Session 3
Paper (c)

PREDICTING AND CONTROLLING LOG OUT-TURN

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INTRODUCTION

Trees can yield a wide variety of log products at the time of harvest, dependent on the log specifications used by the logging gang and on the decision making when cross-cutting ("bucking") the stem into logs. The amount of merchantable volume of each of the different log types from a logging operation depends both on the characteristics of the trees within the logging coupe or setting, and on the log making process itself. When assessing standing trees prior to harvest in some form of pre-harvest inventory, it is incorrect to assume that the logging coupe contains quantities of the different log types as fixed percentages of the total merchantable volume. Any predictions of log out-turn must take into account the log making process and the specifications of the log-types, see Twaddle and Goulding (1989).

Because the quantities of the log products can be changed in practise, there is ample opportunity for failing to realize the maximum potential value of the stand and optimizing the profitability of the harvest. One of the first studies carried out in New Zealand, Ferrow and McEwen (1979), showed that over a third of the potential value of a sample of trees was unrealized, due to failure in planning to match bucking strategies with stands and markets, and in sub-optimal control of the log making.

Managers can be assisted in meeting their profitability target when provided with:

1) timely, accurate information from a preharvest inventory system

2) short and medium term logging planning and log allocation systems

3) methods of operational control of bucking practise.

OPERATIONAL SYSTEMS

New Zealand forestry has long been involved in studies of methods to optimize value recovery. In 1976 a new pre-harvest inventory system was introduced which incorporated dynamic programming in its analysis routines in order to predict log-product yield as independently of the field assessment procedures as possible. The system, a Method of Assessment of Recoverable Volume by Log-types, MARVL, is now used throughout New Zealand and was originally described by Deadman and Goulding (1979). It has since been extensively upgraded and implemented as MicroMARVL, to run on IBM compatible personal computers (PC's), Deadman (1990). The operational application of the method is described by Goulding et al. (1992) and Goulding (1992).

The inventory data provides part of the information required for marketing, harvest planning and log allocation. Linear programming systems are used operationally in New Zealand plantation forestry, derived from the model FOLPI, Garcia (1984). They have been routinely used for long term yield regulation and the valuation of forestry enterprises. FOLPI has also been modified to integrate long term planning with optimal log allocation to markets, Manley and Threadgill (1991), and to solve the problem of integrating long- and short-term harvest planning, Papps and Manley (1992).

Harvesting New Zealand's plantations is most commonly by tree length extraction and motormanual bucking on skid sites in the forest. Extensive use of MARVL led to disputes over differences between the predictions of product yield and actual realization . The assumption in MARVL that bucking the tree stem to maximize value mimics reality is not always true. In order to distinguish between genuine errors in inventory practise and a failure of logging control to obtain the maximum value from the trees, the Assessment of Value by Individual Stems, AVIS, system was developed, Geerts and Twaddle (1984) and Twaddle and Threadgill (1986). This system measures the sizes and qualities along a tree stem after felling but before bucking, calculates a result using optimal bucking, then compares this to actual practise. Two versions are available, one implemented on a PC in an office to provide a formal auditing facility, the other implemented on a hand-held field computer, the Husky Hunter, to be used out in the forest during logging.

The optimal bucking algorithm used by MARVL and AVIS is that of Pnevmaticos and Mann (1972) extensively modified to provide a full, practical implementation. Both systems can use log length specifications accurate to 0.1 m, (or less, but execution time increases), and pieces of waste of any length can be cut anywhere along the stem. Consideration of the algorithm of Danielsson (1985), whilst not directly applicable to New Zealand conditions, led to improvements in execution time so that even on the CP/M based 8088 processor in a Husky Hunter a tree stem of 40 m could be processed in a few seconds. MARVL implemented on a '486' PC can analyze an inventory consisting of a stratified random sample with double sampling and involving over a thousand trees within a few minutes.

AVIS and MARVL differ in the important respect that AVIS assesses the trees at time of logging and when felled, whilst MARVL assesses standing trees any time up to 15 years before harvesting. AVIS can thus measure quality features directly, and uses interpolation between measurements of upper stem diameters on felled trees. MARVL is a "cruising" system of inventory and predicts the stem diameters on standing trees from individual tree taper equations. However, apart from differences in the tree data due to this aspect, the results of predictions of log products from a stem by the two programs should be identical.

MARKET CONSTRAINTS

Both AVIS and MARVL optimise value on individual stems, unconstrained by market or operational constraints. There are situations where the optimal bucking pattern applied to a stand will result in the volumes of one or more of the log types being produced in quantities that are unacceptable to the current market. Murphy (1993) described some of the more common constraints. In brief, constraints can be divided into:

1) levels of volume, for example, a minimum (or maximum) volume of 10,000 m^3 of short sawlogs.

2) average piece size, for example, a minimum average small end diameter (SED) of 30 cm.

3) mix of logs, for example, at least 70% of the supply in long lengths.

4) time constraints, for example, deliver 5,000 m^3 by Friday.

5) suitable equipment and gangs for the stands, for example, steep country logging.

6) other operational constraints, for example, continuity of supply, or gang availability.

Several authors have suggested methods for assessing the potential log yield of a forest, allocating stands, logs and markets, and controlling log out-turn to yield optimal profit under constraints in an integrated manner. Nasberg (1985), Eng et al. (1986), Sessions et al. (1989) and Murphy (1993) review a number of approaches, as well as suggest their own. However, the suggested solutions only go some way to providing a complete system, have only been tried experimentally, if at all, and have not been used operationally for any sustained period. It is worth while examining the pattern search / DP formulation of Murphy (1993) and the Linear Programming (LP) / Dynamic Programming (DP) formulation of Eng et al. (1986) which view two aspects of the problem.

Murphy (1993) used a pattern search

procedure modified from Hooke and Jeeves (1961) to change the list of log specifications given to the logging crew when bucking to meet operational and market constraints. A sample of trees was measured, and a first solution to optimal bucking obtained using the DP system implemented in AVIS. Control variables were selected from the variables determining log specifications, specifically the relative values and minimum SED of the log types. These were then varied using the Hooke and Jeeves search algorithm, with the DP implementation embedded within to re-estimate log product yield and total value at each iteration. Some 5 or 6 iterations were required to attain the true optimal value when there were up to two size or mix constraints, and over 35 iterations when there were three or four constraints. It was estimated that a test data set of 199 sample trees could have been solved in 15 to 20 minutes on a "486" PC if implementation of the Hooke and Jeeves algorithm had been fully coded.

The method therefore offers the potential to modify the variables of a list of log specifications used for bucking. However, the method as described does not distinguish between several logging coupes, nor offer solutions which allocate gangs to coups, bucking patterns to gangs, and logs to markets.

Depending on the tree characteristics and the log specifications, the ability of a gang in a given coupe to change the volumes of log products in response to change in relative values alone may be quite limited, whilst raising the SED limit above the original one specified by the market may be less optimal than moving a gang into a stand of trees where the log types may be less prevalent.

As an illustration, an inventory of a logging coupe was reanalysed, changing variables in a typical list of log specifications. Assume that a premium value, pruned sawlog has a restricted range of permissable lengths (5 to 6 m) and SED's (> 30 cm), along with demanding specifications for quality. Figure 1 shows the effects on the pruned sawlog volume of changing its relative value. Because of the quality, size and length specifications of it and the other log types, any value less than 50 units / m^3, which is the value of the next most valuable log type, results in no volume being cut, all is cut into the competing product. When a value of 50 units / m^3 is used, some 110 m^3 / ha is cut, this being the volume that can be cut without sacrificing any volume of the next most valuable log type. Even a small increase in value to 50.50 units / m^3 results in a 10% increase in volume, whilst doubling the value to 100 units / m^3 only results in a further 5% increase, within 1 m3 / ha of the absolute maximum. On the other hand, if the market could have been persuaded to reduce its minimumum length, or demanded an increase in the minimum SED requirements, a significant change in the volume of that product could eventuate, see figures 2 and 3.

Eng et al. (1986) attempted to integrate stand assessment, bucking strategy optimization and log allocation under market constraints. They

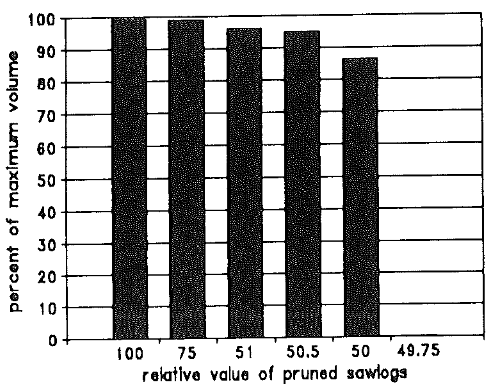

Figure 1 Change in volume /ha versus relative value of pruned sawlogs.

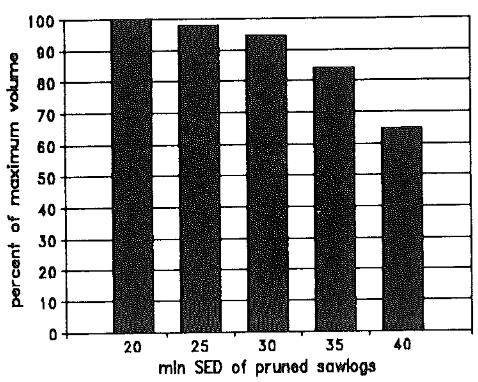

Figure 2 Change in volume /ha versus minimum SED of pruned sawlogs.

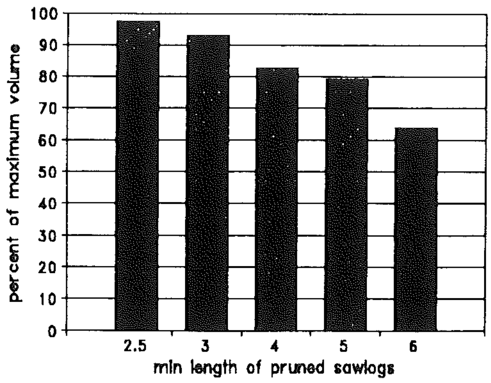

Figure 3 Change in volume /h versus minimum length of pruned sawlogs.

used DP interfaced with LP through Dantzig-Wolfe decomposition. Unfortunately, the mensuration aspects were mis-specified, resulting in an incorrectly formulated problem and an impractical application. In the inventory procedure, tree stems were assessed for size and quality, and classified into stem classes. The objective was to maximize value and the decision variable was therefore the number of stems to be bucked in a given stem class using a given list of log specifications, or bucking patterns. DP was first used to solve the bucking pattern problem for each stem class, generating several alternatives for each, but with no constraints. LP was then used to allocate numbers of stems by class to bucking patterns to maximize the return. The shadow prices resulting from the LP solution for each of the constrained log products were used to alter the values of the logs in the log specification lists for the DP bucking solution. The bucking pattern problem was resolved, followed again by the LP problem, iterations continuing until a final optimal solution was reached.

However, because bucking patterns differed for each tree stem class, workers making logs from tree lengths extracted to skids had to classify each tree into the correct stem class, remember which one of many lists of log specifications with differing relative log values to apply, then decide how to buck the tree optimally. There were over 300 stem classes. Because of damage due to hurricanes and fire, coupled with stem defects associated with variable stocking, individual stems were inadequately described by stem class averages, resulting in difficulties assessing the stems during inventory and after felling prior to bucking. The method was trialled in Fiji, but abandoned there and replaced by inventory assessments using the MicroMARVL system.

If the decision variable were to be redefined as the area of a logging coupe to be cut whose tree stems were to be bucked using a particular list of log specifications, and the estimates of log product yield made using MicroMARVL, then the idea of modifying the relative values in the DP bucking problem using shadow prices from a LP log allocation model would still be of value. Eng et al. (1986) showed that only one or two iterations were required to obtain a solution within 99% of the theoretical optimum, suggesting that the method could be practical even when the LP and inventory system implementations were independent.

MULTIPLE TIME PERIODS

Neither of the problem formulations discussed above consider multiple time periods. Even in a planning system concerned with the next week's (or even day's) production, it is still necessary to take into account what may occur in the future. This is particularly true for those products with high value which are in short supply. It is common for stands, and blocks within stands, to be very variable with regards to tree stocking and percentage product yield. There is little point in optimizing the value of this period's production at the expense of subsequent periods.

Extending the log allocation problem to be solved by LP from single period to multiple periods is simple, theoretically. The decision variable redefined from Eng et al. (1986) as suggested above is extended to include the period in which felling occurs. The multi-period, LP based, planning systems of Manley and Threadgill (1991) can then be used with some modification. In practise, care must be taken to ensure that any decision support system is user-friendly with regards to the management of data, and is understandable by non-computer specialist marketing and logging managers. An integrated system of data bases, growth prediction, inventory analysis and optimization is required.

PRECISION OF INVENTORY PREDICTIONS

Preharvest inventory supplies the information in advance of planning. A mid-rotation inventory is often carried out to determine a stand's actual condition (as opposed to relying on its supposed condition specified by the silvicultural prescription), and thus provide accurate starting values for growth models to predict future yield. Some three to five years before logging is due to take place, a more detailed inventory is necessary. The inventory results provide information for harvest planning with emphasis on determining log product availability and satisfying existing commitments. Often, the information should be used to negotiate sales contracts or, in vertically integrated organisations, future internal transfers to the processing facilities. It is important that the data be re-analyzed in a systematic way to determine the sensitivity of the timber supply to changes in possible constraints likely to be imposed by the markets, and for the supplier to be aware of the trade-offs between price per unit of volume and those constraints and their effect on the total value of the supply.

This analysis should be carried early enough when there are only minimal, market constraints. The MARVL system allows reanalysis of the field data changing log specifications, as shown above. An investigation in the past inventoried and reanalysed the three year log supply of a forest firm using over 15 different lists of log specifications. These were varied to determine the effects on the total value of introducing a new log type, of the marginal value of changing minimum average piece size versus availability, and of the opportunities to change the percentage composition of the log mix by length classes. The analysis provided the timber supply sales staff with information to be used at sales negotiations.

The sampling population and intensity of the three to five year inventory is broad based but is still often used for logging planning. However, in most New Zealand companies, there is only one plot per four or five hectares, and planning and control at the logging coupe level may be based only on data from one to three plots, involving possibly as few as six trees clustered in a group. The chances that these accurately predict the profit performance of a logging gang's production in any one week is not high, and care should be taken when using such broad based inventory as an operational control mechanism.

A further inventory with more intensive sampling is required shortly (one year) before logging to provide the detail required to differentiate the log out-turn between logging coupes. With current inventory systems, obtaining estimates with an adequate level of precision requires an intensity of sampling that is not normally carried out. There is a need for sampling systems which can provide such precision for small areas at an economical cost.

CONCLUSIONS

No one currently operational system of inventory, planning and control meets all the requirements of the current harvesting environment. There are ideas and techniques suggested in the literature which, when combined, would begin to go some way to meeting those requirements.

Pre-harvest inventory is required before making any supply commitments, except those determined by the long term yield regulation system. Data is required of individual trees, and not by classes. The data should be reanalysed to determine the sensitivity of the product yield to changes in log specifications and price. The results are useful as a basis for sales negotiations. The sampling intensity is relatively low.

Short term operational logging planning requires a more intensive sample, there should be enough plots to obtain adequate confidence limits of a logging coupe. The MicroMARVL system is useful for both cases, and is accurate provided the limitations of ocular estimates are taken into account, and the planning and assessments are carried out competently.

A planning and control system should be multiperiod and cover many logging coupes. It should respond to, and indicate changes to, log specifications and prices. It should not only assist in determining the bucking strategy, but also determine the order of felling, allocate gangs to coupes, bucking strategies to gangs and log products to markets.

An inventory support system is required to manage the inventory data, project that data to different times of harvesting, analyze it with different bucking patterns, and present the results in a form readily accessible by LP planning systems. The ability to perform planning in an iterative fashion is also required, even when the basis for the methods is an optimization procedure such as LP.

A logging performance control system should be based, in the final analysis, on direct measurements of trees as they are being harvested, as in the AVIS system. Sufficient samples should be taken at frequent enough intervals to ensure that the true performance is being assessed.

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