Optimising algorithms for forest planning and decision-making

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Abstract

Optimising algorithms can help to inform planning and enhance decision-making by those forest managers who are able to employ the technology. Their benefits for determining sustainable yield and timber harvest scheduling under different management scenarios have been established, but they also have significant potential for wider application to evaluate trade-offs between timber production and other forest values. Although previous applications have typically been computationally intensive and required a high degree of specialist technical knowledge, the increased capacity of personal computers combined with greater accessibility of software now makes the techniques available to a wider range of users. This paper overviews optimising algorithms for forest planning and decision-making, and reviews three software packages for this purpose: Microsoft Excel ™ Solver, Habplan and Spectrum.

Introduction

Forest Managers are increasingly relying on data and tools for decision-making in a competitive operating environment where technology may make the difference between a profitable or unprofitable venture.

There is a growing compendium of toolkits that have been developed with small forest growers in mind. For example the Farm Forestry Toolbox developed by Private Forests Tasmania (PFT 2000) provides a suite of tools including site productivity, inventory and management calculators. Effective use of optimising algorithms to assist decision making and planning depends upon an understanding of available applications, the potential benefits, how to formulate problems, plus data and system considerations.

Optimising algorithms have been employed by government agencies and researchers for strategic, tactical and operational planning (eg. Chikumbo et al 1999). Small forest growers and consultants would benefit from better informed forest planning and decision making that can be achieved, through generation and evaluation of alternative scenarios and the ability to evaluate tradeoffs between competing objectives.

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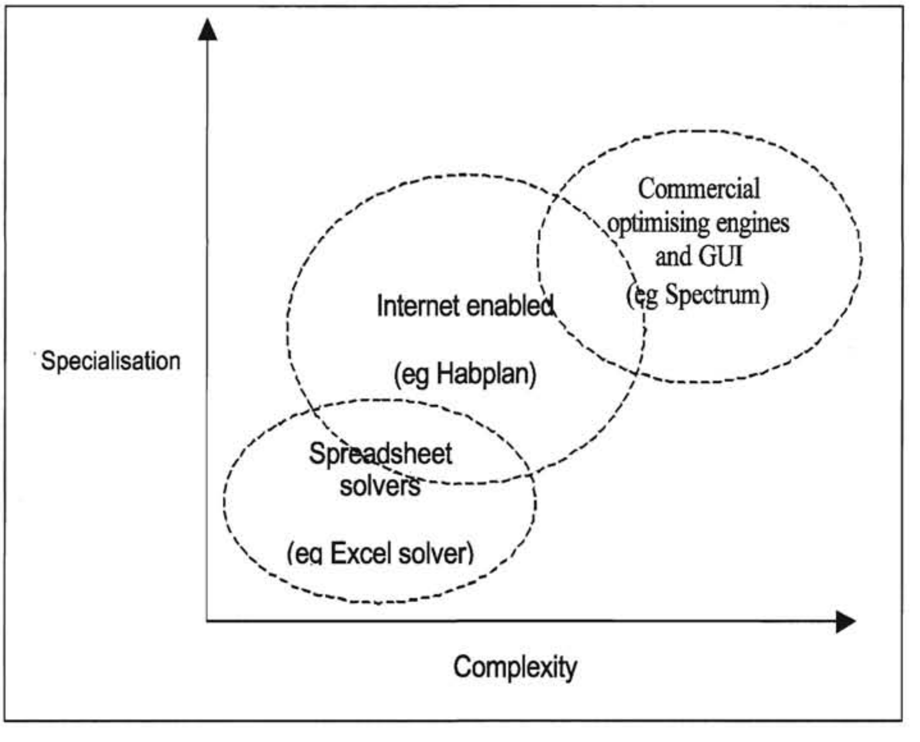
This paper outlines concepts for applying optimising algorithms to forest planning and decision making and reviews three software applications that may be suitable for small forest growers: Microsoft Excel ™ Solver, Habplan and Spectrum. These three software applications have different levels of complexity and degrees of specialisation for forestry applications (Figure 1). Microsoft Excel ™ Solver is an add-in for a commonly available spreadsheet. Habplan is a relatively recent development for forest harvest and habitat scheduling, whereas use of Spectrum, the latest generation of Forplan, for forest harvest scheduling has been well established. The basic theory of optimisation and associated algorithms are provided for readers who are not familiar with the subject.

Optimisation

Optimisation involves minimising, or less commonly maximising, some objective function subject to a set of constraints, where the objective function represents a measure of the thing of interest (USDA 1995a; Ragsdale 1998). A solution is obtained when the objective function is at its minimum or maximum, depending on the type of function employed.

A solution can be either a 'local' optimum, which occurs when the objective function is optimal within a limited portion of the possible solution space, or 'global' optimum, which is when the objective function

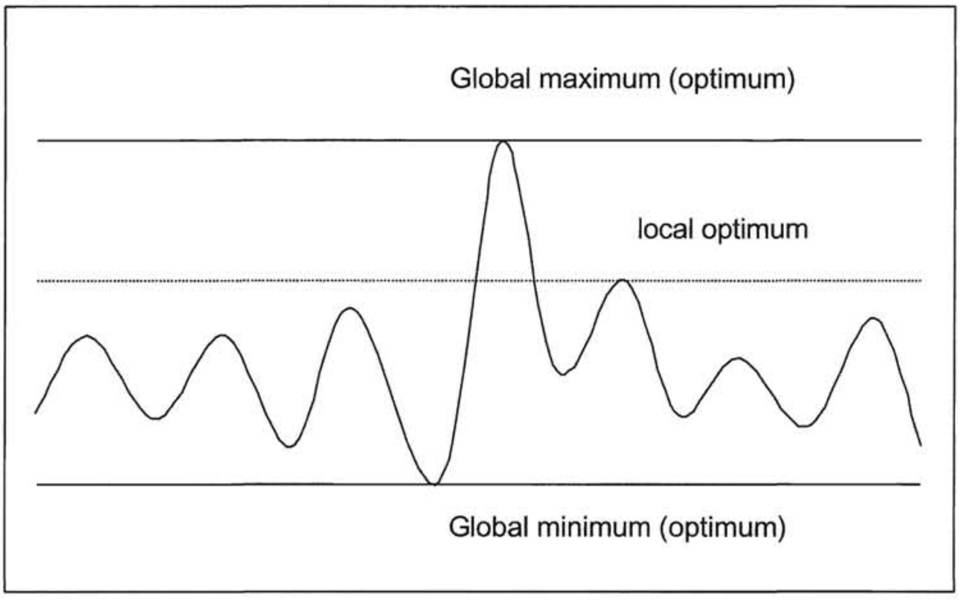
Figure 1: Suitability domain for optimisation software



is optimal across the entire solution space (Figure 2). The global solution is normally sought, but a local solution may suffice when the algorithm starts from a known position within a predetermined range of values.

In optimising problems, constraints are specified to set limits on one or more of the variables that determine the objective function. Goals and weights are also commonly employed. Goals are less precisely defined than constraints and objective functions, in that the goal is to get as near as possible to a desired value. A common use is to optimise several objectives simultaneously. Weights are also useful for assigning relative importance to each parameter that determines the objective function to solve the problem.

Figure 2: Global and local optimums



Forest Planning Applications

The use of optimising algorithms to find the 'optimal solution' implies that the best possible solution is obtained. However, natural resource management problems are complex and often involve evaluating many different conflicting objectives that are poorly understood or difficult to quantify. For these reasons optimising algorithms are most effectively used as a means for exploring the possible range of solutions to determine what is possible under specified constraints and assumptions, rather than for identifying a single, definitive answer to a problem.

A typical forest planning problem may involve achieving a desired level of timber volume for each year in the planning horizon, while ensuring that other multiple use objectives are also satisfied. Examples, illustrating successful applications of optimising algorithms for a range of research and forest management planning applications include;

- Spectrum: determining sustainable yield of natural forest for the NSW Regional Forest Agreement negotiation process,(State Forests NSW 2000),
- Habplan: managing an estate for a range of land uses as a whole productive unit (Chikumbo et al.2001),
- Simulated Annealing: design of nature reserves, (Ball et al 1999),
- Evaluating non-timber forest products and services eg (Nieuwenhuyse et al 2000),

Optimising algorithms also have the potential to assist planning and decision making in:

- Cooperative scheduling of yield from a number of small forest owners;
- Operational planning at local scales (eg Chikumbo 2000), such as those required by small forest growers; and
- Modelling the yield of carbon, salinity and biodiversity credits using a variety of criteria and indicators.

Optimising algorithms

Linear programming (LP) involves solving a set of simultaneous linear equations consisting of an objective function and a series of related constraint functions to determine the solution that best satisfies the objective function. Simple LP assumes linear relationships between continuous variables, like hectares, tonnes or cubic metres. Therefore it cannot handle integer variables where the value is a whole number, such as the number of compartments harvested. Integer LP executes a series of cascading individual LP problems based on the limits set by the integer constraints.

Goal programming involves specifying a soft objective function in which several different goals influence the objective function. The relative weighting of the goals can then be altered to evaluate the solution that provides the best trade-off, as determined by the user. For example achieving a desired level of timber product may have greater weight then reducing effects on streamflow.

Non-linear algorithms are used to solve problems that cannot be formulated with linear relationships. Classical methods, including the calculus, and non linear methods including gradient, penalty or barrier methods can provide a global optimum in a feasible region but are only practicable for small problems of few decision variables (Daellenbach 1978). Because of this limitation, heuristic approaches (discussed below) are employed for solving larger problems.

A heuristic is the outcome of a computation for which the answer is not pre-determined. Heuristic problem solvers repeatedly search a solution space to obtain a better answer than the previous iteration. They all incorporate methods to search in the most promising direction whilst avoiding entrapment in local optima. Since they do not complete an exhaustive search, they cannot guarantee solving the global optimum. By their nature they lend themselves to parallel processing on several separate computers, algorithms which have gained prominence recently include Monte Carlo, Simulated Annealing and Genetic Algorithms.

Both LPs and heuristics explore many permutations of alternative product flows to solve a problem. Optimal or best solutions from alternative "poor" formulations may be inferior to those achieved with "rich" formulations so it is important to provide a range of alternative product flows, including a zero production alternative. In tight solution spaces these methods may be unable to find a feasible solution.

Data requirements

Optimising spatial configurations over time requires a variety of data that are usually obtained using a Geographic Information System (GIS). A typical forest harvest scheduling problem requires:

- Spatial representation of the resource by analysis units, such as compartments or stands, that are areas of land with values that can be determined for things of interest;
- A schedule of product flows which match the time scale of the operation (planning horizon) which relate to analysis units;
- A description of management regimes applied for the duration of the planning horizon and production estimates (yield tables);
- Description of other features, such as stream buffers, that are not spatially represented.

Extensions to the basic harvest scheduling problem can be used to address more complex planning issues such as changing management regions within the planning horizon and spatial configuration of management units. Management regimes are typically multi-period, occurring over many years, but regimes applied to a particular management unit may also change over time. Representation of spatial relationships is necessary to consider spatial configurations, such as adjacency of harvested areas to conservation areas and scheduling of other units within a district where harvesting operations are being conducted. These extensions of the basic methodology produce a more complex optimising problem.

Software

Ten criteria were defined for evaluating, comparing and contrasting the three different software packages, as summarised in Table 1. Specific characteristics of the software and applications are then described in greater detail in the following sections.

Table 1: Comparison of Excel Solver, HabPlan and Spectrum

Criteria	Excel ™ Solver	Habp lan	Spectrum
Systems	Windows 95, NT and 2000 with Microsoft Excel ™.	Any operating system with Java including UNIX and Windows	MS-DOS with C-WHIZ
Accessibility	Microsoft Excel ™ add -in. Additional add -ins available for more complex problems.	Can downloa d evaluation version for not -for profit use limited to 500 polygons. Full version available by agreement.	Spectrum freely available from USDA. C-WHIZ requires commercial licence
Ease of Use	Simple and easy to use for small problems.	Requires some technica l competence and problem formulation experience.	Requires high level of experience and specialist knowledge.
Interface and reporting	Wizard	Nice visual interface, real time view of solution progress	Menu driven DOS based interface. Can link with SPECTRA - VISION for ESRI ArcView ™ for GIS display
Algorithm	LP and Non -linear	Metropolis with plans for links with genetic algorithms	LP only
Problem size	Linear; 200 variables by 200 constraints Non -linear; 200 variables by 100 constraints	500 stands in trial version	49 time units and 6 analysis units
Previous applications	Many applications, but limited forestry specific examples	Recent development few existing applications, has potential	Long history of evolution and application to forestry problems
Other sup porting Information	Standard Microsoft help file and additional reference material widely available	Some user documentation and published articles available	Comprehensive user manuals, published articles and existing expertise
Strengths	Widely available a nd suitable for simple applications	Flexible, future proof, suitable for web delivery and distributed computing	Forestry specific, suitable for large problems
Weaknesses	Forestry specific examples of use required	Needs further evaluation and adoption	Use by small operators not likely due to complexity
Overall rating for small growers	Solid ★★★★	Promising ★★★★	Powerful ★★★

Excel ™ Solver

Solver is an Add-in provided with Microsoft Excel ™ that is the most commonly used spreadsheet application. Solver attempts to find an optimal value for the formula in a target cell on a worksheet by changing values for a group of cells, called the adjustable cells, that determine its value (Microsoft Corporation 1997). Excel ™ uses a Generalised Reduced Gradient Algorithm, for its non-linear solver, as explained in Ragsdale (1998). The simplex method with bounds on the variables, and the branch-and-bound method are used for linear and integer problems (Microsoft Corporation 1997).

Excel™ Solver is widely available with the Excel™ spreadsheet and many users are familiar with its use. Various publications cover spreadsheet modelling, including Ragsdale (1999). Typical applications include maximising investment return to meet certain cashflow requirements, multi-period cash flows, equipment replacement decisions and network flows (Ragsdale 1998). Despite the widespread availability of Excel ™ Solver, there are few examples of forestry specific applications. Spreadsheet solvers are not well suited to large, complex problems common in forest management such as scheduling harvesting multiple compartments over many years. However, Spreadsheet Solvers are ideal for simple models such as the corporate forest industry planning model proposed by Daellenbach et al (1978) and high level problem investigation.

Habplan

Habplan is a landscape management and harvest scheduling program developed by NCASI that was designed to deal with spatial objectives, but can be used for harvest scheduling where there are no spatial or adjacency issues (NCASI 2000). The software and manual can be downloaded from their website (NCASI 2000).

Habplan is programmed in Java so that it can run on many computer platforms and has a feature to monitor several instances on a central computer. It uses the Metropolis Algorithm to randomly generate many different alternative schedules (NCASI 2000). The Metropolis algorithm, as described in Van Deusen (1999), is a type of heuristic discussed earlier.

Habplan is a relatively new software application with few examples of its use, but it has been rapidly adopted for forest management applications. Van Deusen (1999) describes application of the Metropolis algorithm for multiple solution harvest scheduling. Chikumbo et al (2000) describe a Habplan model for a mixed aged forest managed for water yield, sediment production, wildlife habitat and timber production.

Spectrum

Spectrum (USDA 1996) is an LP matrix generator specifically designed to schedule management options for forested land over time (Chikumbo et al 1999). Spectrum is an evolution of Forplan that was developed for integrated resource planning of national forests. Spectrum has enhanced capability, including expanded modelling options and new analytical capabilities (USDA 1995a).

Spectrum provides a graphical user interface (GUI) for a commercial linear optimising engine, C-WHIZ, developed by Ketron Management Systems (2001). C-WHIZ can solve the very large complex problems necessary to exploit the modelling and analytical capabilities of Spectrum. Spectrum also comes fully documented with a user manual and examples.

Spectrum has been employed in NSW (Chikumbo et al 1999), to determine the effect of new reserve designs on timber harvest volumes for the NSW Regional Forest Agreements. Chikumbo (2000) subsequently demonstrated a Spectrum model incorporating the effects of timber harvesting on water yield, sediment production and animal populations including an objective function maximising net present value of timber products.

Discussion

Successful application of optimising technologies depends on the ability to formulate problems in ways that can be addressed by the software as well as the availability of data and system capacity. Prospective users may find that there is insufficient data available to construct the data matrix required to solve a problem. As applications and data become more widely available, understanding of the problem and the ability to represent it in a format suitable for employing optimising algorithms will become the most limiting factor. For this reason, investigation of applications is an active area of research.

Chikumbo et al (2001) categorised forest management into strategic, tactical and operational levels with increasing complexity and data requirements. The benefits from applying optimising algorithms to strategic and tactical planning will result in Spectrum and other software continuing to be used in these and other forest planning roles (for example West 2000). This approach can be extended to include operational requirements, such as those of small forest growers. There is a clear role for functional and available software, such as Habplan, in fulfilling operational planning and other roles. Spreadsheet solvers, such as Microsoft Excel ™, are useful for investigating simple problems where information is limited and also for exploring the problem domain.

Excel ™ Solver is the most accessible application at present. Rapid development of the Internet and web-enabled technologies suggest that Internet delivered data and algorithms are going to be more important in the future. An example is NEOS that is attempting to provide Web-based optimising engines in an ambitious, but potentially revolutionary project (Neos 2000). However, the limitations provided by data volume and bandwidth limitations mean that local processing is likely to remain the most viable option for some time.

Excel ™ Solver has the advantage of being able to employ both linear and non-linear techniques depending on the type of problems. Enhanced solver and spreadsheet add-ins are also available from the developers of Solver and other vendors for tackling more complex problems (Frontline Systems 2001; Lindo 2000; Palisade 2000; ExaTech 2000). Habplan is currently limited to the Metropolis algorithm, although linking this with genetic algorithms to take advantage of the benefits of both approaches is currently being investigated. Spectrum is constrained to only employing LP.

Spreadsheet add-ins, such as Excel ™ Solver, are not suitable for large forest management problems requiring automated data entry and data management. While Spectrum and Habplan have facilities to assist data entry, this remains a time consuming task that will inhibit widespread adoption and use of the software. Spatial data, in particular, is becoming available through spatial data directories (for example CSDC 2000), but may not be of sufficient quality or resolution for operational planning purposes. Where adequate data is not available, users may need to use their best-guess or expert judgment on the most likely value and possible range of values. In these cases, techniques such as Monte Carlo simulation can be used to simulate uncertainty in the data and a what-if scenario analysis used to explore the possible implications of certain decisions.

This paper has provided an overview of the concepts and possible forest applications of optimisation software. There are other more advanced techniques and applications that would have required a more in-depth coverage than what was possible here. With greater experience in employing algorithms in forest planning and decision making, more novel and sophisticated applications are likely.

Conclusions

This paper has reviewed application of optimising applications for forest planning and decision making using three software packages available for this purpose. Microsoft Excel ™ is suitable for relatively simple problems that the user can formulate in a spreadsheet. Spectrum is well established for forest applications for large, complex problems but is unlikely to be adopted widely by small growers because of its complexity. Habplan offers considerable potential as an Internet enabled technology, but there is limited experience in its application to forestry problems.

Employment of these technologies is currently dependent on understanding of the technology, ability to formulate problems and obtain required data. It is not limited by processing capability unless large problems are being formulated that are not the domain of small growers. The impediments can therefore be overcome by provision of information and greater accessibility so that the benefits of the methods for many forest planning applications will be fully realised.

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