method to aid in the selection of logs for a particular set of objectives that does not require extensive input data or complicated algorithms. However, used by itself as a decision tool, dominance does not produce the level of detailed information obtainable from more sophisticated approaches. The method provides no insight as to which specific product grades should be cut from particular log grades, and does not consider capacity and labor constraints. In cases where detailed analyses are needed, however, this method can also be employed as a means of reducing the volume of input data. For the integrated firms producing a number of products in several facilities, the feasible log grades identified with the dominance test could be used as input for a resource allocation algorithm such as single or multiple objective linear programming. Excluding infeasible log grades from consideration could significantly reduce the quantity of input, making the analysis less cumbersome and less expensive.

While the hypothetical cases analyzed have yielded results similar to those reported in the literature, there are some differences worth noting. For nonstructural lumber, the larger, higher valued, old growth logs are generally considered to be most suitable. As shown by the results, however, high grade second growth logs may be preferred over some grades of old growth logs for this purpose. Lower valued second growth logs are usually considered to be most suitable for structural dimension lumber but, as this analysis indicates, some low grade old growth logs may be preferred over some second growth grades for this type of lumber. As a general rule, it appears that peeler logs, both old growth and second growth, are most suitable for nonstructural lumber while both old growth and second growth sawlogs are most suitable for dimension lumber.

The results for the 1960 data indicate that this situation has prevailed, for the most part, over the last two decades. For the cutting and dimension mills, the feasible log grades did not change between 1960 and 1984, although the value added in conversion did decline. In the case of the integrated mill, one old growth log grade that was feasible in 1960 had been replaced by a second growth grade by 1984.

This lack of flexibility in log choice ultimately stems from the conversion technology itself. Sawing results in a direct correspondence between log size and quality and lumber size and quality, thereby limiting the degree of resource substitution that can be employed in response to decreases in value added. This implies that the firms analyzed have had to rely on other means for improving their value added performance over time. Historically, this has involved incremental technologies that improve yield and/or reduce production costs through labor saving automation. As the natural limits of these improvements are reached, new technologies to produce composite commodity structural products from low grade resources should become more prevalent and noncommodity specialty products should command higher premiums to recover higher resource costs.

Although the hypothetical cases used in the analyses were simplified for demonstrative purposes, further refinements are possible. The decision criteria matrices could be expanded to include specific product grades. Similarly, log diameters or diameter classes could be included. This would require more detailed data, but would also result in a more specific description of feasible logs and would allow the satisfaction of more specific objectives.

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