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# USING MEASURED AND MODELLED WOOD QUALITY INFORMATION TO OPTIMISE HARVEST SCHEDULING AND LOG ALLOCATION DECISIONS*

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## ABSTRACT

During pre-harvest assessment, wood quality information is measured with the software package *A*TLAS Cruiser. Various modelling methods are applied to this information to predict log yields for different stands, through time and under different cutting strategies. This yield information allows the scheduling component (*A*TLAS Market Supply) to find an optimal way of meeting the demand for logs of varying qualities from the available stands, given harvesting capabilities and transport distances.

Assuming the issues arising from initial use of the system can be addressed, the indications are that the combined system of pre-harvest forest assessment and optimisation of harvesting and log allocation is able to characterise the resource in terms of wood qualities and provide the best match of logs to customer demands, thereby maximising the returns to both the grower and the processor.

**Keywords**: log allocation; harvest scheduling; pre-harvest inventory; wood quality assessment; optimisation; yield prediction.

## INTRODUCTION

The bulk of the New Zealand plantation resource consists of some 1.6 million ha of *Pinus radiata* D. Don, with an annual harvest of about 20 million $m^3$ (NZ Forest Owners' Association 2006). *Pinus radiata* is extremely versatile, being used for domestic and commercial construction, furniture, panels (such as veneer, plywood, particleboard, fibreboard), posts and poles, and pulp and paper. However, as a raw material its performance quality is highly variable, and this variability has a significant impact on the suitability of logs for a given end-use.

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Variability in the key performance properties of stiffness, strength, and appearance is due to complex interactions of genetics, site, and silviculture, and has increased as a wider range of seedlots, sites, and management practices have been used. Knowledge of the causes and impacts of this variability is patchy but, in general, excessive variability has an adverse effect on the profitability of wood processing.

Therefore, log processors have become more discerning, moving away from "run of bush" supply contracts towards optimising their mills for the conversion of a narrower range of log types, which must be supplied to tighter specifications. Log parameters of interest (Shelbourne *et al.* 1997) include:

- size (diameter, length)
- shape (e.g., taper, sweep)
- branching (e.g., internode index, branch index, maximum branch diameter)
- internal wood properties (e.g., spiral grain, microfibril angle, compression wood, stiffness, strength)
- defects (e.g., resin blemishes).

There are potential gains for both growers and processors (the growers' customers) from having a good understanding of the fundamental resource properties. In New Zealand, most "structural" grade logs are not yet segregated on stiffness, even though it is now technically feasible to do so (Treloar 2005). For example, acoustic tools have been used to segregate logs in mill yards, allowing an appropriate saw pattern to be applied to batches of logs. However, by this stage trees have already been felled, cross-cutting has been applied, and the logs have been allocated to a customer — decisions which cannot be reversed. Hauling tree-length stems to central processing yards allows log making and customer allocation decisions to be optimised but, again, the wrong trees may have been felled.

The system described here attempts to make optimal decisions earlier in the value chain. Measuring and modelling properties in the standing crop well before harvesting enables the "right" harvesting crews to produce the "right" log products from the "right" stands (harvest units), and allocate them to the "right" customers. Making the best choice at each of these linked decision points results in an optimal solution which benefits both growers and processors. This estate-level optimisation of harvest scheduling and log allocation is based on the ability to assess crop quality using pre-harvest forest assessment techniques, model any variation over time and within and between stems, and match supply to demand using a mathematical programming algorithm.

The composite system, which uses both measured and modelled wood quality information to optimally schedule harvesting, is based on the *A*TLAS Cruiser pre-harvest method for forest assessment and the *A*TLAS Market Supply harvest scheduling component. The flow of information through the system is illustrated conceptually in Fig. 1.

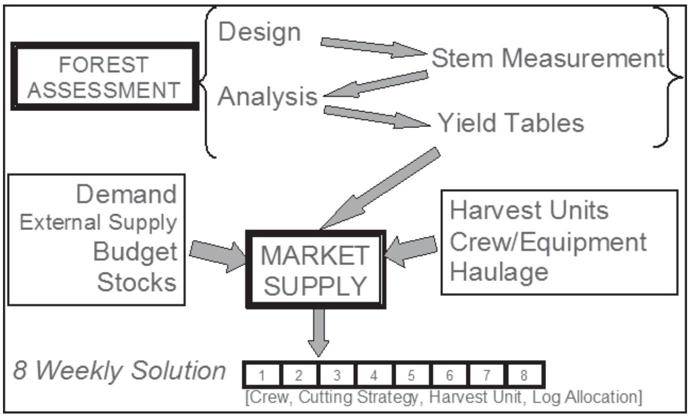


FIG. 1–Information flow through the forest assessment and market supply components. Assessment design, measurement of stems, analysis and the generation of yield tables, are phases of forest assessment. The market supply component takes these yield tables, together with other information, and finds an optimal solution for each of the next 8 weeks. The solution, which is re-run weekly, specifies which crews should cut particular log mixes from which stands and how these logs should be allocated to processors.

The paper first describes the pre-harvest assessment system which incorporates both measured and modelled wood quality information. It covers the design of assessments, the measurement of sample stems, and the analysis and production of yield tables. Then the harvest scheduling problem is described by explaining the optimisation model, how the model is solved, and details of the implementation and the results it produces. Finally, conclusions are drawn regarding the difficulties encountered and suggestions for improvement.

## CHARACTERISING THE RESOURCE

### Pre-harvest Forest Assessment

A reliable assessment of the potential yield (volume per hectare by log product) from a forest stand is important information for the forest grower. Pre-harvest assessment aims to provide this information at 3 to 5 years before harvest date. Cruiser can produce the yield estimates at the time of measurement and can also produce a yield table, which is a time series of yield usually in annual steps from the time of measurement. Because there are many ways of cutting a stem into logs, the cutting strategies (the set of log products (grades) and their prices) that are used adds another dimension to the time series, resulting in a family of yield tables. This cutting strategy dimension is the basis for optimally selecting the contribution a stand (or harvest unit) can make to meet the demand for specific types and quantities of log products from the whole estate.

The design phase of a forest assessment includes determining a sampling strategy and stem selection methods.

### *Design — Sampling*

New Zealand plantation forests of *P. radiata* may return a net value of up to NZ$50,000/ha (NZ Forest Owners' Association 2006) but it is still not cost-effective to assess every stem in a harvest unit. Selected stems must be measured within a sampling framework so that unbiased estimates of the yield can be calculated and measures of precision determined. Firstly, the sample units must be defined. Two types of unit are supported by the Cruiser system: the individual stem from which yield estimates per stem are obtained, and the plot, that results in yield estimates per hectare. The sample units can be divided into strata, which are often spatially distinct areas of forest, to reduce the variation between units within each stratum. Stratification effectively allows the practitioner to add additional information to the assessment which translates into more precise estimates for the same cost of sampling.

Units within a stratum can be a simple random sample or a "double" sample. With double sampling, basal area is measured on all units but only a proportion of them are fully assessed. Because of the relationship between basal area and log product yield, a more accurate estimate of yield is obtained at a lower cost.

### *Design — Mensuration*

Area-based sample units (plots) can be established using several different stem-selection strategies. Bounded or area plots, although of different sizes and layouts, all have a known spatial extent, and all stems within a harvest unit have the same probability of being included in a randomly located plot. Point, or angle-gauge, plots use the angle subtended at the observer's eye by the stem's over-bark breast-height diameter (dbh) as the criterion to include a stem. The probability of a stem's inclusion in an angle-gauge plot is proportional to its squared breast-height diameter. Another plot type is the horizontal line plot, where stems are selected by using an angle-gauge at right angles to a transect line. In this type of plot the probability of a stem's inclusion is proportional to its breast-height diameter.

## Stem Measurement

Stem measurement (cruising) is the process of systematically describing the structure and quality of a sample of standing stems on the area being assessed. This is done by field workers entering stem measurements of height, lengths, qualities, and diameters into portable computers. The measurements are a superset of those collected in a MARVL assessment (an industry standard method of forest assessment

— Gordon *et al.* 1995), so the analysis process is fully compatible with MARVL data. These data are collected plot by plot and later collated to conform to the sampling scheme under which the assessment was designed. The measurements fall into several categories.

### *Structure*

Although the majority of stems in *P. radiata* plantations have a single leader, a proportion are forked into two or more leaders, each of which may fork again. This structure is described by recording the height of forking and the parent of each forked piece. The over-bark diameter at breast-height above the fork height is measured or estimated. When a change in diameter occurs that is significantly larger than the normal taper of the stem, the piece above is recorded as another piece of the stem in the same manner as a fork. This allows the processing system to construct a composite piece that has diameters predicted from two taper curves. Occasionally branches large enough to produce merchantable material are found. By definition, merchantable branches can be cut from the main stem without affecting its average taper. An over-bark diameter is recorded at breast-height from the point of attachment and the length of the piece measured. If a stem has a broken top its height is recorded, allowing the model to estimate its unbroken height and hence taper/shape and to note the point above which no volume can be extracted.

### *Branching*

Branch size is often a critical log quality characteristic. Maximum branch sizes are assessed by dividing the stem into zones of specific maximum branch size. For example, if the key branch sizes for the target log products are 40 and 100 mm, then the stems can be zoned into just these two categories (Fig. 2), although finer detail gives more flexibility when predicting the likely yield of different log products.

Unbranched (“internodal”) sections of stem can be recorded using a maximum branch zone of zero. The height to which the stem has been pruned and the rate of clustering over the lower stem can also be recorded.

### *Shape/Sweep*

Sweep is any lack of straightness over part of a stem. It is an important characteristic as maximum sweep is specified by most log products, usually as the maximum allowed deviation from an end-to-end line, in terms of the proportion of the log small-end under-bark diameter. Sweep on the standing stem is described by identifying the start and end of the swept section and recording the shape and size of the deviation in the worst plane. For example, a 6-m section of stem, fitting the “normal sweep” category with a deviation of 50% of the over-bark diameter at the end of the section, is shown in Fig. 3.

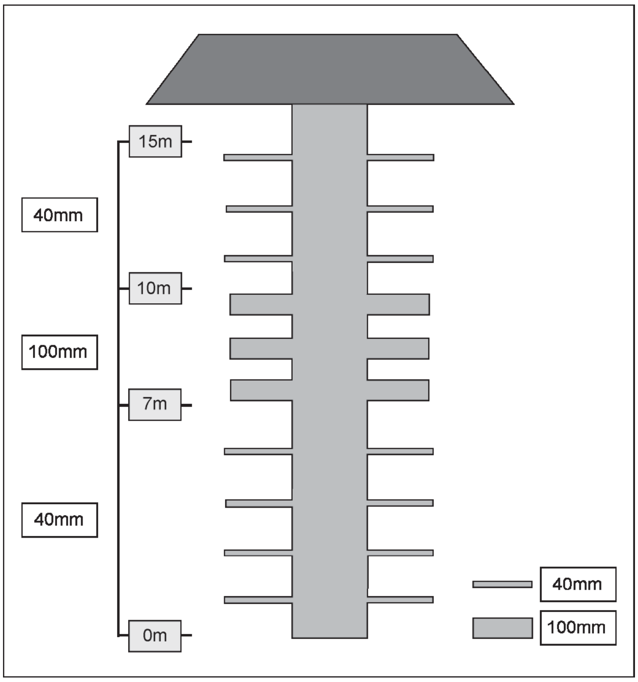


FIG. 2–Classifying maximum branch sizes on a standing stem

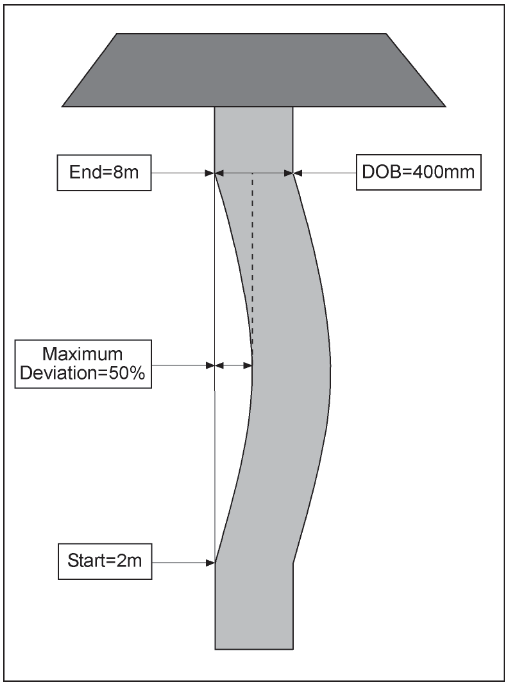


FIG. 3–Sweep assessment: “Normal” shape category

Other shape categories are “wobble”, “hockey stick”, “leader replacement”, and “bend” (Fig. 4).

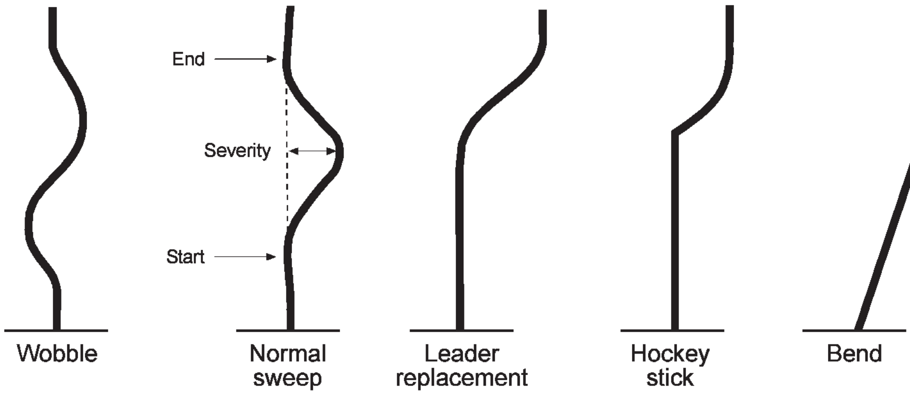


FIG. 4–Stem shape categories used to classify and assess sweep.

*Stem features*

Stem features, such as thinning damage, out-of-round, scarring, fluting, nodal swelling, etc., can be defined by the user of the system to tailor the assessment to the particular qualities that are specified by the potential log products to be estimated. Features are defined in a dictionary and then recorded as affecting a particular section of the stem. Optionally, a measurement of severity can also be recorded.

*Wood properties / User-defined variables*

Wood density (outer-wood basic density at breast-height, OWDBH) of the standing stem has traditionally been measured from a core taken in the outer-wood at breast-height. This value can be recorded for every stem in the sample, or for a sub-sample, or as an average value for a stratum. It provides a starting point for wood density models to predict the density of stem sections through time and from ground-level to stem tip.

The system can be extended to include user-defined variables that are measured at the stem, plot, or stratum level (Fig. 5). For example, the incidence and severity of resin bleeding can be measured, and its effect on yield determined, by assigning each sample stem a severity rating and including a constraint in the log product definitions specifying the maximum resin bleed rating allowed. Similarly, measurements of acoustic speed in the standing sample stems can be taken using one of the currently available tools (Ross & Wang 2005; Lindstrom *et al.* 2002). Acoustic speed is commonly used as a surrogate for stiffness to segregate logs into stiffness categories. By incorporating minimum acoustic speeds into the definitions of log products, it is possible to predict the log product yield by stiffness.

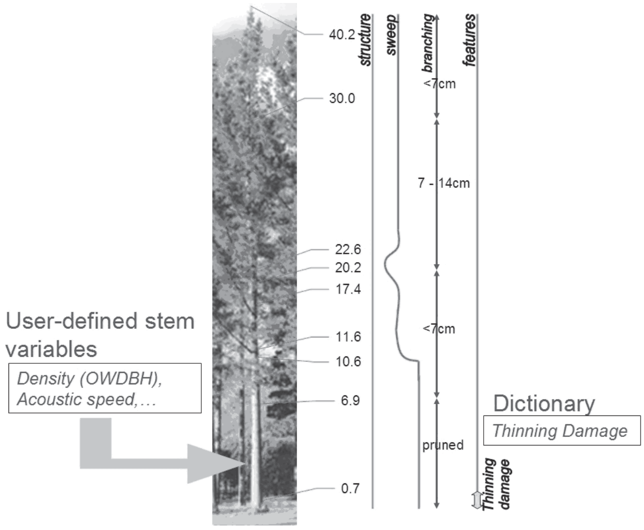


FIG. 5–Five categories of stem quality description are shown: structure (forking, broken tops), sweep, branching (maximum branch size classes), other quality features of sections (thinning damage), and user-defined variables that apply to the whole stem (outerwood basic density at breast height, acoustic speed).

## Analysis

To support the Market Supply component, the log product yield must be known through time and under a variety of cutting strategies for each potential harvest unit. Several models must be used in concert to calculate these arrays of yield.

*Fill-in* models are used to elaborate the detail of physical entities that are only partially measured or sub-sampled. For example, there is usually a positive relationship between stem height and breast-height diameter. As breast-height diameter is easier to measure than height, a model of this relationship can be used to estimate a height for every stem. This model can be pre-fitted and may be localised, given the plot dominant height and dominant breast-height diameter, or the relationship can be fitted automatically (by stratum) if a sub-sample of heights and breast-height diameters have been measured (Fig. 6).

Models of branch size and location (Grace *et al.* 1999) are used to describe the full branching habit of a stem, given measurements such as the number of branch clusters over the lower bole, pruned height, and the classification of the sizes of the largest branch per cluster.

*Descriptive* models predict physical dimensions of stems. For example, stem taper models predict the under-bark diameter, and hence the volume, at any point on the stem. The wood density model predicts the basic density of any stem section from ground to tip.

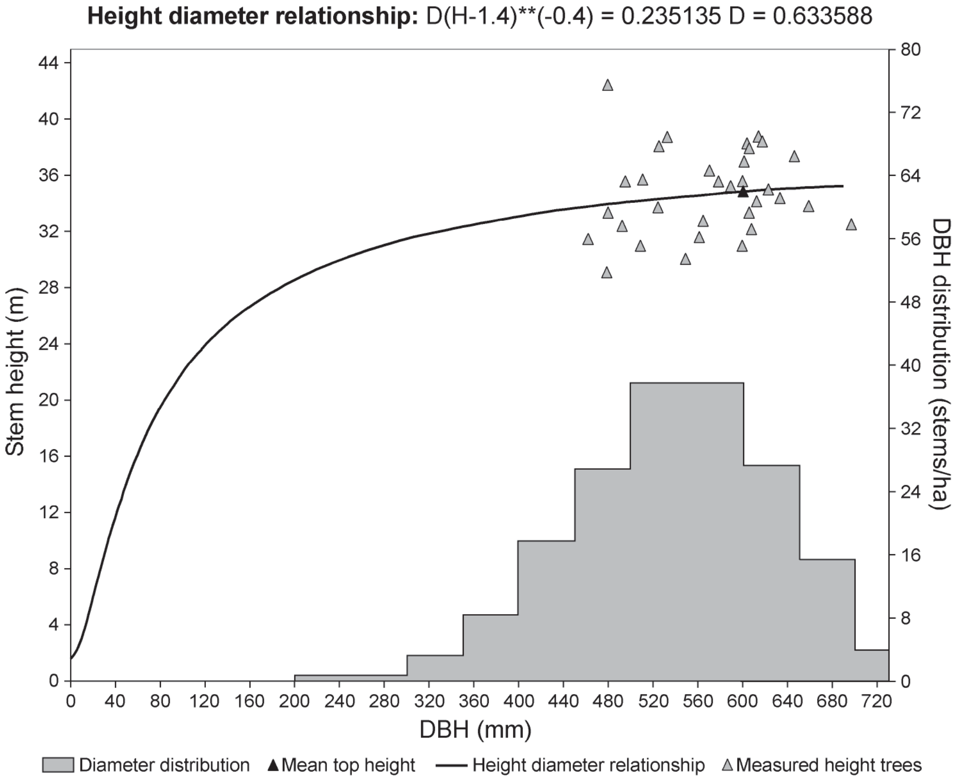


FIG. 6–Fitted height/diameter at breast height fill-in model in relation to the distribution of stocking by diameter at breast height.

*Growth* models predict the changes in a stem or stand through time. Traditional forest growth models are used to project stand-level characteristics, such as basal area, dominant height, and stocking, in annual steps (Mason 2005). Other models grow individual stems (independently of the distance between them) rather than stand averages and some models grow both forwards and backwards in continuous time. A common interface to these growth models requires only discrete-time predictions. Intra-annular growth is interpolated on the basis of models of monthly growth proportions which are usually specific to regions, as growth is usually related to changes in temperature and the availability of moisture. Growth is also predicted by other models — for example, growth in branch size and the initiation of new clusters of branches. The wood density model has a growth component to predict the increase in sectional wood density with stem age.

*Processing* models are used to determine the effects of non-natural events such as harvesting. The height of the stump and the position and length of shattered sections of the stem are important characteristics of the first part of the harvesting process.

Cross-cutting the felled stem pieces into logs (either by a harvester or after extraction to a skid site) is a critical part of the utilisation of forest resource in terms of the potential for gain or loss in value. The price for high-grade logs may be several times that of low-grade logs — for example, pulp logs at $40 and pruned logs at $170 /m$^3$ (Woodnet 2005). At these prices, the value of an average, single *P. radiata* stem (2.4 m$^3$ recovered volume) can vary from $100 to over $200, depending on the cross-cutting decisions (Murphy 2000). To model cross-cutting, a dynamic programming algorithm is used to find the mix of logs that can be cut from each stem piece between stump height and the break point that will produce the highest value (Deadman & Goulding 1979).

## Generating Yield Tables

In the composite system, the end point of the forest assessment system is the production of yield estimates. A yield table holds yield per hectare by log product and through time. The forest assessment analysis system is able to estimate the log product volume for any number of assessments, through a set of harvest dates, under different cutting strategies. So the analysis results in an array of yield tables by cutting strategy and by harvest unit.

### *Cutting strategies*

A list of cutting strategies is supplied to the analysis process. Each strategy incorporates a set of the log products whose volumes are to be estimated. Log product definitions comprise a series of constraints on log dimensions, branching, shape, features, wood property indicators, species, and other user-defined variables. Dimensional constraints include the range of small-end diameter, the maximum large-end diameter, and a series of allowed length ranges. Branching constraints cover pruning, including partially pruned, branch size maxima, minimum branch angle, and "internodal" wood (the frequency and length of sections of clear stem between branch clusters). Sweep is defined as the maximum deviation of the log centre line from an end-to-end straight line, and can be specified as a constraint in absolute terms or relative to the log's small-end diameter. The maximum log taper can also be specified.

During field assessment, sections of the stem may be recorded as having certain quality features. These are defined by the user and are usually construed as defects. For example, a section may be recorded as being out-of-round, or scarred, or damaged by previous thinning extraction. Features may overlap and may have a value associated with them. The log product definition can then specify which features are not permitted, or are not permitted beyond a certain value.

The only built-in wood property constraints are the set of species that the log may be cut from and the minimum density of the log. Other wood property characteristics can be specified using user-defined variables. For example, acoustic speed measured on the standing stem can be used as a constraint of a particular log product that would allow these logs to be produced only from a stem with a speed of, say, at least 2.3 km/s. Because of the strong relationship between the speed in the stem and the speed in logs (Ross & Wang 2005), the predicted log yield will mirror the mix of logs obtained by segregating logs after manufacture, based on acoustic speed measurement.

Although each log product has a default price, pricing is assigned when assembling a set of log definitions as a cutting strategy. Since the cross-cutting model is based on an optimisation for maximum value, the prices assigned within the cutting strategy are used to set the priority given to different log types. Both market prices and relative prices can be used to produce yield tables. (Relative prices have a fixed relationship to each other but no particular absolute value).

### *Analysis process*

Initially fill-in models are used to elaborate any partially measured stems so that each stem has all the basic dimensions for each structural piece and all branches have been positioned, sized, and aligned with measured branch information. An outer-wood breast-height density has been assigned to each stem if not measured. Then stand growth models are applied to each stratum, initially to ensure that plots measured at different dates are brought to a common date, and then to project the sample to the proposed harvest dates. All models with a time-change component are involved to ensure, for example, that the outer-wood density at breast-height is correct for the stem age, that branch size and vitality are updated, etc.

At each harvest date the stems associated with each sample unit are merchandised. This involves simulating the felling, breakage, and cross-cutting of the stem pieces into log products. To do this, the processing models are applied to the stems that have been elaborated using the fill-in and descriptive models. The resulting set of log products are amalgamated within the sample unit, using appropriate mensurational weighting, so that each unit has estimates of the yield per unit by log product. At this point methods appropriate to the statistical framework (stratification, double-sampling) are applied and the unit values are combined to produce estimates of the population mean and total with standard errors.

Surrounding this analysis process is controlling logic to iterate over the assessment areas, over the harvest dates, and over the different cutting strategies, and to marshal the results into an array of yield tables that can be made available to the Market Supply component.

Not all harvest units have pre-harvest assessment data. In young stands, low value stands, first thinning operations, etc., it may be more appropriate to use modelled rather than measured data. For these harvest units a simulation system such as STANDPAK (West 1997), or its successor *A*TLAS Forecaster, can be used from starting points based on pre- or post-operation assessments or mid-rotation inventory.

The link between the assessment system and the scheduling system is the assignment of yield tables to harvest units. Ideally each individual harvest unit has been assessed, but provision must be made for assigning generic yield tables, or average yield tables, or deriving new yield tables by combining sets of sample plots from other assessments.

## SCHEDULING THE HARVEST

### The Problem

While the pre-harvest assessment system is able to optimise log making at a harvest unit level based on market prices (using dynamic programming), in doing so it does not directly take into account log demand and alternative log supplies. This is the domain of forest estate planning. Linear programming has long been used for estate planning in New Zealand forestry (Garcia 1990). At a *strategic* estate-wide level, it has been shown that the optimum portfolio of regimes implemented and log products harvested will often differ from the stand-level optimum — for example, due to demand constraints (Manley & Wakelin 1990) or future price uncertainty (Manley & Wakelin 1995).

Work at Forest Research (now Scion) by Cossens (1992), Murphy (1998), and Mitchell (2004), and elsewhere (Laroze 1999; Weintraub *et al.* 1991; Sessions *et al.* 1989) has also addressed the harvest scheduling (*short-term*) planning problem. This poses particular challenges in that the problem is difficult to formulate and solve; involves many integer variables; requires up-to-date and accurate data from many areas of the value chain, which may be unavailable, out-dated, too aggregated, or difficult to extract from other systems; and is affected by a range of non-technical issues (e.g., business process change, organisational structure, and culture). Nevertheless, a prototype, *A*TLAS Market Supply, has been developed to optimise the short-term harvest scheduling and log allocation task, over a time horizon of eight 1-week periods.

### The MIP/LP Model

The problem is formulated as a mixed integer / linear programming problem. Integer variables ensure that:

- no more than one harvest crew can be allocated to a harvest unit in a week; and
- a harvest crew must be allocated to a single harvest unit, unless they are idle.

The system is written in C# and uses SQL Server databases to store data and reports, and a third party solver to perform the optimisation.

The model objective (Table 1) is to maximise the revenue from both harvested stands and external supply, minus the transport costs for delivery, the crew production and movement costs, and the costs of purchasing wood from an external supply. A residual value for stands and stocks at the end of the planning horizon can also be included in the objective function — the user has full control over which of these elements is included or excluded.

TABLE 1–Components of scheduling and allocation model objective function

| | |
|---|---|
| $\sum_t \{ \sum_{ink} p_{ink}V_{inkt} + \sum_{jnk} p_{jnk}V_{jnkt}$ | Revenues |
| $- \sum_{ink} ct_{ink}V_{inkt} - \sum_{jnk} ct_{jnk}V_{jnkt}$ | Transportation costs |
| $- \sum_{hi} ch_{hi}V_{hit}$ | Production costs |
| $- \sum_h (cz_hZ_{ht} + ce_hE_{ht})$ | Set-up costs |
| $- \sum_{jnk} cs_{jk}V_{jnkt} \}$ | External supply costs |
| $+ \sum_{ik} iv_kU_{ikT}$ | Residual stock value |
| $+ \sum_i fv_iR_i$ | Residual forest value |

Where indices are: $i$ = harvest units, $j$ = external suppliers, $n$ = customers, $k$ = log products, $t$ = weeks, $h$ = harvest crews.
Decision variables are: $V$ = volume, $p$ = price, $ct$ = transportation cost, $ch$ = harvesting cost, $Z,E$ = crew location/idle variables, $cs$ = external supply cost, $iv$ = residual stock value, $fv$ = residual forest value, $U$ = volume of stock, $R$ = residual area.

There are a number of constraints that can be applied to the problem to force certain behaviour — for example, limiting fluctuations in supply, the levels of in-forest stocks, or the availability of particular harvest units, crews, or customers. These user-defined constraints can also be used to ensure that the solution is consistent with longer-term plans and is feasible given the exigencies of the week.

Market Supply uses the yield tables generated from detailed pre-harvest assessment data of each harvest unit to determine volume by log type by cutting strategy. When combined with log prices, this produces the potential revenue that is the primary component of the objective function. Where there are no forest assessment data, Market Supply will accept yield tables derived from stand simulations (using Forecaster, for example), or user-entered values.

Other inputs include information on harvest units, harvest crews (e.g., location, capability, production rates, and cost), haulage costs and distances, existing log stocks (location and volume by log type), sales (customer demands and prices), and other constraints (e.g., targets to ensure compatibility with longer-term plans and budgets).

## Solutions

In practice, the system is used initially to solve a small problem with minimal constraints. Constraints can then be added and alternative solutions examined. The ability to quantify the difference between alternatives is a major advantage of the system over other scheduling procedures. The solution lists, for each week of the 8-week period, the harvesting crews and the harvest unit and cutting strategy they are working with, and the assignment of log production (or stock) to customers (or stock).

## Trial Implementation

The system has been tested on a 90 000 ha resource that produces 30 000 $m^3$ of logs per week, supplying 8–13 main mills per week from 11 main harvesting crews. Problems with up to 170 harvest units, 20 cutting patterns considered for each harvest unit, 10 crews, 30 log products, and 10 customers have been solved successfully on a 3.0 Ghz Pentium 4 with 2 GB of memory in approximately 30–40 minutes using the Dash XPress-MP solver. Typical problem size is about 50000 rows and columns, of which some 20% are integers. The system itself has no internal limits on the number of harvest units, crews, customers, etc. that can be modelled.

As expected, testing highlighted a number of issues, many of which were unrelated to wood quality. Because of the long solution times, problem complexity, and limited infeasibility diagnostics from the solvers, it was found necessary to create a set of dummy variables that would ensure that a feasible solution would always be found. It was also necessary to closely integrate the model database with the separate systems that maintain the current area of harvest units, and the current level of in-forest log stocks.

There were some interesting issues associated with wood quality. There was concern about the quality and quantity of pre-harvest assessment data. Generally, the inventory data used had been gathered for strategic planning purposes, and so was not specific to individual harvest units. Although the set of yield tables for each harvest unit could be imported from the Cruiser database and assigned to the appropriate harvest units automatically, users sometimes wanted to manually override yield tables. However, the basis for doing this was not always clear. For example, local staff questioned the model's decision to move a crew from a harvest unit where they had expected it to stay and produce veneer grade. Examination of the yield tables for the harvest unit suggested that little if any veneer grade was present, and the reason for this became apparent when the pre-harvest assessment data were examined. It appeared that the harvest unit had been pruned only once and then heavily thinned in anticipation of further pruning that was never undertaken. The consequent heavy branch growth had resulted in branch diameters that were too large to meet the partially-pruned veneer grade specification. In reality, while the model had responded appropriately given the data, there were other options available. It is likely that the sampling error around the mean veneer grade volume was high, suggesting that if the harvest unit was sampled more intensively a yield table with a sufficient quantity of acceptable logs could possibly still be created. In the "real world", the written log product specifications may not be applied as strictly as in the "modelling world", and growers can also chose to supply some logs that are outside the specifications to a degree.

In general, the more sophisticated wood quality parameters that are becoming of interest for pre-harvest assessment and in log product specifications, such as acoustic speed, have not featured in the trial implementation. Log product specifications were in terms of log small-end diameter, sweep classes, and branch sizes. To some extent the customer requirements included surrogates for quality, such as specifying the source of the logs (thinning *versus* clearfell), and minimum clearfell age. It is also possible to specify a constraint on average small-end diameter that can force the solution to incorporate logs from two or more harvest units to meet this size requirement for a specific log product by one customer.

Charts illustrating a scheduling solution are shown in Fig. 7.

## CONCLUSIONS

In this paper a system has been outlined that is used to supply logs of the correct quality to meet a weekly demand via an optimum schedule. Although traditionally wood quality has not been measured directly in pre-harvest assessments, this is changing as methods and tools for quickly assessing standing stems and logs become more widely used. Identifying log quality so that a "fit for purpose" log is produced and supplied is seen by the industry as key to the future profitability of both log grower and processor (Drummond 2004).

The implementation of this system has highlighted several short-comings in the processes and in management practices. Supplying timely, accurate, input information in sufficient detail and quantity is a challenge for existing information management systems, especially those bridging two enterprises. But progress can be made quite rapidly in this area — for example, tracking log stocks in both quantity and location.

One of the challenges the system faces is the need to take into account what is practical on the ground — for example, the number of products that can be recognised by the forwarder operator, the maximum products a crew can cut, and maximum number of products that can be stacked separately on the skid.

There is need for agreement on common measures of wood quality that are appropriate for standing stems and logs. Efforts to introduce new national log grades in New Zealand (Young 2005) may be a catalyst for this. If, for example, acoustic speed in the standing stem was an accepted component of resource description, then models to adjust this variable to any potential log along the stem

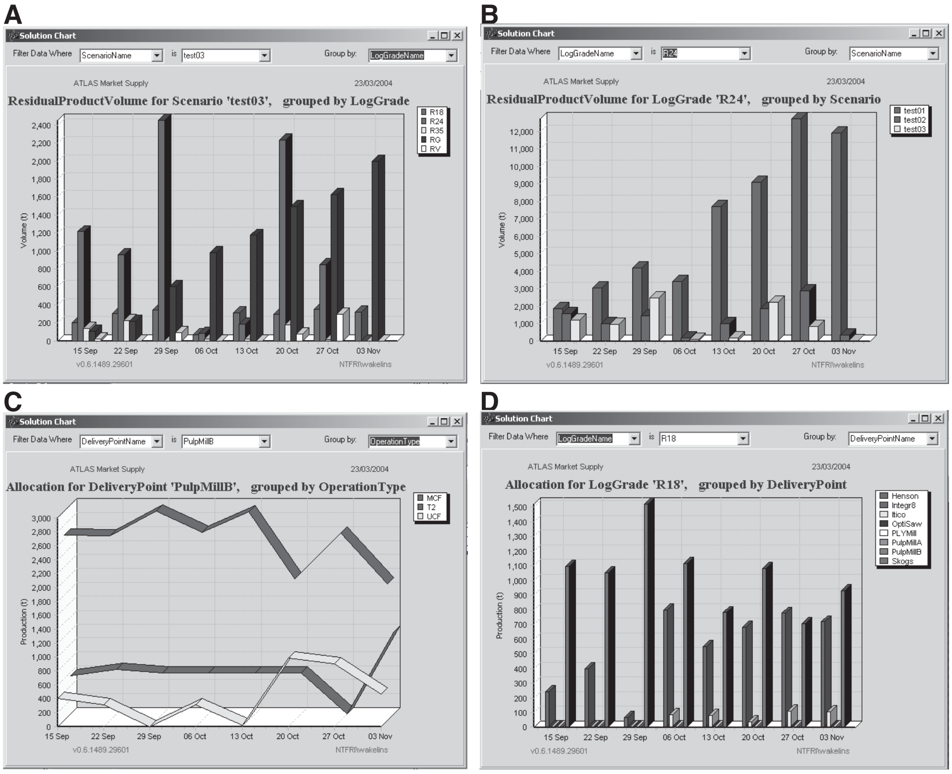


FIG. 7–Charts can be used to examine production, allocation, and stocks. Almost any combination of variables can be graphed and/or constrained within the system. Weekly closing stocks are shown in Chart A, aggregated by broad log product. Stocks of pulp logs gradually accumulate over the 8 weeks because a minimum stock requirement of 2000 $m^3$ was set for Week 8. The stock for a particular product (R24) can be seen in Chart B under three different scenarios. In C, the supply of pulp logs to a particular customer is shown by source — initially the mill is supplied mostly from first thinnings, but this drops away to be replaced firstly by unthinned clearfell and then by mature clearfell. The allocation to customers for a particular product (R18) is shown in Chart D.

and to "grow" it through time would allow the estimation of a full range of yield predictions under different cutting patterns. Once the resource can be consistently described in quality terms, and a practical system is available to manage the harvest, segregation, and delivery according to log quality, then log specifications can be changed to reflect the actual quality parameters of interest. Both log grower and consumer can profit by matching the right log to the right process.

There is potential to further exploit existing information, such as the precision of the yield estimates within a yield table, and also potential to feed actual yield information back into the yield estimates using adaptive control methods (Murphy *et al.* 2004).

Assuming these issues can be addressed, the indications are that the combined system of pre-harvest assessment and optimisation of harvesting and log allocation is able to characterise the resource in terms of wood qualities and provide the best match of logs to customer demands, thereby maximising the returns to both the grower and the processor.

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