Log sawing optimisation directed by market demands

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Abstract

Throughout the forest-to-mill supply chain there are many instances where provision of accurate data can enhance decision-making and profitability. Software tools designed to aid decision making include FOLPI, MARVL and AUTOSAW. FOLPI can be used to optimise stand harvest scheduling and log allocation to markets, MARVL provides optimal log bucking solutions that maximise the total value of logs obtainable from each stem, and AUTOSAW can provide optimal sawing solutions that maximise total lumber volume or value yields.

In generating optimal volume or value solutions, both MARVL and AUTOSAW assume open market conditions. Whether cutting stems into logs, allocating logs to processes, or sawing logs into boards, key drivers in the solution process should take account of market demand. While FOLPI already addresses this at the strategic and tactical levels, work is currently underway to include market demand in AUTOSAW.

This paper reports on a prototype system that is implemented and tested in the AUTOSAW log sawing simulation system. The "product optimisation" system dynamically controls production to fulfill lumber orders by feedback from regularly updated production tallies.

Graded yield from volume-, value- and product-optimised solutions was generated from the simulated sawing of pruned *Pinus radiata* logs using three orderbooks that consisted of lumber orders specified by grade and volume. In each case, the prototype required fewer logs to satisfy each orderbook than either volume- or value- optimisation. Furthermore, over-production of unordered products was significantly reduced. In practical terms, these results suggest that potential gains at the sawmill may be obtained through the purchase and processing of fewer logs to meet the same demand and an accompanying reduction in storage requirements for surplus products.

Introduction

Lumber production from radiata pine plantations in New Zealand has steadily increased over the past decade. Currently about 3 million cubic metres of lumber is produced annually from nearly 6 million cubic metres of roundwood. This is expected to increase over the next 20 years providing opportunities for increasing profitability throughout the forest to mill value chain.

At the harvesting level, decision support systems

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(DSSs) have been developed to aid value-addition. A prime example is MARVL, Method of the Assessment of Recoverable Volume by Log-types (Deadman and Goulding, 1979). MARVL uses a dynamic programming algorithm to simulate the log merchandising (bucking) of the trees measured in inventory sample plots in order to accurately predict the potential yield of log-products at harvest. With the use of remote sensing in conjunction with operations research (OR) techniques, better DSSs are expected to result (Goulding 1999). OR techniques, and in particular linear programming (LP) methods, have a major role in FOLPI, the Forest-Oriented Linear Progamming Interpreter (Garcia 1984, Manley et al 1991).

"OR is the systematic application of quantitative methods, techniques, and tools to the analysis of problems involving the operation of systems. The objective of OR is to improve the effectiveness of the system as a whole" (Daellenbach and George, 1978). Generally this involves optimising some operation of a system, such as minimising production costs, maximising profits, or minimising wastage. At many sawmills the traditional goal has been to increase log conversions by maximising lumber volume outturn. To this end, workers are often rewarded on mill throughput and lumber production. Although this may provide an incentive to mill workers, it encourages quantity over quality. It is from the recognition of quality that value-added solutions can be obtained. However the pursuit for quality alone can lead to other pitfalls. Production of large volumes of high-valued products will add to the base-line only if there is sufficient market demand. The aim of this project was to take these factors into consideration and maximise lumber value while considering demand for products of specified qualities (grades). We have called this "product optimisation".

In the prototype product optimisation system a grade-sawing pattern (Figure 1) is used for sawing pruned logs. Grade sawing, although characterised by relatively slow throughputs due to log turning, involves sawing around the log, with the aim of maximising the grade yield of high quality boards. As such, it is well-suited to the sawing of pruned logs. In contrast to grade sawing are live sawing, quarter sawing, and cant sawing (also depicted in Fig 1). Live sawing patterns have the advantage that they are fast and minimise log turning. However, they tend to produce a lot of spike knots, as opposed to face knots, so rely on good edging and trimming practices to improve grade recovery. The quarter sawing pattern is a specialised cutting pattern that finds application with hardwoods as it is designed to show off the grain of decorative timbers. The log is primarily sawn into quarters and each quarter is then broken down to produce boards. Its main disadvantage is that it is

slow. The fourth cutting pattern, cant sawing, is applicable to both pruned and unpruned logs and suits high production mills, especially those with a gangsaw downstream.

The cutting patterns produce flitches that require edging and trimming. Sawing simulations with AUTOSAW (Todoroki and Rönnqvist, 1999) have indicated that increases in lumber value of about 13% may be obtained with grade-optimised edging solutions in comparison to volume-optimised solutions. In those simulations, while the same sample of pruned logs were sawn under identical conditions using a live sawing pattern, no consideration was given to market demand for lumber products.

In the work presented here, the sawmill's orderbook that contains a list of customer orders for lumber products by grade and volume is used to direct the optimisation process. Unlike grade- or volume- optimisation systems with constant values, the product optimisation system is based on dynamically changing product values that fluctuate according to the current production levels of the different products.

The product values are automatically calculated by feedback from regularly updated production tallies.

Figure 1: Generic sawing patterns displayed on a schematic representation of a pruned log

Method

A prototype system for linking log sawing optimisation with lumber demand was developed using OR techniques and the solution implemented and tested in a log sawing simulation system, AUTOSAW (Todoroki, 1990). To benchmark performance, comparisons were made with volume- and value/grade-optimised solutions and effectiveness measured in terms of the number of logs processed in order to satisfy demand.

Development of the Optimisation Framework

Mathematical formulation of the product optimisation problem is similar to the volume- and value- optimisation methods used by Todoroki and Rönnqvist (1999). However there is one key difference. Instead of using constant objective function coefficients (cost coefficients), as is the case for many optimisation systems, dynamic cost coefficients are used. Cost coefficients provide the means by which the effectiveness of a system can be measured. Each and every decision or activity has an associated cost or value that is determined from the technology of the problem. In general programming formulations the cost coefficients are constant. They do not change during solution of the problem. In most cases this is practical and is not seen as restrictive, however in the product optimisation system presented here, the cost coefficients are dependant on past levels of production. The coefficients are automatically re-calculated after feedback from production checks and updated regularly during the sawing optimisation process.
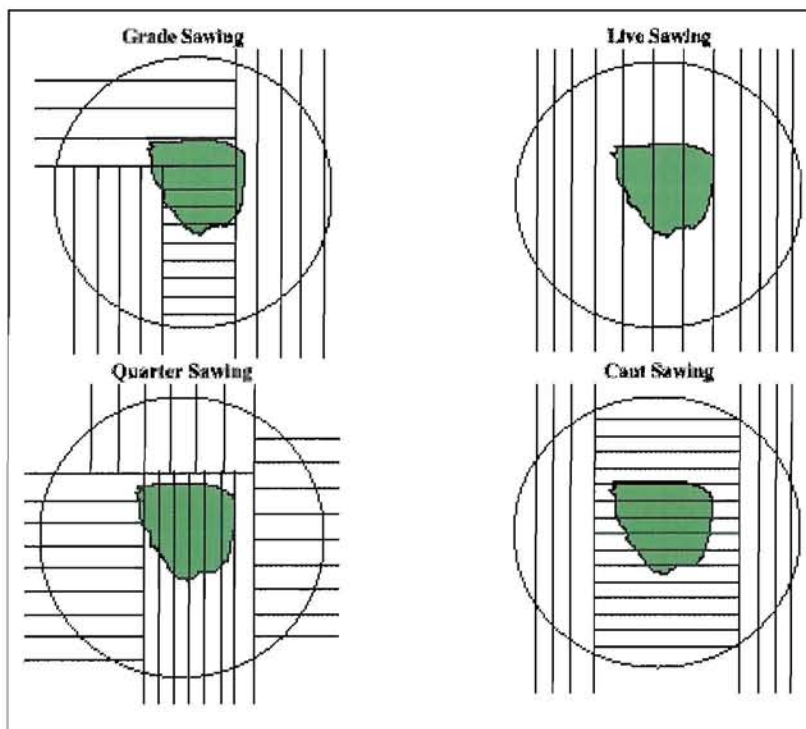
Rönnqvist and Gustafsson (1999) tested the use of dynamic cost coefficients in a wood remanufacturing industry in Sweden. They tested three control strategies, fixed, scaled, and dynamic, for updating cost coefficients for a board cross-cutting operation. The fixed strategy simply assigns a constant coefficient for each product. However once demand is met, the product is removed from the orderbook by setting the coefficient equal to zero. Scaled uses a relative value that is based on the proportion of the current production level for each product. Carefully selected initial product values are required for good solutions (in terms of minimising the number of boards used to meet demand). The dynamic strategy is based on a dynamically changing value where the product values fluctuate according to the current production levels of the different products. The scaled and dynamic strategies demonstrated better results than the fixed strategy. As the success of the dynamic strategy was not as dependant on initial values to the same extent as the scaled strategy, a dynamic approach was chosen for solving the log sawing problem.

Computer Implementation

There were several ways in which the solution methodology could be implemented, and several questions to answer before incorporating the problem within AUTOSAW:
1) What level of detail would be required for the orderbooks?
2) How often should the cost coefficients be updated?
3) How often should production[1] be checked?
   The answer to the first question is largely dependant

on customer product specifications. Some customers place orders, for example, for x cubic metres of timber of one quality (grade), and x m of another; others request timber products by both specific dimensions and grade. As the AUTOSAW cutting routines can be readily set to accommodate product dimensions (and will not cut any product that is not specified) the former orderbook type, consisting of customer demands for differing products by quality and volume was regarded as being sufficient. However, should it be seen to be inadequate, the framework

upon which to extend the problem will have been set.

Cost coefficients could be updated on a piece by piece basis, or flitch by flitch, or log by log, or even after processing a given number of logs. In this case, the log by log option was selected. Tallies of lumber products are also updated on a log by log basis.

The above solution methodology for product optimisation was implemented in AUTOSAW and new procedures added to include orderbooks, dynamically update the cost coefficients, and track production of timber products (i.e. production of boards of differing quality classes).

It is important to note that a board is graded according to its quality as defined by a set of grading rules. Once graded it was assumed that it could not be re-graded (i.e. downgraded). This prevents, for example, a clear board (highest value) being re-graded as box grade (lowest value). In short, this implies that neither the orderbook nor the product optimisation system will be manipulated.

Figure 2: Demand profiles for Orderbook 1 during the sawing process

Sawing Simulations

Simulations were performed for each of the three case studies given by Orderbooks 1, 2, and 3 (Table 1) using four grades: Clear grade products must be free of defects; Select A, allows defects on one face and edge; Knotty allows knots but not pith, and Box allows both knots and pith. Orderbook 1 assumed equal demand for each of the four grades. Orderbook 2 had higher demand for the lower quality Knotty and Box grades, while Orderbook 3 had high demand for both Clear and Knotty, and low demand for Select A and Box grades. A batch of 430 pruned *Pinus radiata* butt logs was made available to each set of simulations.

Data for the pruned logs, that ranged in quality from poor to excellent, had been collected from a series of previous sawing studies (Park and Leman, 1983). While it could be argued that Orderbook 2 should be fulfilled with unpruned, rather than pruned logs, the orderbooks served to test the new algorithms in extreme conditions as well as more regular conditions.

The pruned logs, although not sorted in any particular order, were sawn using the same log sequence for each set of sawing simulations. All logs were sawn with a grade-sawing pattern that "boxed in" the defect core (refer Fig 1) and used identical sawing parameters

Table 1: Orderbooks used in the simulations

Order \ Grade	Demand (m³) by grade			
	Clear	Select A	Knotty	Box
Order 1	35	35	35	35
Order 2	30	20	50	50
Order 3	60	20	50	20

Table 2: Grades and prices (per cubic metre) by width

Grade	Price ($/m³) by width class (mm)		
	50, 75, 100	150, 200	250, 300
Clear: boards with no defects	500	550	650
Select A: defects permitted on one face and edge	400	450	520
Knotty : boards with knots but without pith	200	230	275
Box : boards with pith	170	180	210

Table 3: Number of logs processed to satisfy product demands in each of the Orderbooks.

Sawing Strategy	Orderbook 1	Orderbook 2	Orderbook 3
Volume Optimisation	375	> 430	424
Value Optimisation	378	> 430	409
Product Optimisation	321	332	373

(such as kerfs, number of saws, number of carriage knees, and product sizes).

To benchmark performance, simulations were repeated with volume- and grade/value- optimisation objectives. The value optimisation system invoked the pricelist given in Table 2. Simulation stopped once the last order was fulfilled.

Results

The number of logs used to completely satisfy each orderbook was used as a performance indicator. Results for fulfilling each of the orderbooks are given in Table 3. To fulfill lumber orders in Orderbook 1, the volume-optimisation strategy required 375 logs, value-optimisation required 378 logs, while the new product-optimisation system completed the order with 321 logs. Both volume- and value-optimisation strategies failed to fulfill all orders in Orderbook 2 with the 430 logs that were available for the simulations. However the product-optimisation strategy fulfilled that same order using only 332 logs from the same log source. With Orderbook 3 product-optimisation again provided the best result.

The rate at which orders were filled differed according to orderbook and sawing strategy. This is illustrated in Figure 2 which shows demand profiles for Orderbook 1 during the sawing process. At the onset, demand for each lumber grade is 35m (as given by this orderbook). After each log is processed and production tallies updated the remaining demand is calculated and shown in the figure. The orderbook is fulfilled only when demand for all lumber grades is fulfilled, i.e. when the last demand profile reaches the x-axis, and remaining demand equals zero for all grades. For volume optimisation 375 logs were required to fulfill the entire order. However the demand profile shows that the order for knotty lumber was satisfied after 269 logs had been processed. Thus any knotty lumber produced from sawing the remaining 106 logs, would be additional to re-

quirements and would need to be stockpiled. Excess stocks of Select A and Clear grade timber would also accumulate. With value optimisation, all demand was satisfied after 378 logs had been sawn. As for volume-optimisation, there was a large difference, in terms of the number of logs needed to satisfy demand for the different timber qualities. Thus stockpiles of Knotty, Select A, and Clear grade timber products would also result. On the other hand, with product optimisation all demand was satisfied after processing only 321 logs. Furthermore, very little stockpiling of unordered timber would be necessary as there were only three logs that separated the demand requirements for Knotty grade (first order satisfied) and Box grade (last order satisfied).

Discussion

Results from the three case studies indicate that an optimisation system that regularly tracks and controls lumber production can provide better utilisation of the log supply by reducing the number of logs needed to satisfy given orderbooks. Although down-grading was not permitted in this exercise, downgrading to fulfill unsatisfied demand for lower quality products is an option that could be considered. Potential benefits include: the purchase and processing of fewer logs, and reduced stockpiles of unordered products. Yet further improvements may result if more regular system updates are employed (e.g. piece by piece instead of log by log).

In the cases presented here, although all logs were pruned, they were not sorted in any particular order. This raises the question "Is it possible to satisfy demand with even fewer logs if sorting or selection criteria are applied to obtain the "right" logs?" This poses another interesting question: "How does one select the right log mix?" Further simulations with AUTOSAW could provide some insight into this problem area. Ideally, the development and application of further OR techniques could resolve this issue.

Throughout this paper it has been assumed that it is beneficial to meet orders with as few logs as possible.

However this does not consider economic trade-offs: e.g. it may be more economic to purchase and saw a greater number of lower quality logs than a lesser quantity of high quality logs. Future extensions to the prototype could include a cost-benefit analysis to help the decision-maker and provide better decision support for sawmill and log sawing planners.

More immediate work will see the prototype tested with unpruned logs and with lumber graded accord-

ing to cuttings and visual structural grading criteria, in contrast to the use of pruned logs and appearance grades as presented here.

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