Integrated Forest Planning System (IFPS) – A Practical Approach to Decision Support Framework Design

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Abstract: The focus of this paper is to discuss the evolution of a decision support framework from a linear programming matrix generator. Increasing demand on forest managers to exercise sustainable management has led to development of an integrated forest planning system (IFPS) approach in Victoria. The IFPS approach relies on the interaction of several technologies and processes to increase the involvement of interested parties in the modelling. The rationale behind this framework is to potentially empower all stakeholders in the decision-making process. It ensures the relevance and practical application of modelling results across various planning scales in a transparent manner. To achieve these goals, geographic information systems, simulation models, a linear programming matrix generator and remote sensing are linked in iterative cycles of modelling, where visualization techniques play a crucial role. The hierarchical approach to data preparation and the construction of models for different scales allows greater transparency in the interpretation of the modelling results. It also decreases the risk in decision making because of more precise input data definition. The ability to visualise the results of modelling across a planning horizon through a high-resolution virtual landscape, allows for corrections to the models and also more directly involves parties interested in the modelling outcomes. The spatial representation of modelled activities through a planning horizon allows other models that require spatial input to be linked. This facilitates more specialized economic or environmental analysis. An important benefit of the discipline of an IFPS approach to the spatial aspect of modelling is the ability to visualise as well as monitor changes in the landscape. Although the IFPS decision support framework was designed in 1990, its practical implementation is still continuing to improve and its importance to forest decision-making is being recognised. Previously built models are continually used to support additional "what if" analyses.

Keywords: Visualisation; Decision support framework; Multi-scale analysis; GIS; Remote sensing

1. INTRODUCTION

The Department of Natural Resources and Environment (NRE) is responsible for the care and management of most of Victoria's publicly owned native forest.

The success of the government forest policy of ecologically sustainable timber production depends on the ability to involve all interested parties in decision making.

Forestry, with its very long production times, requires a modelling framework that should encompass the entire planning horizon. The government of the day, forest managers and timber industry can evaluate the impact of different management scenarios not only by political means, but also by quantitative analysis.

This paper focusses on a modelling framework provided by Integrated Forest Planning System (IFPS). This IFPS was developed to assist in the strategic forest planning in Forest Management Areas (FMAs) in Victoria [Lau *et al.*, 1994].

2. THE FRAMEWORK - INTEGRATED FOREST PLANNING SYSTEM (IFPS)

2.1 Common open Modelling Environment

This approach was the result of the enormous acceleration in the development of computer hardware and software applications, as well as the budgetary and organisational constraints of our relatively small government organisation.

The IFPS consists of many separate applications linked to each other by an interface and a database [Lau *et al.*, 1995 and 1998]. Such an approach has proven to be practical and beneficial. The main benefits are the relatively low costs and the flexibility in adopting new applications for new analysis. However, the main drawback of such an open system arrangement is its reliance on constant expert support.

At the core of the system is a relational database, SIR (Scientific Information Retrieval) with proprietary interface, facilitating exchange of data and information between GIS/remote sensing, optimisation, growth and yield models. For the geo-spatial data preparation and spatial analysis ESRI ARC/INFO and ArcView are used.

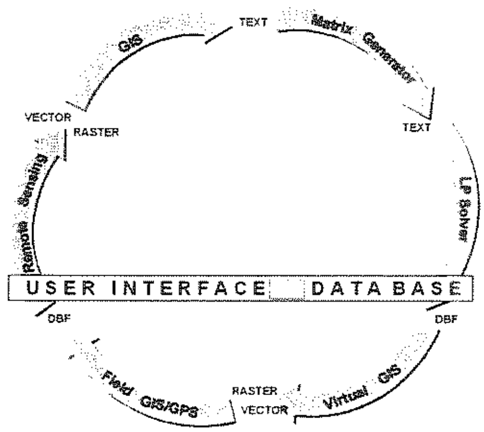

Figure 1. Diagram representing IFPS open system design where applications can be brought in and discarded with ease. No "hard wiring" between applications. Communication via database, text, vector or raster files.

ERMapper and ERDAS Imagine are employed for the preparation and analysis of remotely sensed data. As a Linear Programming (LP) matrix generator and report writer USDA PC Dos/Windows based SPECTRUM was adapted to the UNIX environment. An industrial version LINDO by Lindo Systems Inc. is used as LP solver.

2.2 Data Organization

The Department of Natural Resources and Environment (NRE) maintains a corporate geo-spatial library containing vector coverages, grid and image data in map tiles in three major scales: 1:500,000, 1:100,000 and 1:25,000. The IFPS relies predominantly on 1:25,000 spatial data.

Although the ARC/INFO corporate geo-spatial library is functional and contains large amounts of data, in its current state this is not fully suitable for direct use with a modelling system like IFPS. The main reasons for this is the data quality control, its spatial accuracy and the specific needs of IFPS for data preparation. For those reasons the corporate geo-spatial library is currently only used as a mere repository of data. The need for a separate, more specialised form of geo-spatial library has been identified.

The IFPS Virtual Forest Library already contains raster and vector data that has been prepared for Forest Management Areas (FMAs) in the process of developing analysis units [Lau *et al.,* 1998] as a part of construction of spatial management models. Currently, data stored in the corporate library is accurate to approx. 60-100 meters and is stored in map tiles that often do not match data along their edges or represent inconsistent levels of detail. This data still contains inherited low spatial accuracy.

Recently, a high accuracy data set was obtained for an area of 250,000 hectares of forest in Matlock Modelling Study Area, which is devoted to modelling experiments, testing and validation. This data is accurate to approx 1-2 meters. Such accuracy is essential in the construction of a digital virtual forest environment where modelling for forest planning and management takes place, in order to achieve greater confidence in the modelling outcomes.

2.3 Data Preparation

This is a demanding task of multi-dimensional, complex nature that requires careful attention. Generally data preparation within IFPS is structured around two main processes:

a. Correcting inconsistencies and quality checks;

b. Developing and applying processes aimed at describing the forest in the most accurate manner for the development of forest management models.

The latter process involves an array of GIS and remote-sensing procedures all aimed at achieving an as accurate as possible description of land units used in modelling.

2.3.1 Variable-width buffers

One of the main considerations in determining the areas available for timber production is the determination of riparian zone exclusions or stream reserves in the form of stream buffers. Under the Victorian Code of Forest Practices, timber harvesting is not allowed in streamside reserves. These are primarily established for the protection of streams from the adverse impacts of forest activities like logging, site preparation and road construction. Under current regulations and practice, a 20-metre uniform width is used in creating stream buffers.

The effectiveness of this buffer design and structure is limited because it does not take into account the following:

1. Drainage networks are spatially represented as lines and no information is provided about width and the extent of saturated zones, and

2. Interactions between slope, tree height and streamside reserves are physical limitations to the application of the Code due to the tendency of trees to fall down-slope during harvesting operations.

An alternative approach recently introduced is the design of variable-width buffers based on streamside slopes. This takes into account the physical variability of the topography along streams.

Buffer width rules are applied depending on the mean slopes. These buffer rules were the results of numerous consultations with regional staff, analysis of stand heights of mature stands within 80 metres on both sides of streams, and field measurements of streamside reserves from logging coupes. The following rules are applied in creating the variable-width buffers:

1. If mean slope is from 0 to15 degrees - buffer width is 25 metres

2. If mean slope is from 15 to 20 degrees - buffer width is 40 metres

3. If mean slope is greater than 20 degrees - buffer width is 60 metres

The watershed for each stream segment was also delineated. Serving as the maximum width limit for the buffers, the watershed boundaries ensure that buffers do not extend across watershed boundaries. (Figure 2)

When combined with management zoning, the variable-width buffers serve as additional filters on area availability for timber production.

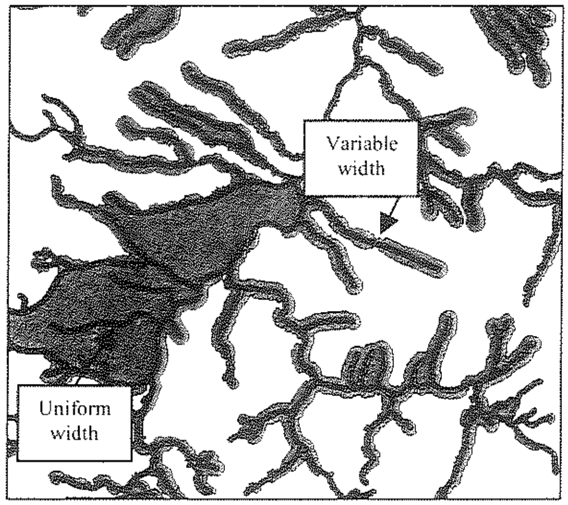

Figure 2. Comparison of stream buffers created using the 20 metre uniform width and the variable width approaches.

2.4 Multi-scale Approach

One of the least recognised challenges in the search for a balanced forest management plan is the diversity of scales that need to be addressed to make the strategic forest plan transparent, practically meaningful and operationally achievable.

The State-wide Forest Resource Inventory (SFRI) provided updated data for Benalla-Mansfield and North-East FMAs [Forest Service, 1999]. The updated data sets consist of stand maps at 1:25,000 scale and stand volume estimates based on modelling of inventory data. The model-based approach was used in North-East FMA to sample an area of 227,000 hectares, using only 271 plots. In this case a stratified random sampling would have required substantially more plots to reach estimates of similar precision [Hamilton and Brack, 1999]. The new 1:25,000 SFRI mapping of forest enables us to undertake a two-step hierarchical approach to modelling, making better use of over 140 growth curves describing growth of forest in Benalla-Mansfield FMA.

Step one involves construction of a general model for a Forest Management Area (FMA). Step two requires construction of a number of detailed models for portions of the same FMA. The initial results from a general model determine the solution's outer boundaries, providing initial guidance in construction of the detailed models. This approach allows for segregation of constraints and variables according to their suitability from the point of view of spatial or time scales. The results from detailed models can then be used to alter the initial general model.

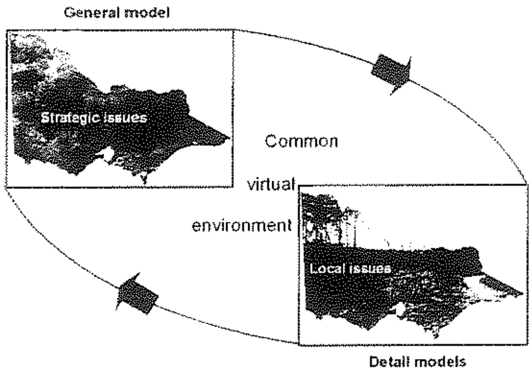

Figure 3. Linking of different planning scales.

The main reasons for the two-step approach are:

- Common mismatch of scales within and across models;
- Difficulty in answering more specific planning concerns relating to areas smaller than FMAs;
- Computational limitations eased by breaking up the FMA to smaller portions;
- Difficulty in determining scaling rules for variables used in general models.

In IFPS, the link between different planning scales relies on the availability of detailed representation of the land units used in modelling. Their description, homogeneity and size largely determine their suitability for a given scale of modelling and set the limits for a given model. The two-step modelling approach offers a way of addressing the multi-scale nature of inventory data and management requirements and better copes with greater complexity. [Lau *et al.*, 1999].

2.5 Visualisation

Forest planning has been and will remain driven by people and their subjective feelings. Visual, intuitive ways of interacting with a model and producing transparent results would gain more professional and public acceptance.

The ability to visualise the results of modelling, throughout the length of a planning horizon in the context of a high-resolution virtual landscape is an important feature of the IFPS modelling framework. It contributes to spatial sensitivity, interactivity and accountability of SPECTRUM-built Linear Programming (LP) models. For each LP model a set of land units is developed in ARC/INFO and maintained throughout the cycles of modelling. These land units, together with remotely sensed data, digital elevation model (DEM) and temporal information form a planning virtual space. Visualisation also plays an important role in correcting major spatial and interpretation omissions and errors before the modelling process begins.

2.6 Optimization, Iterations and Interactivity

Visualisation of changes in the forest landscape as a direct result of a given management strategy, assists with reassessment of assumptions and often leads to change of planning direction.

More importantly, visualisation of modelling results, in the context of the landscape, allows for moderation of an optimal solution by involving regional forest staff in assessment of its feasibility and practicality from a field management perspective. Such feedback remains the backbone of interactivity of IFPS. It is an essential process since linear programming has proven attractive for decision analysis in forest management. However the LP model has recognised inadequacies. The iterative use of LP in search of a realistic balanced solution is greatly enhanced by visualisation.

The involvement of forest field staff in the process of modelling builds a sense of ownership of the planning decision.

The IFPS iterative cycles of modelling set the framework for exploring decision space more comprehensively than just a one-way process.

Furthermore it opens possibilities for involving complex simulation models into the spatially defined LP decision "playing field". Finally the iterative visual approach allows exploration of decision space by anyone interested in management outcomes [Lau *et al.*, 1996].

Figure 4 encapsulates three major cycles of modelling in IFPS framework. These are: first, determined by supporting simulation models;

second, by prescriptive alternative management strategies; and third, by changes in landscape detected by monitoring.

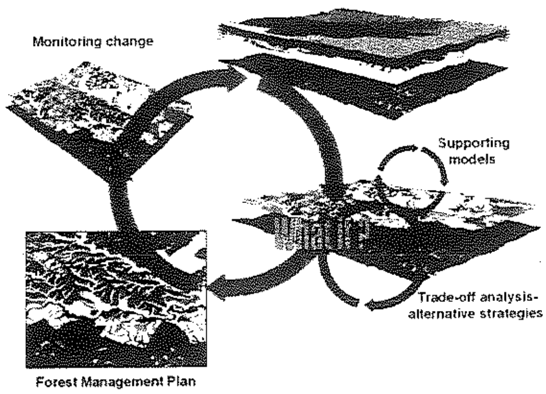

Figure 4. Iterative modelling cycles of IFPS framework

3. MODELLING FRAMEWORK AND ITS IMPLEMENTATION

3.1 Forests Management and IFPS

Although the IFPS decision support framework was designed in 1990, its practical implementation is still continuing to improve and previously built models are continually used to support additional "what if" land management analysis.

3.2 Spatial and Temporal Scales in IFPS Analysis

Victoria is divided into 14 Forest Management Areas (FMAs) for which strategic plans are prepared with a 10 year planning horizon. The area available for timber production varies substantially from FMA to FMA (see Table 1).

The IFPS approach has been used in 6 FMAs so far. However, only in Benalla-Mansfield FMA was the new generation inventory data from SFRI program used. For each of those FMAs spatially referenced LP models were constructed. The minimum size of a unique analysis unit, representing a unique feature on the ground, varies between 1 and 5 hectares. The size of available forest in FMAs, for which models were constructed, varies between 48, 400 and 173, 000 hectares. The number of unique polygons in each of the general models varies from 3900 to 10500.

For strategic scheduling of harvesting and estimates of sustainable levels of timber production, 5 or 10-year time steps are used stretching to a 200 year planning horizon. The assumption is that harvesting and other activities represented in the model take place in the middle of each 5 or 10-year time step.

Table 1. Description of unique land units in general models.

Forest Management Area (FMA)	Number of polygons	Number of Analysis Units	Smallest Analysis Unit (ha)	Largest Analysis Unit (ha)	Total Available Area (ha)
Benalla – Mansfield *	10900	2220	1	862	48400
Central	8200	665	3	2146	103000
Central Gippsland	10500	851	1	3017	173000
Dandenong	10500	792	5	2100	120400
Midlands	4700	840	1	1289	115300
North-East	9700	1108	1	2700	94000

(*) The new generation inventory data from SFRI program was used.

Such time steps are considered adequate and practical for a strategic overview, and they allow for faster processing. However, 10-year time steps can have adverse ramifications when a more detailed level of planning is needed. The necessity for extrapolation of growth information can cause doubtful results in forecasts for heterogeneous landscapes.

The process of spatial disaggregation after a solution to the model was found, only tends to compound such errors. To assist with addressing this problem the decision was made to construct models with analysis units as detailed as practicable.

3.3 Monitoring

Monitoring is a vitally important process and at the same time most underdeveloped in the workings of Victorian forest management. The

IFPS provides the necessary points of reference against which changes in forest are quantified. Without such reference any monitoring would be ineffective. In the case of IFPS the land units developed for the analysis form a network of polygons which is very useful for monitoring. The change in forest cover is measured against those polygons.

Such an approach to monitoring allows for an annual check whether activities scheduled by the management model took place and to what degree. This information is used to alter the model and re-run it to assess the impact of change and its adherence to modelled management strategy.

At this stage, IFPS monitoring of change and detection of inconsistencies in assumptions and data generally relies on three major processes:

1. The yearly purchase of satellite imagery facilitates the remote sensing process of change detection.
2. The field extension program provides hand-held computers with subsets of vector and raster data used in models combined with GPS. The field staff are able to locate themselves in real-time in the forest and compare what they see with data sets used in models and virtual forest.
3. Importantly, the SFRI conducts a monitoring program assessing predicted versus real timber yields by means of felling plots.

4. CONCLUSIONS AND RECOMMENDATIONS

Despite the recognized inadequacies of a linear programming model for decision analysis, given the right spatially transparent and accountable framework for its use, LP still remains the most robust "work horse" for analysis of management options in Victoria. At this stage the issue of suitability of LP in forest management lies in how LP is used.

In the IFPS approach the effort is made to make the LP solution fully spatially transparent, to construct relatively simple problems, and to treat LP as a "level playing field" where the results of more complex models can be brought into the analysis. It is paramount for the credibility of the modelling framework that the involvement of field staff and the forest industry in construction of management model is assured.

It is vital for the implementation of modelling framework to construct a virtual environment that as accurately as possible reflects the situation in the forest. Even more crucial for the level of risk involved in forecast of timber availability is to build scale-sensitive models from (if possible) hierarchically structured data.

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