It seems Dr Bigsby has made the error of assuming the change in a product is the product of the changes in its factors. As a piece of historical trivia, I note that according to Professor Bell ("Men of Mathematics", chapter 7), Gottfried Liebniz (1646-1716), the discoverer with Isaac Newton (1642-1727) of the Calculus, at first made the same mistake when trying to find the product rule for derivatives.

Garry Herrington

Dr Bigsby responds

The formula is a definition of NPV and is meant only to illustrate the point that changes to NPV will arise from changes to any or all of prices, volumes per area and area over time. My apologies if I have misled anyone as to how the changes would actually have to be calculated. With any luck, Liebniz will read this as well and not feel compelled to have to return and pull me up for it also.

Hugh Bigsby

ARTICLES

RegRAM-I – A flexible, forest harvest scheduling and industrial processing, global optimisation model

Brian McGuigan[1] and John Scott[2]

ABSTRACT

This paper describes a Regional Resource Allocation Model, known as ***RegRAM-I****, that has been used by Tasman Forestry Ltd, since 1991 as the company's major resources planning tool. RegRAM-I allows the user to interactively describe the objects to be modelled, (forests, processes, external suppliers, markets), transport costs between various locations, and how time is to be treated, on separate independent spreadsheets. The system uses both optimisation and simulation techniques, and can generate: individual stand models, single time period resource allocation models, single forest 'on-truck' models, multiple forest 'delivered to mill gate' models, multi-location integrated forestry and processing models – all without the need for separate mathematical formulations.*

COMPANY BACKGROUND

Tasman Forestry Limited is the forest growing and harvesting subsidiary of New Zealand's largest company, Fletcher Challenge Ltd, and is the sole log supplier to the wood processing companies in the Group:

- Tasman Pulp and Paper Ltd,
- Tasman Lumber Ltd,
- and Fletcher Wood Panels.

In New Zealand the Group's current annual production is:

- 342,000 tonnes of newsprint,
- 153,000 tonnes of kraft pulp,
- 190 million board ft of sawn timber,
- 402 million sq ft of wood panels,
- 800,000 m^3 of log exports.

The company has two major areas of operation in New Zealand: the Central North Island where it owns 165,000 ha of forest, and Nelson/Marlborough, where it jointly owns 60,000 ha of forest.

The Central North Island is by far the most complex region, with all the Group's processing plants situated there, including: newsprint and kraft pulp mills at Kawerau, sawmills at Kawerau, Putaruru, Rainbow Mountain and Taupo, and particle board and medium density fibre board plants at Taupo.

The company also supplies logs to other companies and small sawmills throughout the region, as well as substantial volumes of log exports via Mt Maunganui.

The company logs its own forests, state-owned forests, and minor woodlots, throughout the region. Wood residues such as sawmill chip, for its pulp and paper and wood panels' plants, come from both its own and external processing plants.

THE PROBLEM TO BE SOLVED

The pattern of log allocation between the forests and processing plants in a region varies over time, because the availability of logs from each forest varies. Since cartage costs can be a significant part of the delivered value, it is impossible to decide the best time to harvest a crop without knowing where the logs will be sold. However, where logs will be sold depends upon the log availability from all other forests. Thus even for a pure forest owner, harvesting decisions need to be made in conjunction with log allocation decisions.

For an integrated forest owning and processing group, the situation is even more complex. For example, the more wood residues that are produced, the fewer pulp logs that will be required by the pulp plants. Thus the volume of logs to be delivered to the pulp mills cannot be determined until you know the volume of sawlogs going to the sawmills and how much chip will be produced as a result.

Since a substantial proportion of the costs at existing processing plants can be regarded as fixed, the marginal value of logs to existing processing plants can be very high. Marginal values will also vary from one grade of log to another. Moreover, the differing log grades can incur different processing costs, and consume different amounts of plant capacity.

These considerations were persuasive enough to suggest that the work done on an earlier single-period resource allocation model, LOGRAM (McGuigan 1984), should be carried forward into a new multi-period version RegRAM-I, that would include harvest scheduling as well as resource allocation. This paper describes the new model and some of our experiences to date.

DESIGN OBJECTIVES

Fletcher Challenge is an exceedingly dynamic company. The only thing that is permanent is change. Thus any system developed had to be highly flexible. There was no point in developing a system

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for the existing forestry/processing complex. This is illustrated by the fact that during RegRAM's development the Group acquired two major new forest areas, closed one sawmill, opened another two, built a new kraft digester, and had two major reorganisations! What was needed was a system capable of solving the broad class of problems appropriate to the group's operations.

From the user's point of view the system had to be easy to use, with straightforward data input, in terms that could be understood, and a system that suggested realistic answers (Whyte 1991). Most potential users were familiar with the use of spreadsheets for the objects that they were modelling:

- forests,
- external suppliers,
- transport costs,
- processes,
- markets, etc

and then specify which were to be included in any particular model. In this way it would be possible to have the same data sets being used by more than one model.

The system also needed to be able to generate such models from the point of view of just the forest owner, the processing plants' owner, or the integrated group.

Further, it was desirable to be able to generate a series of related models, constrained to be compatible with one another. This arose because of the difficulty of identifying which stands belonging to a crop type should be clearfallen each year, as any age class of one crop type may consist of several stands scattered around the forest. In order to do long-range resource planning it is necessary to aggregate stands into crop types, simply to reduce the size of the problem. However, when it comes to putting those plans into practice, it is important to answer the question: "Which stands should be clearfallen this year?"

ENTITIES MODELLED

Experience with LOGRAM indicated that RegRAM should model the interaction of:

- crop types,
- resources,
- locations, and
- processes

over time, with the user having total control over the composition of each entity modelled.

Crop types are resources that grow and mature with time, but which cannot move between locations. *Resources* are physical resources like logs, sawmill chip, newsprint etc, which can be moved between locations in any time period, and be bought and sold at other locations. *Locations* are physical points in space between which resources may be moved at a cost. The original LOGRAM concept of a *process* that converts resources of one type into a mixture of other resources, with or without cost being involved, was retained.

Forests become locations that contain crop types. *Log types* are merely resources produced by thinning or clearfelling. *External suppliers* become locations at which resources may be purchased. *Manufacturing sites* become locations that contain processes. *Products* become resources that can be sold. *Markets* become locations at which resources may be sold. *Residues and intermediate products* become resources that are produced by one process and used by another.

In order to keep the potential size of the model under control, it was decided to treat time itself as variable. Data are input and maintained on the database in annual increments. Data extraction programs then aggregate this into time periods, according to the user's wishes. This enables the system to generate single-time period models, or multiple-time period models of any length required. Alternative treatments of time can also be tried for the same data, if required.

DATA SOURCES

In any real forest there is substantial variation in the form and growth of the trees both within and between stands. Significant data reduction is required, before any serious modelling can be undertaken, to limit the kinds and quantities of crops in a forest, and what can be produced from them.

Figure 1 shows how data are accumulated and stored in a *Stand Record System. Stand Growth Models* are run, output from which is then analysed with a *Stand Yield Prediction System.* This uses statistical cluster analysis techniques to suggest crop type yield profiles, and then assign either an individual stand or stands to each crop type. By controlling the level of aggregation in this way, models containing differing amounts of detail can be generated as required. The consequent file of crop type, area and yield table details is produced and input to RegRAM's database.

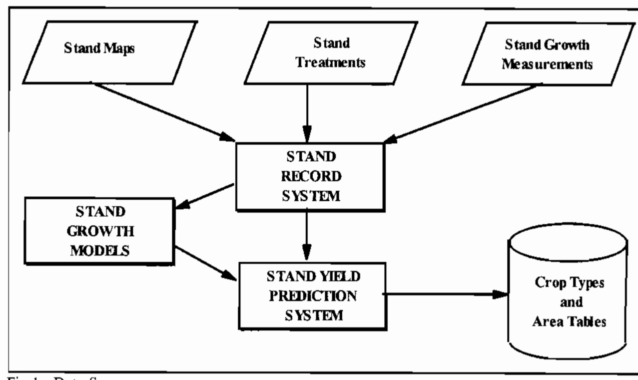

Fig 1 - Data Sources

STRUCTURE OF THE SYSTEM

Users define any set of objects: *Forests, Suppliers, Processes, Markets, and Transport Costs* within a region, on separate spreadsheets.

Since the information in the *Stand Record System* does not contain details about planned future costs, these have to be input manually to RegRAM's database – as does all the non-forestry data. (See Figure 2.)

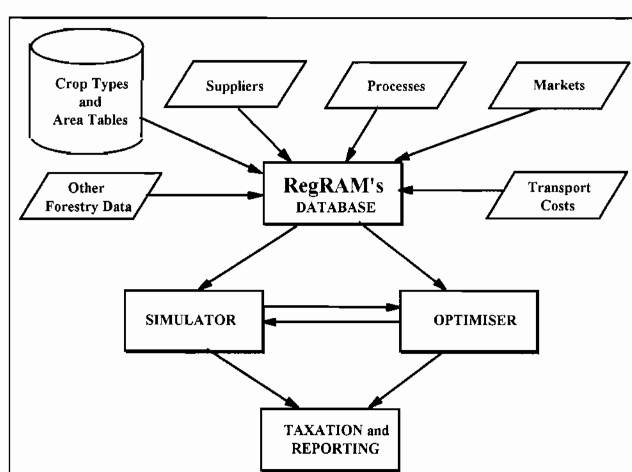

Fig 2 - Structure of the System

The interaction of these *objects* over time can involve, either, or occasionally both:

(a) An individual forest harvest simulator that enables the user to interact with it on a year-by-year basis. In this mode the simulator remembers the harvest strategy adopted by the user. Alternatively, the harvest strategy can be predefined by the user, or an existing one modified, and the whole simulation run in batch mode.

(b) An optimiser that will determine the optimum harvest and resource allocation strategy for an entire region, simultaneously for many time periods. Thus, if there is a problem with the resource allocation to the processing plants or final markets, then the harvest strategies for the forests will be adjusted to compensate, in either the same or earlier periods. Similarly, any harvest scheduling problems will be minimised by adjusting resource allocations where possible.

These then both feed into a taxation and reporting phase that enables the same reports to be generated for a forest, no matter how the plans were produced. This phase also calculates post-tax forest values, and will calculate forest purchase prices that can be paid under a wide variety of assumptions and taxation regimes.

THE OPTIMISATION SUBSYSTEM

The system is divided into database, simulation, optimisation, and reporting subsystems (Figure 2). This paper discusses the most important component – the optimiser, which is based on a linear programming formulation.

What the optimiser advises (its decision variables)

The system advises the user on the "best" thinning and clearfelling program, the resultant log resources produced, how much external resource is to be purchased from each supplier, how to move resources between locations, which process should use them at each location, the consequent production of other resources, where they in turn should be used, and the markets in which they should be sold, all within a set of user-defined guidelines or constraints.

What the optimiser tries to achieve (the objective function)

The system tries to maximise the present net worth of future cash flows before tax and funding, for the scope of the model defined by the user. If the user inputs processing costs and revenues, overall cash flows are optimised – otherwise only forestry cash flows are considered.

User Controls (the constraints)

There are certain constraints over which the user has no control. Obviously constraints must exist to prevent areas harvested exceeding the areas available. Resources used must also not exceed resources available. Beyond these, the user has a considerable choice of other controls that can be imposed on models.

Minimum and maximum ages of clearfelling can be set for each crop type, as can a maximum delay in the age of scheduled production thinning. Total harvest volumes can be specified for each forest. Specific instructions can also be given on when to harvest particular stands – even for a whole forest. Complex constraints often found in the terms of forest leases can also be modelled. Constraints exist to allow the user to: set a minimum mean annual increment for any forest to prevent overcutting; produce non-declining volume or stumpage income from year to year; or limit the years between which a forest may be harvested, or clearfallen.

Maximum supplies of externally purchased resources, such as State contracts and sawmill residues, can be set over a number of years, together with minimum quantities that must be taken in any one year. It is also possible to define complex supply tradeoffs, such as log export penalties and sawmill/chip exchanges. Maximum and minimum sales levels can also be set for any resource, or group of resources, at any location.

Maximum and minimum capacity levels can be set for any process. Quality limits on the mixture of resources used by any process can also be defined. Dummy processes can be used to: aggregate resources, approximate log making or bucking alternatives; impose quality limits on resources purchased or sold; or set quantity limits on trade-offs.

It is also possible to constrain the movement of resources between locations so that, for example, the export of State sawlogs can be banned, and contractual commitments be enforced (even if uneconomic).

Constraints can be imposed to force a short-term, more detailed model to have the same age-class distribution at its end as the one that exists part way through a longer-term, less-detailed model. A control also exists to make a longer-term model have a similar age-class distribution at its end, as exists half way through. This can be used to overcome any bias in a model, caused by the choice of discount rate, to clearfell as soon or as late as possible. To date it has never been needed.

If required, the user can also limit the total cash flow in any year to the maximum level of expenditure – or minimum cash inflow required. It is also possible to force the system to produce a non-declining total cash flow.

The system always generates the marginal cost of user controls. The total cost of any control can be determined by performing two runs – one with, and one without, the constraint or control.

EXPERIENCE AND EVOLUTION TO DATE

All of the above features did not exist when the system was first put to work. This section reviews briefly the models that have been built with the system to date, and shows how this experience has influenced the evolution of the system.

A Single Forest Model

The first model built with the system was an 'On-Truck' model of Tarawera Forest. This tested the short-term harvest-planning features of RegRAM, that enable it to plan the harvesting of individual stands of trees. It also enabled users to compare the existing harvest plan, generated with RMS80 (Allison 1987), against whatever RegRAM would produce.

Accordingly, data was collated for 67 individual stands, for which pre-harvest inventory assessments were available and were scheduled for clearfelling during the next four years. At that time, RegRAM did not have a constraint that would force it to cut specific felling areas within a forest. So these 67 stands were divided among four separate 'forests' at the same location, with each 'forest' containing the stands scheduled to be felled in a particular year. This enabled users to constrain these forests to be harvested in a specific year, if required, using the harvest-year constraints. A fifth 'forest' contained all the younger stands, divided into five crop types.

At that point RegRAM only had a non-declining volume constraint, as it was believed that a non-declining volume would be bound to produce a non-declining income. This was what was actually needed, according to the terms of the Tarawera Forest lease agreement. However the resource planners argued persuasively that, since the younger crops had higher values than the older crops, a non-declining stumpage income constraint would allow more clearfelling of the less economic, older crops early on. This, they argued, should produce a higher net present value. When a new non-declining income constraint was formulated and included, the net present value went up by $NZ 13 million.

Initially RegRAM only had an earliest **harvest**-year constraint, but when attempting to reproduce the existing harvest plan for the first three years, RegRAM chose to clearfell some of the younger crops as well. If the 'forest' containing the younger crops was constrained to prevent this happening, this prevented thinning of the young crops. To avoid this problem it became necessary to modify the system so that an independent earliest **felling** year could be specified for each forest. Once this was done, rerunning the model produced a new harvest plan with a net present value $NZ 3.6 million higher than the existing plan in the first three years alone,and $NZ 11 million higher overall.

Nelson/Marlborough Model

This, the first truly regional model, had three forests, three market locations, and one dummy processing plant to convert volumes of logs with differing basic densities into tonnes. Other than that, it was a pure 'delivered to mill gate' model.

Some problems were initially encountered when building this model too. Local sawmills accepted sawlogs of several grades, at varying prices, to satisfy their overall demand. At that point it was possible to constrain demand only for individual resources, so it was necessary to extend this to any group of resources.

Once again one of the objectives in running this model was to compare the results of RegRAM with the existing cutting plan, previously generated with the simulation model RMS80. However, there was no way of knowing what log allocations would have taken place had the original RMS80 harvest plan been followed. To resolve this, it was decided to use the 'felling strategy file' from RegRAM's simulator, to generate bounds for the optimiser. RegRAM would then be forced to follow RMS80's harvest plan, but be allowed to allocate the logs produced optimally. In this way it became possible to force the optimiser to:

- fell specific areas of each forest, and
- produce specific volumes from each forest each year.

An initial unconstrained run with this model produced a cash flow that was considered too low in some years. The existing cutting plan had also been produced in order to generate a non-declining cash flow from the region. Minimum cash flow and non-declining cash flow constraints were therefore formulated. Once this had been done, RegRAM showed that it could identify a cutting plan that would increase the NPV of the cash flow by $21 million, and obey all the marketing constraints, whilst producing satisfactory cash flows in every year.

Central North Island Model

A model of the Central North Island, the company's most complex region, required no additional constraints. Indeed the cash flow constraint introduced for the Nelson/Marlborough model proved most useful. This model had:

- 12 forest locations,
- 5 external supply locations,
- 13 market locations,
- 14 dummy plants to convert various log grades into 'logs sawn' and 'logs pulped'.

It was a purely 'delivered to mill gate' model with no attempt being made to model real processing plants.

As a result of these runs, the cutting levels and budgets for the current year were set, and RegRAM became fully established as the major resources planning tool of Tasman Forestry Ltd.

CONCLUSIONS

RegRAM is a highly flexible resource allocation modelling system that allows the user to describe objects to be modelled on separate independent spreadsheets. By specifying which objects are to be included in a model, models can be generated ranging from individual stand models to multi-period models incorporating all the forests and processing plants in an entire region.

The system has evolved into a hybrid planning system capable of being run as a straight simulator, a straight optimiser, or even a hybrid of the two. It is now possible to get RegRAM to:

- cut the forest in an exactly specified manner, and allow the optimiser to work out the subsequent resource allocations;
- choose the total level of cut for each forest, as one normally does with a simulator, and allow RegRAM to pick the stands to produce that volume optimally;
- constrain the cut only with marketing and processing constraints, and allow RegRAM to choose how much to cut from each forest;
- run a series of subjectively chosen changes to the system, to cope with practical requirements not explicitly modelled by constraints.

Examples of its use in practice to generate pure forestry 'delivered to mill gate', crop-type-based models indicate that the system seems to be capable of improving the cash flows arising from forest assets by 3 to 5%, of the value of those assets. For Tasman Forestry alone, this could potentially be worth $NZ 36 to $NZ 60 million.

Work is continuing on using the system to generate shorter-term more detailed stand-based models, as well as the global optimisation of integrated forestry and processing models.

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