A Comparative Assessment of SFMM/Stanley & COMPLAN for Forest Management Planning in Ontario

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ABSTRACT

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The growing complexity of forest management planning issues requires the best planning tools available. A key question facing forest management planners in Ontario is whether SFMM (and its harvest-blocking tool Stanley) are the appropriate tools. The most effective method to evaluate SFMM/Stanley's appropriateness is to compare it with a model proven in other jurisdictions.

Through the study the differences in the approaches to forest management taken by each model became apparent. The differences between optimization and simulation apart, the biggest difference derived from the role the model developers envisioned for their model. SFMM was designed as a tool to develop management strategies in even-aged forests. The scope is over a large area and long timeframe, typical of preparing a forest management plan in the province, this makes allowance for a loss of a certain amount of detail. COMPLAN was designed in partnership with industrial clients and emphasizes operational considerations, much more so than SFMM. COMPLAN attempts to maintain as much detail as possible. The model also integrates the spatial component into the operational planning, as spatial constraints are identified as a key factor in the operational planning process.

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1.0 PROBLEM STATEMENT

Forest sustainability as described in the Crown Forest Sustainability Act (CFSA) (RSO 1994) means "long-term Crown forest health". The Act defines Crown forest health as "the condition of a forest ecosystem that sustains the ecosystem's complexity while providing for the needs of the people of Ontario" (MNR 1995). Forest management planning establishes the long-term strategic direction for managing the forest to achieve the desired future condition of the forest (MNR 1996A). Various combinations of objectives and strategies are formulated into a number of management alternatives, each of which is analyzed for its ability to provide the desired benefits in a sustainable fashion over time. The analysis includes an initial test of sustainability for each management alternative through the use of non-spatial measurable indicators of forest sustainability criteria. The result of the analysis is the selection of a preferred management alternative. Thus, the establishment of the long-term strategic direction for the management of the forest is an iterative process.

Forest management planning requirements for the Province of Ontario are specified in the Forest Management Planning Manual (FMPM) (MNR 1996A). The FMPM was written to incorporate requirements for decision-support tools. However, the decision-support tools were still under development when the FMPM was completed. The Strategic Forest Management Model (SFMM) is the model developed by the Ontario Ministry of Natural Resources (MNR) to assess forest sustainability and resource availability.

Many people charged with preparing management plans according to the FMPM commonly describe SFMM as a 'black box'. The term 'black box', when used by model users, indicates they do not understand the relationships that link input and output variables, i.e. there is a hidden logical structure among the underlying causal relationships. In addition, since SFMM was introduced into the planning process, a number of perceived shortfalls have been identified by SFMM users. Currently, the MNR and the forest industry are looking at developing a replacement for SFMM to address some of these shortfalls.

Model users in Ontario require some reassurance about the functionality and accuracy of the forest planning models offered for their use. One source of concern is that SFMM was developed by the MNR, an agency that also mandates its use in forest planning on Crown lands that dominate the forested portion of the province.

The growing complexity of forest management planning issues requires the best planning tools available. A key question is whether SFMM (and its harvest-blocking tool Stanley which was developed by a consulting firm in Eastern Canada) are the appropriate tools. The most effective method to evaluate SFMM/Stanley's appropriateness is to compare it with a model proven in other jurisdictions.

The models and approaches studied include SFMM which is an aspatial optimization model with the Stanley spatial blocking tool, and GIS-COMPLAN (COMPLAN), a spatial simulation model. COMPLAN is widely used in the Pacific Northwest of the USA and Western Canada (ORM 2001). The purposes of this paper are to describe the two approaches in general, explain their capabilities, and compare their relative advantages. The models are assessed based on their utility in preparing a forest management plan in accordance with the requirements of the CFSA and their ability to handle a variety of management objectives commonly encountered in boreal forest management across the country. This study will provide an unbiased evaluation of the two models to the public, government and industry stakeholders in forest management. This discussion should enable existing and potential users of the approaches to understand and evaluate them better. Hopefully, new insights into forest management planning models will be gained and the choice of forest management models will be broadened or supplemented to include other approaches.

1.1 Evaluation Criteria for Ontario: Strategic Direction and Determination of Sustainability

Forest management models may be constructed at a number of scales based on the size of the measurement unit adopted. Each different scale requires a different level of information. The models studied in this paper are designed to operate at the forest management unit level (several thousand hectares) and this is the scale at which they will be evaluated. It is at the forest management unit level that sustainability is evaluated in Ontario.

The forest modelling component of a Forest Management Plan (FMP) projects how the forest might develop through time under alternative management strategies. As a part of the analysis a "natural" benchmark must be established. This purpose of this benchmark is to predict what the forest might look like without human intervention and offer ecological targets for the managed alternatives. In determining sustainability, the FMPM requires the forest modelling component to be assessed against six indicators of sustainability:

1. Landscape pattern indices;
2. Frequency distribution of clearcut and wildfire sizes;
3. Forest diversity indices;
4. Managed Crown forest area available for timber production (by forest unit);
5. Proportion of available harvest area which is utilized (by forest unit); and
6. Habitat for selected wildlife species.

The combination of a set of objectives and associated strategies for their achievement is called a "management alternative" (MNR 1996A). The planning team develops a range of management alternatives with the assistance of the Local Citizens Committee (LCC). Each management alternative is analyzed with respect to two important considerations: (a) the future forest condition which is expected to result from its implementation; and (b) the implications of the management alternative in terms of its ability to ensure forest sustainability and to produce the desired benefits or outcomes over time. The MNR requires analysis of three specific management alternatives based on:

1. available revenues for silvicultural funding;

2. the assumption that all required silviculture funding is available; and
3. providing for the anticipated industrial demand for timber, assuming that all required silvicultural funding is available.

The MNR has stated that a comprehensive guide to analytical tools and procedures for their use in forest management planning will be developed (MNR 1996A). The guide will describe the analytical tools available and how they can be integrated, as well as the systematic analytical approach which must be used in assessing management alternatives in forest management planning. In Appendix IX of the FMPM (MNR 1996A), the section on the future of decision-support tools states that "as tools are implemented, they will become the standard by which the development of other similar tools will be evaluated". Therefore, SFMM is the yardstick against which all models proposed for use in Ontario will be judged.

The only forest management tool listed by the MNR in the FMPM is SFMM. If the plan author wishes to use another model for the forest modelling component of the plan, any such model must have the ability to use the same information and produce the same or similar products as SFMM in the analysis of management alternatives. Whatever analytical model is used, all requirements of the FMPM must be met (MNR 1996A). The use of any model other than SFMM must be authorized by the Director of the MNR's Land-use Planning Branch, Main Office, before the terms of reference are approved by the MNR Regional Director (MNR 1996A).

A number of sources (some which have already been discussed) provide model evaluation criteria to assist users (USDA Forest Service 1979, 1981, 1989, 1997, Brand and Holdaway 1983, Buchman and Shifley 1983, Deschamps 1990, Morton 1990; Forestry Canada 1991; Duinker 1997). Each focuses on a specific model or model type; however, they all stress the importance of developing criteria specific to the intended usage. The FMPM contains specific requirements for management plans prepared under the CFSA. Therefore, these requirements will form the basis of the criteria used in this evaluation of SFMM and COMPLAN.

To be considered for use, any proposed forest model must:

1. Be capable of tracking the entire landbase of a management unit through time, including all forested areas, whether managed or unmanaged, and non-forested areas;
2. Evaluate all forested areas, whether managed or unmanaged, for their contribution to forest diversity, timber production, and wildlife habitat;
3. Produce projections of forest structure and composition for a minimum of 150 years;
4. Incorporate expected rates of natural depletion agents, such as forest fire, windthrow and insects;
5. Incorporate current and potential levels of silvicultural investments; and
6. Be capable of assessing a wide range of management alternatives, including the three mandatory alternatives described above (MNR 1996a).

The above set of model criteria are specific to Ontario: however, they do address a number of issues relevant to forest planning in a number of jurisdictions. Whatever analytical model is used, all requirements of the FMPM must be met. However, the criteria that have been developed to help in assessing the model's suitability for forest management in Ontario may also help in evaluating their utility in other jurisdictions.

2.0 INTRODUCTION

2.1 Definition of Forest Management

Forest management, as defined by Baskerville (1990), is the control or regulation of the pattern of stages of stand development, across the area of the forest and across time. On-the-ground forest management control is exercised by temporal and spatial regulation of harvesting, product recovery, silviculture and protection. To maintain the forest industry, managers must regulate the development of stands so that there are always stands at the right stage of development and in sufficient numbers to yield the desired raw material mix. Baskerville (1993) described forest management as a six-step loop process (Figure 1):

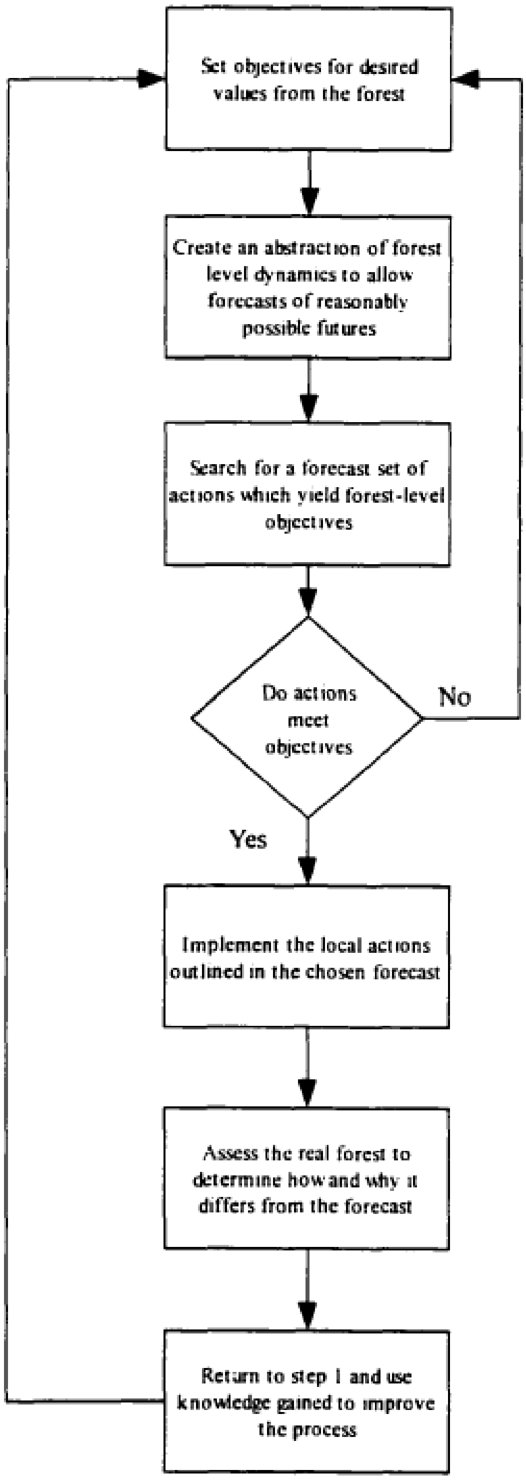

Figure 1: Steps in forest management

Adapted from Baskerville 1993

Forest management is the means by which forest dynamics are regulated to achieve the desired goals. The difference between a managed and an unmanaged forest is that the manager attempts to control or influence the future. Forest managers have four tools available to them to control forest development: scheduling the harvest; distribution of the harvest; renewal of resources; protection of the resource (FUS 1983).

Management planning is the process that links the four tools together by geographic location and time (FUS 1983). The mix of the four actions and the intensity with which each is utilized depends on current management goals for the forest. Having chosen a desired forest condition, the four kinds of management actions are then used to regulate forest dynamics so the desired future unfolds.

Forest management is a series of decisions aimed at integrating the four management actions over the planning period so that the forest develops as required. The forest manager identifies a desired future forest condition, so choices are between different forecast forest conditions rather than individual actions (Baskerville 1993). For example, the choice is not between planting or natural regeneration of a stand but rather between a forest with intensive management or one without (or an almost infinite combination of intensities). Therefore, the ability to forecast the dynamic development of stands and forests is one of the key features of a forest management model (Deptha & Brathvode 1990; Skovsgaard et al 1998).

Management decisions are made using the best available information. Poor information is the most likely cause of bad decision-making. Understanding the spatial and temporal relationships amongst these processes allows managers to target the correct causal mechanisms. Management planning involves forecasting future development for one strategy and. using indicators. comparing these outcomes to existing knowledge and analyzing causal relationships (Baskerville 1990). Management planning involves the application of the four basic tools of scheduling. distribution. renewal and protection over a management area and across time (FUS 1983). While these decisions are made regarding the treatment of specific location. management concerns the relationship between these treatments and the development of the forest as a whole (FUS 1983).

2.2 The Role of Models in Forest Management

Given the management objective to regulate the development of forest stands. it is necessary to create a system that will allow analysis of the biological components and processes in the forest (Kimmins 1990). Computer models are the most economical and effective tools available (Goodall 1972). Computer modelling produces alternative forecasts that are consistent with the underlying dynamics for all management alternatives (Bunnell 1989). The forecasts are the result of defined: 1) initial conditions; 2) rules of change; and 3) responses to intervention (Baskerville 1993). Models can be inspected to determine if these inputs are accurate reflections of natural processes (Rennolls & Blackwell 1988).

Management tools are applied at two scales (FUS 1983). First, individual management actions are taken at the stand level. Second, effects of stand-level actions are planned and evaluated at the forest level. Forest-level forecasts are determined through the mechanics of computer models by the assumptions used in the form of yield and cost curves, and rules for silvicultural treatments and harvest (Walters 1993).

2.3 Approaches to Forest Management Modelling

Pearse (1976) recognized the need to plan forest management based on large units 'tributary' to major manufacturing facilities. He also recognized the need for increased consideration of ecological and other resources in management planning. This expanded management focus requires tools that consider resource-use interactions, long-term wood supply, land-use changes, utilization changes, management program options, and harvest schedules. This expands management planning from a simple harvest volume calculation (Carson 1995). Planning requires analysis of different options based on how they affect both current requirements and the future forest condition. These expanded planning requirements demand tools capable of more than just calculating allowable harvest (Nelson et al. 1991). In response to the new management regime, a number of tools were developed, including forest estate simulation models, and mathematical programming models.

2.3.1 Forest Estate Simulation Models

Watt (1983) defined simulation as a technique to gain understanding of a complex system by constructing and studying a simplified version of that system. Simulation models, such as COMPLAN, have been used in forest management since the 1960's (Jamnick 1990). Simulation models grew out of area volume allotment check (AVAC) calculations used in determining annual allowable cut (AAC) (FUS 1893). Simulation models are used primarily as descriptive, rather than prescriptive, decision tools. Simulation models are also known as "what if" models since they are designed to answer the question "what happens if we undertake this management strategy?" (Davis 2000).

Simulation models successively harvest and grow the forest for a specified number of periods (Dykstra 1984). Forest estate simulation models generally have simple data structures. Most simulation models require:

- An inventory categorized into volume classes and area assigned to even-aged age-classes or timber classes;
- Yield curves for managed and unmanaged regimes, for each volume class; and
- A harvest regime defining the total volume (or area) per iteration, harvest priority rules and constraints regarding the portion of growing stock that may be considered operable in any term.

Simulation models are not structured to identify which strategy is best to achieve a stated objective (Hoff et al. 1986). In a simulation model, the harvest and renewal regimes are inputs rather than outputs of the model. Where there is ambiguity in the problem, a simulation model is used more to articulate the problem than to solve. However, it is useful for displaying the impact of a particular policy or changes to it. Simulation models are not tied to a particular mathematical structure and therefore can flexibly and efficiently handle large amounts of data and detail. (Morgan et al. 1995) Simulation models are generally cheaper and quicker to execute than models that use mathematical programming (Jamnick 1990).

2.3.2 Mathematical Programming

Mathematical programming addresses the problem of allocating scarce resources to optimize the objective function, subject to defined constraints (Forrester 1968; Dykstra 1984). The model generates what is known as the optimal solution, that is, the solution that produces the highest (or lowest) value for the mathematical equation used (Roise 1990; Gaither 1992). The optimal solution is defined by the mathematics used, and are particular abstractions of the real world problem under scrutiny. Typically, linear programming (LP) harvest scheduling models, such as SFMM, maximize the volume harvested or the total values of timber harvested, or minimize costs for a specific number of periods comprising the planning horizon (MNR 2000a). The current generation of LP models use 'simultaneous' algorithms (Liu et al. 1996). These consider all periods to schedule activities that optimize the solution over the planning horizon, whereas simulation models solve each period independent of what happens in the preceding or following period (Lockwood & Moore 1993).

LP models are used as prescriptive tools that produce an optimal allocation strategy. If a management problem can be simplified into an allocation or scheduling problem, then LP offers an elegant and efficient technique to identify candidate strategies (Tarp & Helles 1997). However, these models are generally more expensive and time-consuming to execute (Jamnick 1990). Formulating the problem takes considerable skill.

Forest planning tools help the manager plan a strategy to achieve a desired future forest condition that yields the required products and volumes (Liu et al. 1996). The tools range from simple yield regulation formulae to more complex forest estate simulation models to mathematical programming models that find the optimal solution to a problem. The differences between model philosophies and structures make direct comparisons difficult.

Using a yield regulation equation, such as the simple area method or Hanzlick's formula would provide a harvest rate for a given period (FUS 1983). If the formula is applied at the beginning of each term to calculate successive harvests the harvest level would eventually approximate the long run sustained yield (LRSY). However, a yield regulation equation would not identify the optimal solution like an LP model nor would it provide the user with descriptive information like a forest simulation model would.

3.0 MODELS & METHODS

3.1 SFMM

The MNR (1999) describes SFMM as "an interactive forest modelling system" which allows users to "represent large forest areas at a strategic level and project them through time". The purpose of SFMM is to help foresters and biologists "manage forests, analyze wood supply, and gain an understanding of habitat components". Additional uses include reviewing the impacts of provincial policy and land-use decisions.

SFMM is a linear program model, using the AIMMS (Paragon 1995) software package. AIMMS allows the use of a Graphical User Interface (GUI). The GUI provides a number of advantages, for example ease of use and ease of understanding. GUI allows the user to quickly develop management alternatives and examine the results. SFMM uses a Windows-based GUI to input data and execute the model. By following the outline and selecting the appropriate tab, input information is easily entered into the model. The AIMMS software package also allows the user to paste information, such as yield curves, from other applications such as spreadsheets (e.g. Excel).

3.2 Stanley

Stanley was created for use as a stand-alone harvest block scheduler or with the *Woodstock* model created by Remsoft (1994a). Through an agreement with the MNR, Remsoft adapted the Stanley model to work with SFMM. The MNR felt that it was more practical to use an existing tool than to develop its own spatial harvest scheduler (Davis et al. 1997). The SFMM solution is linked with Stanley through a text file known as the Choices file. Stanley schedules stands for harvest based on this file (Remsoft 2000).

Spatial information is stored in the form of an Arcview shapefile (Remsoft 1996b). Stanley comes with a set of utility programs known as GISpak that allow Stanley to manipulate the information in the shapefile. The Shape-to-Stanley utility uses the attribute information to create the global polygon attribute table (GPAT) (Remsoft 1996b). The Shape-to-Stanley routine also creates the extent and adjacency files (Walker 1999). An additional index file is created by the Shape-to-Stanley routine that stores stand extent information and reduces processing times.

3.3 COMPLAN

COMPLAN is a spatially explicit forest estate model that schedules harvests at the cutblock or stand level subject to adjacency (green-up) and non-timber resource constraints (cover constraints) (SRC 1997a; SRC 1997b). The model's built-in flexibility makes it possible to evaluate many scenarios with a large degree of realism. COMPLAN uses a hierarchical data structure that takes advantage of a Compartmental Management approach to spatial data organization. Advantages of this approach include easy integration with GIS systems, adaptation to a wide variety of tenure administration structures and integration of both strategic and operational planning.

COMPLAN was developed by Simons Reid Collins (now ORM) and is used widely in Western Canada and a number of foreign jurisdictions (SRC 1997b).

The model is best described as a sequential inventory projection model, which has been developed as a management tool to aid in evaluation of specified forest management strategies (SRC 1997b). It is a simulation rather than the statistical model, and is not driven by any complex mathematical relationships. It serves as a bookkeeping device, which permits the user to describe a resource in quantitative dynamic terms, specifying harvesting/silvicultural activities, and track the changes in the resource over time in response to these activities.

3.4 Evaluation Methods

Each model is a unique set of arithmetic formulas that pose specific questions and generates specific responses; this applies to all models, not just SFMM and COMPLAN. This makes direct comparisons of their outputs difficult, if not misleading. Watt (1983) notes that even if the inputs are standardized (as much as possible given input requirements), the intrinsic properties of the models can not be overcome. Watt (1983) also claims it is nonsensical to try and determine "rightness" or "wrongness", and "agreement" or "disagreement" when comparing models.

The demand for inclusion of additional details (above and beyond harvest level) in forest management plans makes the process increasingly complex. Under the CFSA and FMPM, calculation of the harvest level is a multi-attribute problem that encompasses many objectives not related to timber management. As a result, models have also increased in complexity. This increase in complexity has been accompanied by a corresponding increase in the number of models available. These are principally computer models whose programmers have tried to take advantage of the increase in computing power to create a predictive model to fill a niche in forest management or improve an existing model. Since direct comparison of outputs is difficult, evaluation should be based on the models usefulness in decision-making, whether that is in the form of bench-marking, basic insight into the issue under scrutiny, or suggesting a forest management strategy (Walters 1993; Rennolls 1996). Therefore the most logical approach is to compare how models perform in various steps in FMP preparation and based on FMPM criteria.

The study was originally intended to be a qualitative and quantitative analysis of the models. A number of system changes that took place during the development of this paper meant that the data from the Black Sturgeon Forest could not be used to complete the analysis for this project. The problems encountered were of a technical nature, related to the operating system and supporting software used and not related to COMPLAN's ability to be used for forest modelling in Ontario. Section 4.1 *Preparation for Analysis* contains more detail of the work required organizing the models' inputs.

4.0 RESULTS & DISCUSSION

4.1 Preparation for Analysis

The first step in the analysis of management alternatives is preparing the landbase for analysis. This requires identification of the tools to be used, determining plan objectives and preparing the forest data for use. During this stage, qualitative factors such as system requirements, ease of use and data requirements are considered to be important. In addition, no model comes preloaded for analysis therefore some manipulation of the data is required as an input into the model.

4.1.1 Operating/System Requirements

In the past, the biggest factor limiting the use of optimization tools was the long processing times required to solve linear programming problems (Hof 1994). Adding complexity (constraints and goals) to an optimization model increases model size and solve times. In recent years, the increase in computing power, combined with a decrease in computing costs, means that the most complex problems encountered by forest managers can be solved with SFMM (Davis 2000). COMPLAN is a simulation model and as such requires less computing power than an LP model to solve; however, it is the amount of detail carried in the model that determines the processing power required (SRC 1997a). While there still remains a difference in the amount of memory required for each model, the discrepancy is not significant given the power of even the most basic personal computers on the market today. As for the best operating system or minimum requirements, the advice offered by Remsoft (1997) applies: 'get the most powerful computer you can afford'.

4.1.2 User skill level required

The complexity of the model and the ability of the analyst to use and understand the output is an important consideration. If a model is overly complex. it is unlikely to be adopted for use in the FMP process. The tight timelines and pressures most planning teams find themselves against means that there is little time available to learn complex tools. Another problem with complex models is that the solutions they provide are often difficult to interpret. If the analyst can not understand the outputs. or the processes that created them. it is unlikely he/she can improve on them.

COMPLAN is easy to understand and the creation of forest management planning scenarios is relatively simple. COMPLAN also has a detailed reporting function. COMPLAN has a series of pre-formatted reports to address the most common requests. such as harvest area and silviculture expense. It also has a report writer function that allows the user to create custom reports. Simulation modelling is generally much simpler than linear programming. in fact. ease of use is often cited as the reason for choosing such models. Jamnick (1990) notes that while ease of use is an important consideration, models which are purposefully structured to make the user's job easier are limited in terms of model flexibility and their ability to solve complicated problems.

SFMM is also easy to use and learn. certainly one of the easiest LP models on the market today. SFMM uses a simple-to-understand GUI to set up the problem, with all values being input in a series of input pages (Street & Arlidge 1997a; Street & Arlidge

1997b). The model may also be modified using any common text editor; this assists the user in making changes and additions. Model outputs are in the form of predetermined graphs and tables. The user chooses the desired outputs from the results menu. Custom reports must be generated in a separate application, such as Excel, using values from the SFMM output files.

The GUI used in SFMM addresses one of the most common criticisms of LP models, namely, the difficulty in creating the objective function and setting up the problem. However, this creates a problem similar to COMPLAN in terms of dealing with complicated problems. SFMM's ability to handle complex problems is limited to the values inputted through the GUI. From personal experience, the model may approximate complex problems, but there are limits in terms of accuracy. For example, SFMM was not able to model partial harvest of riparian buffers in a way that matched the operations. However, a number of approaches that approximated the management of these areas could be developed. In a sense, the model can only solve problems identified by the MNR and programmed in the model in advance.

While COMPLAN is easier to learn and understand it takes considerably longer to use effectively. Jamnick (1990) points out that there is an infinite combination of harvest rules and inputs that may be used in a simulation model, so the time dedicated to solving may not be any less than required using an LP.

While both models are marketed as forest management models, they are in large part harvest schedule generators. The models have limited functionality in terms of modelling non-timber values. This is a more serious problem for SFMM, given the broad range of management criteria it is expected to model. The MNR expects SFMM to measure ecological sustainability; this includes non-timber values such as habitat values for selected species and forest diversity indices. The aspatial character of SFMM makes this almost impossible in most instances. While Stanley adds some spatial functionality to SFMM, its role is primarily as a harvest blocking tool. COMPLAN has, at best, only slightly better functionality; however, in jurisdictions where it is used wildlife-specific models are usually developed to address the needs of individual species.

Jamnick (1990) states that "a simpler model is preferred to a more complicated model if they are able to perform the same tasks." However, forest management has become much more complex since the introduction of the CFSA and therefore the management tools used must be able address the complexity. Many of the comments about SFMM's complexity centres on the difficulty in understanding linear programming. However, the complexity of LP is probably overstated; Jamnick (1990) points out that LP is a simple approach and is taught in most forestry programs.

4.1.3 Data Requirements

In preparing a model for use in the FMP, the analyst will take inputs from existing sources, such as the forest resource inventory (FRI), and manipulate it so that it is useable by the model. Alternatively, the analyst will create the data from information from other sources, such as wildlife habitat values.

The basic information required to use SFMM/Stanley or COMPLAN is found in the FRI. In most management units, the FRI is linked digitally to the spatial information in the GIS. The information in the GIS forms the basis for spatial modelling. The spatial information is not stored directly in the models: instead, Stanley and COMPLAN link to an external GIS. The preferred format is an Arcview shapefile. Arcview shapefiles contain the geographic and attribute information required for both COMPLAN and SFMM/Stanley. This information consists of three parts; geometric features, geometric feature attributes, and feature descriptions. Geometric features identify the arcs that comprise the polygons. Geometric feature attributes describe the lengths of arcs and areas of polygons. The final part is the descriptive information associated with each feature, such as forest unit and age-class.

It is possible to run a simple SFMM/Stanley model directly from the FRI with no manipulation. SFMM (run without Stanley) has a low spatial resolution and therefore is not affected by spatially explicit details, such as stand aggregation or grouping based on common characteristics. COMPLAN on the other hand has a high resolution and requires extensive GIS work to prepare the forest for analysis. While it is possible to take a minimalist approach to preparing spatial data for SFMM/Stanley, the level of analysis required in an FMP or operational plan requires a similar amount of work to COMPLAN. The preparation of spatial data was the most difficult and time-consuming part of the study. This is consistent with the experiences of spatial analysts in other jurisdictions, where spatial data preparation took up 75% of the time (HHL 1999. FESL 2001a).

One of the issues that must be reconciled in preparing a SFMM/Stanley analysis is the use of subunits. In SFMM. subunits are usually ecologically (or administratively) based. To properly manage the allocations, Stanley requires the subunits to be operationally based. Non-operational subunits can make the task of allocating stands even more difficult. For example. a subunit that is fragmented across the management unit may be composed entirely of polygons that are below minimum operable sizes. Therefore. if SFMM is to be used in conjunction with Stanley. the creation of subunits has to consider operational factors. Another consideration is that the fewer subunits used, the easier time SFMM and Stanley have in generating a solution.

4.1.4 Model Inputs

The primary model inputs for both COMPLAN and SFMM are growth and yield and landbase information. The landbase information is usually derived from the FRI. The forest inventory contains most of the information required for modelling. The primary task of the model user is to aggregate stands into useable groups that address the ecological and operational concerns of the planning team.

Information about growth and yield, stand development, and habitat development is known as forest dynamics. For the most part. this information is not readily available to planning teams. It must be developed or created as part of the planning process. Forest dynamics are built based on local knowledge, sample data from PSP's and TSP's, and intuition.

COMPLAN does not track forest dynamics at the same level of detail as SFMM. SFMM tracks forest succession, disturbance and rehabilitation. In COMPLAN, almost all information is entered into the yield curves. Yield tables are used by the model to describe various stand characteristics as a function of age. These characteristics are user-defined, and may include items such as volume, diameter, height, density, or clearcut equivalencies. Yield table columns that are area-based (e.g. volume or density) may link to secondary tables that provide proportions of various product classes. Yield tables describe the way in which stands grow over time. There are three types of yield tables, one for each of three silviculture system classes: Clearcut, Multiple-Entry Even-Aged and Selection.

The model "grows" stands through time according to defined yield tables. Different silvicultural regimes and systems are modelled with different yield curves. Stands may shift from one yield curve to another. When a stand is harvested, it will regenerate to the default regeneration curve specified. However, it is recognized that shifts in yield curves cannot always be forecast in advance. For example, spacing may be an option for certain stands that have been previously planted. However, the maximum area thinned in a given year might be limited. The assignments of allowable areas for treatments can be varied by period.

A drawback of COMPLAN was its inability to accurately simulate succession (a requirement of the FMPM). If the stand is not harvested in the term, it is aged accordingly. As a stand ages, it moves to the next class after each iteration. Over time, this results in stands piling up in the highest age-class. In reality, these stands would break up and succeed to new species and curves. One strategy is to add a second curve to the tail of the original curve to simulate the growth of new species. This allows the stand another chance to be harvested when it passes through the original operating limits. Using the oldest-first rule, these stands would be at the front of the queue and given the highest harvesting priority. However, this would not accurately reflect forest management practice in the field.

The highest level of uncertainty in modelling is associated with the forest dynamics. While intensive sampling may be able to provide a reasonable assurance as to the current state of the forest, it may not be an accurate predictor of future development. This is especially true when dealing with predicting values that currently do not have inventory data to support them, for instance, what the yield of a second-generation improved jack pine will be in 60 years. This uncertainty, combined with the large temporal and spatial scales used in such models, means that as one moves through time the more the actual results will vary from the predicted. This fact is widely recognized in modelling and most analysts work hard to ensure the inputs are based on the best available information to ensure their predictions are as accurate as possible to minimize the amount of deviation. However, this also means that simple and accurate inputs should be preferred to complex and detailed inputs that do not provide significantly higher accuracy. It is for this reason that SFMM is the preferred choice for modelling in Ontario. The forest dynamic inputs in SFMM are an example of this: they are easy to develop, the GUI makes input easy, and they are reasonably accurate at the scale that the model functions. The outputs of the model also meet all the requirements of the FMP and are therefore acceptable for use. However, these same inputs do not provide the spatial context required in landscape or operational modelling.

4.2 Analysis of Management Alternatives

The analysis of management alternatives includes an initial test of sustainability for each alternative. The result of the analysis is the selection of a preliminary preferred management alternative. Once analysis is complete, one management alternative is selected for implementation.

Each management alternative is analyzed to identify the future forest condition expected to result from its implementation. The implications of the management strategy are also analyzed, in terms of their ability to ensure forest sustainability and to produce the desired benefits over time. This analysis provides data and a consistent approach to the assessment of each alternative. The outputs of the modelling describe the forest as it develops over time, in terms of forest structure, composition and age-class frequency distribution. The accompanying text for this section of the plan discusses the sustainability of each management alternative and why it was or was not chosen as the selected management alternative.

4.2.1 Harvest

Even with all of the additional features and options that most models have, the primary role of forest management models is to calculate the allowable harvest in terms of either volume or area. The initial determination of sustainability, by both the MNR and industry, is based upon the projected harvest levels. Forest-level objectives, which typically includes a timber-supply target, are set through discussions by the planning team members as part of the planning process. The timber-supply target is usually based on the operating requirements of facilities receiving wood from that forest.

The essence of management planning involves adjusting the harvest level to balance all the needs of the forest. Harvest and renewal are the tools that forest managers have available to them as means of controlling the forest condition. By changing the level of harvest, they may be able to meet another target such as an increase in old growth.

In comparing two (or more) models for use in an FMP there is a perception among environmental groups and other outside observers that forest analysts, especially those employed by the industry, would want the model that produces the highest harvest level. However as mentioned earlier, harvest level is most likely the result of model inputs and constraints and therefore direct comparison between volumes is of little use. What most analysts look for is transparency - whether the relationship between harvest level and the inputs can be clearly seen, and whether the overall objectives can be achieved by manipulating harvest.

Timber and other forest-level management objectives (i.e. old growth forest area) are incorporated into SFMM. The use of linear programming software (AIMMS) generates an optimal solution. Harvesting becomes the means by which forest-level objectives are met. In optimization models, timber harvest is a result of the analysis, not an input (as in simulation models). The benefit of this method is that the AAC is the amount of timber that should be harvested to satisfy broader forest and landscape objectives.

As a simulation model COMPLAN helps determine the maximum harvest level in an iterative process. Various harvest levels are explored and after each run the harvest volumes are adjusted up or down. However, COMPLAN comes equipped with a binary search tool. The binary search algorithm is used to determine automatically the sustainable maximum evenflow harvest level. The results of the binary search can then be used as a basis to set harvest targets, reducing the number of iterations required. The fewer spatial constraints the model is subject to, the more likely it is that it will achieve the binary search volume. In addition, harvest priority rules that give the model the most flexibility also help it achieve the binary search volume.

In many jurisdictions where COMPLAN is used, AAC is calculated as a flat line based on the Long Run Evenflow Sustained Yield (LRESY) principle, therefore COMPLAN offers that feature. However this method of calculating AAC is not appropriate for boreal Ontario. The age-class imbalance typical of most forest management units and the relatively short life span of most tree species (less than 150 years) means that a variable harvest level is more appropriate for ensuring that socio-economic benefits from the forest are maximized. A harvest level that is allowed to fluctuate (within certain operational constraints) allows forest managers to capture mortality and maximize harvest over a planning period (Davis 1992).

In working with the data set supplied by SRC. COMPLAN showed some 'internal' differences in results between solutions with different harvest priorities. Rule sets that scheduled harvest based on 'compartment and yield table priorities' produced the highest harvest levels, while 'minimize primary volume loss' was superior to 'oldest first' and or 'minimize cost' in total volume harvested. This is consistent with the results from Jamnick (1990) who found the Forman model (which is similar to COMPLAN in terms of model structure) is sensitive to initial forest structure and the harvest rule selected. He also found that forest structure had an impact on the quality of solutions produced by simulation models; noting that 'maximize primary harvest volume' rule with a balanced age-class structure produced inferior solutions when compared with the results from an unbalanced age-class.

In terms of meeting forest objectives (such as minimum area of old growth white pine) through timber harvest, SFMM is able to achieve this goal (if the other objectives can be quantified as constraints and/or targets) better than COMPLAN. However, the SFMM solution must still be allocated, manually or using Stanley. It is in terms of incorporating spatial objectives into the timber harvest calculation where COMPLAN is better equipped than SFMM.

4.2.2 Renewal

The second tool forest managers have available to them is renewal. The treatments applied to stands after harvest determine their development and thus the future forest condition. The mix of silviculture prescriptions available to the forest manager is known as the silvicultural ground rules. The mix of treatments applied on the ground is known as the silvicultural strategy, and it incorporates future forest condition objectives, harvest levels, resource availability and return on investment to determine the appropriate combination of intensities.

The level of renewal effort is an important consideration when determining the selected management alternative. The conversion of conifer stands to hardwood is a concern that can typically be addressed through more intensive silviculture. Since both models incorporate the allowable cut effect into their harvest calculation, the use of more intensive silviculture will result in higher harvest levels now and in the future. However, the benefit of more intensive silviculture must be balanced with the associated cost. Both the financial and social costs of silviculture must be considered (Brumelle et al. 1988).

SFMM's approach to silviculture is to apply general rules to broad forest classes (forest units). There are fewer rules specified in SFMM and only a small range of treatments applied. In keeping with its strategic focus, treatments are not specified for individual stands, even when using Stanley. COMPLAN, on the other hand, allows more treatments to be modelled. In addition, the analyst may specify treatments for individual stands or harvest blocks.

Renewal actions taken by the forest manager and natural forest dynamics determine the future forest condition. Post-harvest renewal action is addressed in the context of the forest as a whole. Forecasts of forest development indicate what type of renewal action needs to be undertaken and if any additional treatments are required. The model's ability to take into account the forest management options available is an important attribute. However, it is equally important that the model be able to incorporate biological limits. For the model to provide realistic solutions, it must be able to limit treatments based on biological limits. For instance, converting low-value hardwood forests to jack pine may be a desirable outcome, however the model must be able to recognize that this is not possible on all sites (e.g. black ash swamps).

Both models have incorporated biological limits, although they take different approaches. SFMM relies on limits and constraints to accomplish this. COMPLAN uses silviculture and regeneration rule sets to control curve shifts. COMPLAN provides the harvest and renewal schedule for each stand, and the impact of changing the treatments can be simulated.

The SFMM approach is easier and quicker to enter; however, it is less flexible than COMPLAN. While Stanley allocates the SFMM solution, it does not assign the stands treatments; this must be done outside the model. SFMM provides the "optimal" treatment package aspatially; however, it does not suggest what treatment should be applied to each stand. The impact of stands being treated outside the model has not been investigated, so the consequences of applying the wrong treatment to a stand are not known. An additional concern is that Stanley will deviate from the SFMM solution in laying out the allocation; if the deviation is large enough, the strategic solution could be jeopardized because the planned renewal targets may not be achievable.

Silvicultural options in SFMM allow the analyst to specify the treatment options appropriate to the modelled forest - harvest, renewal, tending and partial harvest, and active non-forest rehabilitation treatments. Note that the Silvicultural Options Inputs Menu is designed to describe (not prescribe) options for silvicultural operations. The analyst specifies the eligibility of forest and non-forest lands to receive various silvicultural treatments and the costs and expected results of these treatments. Unlike a simulation model, the analyst does not specify how much area receives these treatments. Rather, SFMM attempts to schedule operations to best meet the stated management objectives.

SFMM creates the renewal program that best meets the objective, subject to the input constraints, as part of the solution (Davis & Martel 1993). Because SFMM has multiple objective functions to choose from, it is possible to explore extreme ranges in silviculture investments. For instance, using the 'maximize timber volume' objective function, the model will treat every stand so as to get the maximum volume over the planning period. In the "minimize harvest area" objective function, the model will create a new silviculture program to maximize the yield per hectare to meet the desired harvest level. Using the "minimize cost" objective function, the model will rely on natural regeneration and other low-cost methods available while still trying to meet the desired harvest level. It is easy to switch between objective functions and therefore the analyst can explore the various silviculture regimes and customize a program that meets the company's silviculture abilities while achieving the desired harvest level. Also, the analyst can explore the impact of constraints such as silviculture spending levels or seedling availability on harvest levels.

COMPLAN will handle different silvicultural systems including clearcutting, selection and multiple-entry even-aged (e.g. seed tree and shelterwood). In addition, commercial thinning can be accommodated. The basic yield table structure for each system is similar. However, multiple entries and commercial thinning require additional tables to describe the extra volume removals.

Optional shifts from one yield curve to another are controlled through the use of treatment categories, treatment ages and latest shift ages assigned to the yield curves. The maximum area that can be treated (shifted) in a given year can be specified for each treatment category. The treatment age is the desired age at which the shift should occur (e.g. the "ideal" thinning age). The latest treatment (shift) age is the latest age at which shifting can occur. This will allow for a "window" within which more-intensive treatments can occur

4.2.3 Non-timber Values/Wildlife Habitat

In addition to harvest and renewal considerations, each management alternative is analyzed for its impact on non-timber values. Non-timber values include wildlife habitat, forest composition and structure and biodiversity measures. The province has identified a number of non-timber values that must be measured and reported in assessing sustainability. These include forest diversity indices and the available habitat for a number of provincially featured species.

In Northwestern Ontario, the habitat for wildlife species to be analyzed includes the featured indicator species for the northern boreal forest – they include woodland caribou, marten and moose. In addition to the featured species, the following selected species have their habitat calculated and documented: white-tailed deer, boreal red-backed vole, northern flying squirrel, snowshoe hare, American kestrel, boreal chickadee, white throated sparrow, Swainson's thrush, American redstart, Connecticut warbler, great grey owl, pileated woodpecker, and the spruce grouse. Data on preferred and preferred-plus-used habitat for all species is included in the Northwestern Ontario wildlife habitat matrix (MNR 1997).

SFMM has the ability to track the provincial wildlife habitat and diversity indices built into the model. Identifying and quantifying the current levels of habitat is part of the preparation of the landbase and is done by SFMMTool. SFMM tracks the changes to habitat as it solves and produces reports that can be included in the FMP. The process is simple and easy. However, the value of the reports is questionable, other meeting the minimum requirements of the FMPM. The habitat area values produced by SFMM are not useful in wildlife planning since, the spatial distribution of the habitat is as important as the total habitat area. Stanley, the spatial allocation tool for SFMM, does not track habitat nor are habitat considerations part of the allocation process (Messmer 1999).

COMPLAN comes with the ability to track non-timber values, however, these values must be created by the user. COMPLAN can be used to track Ontario's featured species, but it requires much more work than SFMM. The analyst must develop the values for each species and relate them to the yield curves by forest unit and age-class. In COMPLAN, the yield tables reflect the relative habitat values for the provincial species, so an additional twenty curves are required for Northwestern Ontario species (220 for all provincially featured species). Non-timber values can be used as a constraint to harvest and objectives for size and spatial arrangement specified. Because COMPLAN can use non-timber values in generating a solution and it tracks the spatial arrangement of habitat through time, it provides a superior solution from an ecological view. However, the planning process is severely regimented and requires 27 tables to be completed, each with specific values, a job better performed by SFMM.

4.2.4 Finances

Each management alternative is analyzed to examine its relative socio-economic impacts. This analysis identified the socio-economic impacts expected from the quantity of timber that is supplied to the wood-processing facilities and the silvicultural investment requirements for the management alternative. The Socio-Economic Impact Model (SEIM) is a provincially-approved analytical tool used by the MNR to identify the relative socio-economic impacts of each alternative. In addition to the large-scale socio-economic analysis, the forest manager must be able to determine the impact on the company's bottom line.

Along with the ability to incorporate tactical and logistical considerations that go into operational forest planning, financial evaluation is an important function of any model. Economic evaluation allows the analyst to determine if the investment will generate a positive return, which alternative has the lowest costs, and in private land management which stands generate the highest revenues. The models' ability to perform economic evaluations most clearly reveals the difference in the target users and uses of the models. COMPLAN allows the users to track a larger number of costs with more detail than SFMM. SFMM takes a cursory approach to financial management with limited revenue and expenditure tracking.

COMPLAN has more detailed costing available to the user. While valuable in management planning, this function is mostly bookkeeping. The model tracks the costs of activities such as silviculture and road construction; however, it is not directly used to determine the final solution (unless "minimize silviculture cost" is chosen as the harvest control method). The analyst uses the financial information as a consideration in the development of iterations and in the selection of the final solution. Most silviculture activities are included in the model as targets, which the model will try to achieve. The model will apply the treatments until the target is met (or the available area exhausted), independent of the value of such treatments. Traditionally, there is a point where the marginal value of silviculture investment reaches zero. COMPLAN treats all areas until the target is met, while SFMM stops treatment at the point where there is no longer an increase in harvest volume. However, this point may not coincide with the point where the economic return has reached zero (MacGillivray 1999). Clements et al. (1990) notes that because simulation models will spend all resources available, simulation models may produce solutions that not only result in inferior harvest levels, but may also be economically inefficient.

SFMM was designed as a tool to measure sustainability, with emphasis on ecological sustainability. While there are objective functions to maximize timber production, greatest net present value of silvicultural activity, and least silvicultural cost incurred over the planning period, the economic analytical value of SFMM is limited. SFMM only tracks two types of silviculture activity: 1) establishment and 2) tending. All silviculture establishment costs, such as site preparation, spraying, and planting, are grouped and applied at the time of harvest, regardless of how much time lapses between harvest and treatment. This makes it extremely difficult to track which individual treatments are being applied. In addition, Stanley does not track or incorporate financial information so it is more difficult to track the actual operational costs compared to COMPLAN. COMPLAN, by contrast, allows the manager to input fixed and variable revenues and costs as well as dependent and independent variables, which results in more detailed financial reporting.

4.2.5 Sensitivity Analysis

In addition to the management alternatives listed in the FMP, hundreds of management alternative subsets are run and analyzed. These supplemental management alternatives reflect a variety of adjustments to modelling inputs to better reflect forest dynamics and local conditions. The development of supplemental management alternatives also acts as a sensitivity analysis, allowing the forest manager to determine the impact of changing inputs or variables. The examination of these alternatives is part of the iterative process of forest management planning, and these alternatives are not included in the final plan document. However, the ability to perform these sensitivity analyses quickly and easily is an important function for any planning tool. The different approaches the two models take to forest management are evident in how they perform sensitivity analyses.

SFMM is an aspatial, aggregation model that uses optimization software to create a strategic management plan for the forest. The strategic solution from SFMM is linked to Stanley to create a tactical plan. The strategic model addresses complex issues and produces a long-term plan. The tactical model is used for harvest blocking and scheduling.

Johnson and Tedder (1983) listed the advantages of linear programming as the ability to consider alternative yield trajectories for the same area, portray unusual yield trajectories, constrain portions of the inventory, and ensure that the optimum solution is found. The perceived benefit of optimization is that the solution is the 'best' of the thousands of iterations the model performs. Following this logic, implementation of this solution is the best solution for the forest. Simulation, by contrast, is useful to assess the impacts and sensitivities of different management rules and objectives e.g. harvest level. To determine the best management strategy for the forest, a number of iterations must be performed using simulation techniques. The selection of the best iteration (preferred management strategy) is done by the users as they examine the results of various iterations.

On the surface, the benefits of using optimization (an optimal solution) seem clear. However, in reality the differences between the two approaches are not readily apparent. The perception that the solution generated by linear programming is the best may be somewhat overstated. While from a purely mathematical perspective the solution best meets the objective function, forests are rarely managed so neatly. All of the possible constraints and objectives faced in operational planning can not be included in the model (Rennolls 1996). In the case of SFMM, the fact that it is an aspatial aggregation model means that the loss of operational realism is further magnified. Indeed, the current poor quality of the FRI in Ontario further challenges the notion of an optimum solution (KBM 1999; Robataille 2000).

LP has been described as a complex "black box" that derives the "answer" in one detailed run (Jamnick 1990). The lack of transparency in terms of the relationship between inputs and outputs causes a great deal of discomfort among some users, especially casual users who do not use it as part of their regular duties (MNR 1998). LP models balance a variety of inputs and constraints to achieve the objective function. As the objective of the model (e.g. maximize harvest volume) remains constant, the impact of changing inputs may not have the predicted results (Davis & Johnson 1987).

COMPLAN is a spatially based simulation model that creates an integrated resource management plan. COMPLAN addresses the strategic and operational concerns in a single solution. Simulation modelling tends to be more operationally focused, so the solutions that it generates are closer to what can be achieved on the forest. This happens for two reasons. First the analyst tends to ask questions that are operationally focused. Second, simulation models tend to be more narrowly focused, concentrating on one function such as timber harvest. During the planning phases, the most common questions deal with changing operational functions such as harvest levels or renewal rates. The narrow focus means that the solutions generated explore the range of management options considered feasible. Simulation models are only able to explore one process effectively; that is, they can simulate harvest and renewal effectively but not a separate set of rules for wildlife habitat (Siitonen 1993).

While the selected solution (from simulation) tends to meet the operational objectives of the planning team, it may not be the best for other objectives. To find a desirable solution, a number of iterations must be examined. However, as mentioned above, the focus of simulation models tends to be narrow. Human nature (and time constraints) being what it is, this means that when a possible feasible solution is found, all future iterations tend to focus on it. Therefore, a broad range of alternatives is not examined. Linear programming, by contrast, will explore the entire feasible area to determine the best solution, although the non-optimal solutions are not presented to the analyst. In addition, linear programming illustrates the trade-off between the goal of the objective function and the goals of the constraints. If the analyst acquires an understanding of linear programming, he/she may use shadow prices to determine the marginal costs of various constraints.

SFMM has the option of reporting on marginal values for selected types of equations. The marginal values section helps the analyst gain an understanding of the relative importance of each constraint on the final solution. Every equation in SFMM has a marginal value. MNR (1999) defines a marginal value as the value by which the objective would change if you changed an equation by one unit (i.e., one hectare or one dollar). Therefore, equations with higher marginal values have the greatest impact on the solution.

MNR (1999) cautions users that marginal values are limited in their scope. However, if you changed the equation by two units, it would not necessarily change the solution by two times the marginal value. If more than one equation is changed, the marginal values will not predict what will happen. In addition, the marginal values are based on the overall objective function (i.e., greatest value of timber harvested over the entire planning period). Therefore, a high value may relate to its role in meeting an objective

150 years from present while an equation with a lower value is much more important in meeting a short-term goal.

Simulation modelling allows the user to see the results of changing inputs quickly and easily. This makes sensitivity analysis easy. Optimization solutions are the result of the analysis and the interplay between a number of variables. The result of changing one parameter in an optimization model may result in a number of changes in the solution, some obvious, some subtle, and some downright mystifying. For example, an objective to provide areas for winter harvest (spruce lowland) may require the user to specify a minimum harvest area increase of 100 ha/year. However, the resulting solution may bear no resemblance to the earlier solution as all allocations are changed to generate the new optimal solution - this tends to be alarming to foresters unfamiliar with how the model functions or frustrating to those who understand how the model works.

Johnson & Tedder (1983) found that linear programming has the advantage of being able to consider alternate yield projections simultaneously for the same area, portray unusual yield trajectories, apply constraints to portions of the inventory and ensure the optimal solution is found (Table 1). Simulation models are able to process large amounts of data and find feasible solutions more quickly and at comparatively low cost (Table 1).

Table 1: Comparison of Simulation and Linear Programming Approaches in Allowable Cut Calculation (* means superior ability) (adapted from Johnson & Tedder 1983).

Characteristic	Simulation	Linear Programming

Portray inventory in great detail – process large amounts of data	*	
Manipulate inventory in unusual ways	*	
Lowest cost per run	*	
Find a feasible solution easily	*	
Consider alternate yield trajectories for the same area		*
Portray unusual yield trajectories		*
Constrain portions of inventory		*
Find the optimal solution		*

SFMM has the ability to perform batch runs of multiple scenarios. The user can create multiple scenarios and then run them in a single batch, and compare the results to see which combination results comes closest to meeting all objectives. However, this works only for the strategic solution. The tactical plan must still be generated by Stanley and there is no guarantee that the preferred strategic solution will result in the preferred harvest schedule. The hierarchical approach used by SFMM/Stanley makes sensitivity analysis more difficult. Sensitivity analyses must be performed with both the strategic and tactical planning tools and typically, a compromise alternative is reached that does not completely satisfy either the strategic or tactical goals.

4.3 Implementing the Solution

After reviewing the analysis of the management alternatives, the planning team selects the appropriate strategy to achieve the forest-level objectives. This strategy is known as the selected management alternative. The next step in the forest management process is taking the strategy and implementing the solution on the ground. This is typically the most difficult task in the whole FMP: operational decisions such as harvest block scheduling and assigning silvicultural packages to stands is done in this phase.

In the past, forest management has focused on the sustainability of timber harvest and supply over time. The focus on wood supply gave prominence to temporal considerations (Borges & Hoganson 1996). The emphasis on timber reduced the management problem to determining the appropriate level of harvest as well as where, when and how to get it in the most economic fashion. The requirements of the CFSA have shifted the focus from timber management to ecologically based forest sustainability. Borges & Hoganson (1996) note that despite the shift to ecosystem management, the problem remains fundamentally the same, namely, how to schedule and arrange harvest and regeneration activities. In the new ecologically-based forest management regime, the spatial arrangement of management activities is as important as the temporal distribution.

Davis (2000) contrasts spatial and non-spatial models. Spatial models allow users to:

- view maps of silviculture activities and forest conditions at each time-step;
- incorporate operational, ecological and biological spatial concerns;
- integrate with other spatially based planning tools;
- integrate short-term operational planning and validate forest-level modelling assumptions; and
- combined with other tools, produce visual images of future forest conditions.

Forest planning has traditionally been divided into long-term strategic and short-term tactical planning. Spatial issues are usually considered in the tactical planning stage. Until recently spatial considerations were limited to planning operations for a single planning period; in Ontario this was five-years. However, changes in the regulatory and operating environment placed a new emphasis on spatial issues. The incorporation of spatial issues has been aided by the development of new, more sophisticated tools. Spatial issues can be divided into operational, wildlife habitat, and quality and scenic considerations.

4.3.1 Harvest Scheduling

When the boreal forest of Ontario was first opened up by logging, clearcut size was limited only by what could be harvested by the work gangs. The introduction of mechanization in the 1960's and 1970's greatly increased productivity and therefore the amount of area that could be harvested. The MNR responded to the concern about large clearcuts by developing guidelines that restricted clearcut size and established adjacency requirements (MNR 1988, MNR 1996b, MNR 2001). These clearcutting guidelines impact on timber supply, harvest cost and renewal considerations.

Incorporating spatial considerations into a harvest scheduling model is not a straightforward process (Borges & Hoganson 1999). Borges & Hoganson (1999) note that spatial and temporal interactions can not be modelled using traditional mathematical techniques. Spatial factors add complexity to the planning problem; however, there are several methods available to generate a solution. COMPLAN and

SFMM/Stanley represent two different approaches to the problem. In COMPLAN, the spatial problem is integrated into the solution. SFMM/Stanley uses a hierarchical approach, separating the strategic and tactical solutions (Kloss 1999).

The major factors limiting the inclusion of spatial considerations in linear programming are the size of the problem and the incorporation of non-linear variables. The solution of an aspatial linear programming problem (such as SFMM) typically generates a large number of variables, constraints, and iterations. This can tax the resources of even the most powerful personal computers. The inclusion of spatial considerations makes the problem essentially unresolvable at anything but the lowest level of resolution. The spatial problem, at the simplest level, is that every possible permutation and combination of polygons must be assembled to determine the "optimal" solution.

As stated by Hof & Joyce (1992), the practical limits of LP mean that only a tiny number of the possible spatial arrangements can be considered. Hof & Joyce (1992) provide an example of how the inclusion of spatial considerations amplifies the complexity of the problem. A watershed divided into 25 polygons (with only two options cut or leave unharvested) generates over 33 million spatial configurations. On a real forest at the harvest block or stand level, the number of possible configurations is too large to allow applications in basic forest management modelling (Hof 1994). To circumvent this limitation of LP, spatial issues are handled separately by Stanley.

Block selection and access planning are simple if unrestricted progressive clearcutting is utilized. Operations simply push forward into the forest, advancing one stand at a time. However, the introduction of opening size restrictions and exclusion (green-up) periods has complicated the process. To satisfy the spatial constraints, harvest blocks must be completely harvested or not at all (Nelson & Finn 1991). Similarly, roads must be completely constructed or left un-built (Nelson & Finn 1991).

In harvest block scheduling with SFMM/Stanley, Stanley attempts to allocate the SFMM solution based within the bounds specified (e.g. minimum/maximum block size, green-up, etc.). When the Stanley solution is generated, the analyst can accept the Stanley solution as the allocation plan for the specified horizon or use what is known as a rolling-plan horizon (O'Keefe & Walker 1999). In the rolling-plan horizon, Stanley schedules the initial SFMM solution. The results of this blocking exercise are then fed back into SFMM to generate a new solution that is then reanalyzed by Stanley, starting the process again. While the rolling-plan horizon method is more complicated, this solution better projects future forest conditions, multiple entries are better modelled, and the impact of spatial limitations on the strategic solution is better illustrated. This approach allows the strategic and tactical models to consider the impacts of the previous term's harvesting activity. While it is possible to do this for all the periods (150 years in Ontario) in the plan, the extra time involved may not be warranted given the small increase in precision after the initial period (10 years).

COMPLAN eliminates this multi-step process. COMPLAN blocks and schedules forest treatments for the entire planning horizon simultaneously. This method allows short-term and long-term planning to be combined into a single process. COMPLAN can be used to make projections for multiple rotations from which the 20-year management and 5-year operating plans can be extracted without further analysis. The short-term operational considerations (harvest units by period) are a direct output of COMPLAN.

Remsoft (1996a) differentiates strategic planning (defined as what to do and when) from tactical planning (defined as where to do it). The first step in forest management is scheduling the harvest; fixing the amount of harvest (harvest volume) and location of the harvest (harvest allocation) for each year of the planning period. Scheduling the harvest requires forecasting the development of each stand until it is harvested and its post-harvest succession.

In comparing available harvest volumes generated by SFMM/Stanley with other single step models (such as COMPLAN), two important considerations must be raised: achievement percentage and deviation. As mentioned earlier, the aspatial solution generated by SFMM results in higher volumes than COMPLAN. However, this solution still has to be allocated by Stanley.

Achievement percent

SFMM is a strategic model and as such, its solutions are not tied to operations. Environmental factors can create highly volatile supply and demand situations, so operational considerations are often made only a week to a month in advance (at some points it may be daily). Experience from previous FMP's, shows that the solutions generated by SFMM are often difficult to implement operationally, despite the ability to input management objectives.

In hierarchical planning, the strategic tool generates an aspatial solution that the tactical tool tries to allocate. The degree to which the tactical planning tool can match the strategic solution is known as the achievement percentage. The hierarchical approach produces good results in certain forest types but does not perform well in fragmented forests where operations have created a number of small harvest blocks spread across the unit. In working with fragmented forests like the Black Sturgeon, the spatial feasibility of the strategic solution is low. Being non-spatial, SFMM does not recognize adjacency constraints when it generates a strategic solution. This results in low scoring of the solution by Stanley since it is unable to generate a spatial solution without deviating from the strategic solution or violating spatial constraints. This is an important consideration, since past and current practices severely limit where and when management activities can be scheduled.

Failure to consider green-up and adjacency delays can result in an overstatement of allowable harvest (Dahlin & Sallnas 1993). The loss of volume attributed to spatial modelling is often overestimated because the strategic (non-spatial) solution includes areas that should not have been considered eligible (Murray 1999). Identifying ineligible areas up-front reduces the differences between the strategic and tactical solutions (O'Hara et al. 1989). To solve the problem of the strategic solution scheduling ineligible stands, these areas should be identified before the SFMM solution is generated. Identifying these areas up-front will likely result in a lower harvest volume than the unconstrained model (Remsoft 1994a). However, the spatial solution will have a much higher score since the algorithms are no longer assessing penalties for not harvesting ineligible stands. The area of the restriction zone is dependent upon spatial arrangements of stands, the required size of the harvest blocks, and the relationship between stand size and harvest block size. Determining the optimal buffer distance in Stanley is an iterative approach; a range of sizes may need to be examined to determine which value generates the best solution. Stanley rarely achieves 100% of the volume calculated by SFMM. In highly constrained situations the model is lucky to achieve 60% of the SFMM solution. The strict application of the guidelines controlling harvest can result in achievement percentages in the low 40's.

Deviation (substitution)

Stanley attempts to match the strategic solution for each term. However, the non-spatial nature of the strategic solution means that it may violate green-up delays or minimum block sizes in the solution. In some cases it is necessary for Stanley to deviate from the strategic solution (Remsoft 1996b). The number of periods that Stanley may deviate from SFMM is defined by the maximum deviation parameter. The higher the value, the more flexibility Stanley has in matching the solution, so a feasible solution is more likely. Deviation may result in an improved tactical solution, higher volume and less fluctuation. However, substitution of one stand for another may result in Stanley violating non-timber constraints, such as wildlife habitat. The use of substitution by Stanley may result in a harvest schedule different than SFMM's, so it is recommended that the Stanley solution be analyzed with SFMM.

The dynamic nature of forest management planning results in harvest volumes that fluctuate between periods. Since the role of Stanley is to schedule the harvest generated by SFMM, the question of harvest variation is somewhat more complicated. The simplest approach is to limit the fluctuation to a fixed percentage of the SFMM solution. However, Stanley may not be able to generate a feasible solution in all cases. An uneven-flow SFMM solution can result in more difficulty for Stanley. The current forest-unit and age-class distribution of Ontario's boreal forest typically results in declining harvest volumes. The following example illustrates the problem, in a situation where SFMM allows declines of 20% between periods and the Stanley tolerance is 5%. Suppose SFMM generates a harvest volume of 100 m^3 in term 1 and 80 m^3 in term 2 and the Stanley schedule is 105 m^3 and 76 m^3, which could be considered within the acceptable limits by Stanley although the actual fluctuation is 28%. Stanley interprets the criteria based on the two terms which deviate most from the strategic solution; for example, if one term is over-allocated by 4% and another is under-allocated by 1%, the 5% tolerance is just met.

Stanley will generate a number of feasible schedules for the strategic solution and must therefore choose the best among many alternatives. To determine the best solution Stanley uses a maximization objective, selecting the solution that generates the highest total output over the planning horizon. This helps to weigh conflict between which set of periodic fluctuations is the most desirable.

Forest operations typically do not take place on a blank tableau. When generating a schedule, Stanley has to consider stands that have been harvested in the recent past and therefore are still subject to adjacency constraints, as well as stands identified for operations in the short term (Remsoft 1994b). In the first case, Stanley must be careful to ensure its allocations do not violate green-up delays. In the second situation, Stanley may use its block augmentation algorithm by attaching additional stands to address harvest flow or adjacency constraints. However, it can not leave pre-allocated or pre-blocked stands unharvested.

A rolling-planning approach results in a better solution being generated by the model. This approach allows the model to consider the impacts of the previous term's harvesting activity. While it is possible to do this for all the periods in the plan, the extra time involved may not be warranted given the small increase in precision after the initial period.

The latest version of Stanley (4.0) (Remsoft 2000) has the ability to determine the stands that are spatially constrained and identify them in the SFMM input file. The SFMM solution recognizes these operating constraints, and identifies them as being ineligible. This integrates the tactical and strategic planning processes and results in more uniformity between the spatial and non-spatial harvest schedules.

The non-spatial solution generated by SFMM lists the stand types for which Stanley must generate a solution. In large forests, many stands will match the criteria in the SFMM solution (e.g. there may be 300 lowland spruce stands between 91 and 100 years of age); if this is the case, Stanley selects the first stand it finds. Certain GIS techniques and procedures subdivide stands resulting in neighbouring stands with the same characteristics. This can result in a harvest pattern that is undesirable. To reduce the time required to locate feasible polygons, Stanley relies on a indexing scheme. However, in the situation described earlier, blocks are oriented in a pattern consistent with the indexing system, that is, long narrow rows of allocated stands. To alleviate this problem, Stanley relies on a shape control function.

Stanley attempts to make the blocks as large as possible while satisfying constraints. In building harvest units Stanley only applies the adjacency relationships. The proximity relationships are applied during scheduling to ensure that spatial constraints are not violated. Strict adjacency and proximity rules add complexity, reduce the likelihood of a successful solution, and lengthen solve times.

Stanley uses the extent information of the harvest block to regulate its shape. Stanley recalculates the extent information of the harvest block each time a new stand is selected for harvest. When considering stands of equal value, Stanley compares the impact of adding the new polygon to the harvest unit and selects the stand which results in the most regular shape. Remsoft (1996b) found that when harvest block shape control was applied to an area. the configuration of the blocks was better. there were few tentacles. and harvest activity was clustered. They also found that harvest flow was improved. The shape-controlled blocks tended to be circular. while the harvest blocks without shape-control were linear. The linear arrangement made it difficult to address adjacency constraints through perpendicular arrangements. The model ran out of harvest alternatives and left large areas of forest unharvested.

Pre-blocking

Stanley allows users to specify a harvest schedule for individual stands prior to executing the model. The schedule is specified on a stand by stand basis by editing the Action. Cut_period. and Pre-block fields in the GPAT file. Pre-blocked stands contribute to the scheduled area and objective as long as the actions and forest classes are valid (i.e. correspond to entries in the choices file). If the model includes pre-blocks. these blocks will be exempted from the minimum or maximum block-size restrictions (Kloss 1999).

COMPLAN also allows the user to specify when certain stands will be allocated for harvest. The attributes of the subcompartment theme include the option of entering harvest year to specify when the subcompartment will be scheduled for harvest. In addition the model allows the user to exclude large areas (compartments and subcompartments) for specific time frames to account for operational or ecological concerns.

Minimum, maximum and target block sizes

Both Stanley and COMPLAN have the ability to set limits on harvest block size. Minimum and maximum block sizes are used to define the permitted size range of harvest blocks. The minimum, maximum and target block sizes are specified in the Stanley parameters. Stanley applies these limits to the entire landbase and will not create harvest blocks outside the specified range. Pre-blocked areas are exempted from the min/max size constraint.

COMPLAN allows the user to set a default maximum for the forest or specify the maximum size for individual subcompartments based on silviculture system. Which stands and how they will be aggregated are based on prioritization rules set by the analyst. Aggregation parameter prioritization methods include: area priority; adjacent length priority; and, common boundary count.

The range in the size of the blocks is controlled by the minimum and maximum block values. Stanley uses the target block value to create the blocks of the desired size. Stanley aggregates stands in pseudo-blocks until the target block size is achieved, thus encouraging the model to create blocks larger than the minimum.

Distribution of the harvest

Distribution of the harvest refers to the allocation of raw materials required by facilities dependent on the forest. The amount and quality of products from a stand in the future requires a forecast of the structural development of each stand. The requirement to balance competing products may require management action to ensure sufficient material is available. Most forest management units in Ontario supply fibre to multiple processing facilities that make different products. It is not uncommon for a management unit to provide softwood to a sawmill, a spruce groundwood mill, a kraft mill, a newsprint mill and hardwood to an OSB mill, a sawmill, a veneer mill, and a paper mill. This presents difficulty to management planners who must balance competing needs, especially when fibre supply is tight.

SFMM allows the user to input product proportions in the model. However, the relationship between SFMM proportions and the actual proportions are weak at best. SFMM proportions are applied at the forest unit level and are not adjusted for age-class, site class or stand density – factors which commonly affect a stand's product mix. COMPLAN allows the user to specify more products than SFMM and adjust the proportions based on additional variable such as age. COMPLAN also uses the product information in other parts of the modelling (e.g. for calculating revenues and expenses.

An important consideration in planning with the models is how the volumes predicted by the model will match the volumes in each stand. The models take different approaches to predicting stand volumes in the allocations. SFMM uses yield curves that predict the average stand volume for each forest class. This information is used in the SFMM/Stanley harvest allocation. Therefore, the volume predicted by SFMM/Stanley represents the average that may be expected for the allocation. Since stocking, site class, mortality, etc. all affect the actual stand volume, the growth and yield information in SFMM represents the values across the entire subunit and may not apply to an individual stand. COMPLAN allows the users to specify the actual stand volume for each stand. The model also allows the analyst to use an 'approach normality' function which will maintain the ratio of the actual value to the predicted yield table value is maintained and adjusted each year according to a linear function (SRC 1997a). Therefore, the volumes estimated from the COMPLAN application are a more accurate indicator of what can be expected than those from SFMM/Stanley.

Road Networks

Another consideration in implementing the solution is how it affects existing and planned road networks. Road networks are an increasingly important issue in the management of forest resources in that:

- They are a major component of timber extraction costs;
- They represent a potentially significant environmental liability; and
- They are a significant factor in the management of wildlife habitat and other non-timber resources (ORM 2001).

The different approaches to forest management planning between SFMM/Stanley and COMPLAN are most apparent in the approach they take to road access. SFMM does not explicitly recognize existing road networks and incorporate them into the plan solution. Access factors can be included into SFMM implicitly; for example, a large unaccessed area can be classified as a subunit and deferred from harvest for an appropriate period. In Stanley, it is also possible to exclude areas until access has been established. However, the road network is not an integral part of the solution. Stanley does allow the analyst to pre-block stands, which may or may not be based on access considerations. In considering access planning, the SFMM/Stanley development team felt that a more appropriate strategy would be to build a road network that resulted from accessing the strategic solution rather than limiting the solution based on a pre-existing network.

COMPLAN integrates road planning in the development of a solution. COMPLAN works with a network of existing and proposed roads that is maintained within a GIS environment. Road classes, bridges and other structures are all handled, which provides a comprehensive solution to the problem. The level of detail used within COMPLAN is based on the level of detail provided by user-defined inputs. COMPLAN generates a detailed schedule of the following activities and the associated costs:

- Construction;
- Maintenance (maintenance costs can be differentiated by whether roads are used for hauling within a given season);
- Deactivation;
- Activation; and
- Hauling (ORM 2001).

Combined with the regular cost/timber harvest reports from COMPLAN, costs can be summarized based on area or volume. The detailed output permits almost any type of report to be created.

The use of the Road Network Module turns COMPLAN from a planning tool into a budgeting and scheduling tool that provides managers with better information regarding management of road networks and the forest resource. This is a key element of the link between strategic and operational planning and one that offers potentially significant cost-savings.

4.3.2 Renewal Activity

Implementation of the renewal schedule is critical if the desired future forest condition is to be achieved (MNR 1997). The ability to implement the predicted treatment regime will also affect allowable harvest levels. As both SFMM and COMPLAN determine current harvest levels based on (among other things) future predicted development, the inability to achieve the desired intensities can affect sustainability. Once again, COMPLAN's operational focus results in a solution that is easier to implement than SFMM/ Stanley.

As mentioned earlier, SFMM creates a renewal program that best meets the objective of the model (usually maximize harvest level) subject to certain constraints (usually funding). Treatments are described in terms of average stand condition and at broad intensities. The treatments are prescribed at the forest unit level, not at the stand or block level. In fact the renewal program is created before stands are allocated; therefore, the implementability of the solution is not a consideration.

The silviculture/renewal schedule generated by SFMM is typically designed to maximize harvest levels and therefore includes a large percentage of intensive silviculture. While the model may include biological limits on treatments, the MNR does not allow the analyst to include operational limits. The lack of operational constraints results in an unrealistic renewal schedule. The best silvicultural system is one that is based on site-specific factors (MNR 1997).

Stanley has the ability to schedule multiple harvest actions, provided they are compatible. Compatible actions are considered those that have the same opening size and adjacency constraints, for example conventional clearcuts and seed tree. Stanley can combine two or more of these activities into a single block. If the activities are incompatible, they must be scheduled in separate runs. This ability should not be confused with multiple-entry harvest systems. When considering multiple harvest actions on the same polygon, Stanley determines which actions contribute to the objective function. It will give priority to treatments on stands that contribute to the objective value. However, it may use the other action to create feasible blocks, even if they do not affect the outcome. While Stanley attempts to balance harvest activity and flow by blocks, it makes no effort to cluster the individual actions inside the blocks.

Another consideration when looking at SFMM's renewal program is that stands can only be renewed after harvest. Earlier sections dealt with the difficulty that Stanley encounters when trying to implement the strategic solution. Stand substitution and less than 100% achievement not only results in lowered volumes but also makes silviculture matching more difficult. When Stanley must choose a different stand than that prescribed by SFMM, it may mean that a prescribed treatment can not be achieved. In addition, if the full AHA is not achieved, then the full renewal program can not be achieved.

COMPLAN, on the other hand, assigns treatments to the stands as they are renewed. Since the harvest schedule is spatially explicit, so is the silviculture treatment package. While SFMM suffers from the fact that the renewal program is generated before stands are allocated, COMPLAN has the opposite problem. The silvicultural treatments for each stand have to be identified before the solution is generated, and this can be a time-consuming and difficult task. This level of pre-planning means that some critical decisions are made before the model results are known and less-than-optimal solutions may be generated.

4.3.3 Non-timber Values/Wildlife Habitat Planning

Ecological and non-timber values are largely influenced by the landscape pattern, and therefore can not be managed effectively at the stand level. The forest spatial structure and characteristics of the component stands determine landscape environmental features such as biodiversity, susceptibility to disturbance, etc. (Hollings 1978). However, timber management and silviculture decisions are usually made at the stand level. Therefore, the definition of stands by forestland classification strategies becomes an important landscape structuring element (Borges & Hoganson 1999). For a forest manager to preserve wildlife habitat, he/she must have the ability to define stands on an ecologically relevant basis, or at least assign ecological values to the stand. Identifying important stand types and patterns allows the forest manager to create spatial conditions that are required to maintain ecological integrity (Pukkala et al. 1997).

According to Borges & Hoganson (1999), environmental considerations may be achieved through the classification of the forest and the control of harvest and regeneration activities. Landscape classification produces the spatial mosaic upon which management decisions are made, providing a framework for the spatial dynamics. The harvest and regeneration decisions affect the mosaic and contribute to the ecological character of the landscape. Borges & Hoganson (2000) note that adjacency constraints help to maintain the original landscape spatial heterogeneity since the stands maintain their individuality over the planning horizon. However, Borges & Hoganson (1999) also note that the limits on maximum opening size may result in the sub-division of some stands that may lead to fragmentation and a loss of spatial heterogeneity. On the other hand, Borges & Hoganson (1999) point out that forest management may target specific spatial conditions, that are ecologically favoured and thereby contribute to other landscape features.

Specific forest management decisions are usually made at the stand level. Borges & Hoganson (1999) defined a stand as a homogenous unit that results from the classification of the forest for management purposes. The homogeneous nature of the stands forms the basis of the patch-corridor matrix that comprises the landscape mosaic (Forman 1987). It is at the landscape level that ecological processes function and should be managed. Several authors (Franklin & Forman 1987, Zonneveld 1990 and Naiman et al. 1993) have noted the relationship between the spatial structure of the forest at the landscape level and its ecological character. According to Walters (1986) and MNR (2001), biodiversity is best preserved in a landscape mosaic with a diverse array of stands. Borges & Hoganson (1996) conclude that "ecosystem sustainability depends on the spatial and temporal interactions of harvest and regeneration scheduling at the landscape level".

While wildlife habitat management at the landscape level is critical to maintaining ecological sustainability, many important features are specific to a single point on the ground (i.e. a salt-lick for moose). The protection of local values such as nesting or calving areas are equally important in maintaining healthy populations. These areas must be precisely identified and managed appropriately; this may include modified operations, the use of timing restrictions, or a complete removal from the allowable harvest area. The nature of these areas of concern requires much higher spatial resolution than broad landscape-level management strategies (Fall & Fall 1996).

SFMM has a wildlife habitat analysis reporting component to help improve strategic wildlife habitat planning, identify wildlife species that may face future habitat shortages, identify forest types that should be considered for retention, and identify where modified silvicultural practices may help avoid future habitat shortages. The SFMM Tool automates the production of the input data for habitat analysis. Habitat for all modelled species is calculated, then data for specific featured or indicator species are available for analysis. Habitat for all regionally selected wildlife species is analyzed and presented in various FMP tables.

The ability of COMPLAN to incorporate spatial wildlife considerations such as landscape patterns is an advantage over the aspatial approach of SFMM. Aspatial targets for habitat may be specified in SFMM and areas of known values may be set aside in Stanley. However this is not an effective way to plan habitat, especially over the long-term. The short planning horizon used by Stanley is also a problem since most guidelines require habitat planning that extend beyond 50 years (MNR 1996b, MNR 2001).

4.3.4 Analysis of Sustainability

The objective of sustainability analysis is to provide a consistent approach to the assessment of each management alternative. The use of models allows the planning team to project how the forest may develop when managed to achieve a different set of objectives. The MNR lists six criteria for determining sustainability. Both models can provide the information required to perform the analysis, although there are differences in the quality of the output data. SFMM is better at providing information for criteria specific to Ontario, such as forest diversity indices. As mentioned earlier, this must be created and inputted into COMPLAN. While analysis of the six criteria is required for an FMP, it should not be considered an exhaustive analysis of sustainability. The real determination of ecological sustainability is much broader and is based on the effect the planned activities have on the landbase.

The discussion so far has focused on the models' ability to generate a harvest and renewal schedule. However, the generation of a harvest schedule is a relatively simple calculation. The models' real utility in forest management planning is its ability to address these kinds of constraints typically encountered in forest management planning. Each model addressed the constraints in a different manner.

Forest management planning uses a variety of constraints to control forest composition and structure. Both SFMM/Stanley and COMPLAN have closed architectures, so the models' outputs are controlled by the options available. However, more open LP models (e.g. Woodstock) can be formulated to control activities through the inclusion of constraints, while simulation models are limited to a single activity (Jamnick 1990). The closed architecture of SFMM means that it is difficult to add constraints to the model. However, the model was designed to incorporate the most common constraints encountered in forest management in Ontario. SFMM allows the users to determine forest composition by specifying forest unit and age-class targets, wildlife habitat area targets, and growing stock. Operational constraints are also handled in SFMM; volume targets and flows, harvest areas and silviculture treatments can all be specified in the model.

COMPLAN does not offer users the same ability to use constraints to achieve management objectives. COMPLAN is a simulation model that uses an iterative process where the rules and parameters are used as inputs into the model. COMPLAN does not try to reach a specific objective; rather, as a simulation model it answers the question "what happens when these strategies and assumptions are applied?". The constraints are implicit in the construction of the model's inputs such as harvest priority.

Spatial constraints are used to control forest structure. Spatial constraints usually include control of block shape and size, block-size distribution and harvest pattern. Stanley is designed to address these questions as it allocates the strategic solution. Stanley uses extent information to determine block shape; all things being equal, it will choose polygon that yields the most regular shape (Remsoft 1997). Stanley does not allow one to control block size directly. The structure of the forest ultimately determines the block size distribution, so Stanley attempts to fit blocks to the forest rather than force a block size onto the forest (Remsoft 1997). Finally, Stanley uses adjacency and proximity rules to determine the temporal and spatial harvest pattern – green-up delays and proximal distance determine how close one block may be arranged to another. Stanley allows the users to pre-block both existing cutovers and future harvest blocks to account for the fact that most harvesting is not done in green-field operations. Stanley also allows the user to apply spatial restrictions based on different thematic values such as species group (Remsoft 1999a). Stanley does not allow the users to manage explicitly for wildlife habitat or biodiversity; rather, these objectives are managed in the strategic model (Remsoft 1999b).

Adjacency and proximity have been touched on above, however they are at the heart of spatial modelling and warrant more-detailed discussion. Adjacency is defined as the distance at which two stands are considered part of the same stand. Proximity is the distance at which harvest blocks are considered distinct (Remsoft 1994b). The concepts of adjacency and proximity are what define the various guidelines that must be addressed, which stands would be considered the same cutover, and which stands would be considered separate for wildlife habitat requirements. The definitions of adjacency and proximity determine the relationship between a stand and its neighbours, and which stands may be harvested versus which stands must be left.

Within the SFMM/Stanley model, the values for adjacency and proximity not only determine the spatial harvest pattern but also the success in matching the strategic solution. Adjacency is like any constraint - loosening the constraint increases the likelihood of obtaining a feasible solution. In the case of Stanley, the more accurately the spatial constraints are modelled in SFMM, the better it is able to approximate the solution. This can be done before the SFMM input file is created by the careful definition of subunits or as constraints in the model such as minimum harvest area or deferrals. Some critics of this approach believe that "hardcoding" the model in this manner limits its ability to determine the optimal solution. However, it is obvious that an "optimal" solution that can not be implemented is no solution at all.

In Stanley, an access restriction is applied to the entire block, even if only a single point is within the proximal distance. Remsoft (1999a) found that as the proximal distance increases, so does the area locked out; however, the relationship is not linear. The actual locked area is largely determined by spatial arrangement and dispersion pattern of the stands. Long, skinny blocks and stands can cause a disproportionate area to be excluded from harvest or an improperly considered block can restrict large tracts.

In COMPLAN, adjacency rules are used to restrict harvesting of a subcompartment based on the conditions of its neighbour; this can be based on age, height or any other value in the yield table. COMPLAN does not determine which stands are adjacent; instead, this done outside the model. The process of calculating adjacency is difficult and time-consuming. This is an area where COMPLAN noticeably lags behind Stanley, which comes with its GISpack suite of tools.

Most spatial considerations relate to the size and distribution of harvest blocks across the landscape. Stanley addresses these issues through the definition of adjacency and proximity. The adjacency and proximity rules are used to determine which stands comprise the same harvest block and how close a return cut can be to the original block without violating green-up requirements.

COMPLAN relies on the use of cover constraints and adjacency rules to create the desired management objectives. A cover constraint in COMPLAN is defined as a rule that constrains harvesting in all or part of a planning area such that a set of characteristics is maintained that area over the entire simulation (SRC 1997a). COMPLAN uses cover constraints to meet biodiversity targets such as seral stage requirements or habitat values.

Using Woodstock as the strategic solution generator, Remsoft (1999a) found that the larger the restriction, the lower the value of the strategic solution. Conversely, it was also found that the larger the proximal distance, the better Stanley performed in matching the strategic solution with the area locked out in Woodstock. While Stanley was more successful in matching the strategic solution at the largest distance (620 m), the value of the objective function was much lower; this was to be expected given the large area locked out.

The Remsoft (1999a) study also found that an increase in proximal distance of almost 200% from the prescribed distance (100 m) resulted in the highest tactical objective function value, 15% higher than the minimum. Remsoft accredited this to the fact that the small proximal distance does not enable the model to create large blocks within the buffer, while at the same time creating numerous small islands of eligible area in the ineligible areas. Stanley was able to create larger blocks after the restriction was lifted and does not have to deal with the residual islands.

COMPLAN uses adjacency and aggregation at the subcompartment level to manage adjacency and proximity. In COMPLAN, adjacency constraints are a function of three main factors:

1. Silvicultural system of the target and adjacent subcompartment;
2. Growth rates of adjacent stands; and
3. Spatial location (e.g. stands in visually sensitive areas may require substantially longer periods of time to allow for visual green-up).

Each subcompartment is assigned to an adjacency class (table) which is used to define the adjacency rules. This adjacency class can be overridden for individual adjacent subcompartments (e.g. to take care of different requirements for upslope and downslope subcompartments). Each adjacency class defines the minimum green-up standards that are required before harvesting can take place. These rules are defined as a minimum value that a stand characteristic (e.g. height) of adjacent stands must meet before harvesting is allowed. These standards may vary with the silvicultural system of both the target and adjacent subcompartments. Also, the size of the maximum contiguous non-greened-up area is defined for each adjacency class. Adjacency constraints may apply to both even-aged and uneven-aged management.

If sustainability is defined by the six criteria in the FMP, SFMM is the tool to use since it produces the results quickly and easily. In addition, the requirement to "incorporate expected rates of natural depletion agents, such as forest fire, windthrow and insects" essentially preclude using a spatial model. As mentioned above, it is very difficult to predict accurately how these events will manifest themselves in any term. However, if the analysis of sustainability is based on the impacts of planned activities have on the landbase then the analyst, at a minimum, requires Stanley. If the analysis of sustainability is to be carried out over the entire planning horizon, then COMPLAN is the appropriate tool since it can project the landscape pattern over the entire 150 years.

4.3.5 Fit in FMP Process

The final important consideration is how the models fit into the FMP process. SFMM was designed by the MNR as the tool of choice in preparing an FMP. SFMM meets all the requirements laid out in the FMPM and produces the outputs required to complete the tables. In addition, the MNR offers technical and training support for planning teams to use SFMM in FMP's.

The MNR, on the other hand, has not approved COMPLAN for use in an FMP. While COMPLAN is widely used in other jurisdictions, it does not meet all the requirements laid out in the FMPM. The biggest difficulty with COMPLAN is its inability to incorporate expected rates of natural depletion. Natural depletion events are unpredictable and while it is possible to estimate the area affected over the planning term, the actual timing, location and shape of the disturbance are impossible to predict. However, relative risks of fire and insect depletions can be calculated. The use of COMPLAN would also meet with resistance from MNR staff who are unfamiliar with the model and would therefore prefer that SFMM were used.

As part of the planning process, the FMPM requires the analysis of three mandatory alternatives. Two of the alternatives are designed to assess the timber production potential of the forest and the third assesses the capacity of the forest to meet the anticipated industrial demand. The first two alternatives are most easily addressed using an optimization model, such as SFMM, using the "maximize timber production" function. The industrial demand question can also be answered by SFMM; if the anticipated demand is higher than the productive potential of the forest, it will create an infeasible solution. If this is the case, SFMM allows the user to specify "soft" targets that the model tries to attain but do not constrain the solution.

COMPLAN can also address the requirements of the mandatory alternatives, but the process is much more difficult. Since COMPLAN is a simulation model, it requires the user to create the harvest strategy which it implements. Using an iterative approach, the analyst can eventually reach a maximum harvest level. However, one can not be sure that this is the optimal approach; because there are so many variables that can be changed, it would literally take thousands of iterations to explore the range of alternatives available. Given the tight deadlines of the FMP process, it is unlikely that an analyst would have the time required to perform such a thorough analysis.

While SFMM best meets the MNR's expectation for a planning tool, there are other considerations such as the quality of the solution and ease of planning. As discussed earlier, the spatial integration of the harvest schedule and plan objectives in COMPLAN generally produces a better solution. In addition, the operational focus of COMPLAN creates a solution that is easier to implement. The actual harvest block layout of the SFMM solution is one of the most difficult parts of the plan even with Stanley, it can be difficult and time-consuming. The desire to achieve a complete match between the strategic and operational solution presents a huge dilemma. If the operational plan differs too much from the strategic solution, the plan will be deemed unsustainable, even if Stanley is used. COMPLAN also requires a great deal of work in laying out blocks for harvest; however, this is done before the model generates a solution. The plan that COMPLAN generates is therefore more closely linked to operations and because COMPLAN is a simulation model, it is possible to make changes and develop new solutions that reflect operational concerns.

4.3.6 Suitability for Different Forest Types

Another criterion that must be considered is the model's ability to deal with a variety of forest types. In Ontario there are two forest types on which forest management is practised: the conifer dominated boreal and the tolerant hardwoods of the Great Lakes-St. Lawrence. Both models can be used on both forest types. In fact, SFMM comes built for both, although Stanley does not deal with multiple entries as well as it does with clearcutting.

Another consideration for large companies is whether the model can be used across jurisdictional boundaries. Most large forestry firms operate in different provinces and typically many countries, so the portability of a model across jurisdictional boundaries makes data management easier. While it is possible to adapt SFMM to different jurisdictions, the closed architecture would make the chore slightly more difficult than with COMPLAN even though the basic management questions (e.g. maximum harvest volume) are the same in most areas. The main advantages of SFMM, i.e. its ease of use and ability to start modelling quickly, would be lost. While SFMM was designed specifically for use in Ontario, it can be used in other jurisdictions as long as the analyst is aware of its 'Ontario-centric' bias.

COMPLAN, on the other hand, is well suited for different forest types given the model's ability to deal with important features, including (SRC 1997a):

- Localized volume tables;
- Silviculture intensity management;
- Financial analysis;
- Silviculture and timber production;
- Harvesting;
- Road construction;
- Product revenues;
- Wildlife habitat;
- Natural forest dynamics;
- Timber species classification;
- Timber product classification;
- Harvest schedule generation; and

- Silviculture treatment scheduling;

5.0 CONCLUSIONS

SFMM/Stanley and COMPLAN have different attributes and are best suited for different applications. SFMM's main function is strategic planning in preparing FMP's in Ontario, so its architecture and reporting are set up to meet the needs of an FMP. SFMM meets all the requirements of Appendix IX of the FMPM (MNR 1996A) for a model to be approved in Ontario. As well, SFMM performs the analysis of the mandatory alternatives required in Section 2.3.4 of the FMPM (MNR 1996A).

COMPLAN was developed for use by a number of clients operating in different jurisdictions; therefore, it is more flexible but requires more information input. Addressing operational concerns was identified as the primary consideration in model development. As a result of the different focus of the model, COMPLAN does not meet all the requirements of a forest model in the FMPM nor does it produce all the outputs required to complete the FMP tables that have become the focal point of the forest management planning in Ontario. However, the evaluation of suitability has to go beyond simply whether models match the requirements of the FMPM to address other concerns.

The two models studied represent divergent approaches to forest management. The simulation approach looks at the effect of a particular forest management scenario on wood supply. LP attempts to find the best or optimal solution for a particular objective function and set of constraints.

The fact that SFMM is able to find better non-spatially constrained results than COMPLAN is consistent with the findings of Jamnick (1990). COMPLAN is a simulation model which uses a sequential, iterative approach to satisfy the model requirements. Each period is analyzed independently, so the model can not make trade-offs between different planning periods. SFMM, on the other hand, generates the optimal solution for the entire planning horizon, delaying current harvest for higher volumes in the future.

The differences between SFMM and COMPLAN are the result of the overall approach to forest management. COMPLAN is better suited for situations where there is a need to integrate the spatial constraints into the solution generated, the problem to be solved is relatively simple, there are a limited number of variables to be included, and the tracking of operational variables such as road construction are a key concern. SFMM/Stanley is a well-developed strategic tool. That means it is best suited for dealing with complex problems with a large number of variables and activities, planning over long time frames and situations where hierarchical planning is a possibility. SFMM/Stanley can also be used effectively where short–term tactical planning can be incorporated into strategic planning but the final solution is not dependent upon the activities in the initial periods. Also, SFMM/Stanley is the best suited of the two approaches for completing an FMP in Ontario.

While SFMM has its limitations and detractors, most of the problems encountered in its use relate to the expectations of the user and the MNR staff. There is a pervasive belief among staff that since SFMM is an optimization model it therefore provides the best (and therefore only acceptable) solution. While the model developers do not share this view (MNR 2000a), it is common in the districts and regions. The MNR staff fails to recognize the model's shortcomings and insist on applying it for purposes other than that for which it was designed. The model is an excellent tool to measure 'long-term forest sustainability', but it is not as useful in creating a short-term forest management strategy. Unfortunately, many people believe its purpose is the latter. Also, the temporal and spatial scale of SFMM is not well understood by much of the MNR staff; much effort is spent picking out details which do not affect the strategic solution (MNR 2000b).

The different approaches the models take to the forest planning problem and their respective strengths and weaknesses make an outright selection difficult since no model performs all tasks better. The differences between the models are in some ways complementary. Jamnick (1990) noted that most model users tend to adopt one approach and use it exclusively. This is unfortunate because the use of both models could provide valuable insight into forest management. Unfortunately, the MNR's current approach to forest management requires stringent adherence to SFMM. An approach that incorporates the operational strengths of COMPLAN with SFMM's strategic solution would result in better forest management plans.

The original concept of this study was to determine which model was the best tool for forest planning in Ontario and recommend this tool to forest managers. However, the forest management environment has changed so much since this project was started that neither model is well suited for use today. The MNR continues to introduce new guidelines that require spatial planning (MNR 2001). These tools represented the state of the art when this study started; however, today they are dated and inadequate compared to the newest generation of models. The current generation of spatial planning tools track all forest stands over time and identify the contribution of those stands to the management unit's social, economic and environmental objectives. This generation of tools represented by FSOS (FESL 2001b) and Patchworks (Spatial Planning Systems 2001) attempt to achieve the desired future condition through dynamic scheduling of harvest and other values at the block or stand level subject to resource emphasis objectives or constraints which are applied at the forest or management zone level.

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GLOSSARY

Due to the technical complexity of forest estate modelling, a rich language of technical jargon has evolved over the years. The following definitions of technical terms are offered below to assist the reader.

Achievement Percentage The degree to which the tactical planning tool can match the strategic solution.

Adjacency The distance at which two stands are considered part of the same stand.

Green-up Period The length of time required for a harvested stand to be considered sufficiently regenerated to allow adjacent stand to be harvested.

Pre-blocking Manually identifying and selecting stands for harvest in certain periods before the computer generates a harvest pattern.

Proximity The distance at which harvest blocks are considered distinct.

Selection An unevenaged silviculture system consisting of frequent and careful felling of trees in all size classes, either singly or in small groups.

Two pass harvesting A silviculture system where the mature hardwood is removed in the first pass, without disturbing the existing conifers. Some time later the conifer is harvested, upon reaching maturity and the stand is renewed.

Biodiversity or Biological Diversity The variability among living organisms from all sources and the ecological complexes of which they are a part; this includes diversity within species, and of ecosystems. Canadian Biodiversity Strategy, Canada's Response to the Convention of Biological Diversity. (CBS 1995).

Biodiversity Indicators Indicators or measures that allow us to determine the degree of biological or environmental changes within ecosystems, populations or groups of organisms over time and space. (CBS 1995)

Clearcut Noun - An area that has been harvested using the clearcut silvicultural system.

Verb - The removal of most or all merchantable trees in a forest stand or group of stands in one operation. An evenaged silviculture system where all merchantable timber is removed in a single pass.

Corridors This term is used in a general sense to refer to measures that are taken to ensure the natural immigration and emigration of populations, species and gene flow. This may be a physical corridor, such as a terrestrial or aquatic migration route, a flyway, or it may refer to a particular management practice that allows a species and populations to continue patterns of movement. (CBS 1995)

Forest Disturbance A natural (e.g. fire) or anthropogenic (e.g. timber harvest) event in the forest that alters the natural succession of a forest stand or stands.

Forest Stand A community of trees possessing sufficient uniformity in composition, constitution, age, arrangement, or condition to be distinguishable from adjacent communities.

Ecological Management The management of human activities so that ecosystems, their structure, function, composition, and the physical, chemical, and biological processes that shaped them, continue at appropriate temporal and spatial scales.Ecological management is sometimes called ecosystem management or an ecological approach to management. (CBS 1995)

Ecosystem A dynamic complex of plants, animals and micro-organisms and their non-living environment interacting as a functional unit. The term ecosystem can describe small scale units, such as a drop of water, as well as large scale units, such as the biosphere. (CBS 1995)

Edge effects Environmental, biological, and anthropogenic factors occurring within the ecotone between two habitat types. In a forested landscape, edge effects may extend from disturbed habitat into undisturbed habitat, making it less suitable for species adapted to interior forest conditions but more suitable for "edge loving" species.

Fire cycle The normal length of time between fire events for different types of forest.

Fire pattern The observable characteristics of wildfire events (includes distribution of burned and unburned patches on a forested landscape, shape and size of disturbances, residual trees, etc.).

Fire process Aspects of ecological function that are affected by the occurrence of fire in the forest. Ecological functions can be affected at many scales from the site level (e.g. nutrient cycling) to landscape scale (e.g. forest age-class distribution)

Habitat The place or type of site where an organism or population naturally occurs. Species may require different habitats for different uses throughout their lifecycle.

Interior area The core of an area of habitat that is free from edge effects. This can be considered the effective area for species requiring interior habitat.

Landscape Complexes of terrestrial ecosystems in geographically defined areas. The forest management unit is the geographically defined area for the purpose of the Natural Disturbance Pattern Guide. (CBS 1995). Forest Management Planning Manual, 1996

Monitoring The collection and analysis of data over-extended periods of time to collect information on past and present ecological, social, cultural and economic trends and a basis for predictions about future conditions.

Natural Established by nature.

Selection System An uneven-aged silvicultural system where mature and/or undesirable trees are removed individually or in small groups over the whole area usually in the course of a cutting cycle.

Shelterwood (harvest method) A method of harvest where mature trees are removed in a series of two or more cuts.

Seed-tree (harvest method) Harvesting method where all trees are removed except for a small number of seed-bearing trees that are left singly or in small groups.

Roadlessness The state of being unaccessed by roads.

Roadless area An area of wilderness that has a road density below some critical threshold.

Silviculture The science and art of cultivating forest crops, based on the knowledge of silvics.

Soil sanitation The neutralization of soil pathogens(i.e. agents of disease).

Sustainable Development Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (CBS 1995)

Sustainable Harvest Rate The rate of harvest that is within an ecosystem's natural ability to recovery and regenerate. (CBS 1995)

Sustainable Use The use of components of biodiversity in a way and at a rate that does not lead to their long-term decline, thereby, maintaining the potential for future generations to meet their needs and aspirations. (CBS 1995)

Traditional Knowledge Knowledge gained from generations of living and working within a family, community or culture. (CBS 1995)