PRODUCTION PLANNING
FOR
VALUE ADDED LUMBER MANUFACTURING

by

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ABSTRACT

Difficulties in effectively managing opportunities for value added lumber manufacturing facilities have led to a need to develop production planning systems for these facilities. Two linear programming based models were developed for this purpose. One model is designed for independent value facilities; the other is designed for integrated value added facilities. In demonstrating the use of the models, analyses were made of a study operation. The purpose of these analyses, was to explore the influences value added facility production policies have on sawmill production decisions for an integrated value added facility. The results suggest that value added facility production decisions can have significant influence on sawmill production decisions for an integrated valued added production operation.
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1. INTRODUCTION

In recent years, the value added wood products industry has received much attention and study in Western Canada and in the United States Pacific Northwest. Governments are interested in opportunities in the valued added industry for expanding their economic bases. Forest companies are examining the methods and benefits of adding value to their current products [6]. Players within the industry are pursuing means to remain competitive while entrepreneurs are investigating opportunities to enter the industry. Moreover, the general public seems to view the issue of value added as an obligation of the forest resource tenure holders such that all value is extracted from the resource while providing increased employment.

Opportunities for remanufacturing commodity products into value added products have long been recognized [1]. As a result, the wood products value added sector has evolved. A study by Price Waterhouse [4] estimated there were 11,660 individuals employed in B.C.'s value added sector in 1990. The study also estimated that in that year, B.C.'s sector had $1.54 billion of revenue. Another study states that in 1991, with estimated revenues of $1.3 billion, the value added sector in B.C. lost $12 million [3]. The same study identified that managers in the sector lack the time to address all the aspects of their business adequately, and this is a factor hindering the performance of the industry. An analysis of the future of the forest industry [2] stated that in order to recognize and manage value added opportunities in the forest resource, new expertise in the decision making process is needed.
1.1 OBJECTIVE:

The research presented in this thesis is an effort to respond to this need. The principle objective was to develop a production planning model for value added lumber manufacturing with particular emphasis on integrated value added manufacturing facilities.

Two production planning models were developed for this purpose. The first model is a production planning model designed for independent value added facilities (the VAF model). It assumes sawn lumber is the input raw material for the facility. The second model is a production planning model designed for integrated value added facilities where the input raw materials are long-logs.

Both models are primarily formulated as linear program (LP) models. The integrated model is an extension of a revised version of the Sawmill Production Control Model (SPCM) described by Maness and Adams [8]. The integrated model connects the VAF model LP formulation with the SPCM's LP formulation. The result is a model which encompasses the entire integrated value added manufacturing process from long-log to finished product. Furthermore it includes the key benefit of the sawmill production control model: the combined optimization of bucking long-logs and sawing of the subsequent saw-logs to produce the raw material for the value added facility.

The two models were designed to model the operations of an integrated value added manufacturing facility in western Canada. The company operating this facility cooperated in this research. As an exercise to demonstrate the use of these models, analyses of the study operation were made using both models. The intent of these
analyses was to explore the benefits of using the independent model alone with the
benefits of using the integrated model and to demonstrate the influence the production
decisions made in the value added facility had on production decisions made in the
sawmill.

2. BACKGROUND

Value added facilities may employ a variety of equipment. Such equipment
includes resaws, chop-saws, finger-jointers, edge-gluers and moulders. Combinations of
this equipment provide numerous possible production programs for adding value to the
raw material mix. These production programs in turn provide flexibility for taking
advantage of possible product opportunities.

With this flexibility, however, there also exists the difficulty of making efficient use
of it. For facility managers, there are several difficult decision problems in planning the
entire production process. To produce the value added products on an operation's current
order file, they first must decide what mix of rough products they require. They then must
decide how much of each product is to be further manufactured by which process. At the
same time, they must ensure they are using as much of the facility's capacity as possible
while minimizing the production of less desirable products.

As a whole, this becomes a difficult problem to handle. Managers will often use a
personal computer with a spreadsheet package to assist in handling business problems.
This problem, however, becomes too large to be solved effectively with a spreadsheet.
More advanced techniques are required. One such technique is linear programming.
There have been a number of applications of linear programming in the wood products industry [9, 10, 11, 12, 13]. Most of these applications are proposals of methodologies to deal with problems in the industry, demonstrating their effectiveness with realistic scenarios.

Published accounts of the benefits of real applications of linear programming in the wood products industry are limited. Hay and Dahl [7] combined linear and dynamic programming to develop a model for planning the flow of wood material from stump to finished product for the Weyerhaeuser Company's southern operations. This model considered the possible flow from numerous tracts of timber through available stem bucking processes and conversion facilities to produce desired products. The company reported that the model was used regularly by company managers and that a typical application resulted in a $200,000 annual opportunity.

The model used in this application was relatively small with up to 700 variables and 350 constraints. This was a result, in part, of using a stem bucking strategy for each specific type of timber tract. Each tract of timber was an activity variable in the model. A more thorough formulation would include an activity variable for every conceivable bucking pattern for every type of possible stem, regardless of the tract it came from. Furthermore, a more thorough formulation would include for every bucked log, every conceivable sawing pattern as an activity variable. However, attempting to include both types of patterns in the model rapidly results in an intractable formulation which cannot be practically solved; however, tractable methods of including both types of patterns have been proposed [8, 10, 11].
Carino and Lemoir [5] developed a small model to successfully optimize wood procurement for cabinet manufacturing [5]. This model did not require stem bucking, as the input stems were logs ranging from 8 to 14 feet only. The authors used regression equations based on a sample of 25 logs to determine the volume and grade of furniture components yielded from each log diameter and length. The model was not used by company management, although the authors suggested it could be. This application was estimated to provide $100,000 in annual savings in raw material purchases.

Both of these practical applications demonstrated that linear programming can be used effectively in the wood products industry. The Weyerhaeuser application also demonstrated that managers without specific knowledge of mathematical programming could successfully use a linear programming based model. However, these models did not include stem bucking or log sawing patterns. Also the problems had relatively few actual production processes to model. For integrated value added operations, a model is required which will model the production process from stem to finished product which includes stem bucking and log sawing patterns and models the large number of possible production processes. Ideally, this model should be user friendly for managers so that they may use model to assist them with the important decisions in managing their operations.

One of these decisions is determining what raw materials to purchase from outside sources, since value added operations are constrained by what is available on the market. If a decision support system were applied, these types of constraints would be considered. The system would provide recommendations on what materials to purchase given the constraints.
For the non-integrated operation the recommendations of the system would likely be to purchase all that is available of some raw materials while not purchasing others. By doing so, profits would be maximized; however, profits could be further maximized if more volume of those specific products were available. But these operations have little control over what volumes are available on the market.

Integrated operations do however have some control over the volumes available of the desired raw materials produced in their primary operations. Although constrained by the characteristics of their stem population, they still have significant control in making more of the desired products. This can be accomplished by manipulating the sawmill's process control equipment.

Modern sawmills apply process control equipment at all stages of the manufacturing process: log bucking, primary breakdown, edging, trimming and sorting. Computer programs controlling the equipment generate processing solutions by either using piece scan data and generating a sawing solution for the piece based on the value of the products it is capable of yielding or by using a predetermined solution from a look-up table for the corresponding piece dimensions. Generating more volume of a particular product can be done by inflating the values of the desired products or by adjusting the solutions in the look-up table.

Whether it be changing product values or adjusting look-up solutions, generating an acceptable product mix is a trial and error process. Not only is this time consuming, the interim side effects of producing undesirable products could prove to be more costly than the added benefit of achieving the desired product mix. Furthermore, once an acceptable product mix is achieved, although it is acceptable, it may not be the best
acceptable mix. What is required is a method of generating and evaluating a set of product values or look-up tables which when applied to a mill's process control equipment will produce a desirable product mix.

The Sawmill Production Control Model was developed to deal with this problem. This model combines the optimization of log bucking and log sawing as dynamic programming models in a master linear programming model. This allows all possible bucking and sawing patterns to be incorporated in the model in a tractable way. Given the sawmill's long-log population characteristics, equipment and desired product mix, the model will generate a set of values and look-up tables to be used by the process control equipment which will steer production towards that desired product mix.
3. STUDY SITE

Before proceeding with the discussion of the model development, it is necessary to
discuss the study site. This project was carried out in cooperation with a forest company
which operates an integrated value added facility in western Canada. The raw material
source is lodgepole pine (Pinus contorta, Doug. ex. Loud). The mill processes logs with
small end diameters ranging from 3.5 inches to approximately 16 inches. The operation’s
sawmill runs a long log merchandiser, a large log primary breakdown line, a small log
primary breakdown line, two optimizing board edgers, trimmer and a multi-bin sorter.

Both sawing lines breakdown logs with the split taper log, split taper curve sawing
cant method [14]. In both cases logs are rotated “horns-down” prior to canting. The
small line sawing patterns are determined by an optimization system, while the large line
sawing patterns are selected from a set table.

The gang edger configurations in the sawmill allow for numerous board thickness
combinations in the cant stack. The large line uses two gangs in line enabling a total of 8
boards to be sawn from a cant. The first gang has two saws which remove two outside
boards. The second gang has 5 saws with variable spacing between the second and third
saws and the third and fourth saws. The spacers between the first and second saws and the
fourth and fifth saws are fixed. Depending on the size of the cant and the number of
board thicknesses, this gang configuration allows numerous combinations of board
thicknesses within a sawing pattern. This differs from conventional gang configurations
used in North America. Conventional gang configurations are set up to produce 2 inch
dimension lumber for North American markets where the gang saws are spaced with fixed
2 inch (nominal) spacers.
The small line uses one three saw gang enabling four boards to be sawn from a cant. This gang has variable spacers between the first and second saws and the second and third saws.

The variable spacers can shift almost instantly permitting gang thickness combinations to change from cant to cant in "real-time". The fixed spacers may only be changed when the machine is shut down.

After kiln drying, rough sawn lumber is graded, trimmed and sorted into rough dry products. Some of these products are sold in this state while the remainder are further manufactured. These rough dry products are the raw material for the value added facility.

The value added facility (VAF) consists of a resaw and a moulder. Both machines may share three sorts. The resaw and the moulder may run in combination with the resaw feeding the moulder or they may run separately both being fed from their own respective infeeds. Providing the combined number of sorts required is not more than three, the moulder and resaw may be run separately or simultaneously.

Generally one sort is dedicated to a finished premium grade value added product, another sort is dedicated to a mid grade value added product and the last sort is dedicated to sub grade products. Any of these grades of products may be packaged and sold as they are or run through the value added facility again to produce other products. Typically the premium and mid grade products are packaged and sold while the sub-grade products are run through again. It possible that this rerunning process can iterate several times. With resawing capabilities and the ability to rerun products through the VAF, the possibility exists for numerous complex VAF production schedules. This brings about the problem of planning efficient production schedules.
4. MODEL DESCRIPTIONS

Two models were developed for this project. The first model is a conventional LP which models the VAF alone. It is formulated to determine the optimal production schedule to produce a desired finished product mix from a given rough sawn raw material mix. The second model was developed by appending this linear program formulation to the master linear program formulation of the SPCM. The new model considers the entire integrated value added manufacturing process and generates the optimal production planning schedule to produce a desired finished product mix from a given stem input mix.

In developing the combined model some modifications were made to the SPCM. First, it was necessary to develop and substitute a new sawing pattern generator. The SPCM's original sawing pattern generator was not readily adaptable to the primary breakdown configuration of the study site. Secondly, changes were made to the SPCM's master LP formulation such that a different technique could be applied in controlling the finished product mix.

4.1 SAWING PATTERN GENERATOR

The SPCM sawing pattern generator was incapable of modeling the complex gang saw configurations of the study operation. Furthermore, there were no capable commercial packages available. It was necessary to develop a pattern generator which could adequately model the study operation's primary breakdown.

Seemingly a difficult task with the added complexity of curve sawing, developing a sawing pattern generator was accomplished in a straightforward manner. The sawmill's
curve sawing primary breakdown system is capable of sawing logs with up to 4 inches of
sweep in 16 feet [14]. Almost all the logs coming into the mill have less sweep than 4
inches in 16 feet. Modeling the sawmill's curve sawing capabilities can simply be dealt
with by assuming that logs arriving at the mill are straight truncated cones.

The same pattern generator is used for both of the study site's primary breakdown
lines. As the small log line is essentially the same as the large line but is restricted to no
side boards, no sub-width cant boards and two less fixed board thicknesses. When
running the pattern generator for the small line, these restrictions are easily applied.

4.1.1 Sawing Pattern Optimizer

The algorithm is an ad hoc procedure which is best described as an exhaustive
search algorithm. Generalized procedures of the algorithm are described as follows.

1. For the cross-section at the distance equal to the minimum lumber length measured
   from the large end of the truncated cone, find the largest cant width and corresponding
cant height.

2. Within that cant height, generate a two dimensional sawing pattern for every
   conceivable lumber thickness combination. And for each combination apply the
   pattern throughout the entire log length to generate a three dimensional cant sawing
   pattern. Select the most valuable three dimensional cant pattern.

3. With this cant pattern, for each possible combination of side boards add the side board
   value to the cant value. Select the side board combination which yields the greatest
   value when added to the cant value. This will be the most valuable sawing pattern for
   the given cant width.
4. Repeat steps 1 to 3 for all remaining cant widths. Select the most valuable sawing pattern as the optimal sawing pattern.

4.2 VAF LP FORMULATION

The VAF LP is formulated to model the study operation's manufacturing processes subsequent to the sawmilling process. This is the manufacture of rough sawn green lumber into finished value added products. The manufacturing steps include kiln drying, dry-sorting, resawing, moulding, sorting, rerunning and packaging. The model is formulated as follows.

Maximize:

\[- \sum \limits_k cRM_k \times RM_k - \sum \limits_i cEQ_i \times EqHrs_i - \sum \limits_j cCGrp_j \times CGrpHrs_j - \sum \limits_i cVAOp_i \times VAOp_i - cKlns \times KlnHrs + \sum \left\{ prDS_m \times DS_m - cODS_m \times ODS_m - cUDS_m \times UDS_m \right\} + \sum \left\{ prVA_n \times VA_n - cOVA_n \times OVA_n - cUVA_n \times UVA_n \right\} + prChips \times Chips + prResidue \times Residue \]

Subject to:

(E) \[RM_k - KlnChrg_k \times VolKlm = 0 \quad (\text{for all raw material products } k) \]

(A) \[\sum \limits_k RM_k \times DSRate_k - DSHrs = 0 \]

(B) \[\sum \limits_i VAOp \times Eqrate_i - EqHrs_i = 0 \quad (\text{for all } i \text{ pieces of equipment}) \]

(D) \[\sum \limits_k KlnChrg_k \times HrsKlnChrg_k - KlnHrs = 0 \]

(C) \[EqHrs_i - CGrpHrs_j \leq 0 \quad (\text{for all } i \text{ pieces of equipment if belonging to cost group } j) \]
(F) \[ \sum_k RMs \times RMDSyldkm - \sum_i VAOpi \times VADSyldim - DS_m = 0 \] (for all \( m \) dry sorted products)

(G) \[ \sum_i VAOpi \times VAyldin - VA_n = 0 \] (for all \( n \) value added products)

(I) \[ \sum_k RMs \times RMChpyldk + \sum_i VAOpi \times VAOpChpyldi - Chips = 0 \]

(K) \[ \sum_k RMs \times RMRsdyldk + \sum_i VAOpi \times VAOpRsdyldi - Residue = 0 \]

(H) \[ DS_m - ODS_m - UDS_m = DSm\text{demand}_m \] (for all \( m \) dry sorted products)

(I) \[ VA_n - OVA_n + UVA_n = VAdemand_n \] (for all \( n \) value added products)

(L) \[ RMs \leq \text{Avail\_RMs} \] (for all \( k \) raw material products)

(M) \[ KlnHrs \leq \text{Avail\_KlnHrs} \]

(N) \[ DSHrs \leq \text{Avail\_DSHrs} \]

(O) \[ EqHrs_i \leq \text{Avail\_EqHrs}_i \] (for all \( i \) pieces of equipment)

All variables are non-negative.

where

\[ cRM_k = \text{the cost per unit of volume of procuring raw material product } k; \]

\[ Rm_k = \text{the volume of raw material product } k \text{ procured}; \]

\[ cEq = \text{the cost per hour of using piece of equipment } i; \]

\[ EqHrs_i = \text{the number of hours used of piece of equipment } i; \]

\[ cCGrp_j = \text{the cost per hour of cost group } j; \]

\[ CGrpHrs_j = \text{the number of hours used of cost group } j; \]
\( cKlns \) = the cost per hour of operating the dry kilns;

\( KlnHrs \) = the number kiln hours used;

\( cVAOp_i \) = the cost of using value added option \( i \);

\( VAOpi \) = the volume of material processed by the value added option \( i \);

\( prDS_m \) = the sales price of dry sorted product \( m \);

\( DS_m \) = the volume of dry sorted product \( m \) produced;

\( cODS_m \) = the cost of over producing dry sorted product \( m \);

\( ODS_m \) = the volume of dry sorted product \( m \) over produced;

\( cUDS_m \) = the cost of under producing dry sorted product \( m \);

\( UDS_m \) = the volume of dry sorted product \( m \) under produced;

\( prVA_n \) = the sales price of value added product \( m \);

\( Va_n \) = the volume of value added product \( m \) produced;

\( cOVA_n \) = the cost of over producing value added product \( m \);

\( OVA_n \) = the volume of value added product \( m \) over produced;

\( cUVA_n \) = the cost of under producing value added product \( m \);

\( UVA_n \) = the volume of value added product \( m \) under produced;

\( prchips \) = the sales price for chips;

\( chips \) = volume of chips produced;

\( prResidue \) = the sales price of wood residue products

\( Residue \) = the volume of wood residue produced

\( RM_k \) = the volume of raw material \( k \) used in production;

\( Dsrate_k \) = the rate raw material product \( k \) can be dry sorted;

\( DSHrs \) = the number of hours the dry sorting system operates;
\[ E_{rate_{il}} = \text{the rate piece of equipment } i \text{ processes material under value added option } l, \]

\[ C_{grp_j} = \text{the cost group } j; \]

\[ K_{lnChrg_k} = \text{the number of kiln charges of raw material product } k; \]

\[ V_{olKln_k} = \text{the volume of raw material } k \text{ per kiln charge}; \]

\[ H_{rsKlnChrg_k} = \text{number of hours per kiln charge of raw material product } k \text{ necessary to dry raw material product } k; \]

\[ R_{MDSyld_{km}} = \text{the yield of dry sorted product } m \text{ as a result of dry sorting raw material product } k; \]

\[ V_{ADSyld_{lm}} = \text{the yield of dry sorted product } m \text{ from the volume of material processed by value added option } l; \]

\[ V_{ayld_{ln}} = \text{the yield of value added product } n \text{ from the volume of material processed by value added option } l; \]

\[ D_{sdemand_m} = \text{the demand for dry sorted product } m; \]

\[ V_{ademand_n} = \text{the demand for value added product } n; \]

\[ R_{MChpyld_k} = \text{the yield of chips as a result of dry sorting of raw material product } k; \]

\[ V_{AOpChpyld_i} = \text{the yield of chips from the volume of material processed by value added option } l; \]

\[ R_{MRsdyld_k} = \text{the yield of wood residue as a result of dry sorting raw material product } k; \]

\[ V_{AOpRsdyld_i} = \text{the yield of wood residue from the volume of material processed by value added option } l. \]

\[ Avail\_RM_k = \text{the available procurable volume of raw material product } k \]

\[ Avail\_KlnHrs = \text{the available number of kiln hours} \]

\[ Avail\_DSHrs = \text{the available number of Dry Sorter production hours} \]

\[ Avail\_EqHrs_i = \text{the available number of production hours for piece of equipment } l \]
4.2.1 Key Decision Variables

The $VAOp$ variables are the key decision variables. These variables indicate the volume of input material to be processed by value added option $l$. Value added options consist of an input raw material (either a dry sorted product or a previously produced value added product), equipment requirements, production rates, and the resulting value added product yields, residue yields, and chip yields.

4.2.2 Constraint Definitions

Constraint (E) composes the raw material into kiln charges.

Constraints (A) (B) (D) are VAF capacity constraints which ensure the available operating hours for the dry-sorter, kilns and equipment are not exceeded.

Constraints (C) allow the equipment to be grouped together into cost groups with respective operating costs. In each cost group, the piece of equipment which operates for the most hours determines the number of operating hours for the cost group. This enables the application of an indirect variable cost to the cost group.

Constraints (F) (G) (J) (K) are material balance constraints which ensure the volume of products and by-products produced equals the volume of raw material consumed. Constraints (F) contain the yield coefficients for the dry-sorted products. Constraints (F) recognize that dry-sorted products may be produced from two sources: directly from the raw material, or indirectly from other dry-sorted products as a result of the application value added policies. Constraints (G) contain the yield coefficients for value added products from the dry-sorted products as a result of applying a value added
policy. Constraints (J) and (K) contain the yield coefficients for the by-products chips and residue.

Constraints (H) and (I) are the dry-sorted and value added product demand constraints. Over and under production are controlled by the application of inventory carrying costs and shortage costs to over and under production of each product.

Constraints (L), (M), (N) and (O) impose upper bounds on the available volume of raw material, kiln hours, dry sorter hours, and VAF equipment hours respectively.

4.3 REVISED SPCM LP FORMULATION

The revised formulation for the SPCM is as follows.

Maximize:

\[
\sum_i \sum_l \{Lum_{Sales} \times Lum_{Price} \} \\
+ \sum_l \{Log_{Sales} \times Logs_{Price} \} \\
+ \{RndWd_{Fiber} \times RndWd_{Fiber \ Price} \} \\
+ \{Grn_{Chips} \times Gr_{Chips \ Price} \} \\
- \{Stem_{Prch} \times Stem_{Pr} \} - \sum_k \{Hours_k \times Cost_Hrk \} \\
- \sum_i \sum_l \{OverPrdn_l \times Inv_{Cost_l} \} \\
- \sum_i \sum_l \{UnderPrdn_l \times Shrtge_{Cost_l} \} \\
- Tot_{Oper\ Cost} - Tot_{Fin\ Cost}
\]

Subject to:

(A) \[ Stem_{Prch} \times \%_{Stem\ Dists} - \sum_B \{Stm_{BucksB} \} = 0 \]

\[
\sum_s \sum_B \{Stm_{BucksB} \times Log_{Recover}lSB \} - \\
\sum_c Logs_{SawnLNC} - Logs_{Sales} = 0
\]
(C) \[ \sum_{L} \sum_{C} \{ \text{Logs\_SawnLNc} \times \text{Lum\_Reco\_LNc} \} - \{ \text{Lum\_Prod\_LN} \} = 0 \]

(D) \[ \sum_{L} \sum_{C} \{ \text{Logs\_SawnLNc} \times \text{Hrs\_Per\_LogVol\_LN} \} - \{ \text{Saw\_Hours\_LN} \} = 0 \]

(E) \[ \sum_{i} \sum_{l} \{ \text{Lum\_Prod\_LN} \} \times \{ \text{Hrs\_Per\_LumVol\_LN} \} - \text{Fin\_Hours} = 0 \]

(F) \[ \sum_{s} \sum_{b} \{ \text{Stm\_Bucks\_LN} \times \text{RndWd\_Reco\_LN} \} - \text{RndWd\_Fiber} = 0 \]

(G) \[ \sum_{N} \sum_{L} \sum_{C} \{ \text{Logs\_SawnLNc} \times \text{Fiber\_Reco\_LN} \} - \text{Grn\_Chips} = 0 \]

(H) \[ \sum_{N} \{ \text{Lum\_Prod\_LN} \} - \{ \text{Lum\_Sales\_LN} \} = 0 \]

(I) \[ \sum_{N} \sum_{i} \sum_{l} \{ \text{Lum\_Prod\_LN} \times \text{Oper\_Cost\_LN} \} - \text{Tot\_Oper\_Cost} = 0 \]

(J) \[ \sum_{i} \sum_{l} \{ \text{Lum\_Sales\_LN} \times \text{Fin\_Cost\_LN} \} - \text{Tot\_Oper\_Cost} = 0 \]

(K) \[ \text{Saw\_Hours\_LN} \leq \text{Avail\_Saw\_Hrs\_LN} \]

(L) \[ \text{Fin\_Hours} \leq \text{Avail\_Fin\_Hrs} \]

(M) \[ \sum_{i} \sum_{l} \{ \text{Lum\_Sales\_LN} \} - \text{Tot\_Sales} = 0 \]

(N) \[ \{ \text{Lum\_Sales\_LN} \} - \{ \text{OverPrd\_LN} \} + \{ \text{UnderPrd\_LN} \} + \{ \text{Demand\_LN} \times \text{Tot\_Sales\_LN} \} = 0 \]

All variables are non-negative.

where:

\[ \text{Stm\_Prch} \] = the volume of stems purchased as raw material for the sawmill.
\%_\textit{Stem\_Dist}_S = \text{the percentage of stem type } S \text{ found in a unit of volume of } \textit{Stm\_Prch}; \\
\textit{Stm\_Bucked}_SB = \text{the volume of stem type } S \text{ bucked according to policy } B; \\
\textit{Log\_Recover}_LSB = \text{the percentage of stem type } S \text{ which results in log class } L \\
\text{when bucked according to policy } B; \\
\textit{Logs\_Sawn}_{LN} = \text{the volume of logs in class } L \text{ which are sawn by sawing line } N \\
\text{according to sawing policy } C; \\
\textit{Log\_Sales}_L = \text{the volume of logs in class } L \text{ which are sold;} \\
\textit{Lum\_Recover}_{iLN} = \text{the volume percentage of lumber of dimension } i \text{ and length } l \\
\text{recovered from a unit of volume of a log of log class } L \\
\text{when sawn by sawing line } N \text{ according to sawing policy } C; \\
\textit{Lum\_Prod}_{iN} = \text{the volume of lumber of dimension } i \text{ and length } l \text{ produced} \\
\text{by sawing line } N; \\
\textit{Lum\_Sales}_i = \text{the volume of lumber of dimension } i \text{ and length } l \text{ sold;} \\
\textit{Hours\_Per\_Log\_Vol}_{iN} = \text{the hours required for sawing line } N \text{ to saw one unit of} \\
\text{volume of a log of log class } L \\
\textit{Hours\_Per\_Lum\_Vol}_{iN} = \text{the hours required to finish one unit of volume of lumber of} \\
\text{dimension } i \text{ and length class } l \text{ produced by sawing line } N \\
\textit{Saw\_Hours}_N = \text{total number of hours sawing line } N \text{ is in use} \\
\textit{Fin\_Hours} = \text{total number of hours required to finish the volume of} \\
lumber sold \\
\textit{Rnd\_Wd\_Recover}_SB = \text{the percentage by volume of round wood recovered from} \\
\text{stem class } S \text{ when bucking policy } B \text{ is applied} \\
\textit{Fiber\_Recover}_{LC} = \text{the percentage by volume of fiber recovered as green chips} \\
\text{from log class } L \text{ when sawing policy } C \text{ is applied} \\
\textit{Oper\_Cost}_{iN} = \text{the operating cost of sawing a unit of volume of product of} \\
dimension } i \text{ and length } l \text{ with sawing line } n; \\
\textit{Fin\_Cost}_i = \text{the cost of finishing a unit of volume of lumber with} \\
dimension } i \text{ and length } l;
Avail_Saw_Hrs_n = the total available operating hours for sawing line n;

Avail_Fin_Hrs = the total available operating hours available for finishing;

Tot_Sales = the total volume of lumber sold;

Demand_{il} = the market demand for products of dimension i and length l as percentage of the total sales volume.

OverPrdn_{il} = the volume of product i and length l produced in excess of the market demand

UnderPrdn_{il} = the volume of product i and length l short of the market demand for product i and length l

4.3.1 SPCM LP Formulation Revisions

The primary difference between this formulation and the original SPCM formulation described in the paper by Maness and Adams [8] is the use of the soft constraints (constraints N) for marketing limitations rather than product demand groups to control production.

Another difference is the use of cubic meters for round wood volumes and lumber volumes rather than cunits (100 cubic feet) and thousands of board feet (MBFM) respectively. This is consistent with the units used at the study site.

4.4 COMBINED FORMULATION

Combining the formulations was done by adding the VAF objective function and constraints to the SPCM formulation. The link between the two models was done by modifying constraint (H) of the SPCM formulation as follows.

\[ \sum_{n} \{Lum_\_Prods\} - \{Lum_\_Sales\} - \{RM\} = 0 \]
In this case the *Lum_Sales* can be considered as the raw material for the VAF. This constraint now allows rough lumber to be sold as *Lum_Sales* or to proceed through the VAF as raw material input *RM*. The addition of the *RM* variables to the constraints is the link between the VAF model and the SPCM. The *RM* variables from the independent VAF model represent the volume of each raw material product procured for VAF processing. The *RM* variables were constrained by upper bounds on the procurable volume available. In the combined model, the raw material is supplied by the sawmill; therefore, the *RM* variables are now constrained by the SPCM constraints on stem usage. Consequently, in the combined model upper bounds on the *RM* variables are not necessary.

4.5 LARGE LINE PATTERN TABLE GENERATION FOR THE STUDY

SAWMILL

As discussed previously the study operation’s large log primary breakdown line chooses patterns from a pattern look-up table. As a log enters the machine it is first scanned for small end diameter. This information is passed on to the line’s computerized control system which then looks up the pattern from a set table defined for that diameter. The log’s length is not considered. The patterns in the set table are predetermined for each small end diameter regardless of length. The reason for this is that the control system is not designed to hold a pattern for both small end diameter and length.

This situation was a problem for the SPCM as it assumes if a primary breakdown line uses a pattern lookup table, that these patterns are defined for each small end diameter
and length class and not by small end diameter class only. To effectively simulate the use of a pattern lookup classified only by small end diameter, some modifications to the sawing pattern optimizer were necessary.

The sawing optimization model generates sawing patterns for each small end diameter and length class. These in turn provide yield vectors for the LP model for each diameter and length class. The cross-sectional sawing patterns generated by the sawing model are not necessarily common throughout the possible lengths for a given small end diameter class, and they are in fact typically different. This is a result of the fact that by taking advantage of the logs' taper, better recovery can be achieved with unique sawing patterns for each small end diameter and length class.

When the mill personnel define a set of patterns, they define two dimensional patterns which fit in the cross-section of each small end diameter class. As a result, patterns are best suited for short saw-logs. The mill personnel are aware that this practice does not result in the best recovery, but they are satisfied with the results.

The sawing model could have been modified to follow the same procedure; however, it was felt better results could be achieved if a better pattern could be generated which considered all the possible lengths for a given small end diameter class. It was decided that a reasonable method of determining the best pattern for the small end diameter class would be to apply the 2-dimensional pattern from the pattern generated for the log of the most desirable length for each small end diameter class. This left the problem of determining the most desirable length for each small end diameter class.

Several options were considered for finding this length. The first consideration was to use the length with greatest marginal value after each iteration of the model. The
problem with this approach is that it is possible that the length for the given small end
diameter with the greatest marginal value is not produced at all. The alternative approach
would be to use the length with the greatest volume produced; however, the length with
the greatest volume produced may be of relatively low value. It was decided that the best
length to use, the “prime length” would be the one with the greatest product of volume
and value.

With this strategy, upon initiation of the model there will be no marginal values nor
saw-log volumes. For the first iteration, the shortest allowable saw-log length is used as
the “prime-length”. After the first iteration of the LP model the subsequent sawing model
runs use the “prime length” procedure to generate patterns for each log length and small
end diameter class.

4.6 MODEL VALIDATION

Numerous runs of both the independent VAF model and the combined model were
executed in carrying out the validation process. The process involved running the models
with realistic and unrealistic objectives and constraints starting with small simple data sets
and progressing to large complicated data sets. After each run, the results were critically
examined. Firstly, they were examined to determine if they were sensible. Secondly, the
results were examined to determine if they were consistent with what was expected, given
the objectives and constraints. If the results were unexpected, then optimal programs
were traced through to understand the reasons for the unexpected results and to decide if
they were logical.
The validation process began with the VAF model. The process started with one raw material product with two simple value added programs. The next runs used more complicated value added programs where some of the output value added products were rerun. The runs were continued with the data sets becoming larger and more complex until the study site's complete data set was run.

During these stages of validation, various changes to the constraints and objectives were made and examples of these changes are described as follows. Production costs were raised to extraordinary levels to see if the model would respond by not producing anything. Upper bounds on available equipment time and raw material were altered to see if the model would respond sensibly. Finally, particular attention was given in testing the product demand objectives to see how the model responded to changes in over and under production costs of various products.

Once satisfied the VAF model was generating valid results, the combined model was validated. Validation of the combined model followed the same procedure.

In the validation of both models, any problems found were usually the result of bad data or bugs in the LP matrix generation software. These problems more often than not resulted in problems with infeasibility or unboundness rather than feasible but nonsense results. However, some nonsense results were attributable to LP matrix generation bugs. In either case, the problems were found and corrected and the models were eventually validated.
5. THE INFLUENCE OF VALUE ADDED PRODUCTION DECISIONS ON SAWMILL PRODUCTION DECISIONS

5.1 INTRODUCTION

The primary focus of this research was to develop a comprehensive production planning model which encompassed the entire integrated value added manufacturing process. The purpose behind this was to ensure that production policies of the value added process are allowed to influence the decisions of bucking and sawing in producing rough stock for the value added facility. Yet the question exists as to how significant is the influence of the value added production decisions on the bucking and sawing decisions.

5.2 PROCEDURES AND METHODOLOGY

In investigating this question, analyses were made using the revised SPCM and the VAF LP model separately, Case 1, and then combined, Case 2. By comparing the results of the models run separately with those of the combined run, it is possible to gauge the effect the value added process has on bucking and sawing decisions.

The revised SPCM was applied first. The results of this run were a bucked log distribution and a rough product distribution. The controlling input parameters were a set of rough product values and production targets for some products. Over and under production penalties were applied such that a feasible rough stock product mix was achieved with minimum penalty.
The resulting rough product mix was then used as the input rough stock mix for the stand-alone VAF model. This run was made to generate the value added product mix and the associated production costs and revenues. The costs and revenues were combined with the raw material and production costs incurred with the SPCM run to produce an overall financial statement for the two runs combined.

The combined model was then run. In this case, value added production was controlled by applying targets with over and under production penalties to the value added products themselves, rather than the rough products as with the SPCM run alone.

5.3 INPUT PARAMETERS

Model input parameters are consistent with the mill’s current operating parameters. These parameters include stem raw material mix, product dimensions, saw kerfs, machine production rates, value added process options and yields, operating costs and product values.

The rough product values used in the SPCM stand-alone run were provided by the mill personnel. These rough product values are based on a simplified weighted average of the yields and values of the subsequent value added products derived from each rough product. These values are used as guidelines by the mill personnel in planning the sawmill’s production of rough material. If only the two separate models were available, these values would be used in the SPCM.

The planning period for both cases was one month. This was defined by limiting the operating hours of the two sawmill breakdown lines to the number of available operating hours in one month.
5.4 RESULTS AND DISCUSSION

The results of the two cases are summarized in the series of tables below. Net revenues for the two cases can be found in Table 1. Net revenue for Case 2 exceeds the net revenue of Case 1 by 20%. These results suggest that the VAF portion of the model has considerable influence on decisions made on the bucking and sawing decisions.

Table 2 lists the bucked log distributions by length for Cases 1 and 2. In Case 2, the proportion of 16 foot saw-logs nearly doubles. (Note the differences between the volume of raw material used from Table 1 and the total volume sawn for both cases is attributable to trim-loss during the bucking process).

As is to be expected, the significant increase in the proportion of 16 foot logs in Case 2 is reflected in a significant increase in the volume of 16 foot lumber. Rough lumber distributions for both cases are listed in Tables 3 and 4.

Table 1: Operating Statements

<table>
<thead>
<tr>
<th>Operating Statement</th>
<th>Case 1 Volume</th>
<th>Revenues</th>
<th>Case 2 Volume</th>
<th>Revenues</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAP Sales (m3)</td>
<td>11571</td>
<td>$3,238,117.46</td>
<td>12152</td>
<td>$3,538,098.43</td>
</tr>
<tr>
<td>Chips (Tons)</td>
<td>13349</td>
<td>$140,167.10</td>
<td>14147</td>
<td>$148,542.52</td>
</tr>
<tr>
<td>Total Revenues</td>
<td>$3,378,284.56</td>
<td></td>
<td>$3,686,640.95</td>
<td></td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RawMaterial (m3)</td>
<td>28143</td>
<td>$(844,284.02)</td>
<td>28659</td>
<td>$(859,781.09)</td>
</tr>
<tr>
<td>Sawmill (hrs)</td>
<td>720</td>
<td>$(600,120.00)</td>
<td>720</td>
<td>$(600,120.00)</td>
</tr>
<tr>
<td>Drying (hrs)</td>
<td>2430</td>
<td>$(48,608.80)</td>
<td>2342</td>
<td>$(46,836.03)</td>
</tr>
<tr>
<td>Dry-Sorting (hrs)</td>
<td>475</td>
<td>$(403,342.51)</td>
<td>464</td>
<td>$(394,304.15)</td>
</tr>
<tr>
<td>Moulding (hrs)</td>
<td>379</td>
<td>$(28,460.15)</td>
<td>480</td>
<td>$(36,000.00)</td>
</tr>
<tr>
<td>Total Costs</td>
<td>$(1,924,815.49)</td>
<td></td>
<td>$(1,937,041.26)</td>
<td></td>
</tr>
<tr>
<td>Net Revenue</td>
<td>$1,453,469.07</td>
<td></td>
<td>$1,749,599.69</td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Saw-log Distributions

<table>
<thead>
<tr>
<th>Case</th>
<th>Length (feet)</th>
<th>10</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>16</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td></td>
<td>3413</td>
<td>4702</td>
<td>6562</td>
<td>4094</td>
<td>9140</td>
<td>27132</td>
</tr>
<tr>
<td>Case 2</td>
<td></td>
<td>1823</td>
<td>1736</td>
<td>2760</td>
<td>2741</td>
<td>18305</td>
<td>27366</td>
</tr>
</tbody>
</table>

The reason for this significant increase in length is attributable to two factors. One is the fact that the longer the piece length the more efficient is production. The other is product price premiums for longer lengths. The mill is not overly concerned with product lengths; consequently, the product values used in both cases were constant for all lengths of a given dimension. Therefore, it appears there is considerable benefits to be achieved by improving production efficiency in the value added facility by increasing length. The model responded by bucking heavily to 16 foot.
Table 3: Case 1 Rough Product Distribution by Volume ($m^3$)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Length(Feet)</th>
<th>10</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>16</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>25x75</td>
<td>14</td>
<td>1</td>
<td>12</td>
<td>16</td>
<td>167</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>25x100</td>
<td>102</td>
<td>4</td>
<td>75</td>
<td>12</td>
<td>42</td>
<td>235</td>
<td></td>
</tr>
<tr>
<td>25x110</td>
<td>345</td>
<td>483</td>
<td>449</td>
<td>375</td>
<td>340</td>
<td>1992</td>
<td></td>
</tr>
<tr>
<td>25x125</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>25x150</td>
<td>16</td>
<td>63</td>
<td>50</td>
<td>46</td>
<td>54</td>
<td>229</td>
<td></td>
</tr>
<tr>
<td>30x75</td>
<td>18</td>
<td>14</td>
<td>45</td>
<td>99</td>
<td>114</td>
<td>290</td>
<td></td>
</tr>
<tr>
<td>30x110</td>
<td>174</td>
<td>42</td>
<td>65</td>
<td>42</td>
<td>50</td>
<td>373</td>
<td></td>
</tr>
<tr>
<td>30x125</td>
<td>49</td>
<td>89</td>
<td>81</td>
<td>81</td>
<td>9</td>
<td>309</td>
<td></td>
</tr>
<tr>
<td>30x150</td>
<td>22</td>
<td>29</td>
<td>55</td>
<td>7</td>
<td>33</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td>40x75</td>
<td>13</td>
<td>93</td>
<td>61</td>
<td>68</td>
<td>588</td>
<td>823</td>
<td></td>
</tr>
<tr>
<td>40x100</td>
<td>64</td>
<td>117</td>
<td>134</td>
<td>120</td>
<td>239</td>
<td>674</td>
<td></td>
</tr>
<tr>
<td>40x110</td>
<td>209</td>
<td>350</td>
<td>397</td>
<td>242</td>
<td>490</td>
<td>1688</td>
<td></td>
</tr>
<tr>
<td>40x125</td>
<td>46</td>
<td>134</td>
<td>134</td>
<td>45</td>
<td>89</td>
<td>448</td>
<td></td>
</tr>
<tr>
<td>40x150</td>
<td>206</td>
<td>314</td>
<td>606</td>
<td>336</td>
<td>533</td>
<td>1995</td>
<td></td>
</tr>
<tr>
<td>40x200</td>
<td>477</td>
<td>338</td>
<td>277</td>
<td>172</td>
<td>269</td>
<td>1533</td>
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</tr>
<tr>
<td>63x125</td>
<td>60</td>
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<td>201</td>
<td>57</td>
<td>144</td>
<td>576</td>
<td></td>
</tr>
<tr>
<td>63x150</td>
<td>121</td>
<td>242</td>
<td>423</td>
<td>121</td>
<td>303</td>
<td>1210</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1943</strong></td>
<td><strong>2427</strong></td>
<td><strong>3065</strong></td>
<td><strong>1843</strong></td>
<td><strong>3468</strong></td>
<td><strong>12746</strong></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1: Rough Product Distributions

Table 4: Case2 Rough Product Distribution by Volume ($m^3$)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>10</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>16</th>
<th>Total Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>25x75</td>
<td>59</td>
<td>35</td>
<td>60</td>
<td>41</td>
<td>130</td>
<td>325</td>
</tr>
<tr>
<td>25x100</td>
<td>45</td>
<td>2</td>
<td>4</td>
<td>11</td>
<td>261</td>
<td>323</td>
</tr>
<tr>
<td>25x110</td>
<td>157</td>
<td>36</td>
<td>87</td>
<td>96</td>
<td>37</td>
<td>413</td>
</tr>
<tr>
<td>25x125</td>
<td>23</td>
<td>17</td>
<td>43</td>
<td>47</td>
<td>0</td>
<td>131</td>
</tr>
<tr>
<td>25x150</td>
<td>2</td>
<td>8</td>
<td>11</td>
<td>7</td>
<td>19</td>
<td>47</td>
</tr>
<tr>
<td>30x75</td>
<td>6</td>
<td>19</td>
<td>7</td>
<td>3</td>
<td>162</td>
<td>197</td>
</tr>
<tr>
<td>30x110</td>
<td>12</td>
<td>16</td>
<td>24</td>
<td>1</td>
<td>217</td>
<td>270</td>
</tr>
<tr>
<td>30x125</td>
<td>5</td>
<td>12</td>
<td>29</td>
<td>3</td>
<td>3</td>
<td>51</td>
</tr>
<tr>
<td>30x150</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>40x75</td>
<td>33</td>
<td>81</td>
<td>56</td>
<td>29</td>
<td>808</td>
<td>1008</td>
</tr>
<tr>
<td>40x100</td>
<td>175</td>
<td>122</td>
<td>221</td>
<td>379</td>
<td>3931</td>
<td>4828</td>
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<td>40x110</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>40x125</td>
<td>59</td>
<td>22</td>
<td>68</td>
<td>28</td>
<td>108</td>
<td>285</td>
</tr>
<tr>
<td>40x150</td>
<td>15</td>
<td>26</td>
<td>47</td>
<td>49</td>
<td>149</td>
<td>286</td>
</tr>
<tr>
<td>40x200</td>
<td>96</td>
<td>224</td>
<td>220</td>
<td>308</td>
<td>727</td>
<td>1576</td>
</tr>
<tr>
<td>63x125</td>
<td>272</td>
<td>179</td>
<td>422</td>
<td>373</td>
<td>710</td>
<td>1955</td>
</tr>
<tr>
<td>63x150</td>
<td>10</td>
<td>22</td>
<td>36</td>
<td>39</td>
<td>196</td>
<td>303</td>
</tr>
<tr>
<td>Total</td>
<td>970</td>
<td>823</td>
<td>1339</td>
<td>1413</td>
<td>7468</td>
<td>12014</td>
</tr>
</tbody>
</table>
With respect to products, the most notable difference is that there was no 40x110 produced in Case 2. The majority of 40x110 rough product is further manufactured into 2x4 dimension lumber; however, the 40x100 is manufactured into 2x4 as well. As a result, with the 40x110 there is significant volume lost to moulder shavings in the conversion process relative to the 40x100. Therefore, it appears that VAF yield information in the combined model has considerable influence on the sawing decisions for this particular product.

It seems clear that in this study, that decisions in the value added facility have significant influence on bucking and sawing decisions. However, in this study the set of rough product prices used to drive the SPCM in Case 1 were based on a simplified weighted average of the prices and yields of products derived from the respective rough products. These prices do not reflect the advantages in production efficiency with longer lengths nor do they consider the detailed yield information associated with the litany of value added options. Furthermore, there was usually only one value added option for each product. It is likely, with prices derived from detailed weighted average calculations, the differences between Cases 1 and 2 would be less significant and thus the benefits of using a combined model would be less significant and perhaps leaving the VAF portion of the LP model unnecessary.

Yet carrying out these detailed calculations is a tedious task in itself. One of the objectives of developing these models was to help mill personnel save time. If the VAF portion of the LP model eliminates the time necessary for mill personnel to carry out the calculations required for product price calculations, it is at least contributing to this
objective. Furthermore, should the value added decisions become more complicated with more options per rough product and should machine capacity become an issue, the VAF portion of the LP model becomes more beneficial.

5.5 CONCLUSION

In considering the results of this analyses, it seems apparent that production decisions in the value added facility can have significant influence on production decisions within the integrated production planning model, given that the prices used to drive the sawmill model alone were a simplified set of weighted prices. If a more detailed set were used, perhaps the influence would be less significant. Nevertheless, having the VAF portion of the integrated model may at least help in saving time for mill personnel by eliminating the need to conduct detailed price calculations to determine the values of the rough products to drive the sawmill portion of the model if it were used alone.

6. CONCLUSION

The value added sector of the forest products industry continues to evolve. This is an effect of members of the forest industry responding to pressures to seek out opportunities to squeeze more value from a resource which is growing in cost. In seeking more value comes the complexity of management decisions in the value added manufacturing process. This complexity has hindered the performance of the industry.

Two models were developed to assist managers in the value added sector in their production planning decisions. The first model is designed for independent value added facilities and assumes raw materials are purchased from outside sources. The second model is designed for integrated value added facilities with the ability of producing their
own VAF raw materials from their primary operations. The second model is an extension of the revised SPCM model described by Maness and Adams. The significance of this model is that it is a comprehensive model encompassing the entire value added manufacturing process from long-log to finished products, thereby allowing production policies in VAF manufacturing to affect the combined optimization of bucking and sawing in sawmilling.

In exploring the influences that VAF policies may have on sawmilling decisions, an analysis was conducted which compared the use of the integrated model with the SPCM model and the independent VAF model used separately. The results of this analysis indicated that VAF production policies can have a significant influence on production decisions in the sawmill.

The extent of the research in value added production planning presented here fell short of practical testing of the developed models. Practical testing will answer the question of how useful the models are in real applications and how easily they can be used and understood by mill personnel with little or no background in mathematical programming.
REFERENCES


