WM-07

Research to Improve the Performance of the Primary Supply Chain

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ABSTRACT: An overview of the primary forest products supply chain has been described that has served as the foundation of ongoing and future supply chain planning research at Oregon State University. This overview describes 5 component system that includes supply management, a demand management, a planning and scheduling system, execution and reporting and knowledge collection components. Following the completion of this overview, new components are being developed that include a annual harvest scheduling component that assigns logging crews to units and schedules them through the year. The second component used Kriging estimates of volume to improve the order fulfillment process. We believe that additional components can be developed to improve the performance of the primary forest products supply chain.

INTRODUCTION

Supply chain management has become one of the dominate business paradigms for operations management. Typically, supply chains are defined as a network of organizations performing a variety of roles from customers, logistic service providers, manufacturing centers and raw material suppliers. The goal of supply chain management is to develop a collaborative relationship across these organizational boundaries that will improve operational efficiency and customer service.

In the United States, the forest products industry has adopted supply chain management techniques for manufacturing facilities and ignored the raw material supply center portion of the supply chain. Recently, Mead Corporation began the implementation of their $125 million supply chain application all eight of its divisions (Shaw 2000). The system emphasizes operations that begin in the mill and ends with the customers and ignores forest harvest activities.

Since the 1980's, the primary forest products portion of the forestry supply chain has emphasized increasing productivity as a method to reduce logging costs (Greene et al. 2004). Because there have been significant increases in harvesting capacity which has resulted in low utilization rates (approximately 65%), additional costs of nearly US$ 1 per ton have been added to the cost of the raw material. Ulmer et al. (2004) recommended that improved coordination between harvesting and mills could create a competitive advantage by developing a more reliable control of logging and inventory costs.

This paper describes ongoing research, conducted by the Department of Forest Engineering, to improve the coordination of the primary forestry supply chain with the larger forest products supply chain. The initial work was to define a framework that characterized the system as is shown in Figure 1 (Boston, 2004). This system describes five major components of the primary forest products supply chain: supply management; demand management; planning and scheduling; execution; and knowledge and reporting. The systems spans from the strategic time frames, often two to three rotations, to the weekly planning schedule. The remainder of the project will focus on the annual and weekly planning levels that coordinate raw material supply and harvesting capacity with customer demands.

ANNUAL HARVEST PLANNING

The goal of this research program has been to develop systems to improve the economic and service performance levels of the supply chain. Two components have been developed to achieve these results. The first component is for the annual planning. The goal of the annual planning is to allocate harvesting crews to cutting units in such a manner that allows for the maximum utilization of crews. That system allows (is allows the right word here?) for lower logging costs through a reduction in the risk for downtime for the harvesting contractor while trying to best meet the markets demands. The mathematical formulation is similar to that presented by Chung and Sessions (2003). The objective function computes the revenue resulting from the volume of products sold to customers less the harvesting and transportation costs from the harvesting unit. The model allows unfulfilled customer demand by penalizing the objective function at whatever value for loss of market share while surplus volume penalizes the objective function value for the additional handling costs, cost of capital and expected product downgrades. The model charges a higher initial move-in cost due to the longer distances required to move-in and the higher constraints required for highway-legal moves. Once in a crew is already in an operating area, moving costs are much lower.

There are a limited number of constraints in the problem. Each harvesting-unit may be logged by just one crew. Each crew is limited to working in one harvesting-unit per period. A crew must remain in a harvesting-unit until it has completed the unit.

Some units have an additional constraint that prevents them from being logged during the winter months to protect soil resources. The data required by the model are:

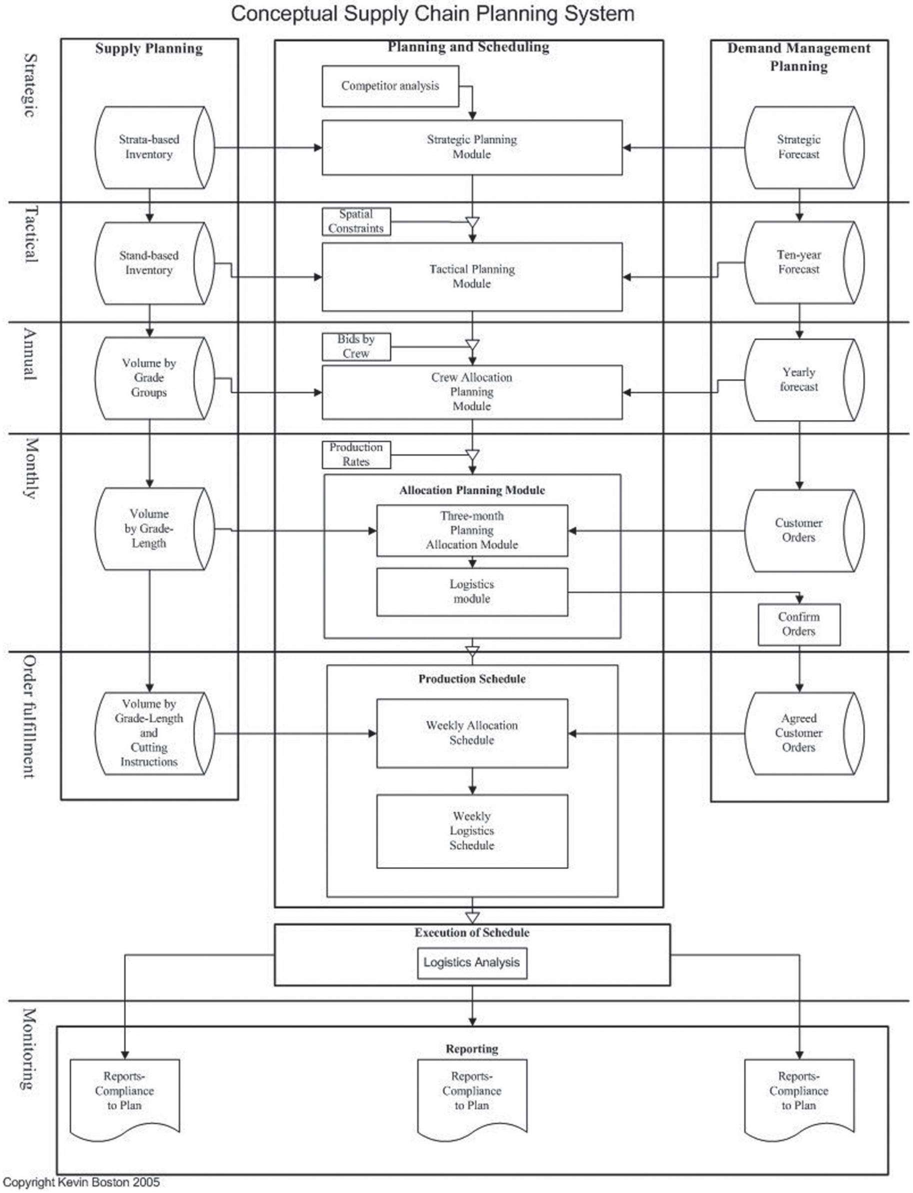

Figure 1. A framework for the primary forest products supply chain planning system (Boston, 2004).

1.Logging cost per unit for each crew – the model recognizes the differences in harvesting crew configurations

2.Productivity per unit for each crew – the model recognizes the differences in the harvesting crews historical work habits.

3. Volume by grade class per unit from the inventory system.

4. Demand by grade class per week generated from annual forecasts.

5. Transportation costs to each customer per unit based on a distance matrix.

Due to the large combinatorial size of the problem a heuristic procedure was used to generate the solutions. Chung and Sessions (2003) used simulated annealing. This method used tabu search, but any of the better performing heuristic procedures could be used such as genetic algorithms, threshold acceptance or great deluge could be used to solve this type of problem as the problem attempts to solve a series of

Preliminary results show that the algorithm is able to assign harvesting crews to units to promote the continuous work for harvesting crews to better capture the untapped capacity described by Greene et al. (2004) and Ulmer et al. 2004.

WEEKLY ORDER FULFILLMENT PROCESS

The second area of research has concentrated on the development of a solution to enhance a firms' order fulfillment performance. This problem is more relevant to market environments such as New Zealand, where logs are made for a particular order and not to a general market with industry wide standard lengths, such as that found in western US markets (Penfold 2003). The advantage of a cut-to-order system is that large log inventories that may not meet the needs of a particular market are reduced or the potential losses from sapstain are minimized.

There are two goals for this system. One is to improve the quality of volume estimates in the stand and the other is to improve the order fulfillment process by matching the current harvesting location within the stand to the volume required by the customer. It achieves this goal by utilizing a spatial estimation procedure, for this example, Kriging is used to prepare a volume surface that will produce a higher degree of precision of the estimated total stand volume and will give a location of volume estimates throughout the stand. This spatially explicit volume information can then be used aid the order fulfillment process.

Until recently, there has been little work that examines the benefits of using spatial data procedures to reduce the variation in production estimates. Murphy et al. (2004) found that they could achieve a 17 to 22 percent increase in stand value, from a 3 percent sample of a radiata pine (Pinus radiata D. Don) stand in New Zealand. The authors concluded that harvest manager's ability to capitalize on within stand variation (harvest pattern selection) and the inability control order book requirements (constraints), it might be possible to reduce variation in production estimates by simply modifying the harvest pattern.

To illustrate this system, a three hectare stem map of a stand located in Maine was used (Walthall et al., 1993). The study site is a three hectare rectangle (150m × 200m) located 56 km north of Bangor, Maine in Penobscot County (45 12'N, 68 44'W). Due to the restriction of our harvest machine routing example to ground based machinery, this dataset was desirable because of the flat to gently rolling topography. An example with a cable operation would have been inappropriate due to the relaxation that we allowed the harvester to relocate to any harvest block within the study area rather than restrict the harvester to a single or continuous path.

The stems were then bucked into log lengths of four meters, to a 2 cm top, using the taper equation presented by Kozak et al. (1968). If the stem could not be cut into a round number of standard log lengths, any remaining stem length was bucked into a short log no less than two meters. Stems were merchandised with a stump height of 0.3 m and each log included 0.2 m of trim. For each log in the stem, the starting and ending height of the log, the nominal length and the actual length (nominal length plus trim), the small and large end diameters, and the Smalian volume was recorded. The volume of all logs with a small end diameter over 10 cm were totaled and assigned as the sawlog volume for that stem record. The log volumes for those logs with a small end diameter less than 10 cm were tallied as pulp volume.

A comparison between the spatial and non-spatial sampling method was made using a set of 0.01 ha fixed-radius plots on a 22.2 m × 16.6 m triangular pattern to simulate a typical preharvest sample. The distance of each stem to the center of each plot was computed to determine which trees would be located within a given plot. Once it was determined which trees were associated with each plot, the total sawlog volume on each plot was computed. A triangular pattern was installed to develop the spatial estimation because it was reported by Webster and Oliver (2001) to give a better estimation of the variagram. The plot, trees and those trees selected for inclusion in the sample are shown in Figure 2.

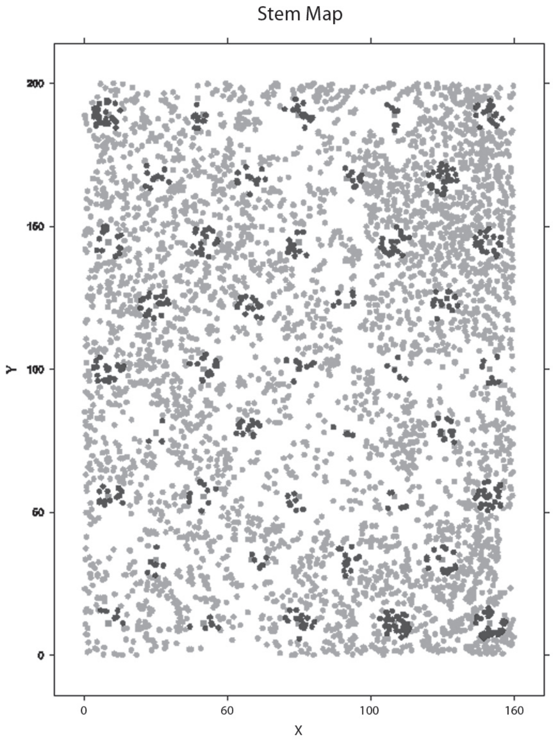

Figure 2. Plot locations with sampled stems where the units are in meters. The light dots represent all individuals in the population and the dark dots represent those trees included in the fixed-radius plots. The squares are located at the fixed-area plot centres.

Since we had few data points to estimate a variogram, we did not attempt refine our variogram by combining models, examining periodicity or anisotropy. The variogram was then used to estimate the sawlog volumes in 10 m × 10 m cells for those cells that did not contain sample points. To compare the estimated variance for the total predicted sawlog volume, we used the methods described by Kim and Baafi (1984) to combine the variance estimates from all the individual predicted cells.

Since the goal of the study was to determine if the inclusion of spatial estimates in a tactical harvest operation was beneficial, we decided to evaluate the Kriging estimates by comparing the deviations between a generated random demand function for a 12 day production period and the predicted sawlog volumes that would result from a spatially explicit harvest pattern.

Once we obtained volume estimates for all unsampled 10 m × 10 m areas, we then divided the area into twelve 50 m × 50 m daily production blocks to simulate a harvest operation. The demand levels represented the sawlog volume required by a fictitious sawmill and were developed so that the sum of the daily demand levels were equal to the total volume produced from the entire study area. To make our demand levels as realistic as possible, the average production required was the sum of the total volume for the area divided by 12 production days. We varied the production requirements from a minimum of 50 m^3 to 140 m^3 per day with a standard deviation of 25 m^3 per day. The daily demand levels are presented in Table 2. To obtain both the combined predicted sawlog volume and the associated variance estimates for each harvest block, we again used the methods as described by Kim and Baafi (1984) to combine the variance estimates from the individual predicted cells for the 12 harvest blocks.

To determine the daily production without the benefits of spatial information, a serpentine path was placed over the 12 blocks and the daily production levels were obtained by summing the sawlog volume for all cells within each cutting block. Then, to obtain an optimal harvest pattern, simulated annealing (Metropolis et al., 1953) was used to find the harvest pattern that minimized the sum of the squared differences between the demand curve and the estimated daily production resulting from a particular harvest pattern. Using two-opt moves and a logarithmic cooling schedule, 50000 iterations were performed for each level. Once the optimal harvest pattern was determined, the daily harvest areas were labeled with a number from one to twelve for visual examination and a plot of the demand, predicted supply and actual supply of sawlog volume was generated to examine the results for any anomalies.

RESULTS

The total predicted sawlog volumes for both the non-spatial and spatial sampling were similar to the actual sawlog volume for the area. The actual total sawlog volume for the area was 1243.3 m^3 with the estimated sawlog volumes for the non-spatial and spatial sampling methods being 1185.5 m^3 and 1196.2 m^3, respectively. The variance estimate for the total predicted sawlog volume from the spatial method was 1067.8 m^3. This was less than one percent of the estimated variance of 74403.4 m^3 for the non-spatial method. We generated the 95 percent confidence limits for the total predicted sawlog volume for both the non-spatial and spatial sampling methods and present them graphically in Figure 3.

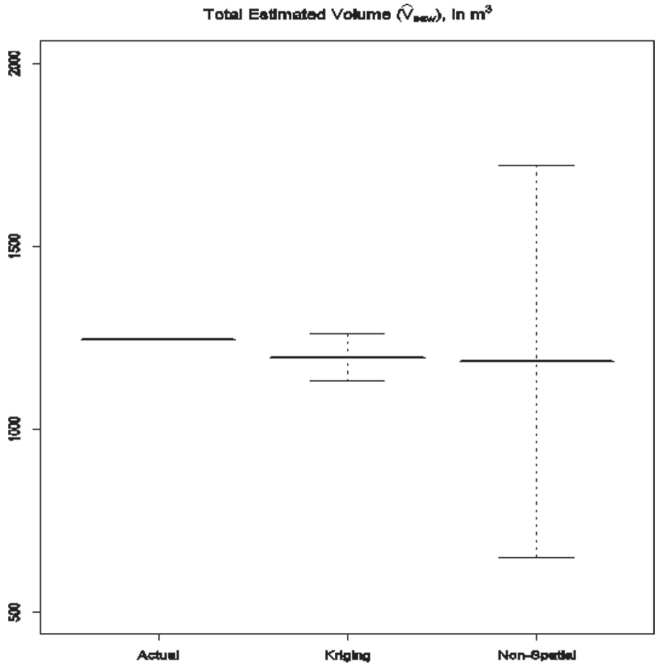

Figure 3. Total estimated sawlog volumes for both sampling methods with 95% confidence limits.

Table 2. Predicted and actual production levels for non-spatial (serpentine harvest pattern) and spatial (optimal harvest pattern) sampling methods.

Production	Customer	Non-Spatial (Serpentine) Pattern			Spatial (Optimal) Pattern		
Period	Demand	Predicted	Actual	Difference	Predicted	Actual	Difference
1	115	103.6	70.9	11.4	99.3	62.0	15.7
2	115	103.6	126.9	11.4	99.8	110.3	15.2
3	115	103.6	106.4	11.4	92.9	106.4	22.1
4	50	103.6	110.3	-53.6	69.3	53.6	-19.3
5	60	103.6	62.0	-43.6	87.0	113.0	-27.0
6	100	103.6	113.0	-3.6	87.0	70.9	13.0
7	105	103.6	91.1	1.4	88.2	105.5	16.8
8	120	103.6	130.4	16.4	129.5	154.0	-9.5
9	140	103.6	154.0	36.4	134.5	119.1	5.5
10	120	103.6	53.6	16.4	127.7	130.4	-7.8
11	110	103.6	105.5	6.4	88.5	91.1	21.5
12	110	103.6	119.1	6.4	92.5	126.9	17.5

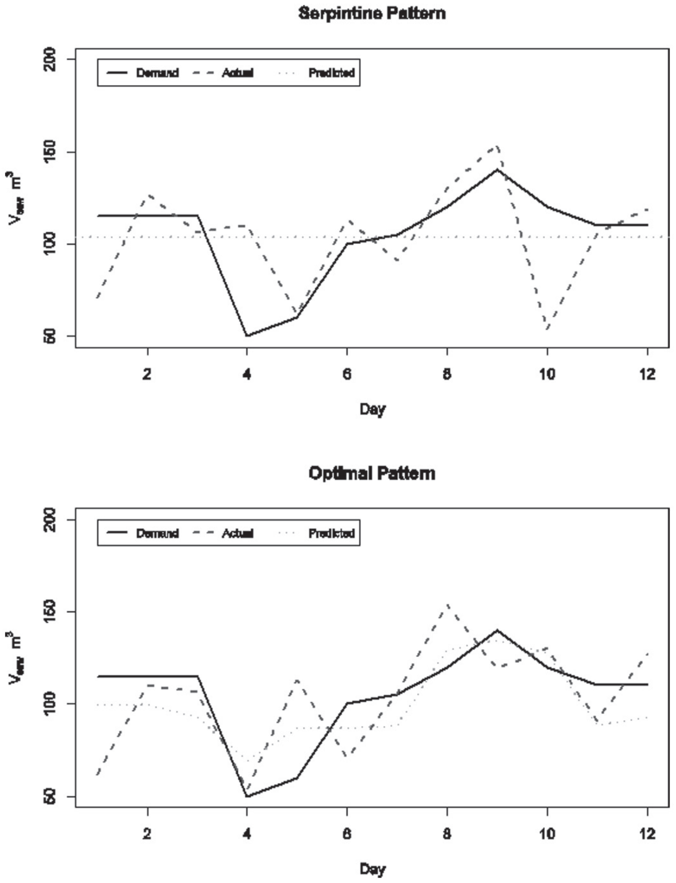

Figure 4. Predicted and actual production levels for non-spatial (serpentine harvest pattern) and spatial (optimal harvest pattern) sampling methods.

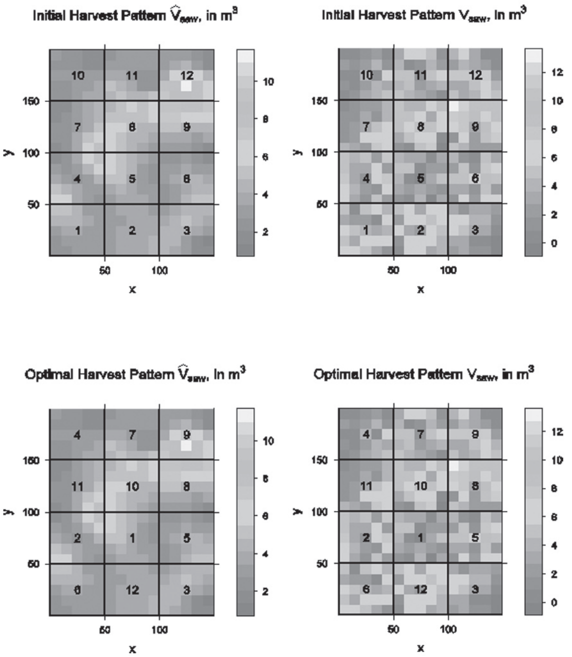

Figure 5. Harvest patterns for the non-spatial sample (top) and the spatially explicit sample with the optimal harvest pattern (below). The left images contain the predicted sawlog volumes in the study area and on the right are the actual sawlog volumes. The numbers represent the harvest order.

The resulting estimated daily sawlog volume production for the two sampling methods differed as well. Since there was no spatial information for the non-spatial sampling method, the predicted daily production was simply the total estimated sawlog volume divided by the total number of operating days. The estimated average daily production from the non-spatial sampling method was 103.61 m^3. The estimated daily production for the spatially explicit sampling method ranged from a minimum of 69.26 m^3 to a maximum of 134.51 m^3 and the actual daily production from the spatial sampling method ranged from 53.61 m^3 to a maximum of 154.01 m^3.

The sum of the squared deviations between required and produced volumes for the non-spatial harvest pattern was 7123.27, or more than twice the sum of the squared differences for the spatially explicit harvest pattern of 3469.15. A table of the predicted and actual production for the initial harvest pattern and the optimal harvest pattern is presented in Table 2. Figure 4 presents a chart of the harvest production for the non-spatial and spatial (optimal) harvest production and Figure 5 graphically displays the non-spatial and optimal harvest patterns.

DISCUSSION

While the ability to minimize the differences between the consumer's demand and the supplier's production is an important part of any attempt to manage a supply chain, there are a multitude of issues that prevent the development of a method to minimize the deviation between the demand and production of log products. Initially, it was assumed a rectangular sampling grid would yield a sufficient variogram such that little effort would be needed to obtain the Kriging results. In retrospect, the major task for this study was simply obtaining an adequate variogram. Once a variogram was obtained, producing a map of the sawlog volume and resulting variance estimates for the daily cutting blocks was trivial with the software we used.

Lead times that determine optimal delivery for logs will be dictated by transportation conditions, consumer capacity and storage requirements. By reducing the deviation between the consumer demand requirements and the estimated production levels, we were able to demonstrate an advantage of spatially explicit harvest operations. By reducing the lead time required to deliver logs to the customer, the customer could then reduce or minimizing storage requirements thus allowing them to focus quality improvements elsewhere and ultimately improving revenue.

The future of these systems

These two planning system are in their original development, but we believe that they can be used to help shift to a demand driven organization that can will be used to improve the efficiency of the forest operations as well as improve customer service, and allow the firm to enhance its competitive position.

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