INTEGRATED RESOURCE MANAGEMENT PLANNING
THROUGH
THE LINKING OF MATHMATICAL AND JUDGEMENT-BASED MODELS

BY

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ABSTRACT

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Key Words: Decision making, forest resource policy, goal programming (GP), initial decision analysis (IDA), integrated resource management planning, judgement-based model, linear programming (LP), Sibley Provincial Park.

The objective of this study was to develop an analytical technique to enable forest managers to handle effectively the complex problem of integrated resource management planning using quantitative and qualitative information. Two different types of modelling approaches were used: 1) a quantitative-oriented linear goal programming and 2) a qualitative-oriented IDA model. These two types of model were linked to complement each other. By means of an inter-disciplinary workshop approach, an attempt was made to strengthen and broaden the power of the models to represent real world problems. Timber, wildlife and outdoor recreation-related objectives and variables were used for this study. Sibley Provincial Park in Ontario, Canada, was used for the trial application of this approach. A ten-year planning horizon and four cutting alternatives were employed. A resource policy which provided all interest groups in the workshop with the highest satisfaction levels was developed. The forest land in the study area was allocated optimally to achieve the multiple objectives of timber, wildlife and outdoor recreation. Determining target levels and weights for goal programming application were improved by linking LP and IDA processes. Subjective judgements of workshop participants were partly assisted and improved by initial LP solutions.

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INTRODUCTION

INTEGRATED RESOURCE MANAGEMENT

Forests, with their many species of flora and fauna interacting, have been important to humans throughout history. These flora and fauna form forest ecosystems that provide the forest products desired by society (Young, 1982). Forest ecosystems produce not only trees for timber, but also many other products and services. They provide food and shelter for wildlife, erosion and flooding control, and the opportunity for recreational and aesthetic experiences.

As our society develops, more products and services are expected from the forest. The values of the non-timber resources appreciate and gain as much importance as timber, with the result that the forest becomes too expensive to be used solely for timber production. This means that as forest resources become relatively scarce, as compared to past overabundance, more groups in society become involved in the demand for forest products and services.

As a result, conflicts of interest among competing groups become intensified and forest managers encounter new problems. A forest manager's role is no longer restricted to timber production, but is also expanded to the management of the natural resource that occur on, and in association with, the forest. Now, the forester can be defined as a land manager responsible for all goods, benefits, and services that flow from the forest (Shirley, 1973). Consequently, it is becoming more necessary for the professional forester to understand and manage the forest in a broader context than he did in the past. Modern forest management concepts should encompass the multiple-uses made of the forest and should handle the problems in that context. The integrated resource management approach can be one way for the forest manager to appreciate and resolve multiple-use management planning problems.

Multiple-use forest management shares most of the concepts and ideologies of integrated resource management. In the United States, the multiple-use concept was developed several decades ago and has been blended into national forest management objectives through the Multiple-Use and Sustained Yield Act that was legislated in 1960.

Even with a complete appreciation of the importance of multiple-use forestry, application of the concept has remained difficult for resource managers in real world situations. Such difficulties may be caused by the inherent complexity of forest resource management problems; for example, forest resource management problems involve many different variables: bio-physical, social and economic. These variables occur both inside and outside the forest. Furthermore, variables are interrelated and may change over time. Variables are compatible or mutually exclusive with others. These variables and the relationships that tie them together constitute a complex resource management system.

LEGISLATIVE REQUIREMENTS

Government legislations require resource managers to be comprehensive in their application of management. For example, in the United States, the US National Environmental Policy Act of 1969 (NEPA) requires managers to encourage productive and enjoyable harmony between man and his environment by utilizing a systematic, interdisciplinary approach to achieve that harmony (Bonnicksen, 1985). In Canada, the Province of Ontario has similar legislative requirements covered in the Crown Timber Act (1980), Forestry Act (1980), Woodland Improvement Act (1980) and Environmental Assessment Act (1980).

The Crown Timber Act prescribes forest preservation by stating that reservations may be designated for forest management, watershed, fire, aesthetic and wildlife protection. The Forestry Act and Woodland Improvement Act state that forestry purposes include the production of wood and wood products, provision of proper environmental conditions for wildlife, protection against floods and erosion, recreation and protection and production of water supplies. The Ministry of Natural Resources is required to provide services to the owners of private lands in Ontario for forestry purposes under these Acts (Anon., 1983b).

The Environmental Assessment Act obligates the timber management planning process to include potential environmental effects of the forest management undertaking, and opportunities for public participation (Anon., 1983c, 1985). Since the passage of the Act in 1975, most forest management activities have been exempted from the Act. The size of the land base being managed and the complexities of managing biological resources have made it difficult to determine an adequate procedure for applying an environmental assessment. Currently, hearings are occurring to determine the most effective means of implementing an environmental assessment on forestry activities. The potential environmental effects encompass all possible impacts by harvest operations on wildlife habitat, aesthetic quality, tourism and outdoor recreation opportunity (Anon., 1983c, 1985).

For administrative regions and districts of the Province, land use guidelines have been prepared. The guidelines describe the competing and conflicting use of forest resources, that are expected to be resolved through multiple-use resource management (Anon., 1982, 1983a). However, the guidelines do not indicate how such conflicts are to be resolved or how production targets are designated.

MANAGEMENT SCIENCE

The ubiquitous nature of human activities that accelerates changes in human and natural societies also contributes to the complexity of managing natural resources. Resource managers facing these changes must deal with the long- and short-term effects. By making decisions on various resource management problems, the resource manager affects society's access to natural resources. The manager's role is important especially when the consequence of a wrong decision is potentially serious. Resource decision making can be aided by management science. Management science is a discipline which applies scientific method to managing organizations or systems (Dykstra, 1984).

There are two important points in management science: one is to achieve optimality, and the other is to integrate different fields to resolve a complex problem (Dykstra, 1984). Management science attempts to resolve conflicts among the components of an organization in such a way that the good of the organization is advanced as much as possible. Often called the optimality criterion, this is a matter of considerable importance in management science (Dykstra, 1984). The integration of different fields is based upon the complex nature of the problems in modern society. One characteristic of modern society is specialization of both social groups and individuals. These groups and individuals tend to concentrate on increasingly narrow and specific issues. They also tend to have less and less appreciation for the concerns of other groups, in spite of their growing dependence on other groups (Bonnicksen, 1985). Therefore, integrating these different disciplines is an important step in handling the problems.

The decision environment surrounding natural resource management problems has the same amount of diversity as modern society. A problem occurs when several different interest groups, each of whom has specific views on the problem, are reluctant to negotiate with others. Meanwhile, one group or individual's dependence upon others increases. As this dependence becomes greater, it becomes more and more important to integrate different interest groups to resolve the problem, but this integration becomes more difficult.

Many applications of management science involve the study of complex systems. It is usually unreasonable to expect that an individual will possess not only the expertise for comprehending such systems, but also the expertise necessary to formulate and solve management science problems. Often a management science study requires a team of persons skilled in several different fields (Hiller and Lieberman, 1980; Dykstra, 1984).

MANAGEMENT SCIENCE IN FOREST RESOURCE MANAGEMENT

Management science provides appropriate analytical techniques for handling complex problems. The number of applications of management science techniques to forest resource management problems has grown since they were first introduced to forestry in the early 1960's (Buongiorno and Gilless, 1987).

As discussed in a later chapter, many of the previous management science applications in forestry focused on a small number of variables which were considered most important for the particular management objectives. Also, the previous applications were restricted to readily quantifiable variables. Applications were concerned mainly with such internal forest variables as timber volume yield and cost of harvesting. However, as our society now expects more goods and services from the forest than it did before, more external demand variables, such as economic and social variables, require consideration by a forest manager. Another aspect that previous applications overlooked was the resolution of conflicts among interest groups. As more external variables become involved in forestry, these interest groups have become and are becoming, more influential on the decision making process of the forest resource manager.

This study applies some management science techniques to a forest resource management planning problem in a broad context. In particular, an attempt is made to achieve optimality for multiple objectives, and to resolve conflicts between various interest groups involved in forest resource management planning problems.

OBJECTIVES

The three primary objectives of this study were: first, to develop a methodology for the resource manager, in order to enable him to understand and handle complex resource management planning problems in a broad context; second, to enhance the solutions by linking both mathematical and judgement-based models; and third, to obtain a methodological improvement in the application of the linear goal programming (GP) and initial decision analysis (IDA) modelling approaches. To accomplish these general objectives, the following specific objectives were met:

1) to develop a resource management policy that could resolve the conflicts and achieve harmony among the different interest groups.

2) to optimize quantitative variables by an improved GP approach. The determination of the target levels and weights for GP were improved by the solutions obtained from judgement-based model solution. The popular subjective judgement approach for determining the target levels and weights in GP application was made more objective to a certain extent by means of IDA model solutions.

3) to improve the judgement-based model's solution by using the result of mathematical models. Linear programming (LP) solutions for quantitative variables were applied to construct an enhanced judgement-based model. Also, information on acceptable policy was used in the GP application for the optimal allocation of resources.

4) to attempt to include in the decision making process soft variables. The soft variables include subjective opinions and judgement about relationships among poorly defined variables (Ortolano, 1984). They are usually qualitative and are not easily or readily quantifiable, but still exercise important roles in comprehending a problem and decision making.

5) to apply a team approach to integrate the various disciplines involved and to maximize their understanding of the problem.

LITERATURE REVIEW

This chapter discusses the theory and their application of the two major modelling approaches used in this study, that is, mathematical models and judgement-based models. In particular, LP and GP are discussed for the mathematical models, and KSIM and IDA models are discussed for the judgement-based models.

MATHEMATICAL MODELS

Mathematical programming, a tool of management science, involves the use of mathematical models to solve certain types of management science problems (Dykstra, 1984). More specifically, mathematical programming addresses optimizing problems which possess a structure that would maximize (or minimize) one or more objective functions subject to a set of constraints (Cohon, 1978). The objective functions and the constraints are mathematical functions of decision variables and parameters. Decision variables are controllable while parameters are given. The intended use of mathematical programming is the optimal allocation of scarce resources among competing ends (Dykstra, 1984). The general form of the mathematical programming problem is as follows:

$$\text{Maximize (or minimize) } Z(x_1, x_2, \ldots, x_n) \qquad (1)$$

$$\text{Subject to } g_1(x_1, x_2, \ldots, x_n) = 0$$
$$g_2(x_1, x_2, \ldots, x_n) = 0$$
$$\cdot$$

$$\vdots \qquad (1)$$

$$g_m(x_1, x_2, \ldots, x_n) = 0$$

Where Z() is the objective function and $g_1()$, $g_2()$, $g_m()$ are the constraints. The x's are decision variables. There are n decision variables and m constraints.

Linear Programming

Linear programming is the most widely used mathematical programming method, and it has been the most broadly applied of all management science techniques in natural resource management and related disciplines (Martin and Sendak, 1973; Holmes, 1976). In addition to its wide use in natural resource management, LP theory is important for multi-objective programming, or linear goal programming, an extension of LP. As a preparatory step for the discussion of multi-objective programming in next section, the basic theory and limitations of LP are presented in this section.

Linear programming is a special case of mathematical programming in which all of the equations in (1) are linear and in which there is a single objective function. The standard mathematical model of LP can be presented as follows:

$$\text{Maximize} \quad Z = \sum_{j=1}^{n} c_j x_j$$

$$\text{for } j = 1,2,\ldots,n \qquad (2)$$

Subject to the restrictions

$$\sum_{j=1}^{n} a_{ij}x_j \le b_i$$

for $i = 1,2,...,m$ (2)

and $x_j \ge 0$

Where

Z = objective function;

x_j = decision variables for which the problem solved;

c_j = coefficients which quantify the contribution of each decision variable to the objective function;

a_{ij}= coefficients which quantify the effect of the ith constraint on the jth decision variable;

b_i = constraints or restrictions imposed on solving the problem.

The first m constraints are functional constraints. Similarly, the $x_j \ge 0$ restrictions are nonnegativity constraints. The a_{ij}, b_i and c_j are parameters of the model because they are already known or given (Hiller and Lieberman, 1980).

Although the above model does not fit all types of linear program problems, it still can handle them with some minor mathematical manipulations. For example, minimizing of the objective function and the inequality of functional constraints can be handled by using negative c_j and b_i values. Functional constraints in equation form can be handled by using both greater-than-or-equal-to and less-than-or-equal-to inequality constraints. Dummy variables can be used for some decision variables to delete the nonnegativity constraints.

Assumptions of Linear Programming

Because not all problems can be solved through LP, it is useful to examine the assumptions about LP in order to make clear the types of problems which can be solved by LP and those which cannot. The following assumptions are from Cohon (1978), Hiller and Lieberman (1980), and Dykstra (1984).

1. Linearity

The objective function and all constraints must be strictly linear over the domain (the entire range of permissible levels) of each variable. If the functions are not linear then a transformation can take place to obtain a linear approximation. Functions must be sums of decision variables (additivity), each of which is multiplied by a coefficient. Decision variables may not be raised to a power other than zero or one. They may not be multiplied together.

2. Divisibility

This assumption implies all decision variables are continuous and not discrete. Therefore, noninteger values for the decision variables are permissible.

3. Nonnegativity

All decision variable must be at least equal to zero; negative assignments are not permitted. Decision variables can take on any value between some lower bound and some upper bound. The lower bound must always be greater than or equal to zero. Positive infinity is also assumed by most solution methods unless otherwise indicated.

4. Certainty

All coefficients and right hand side elements in the LP model (i.e. a_{ij}, b_i and c_j) are assumed to be known and constant. In actual problems, this assumption is seldom satisfied precisely. Linear programming models usually are formulated to select some future course of action. Therefore the parameters used would be based on a prediction of future conditions, which inevitably introduces some degree of uncertainty and randomness. To some extent, the uncertainty and randomness can be dealt with by means of sensitivity analysis. The general purpose of sensitivity analysis is to identify the relatively sensitive parameters (i.e., those that cannot be changed much without changing the optimal solution) to try to estimate these more closely, and then to select a solution which remains good over the ranges of likely values of the sensitive parameters.

In many cases mathematical programming models are used to gain insight about the underlying system. They are used as an analytical tool to assist the decision maker to understand the problem rather than to obtain a specific numerical result. Consequently, LP remains as a useful mathematical programming technique, in spite of its limitations.

Goal Programming

The objective function of LP allows only the statement of one management objective. But in many situations in natural resource management, multiple objectives are involved. Goal programming, developed by Charnes and Cooper (1961), minimizes deviations from multiple goals, or objectives, subject to some constraints that are goal statements and others that are physical constraints (Dykstra, 1984).

The general mathematical structure of GP parallels that of the LP model except that the objective function is changed to deal with deviation from the stated goals. Multiple goals are added as a set of constraints with deviations. The general GP model can be formulated as follows:

$$\text{Minimize } Z = \mathbf{W^+D^+} + \mathbf{W^-D^-} \tag{3}$$

Subject to

$$\mathbf{CX} + \mathbf{D^+} - \mathbf{D^-} = \mathbf{G} \tag{4}$$

$$\mathbf{AX} \leq \mathbf{B} \tag{5}$$

$$\mathbf{X},\ \mathbf{D^+},\ \mathbf{D^-} \geq 0 \tag{6}$$

Where

Z = total deviation;

$\mathbf{W^+}$= vector of weights associated with p under-achievement deviation variables;

$\mathbf{D^+}$= vector of weights associated with p under-achievement deviation variables;

W^{-}= vector of weights associated with p over-achievement deviation variables;

D^{-}= vector of weights associated with p over-achievement deviation variables;

C = p by n matrix of decision variable weights;

X = vector of n decision variables or activities;

G = vector of p goal target levels;

A = m by n matrix of technological coefficients;

B = vector of m available resource amounts or production requirement.

The basic idea of GP is to establish a specific numerical goal for each of objective, to formulate an objective function for each objective, and then to seek a solution that minimizes the weighted sum of deviations of these objective functions from their respective goals.

Though GP has been a powerful and useful tool for multiple-use planning, there has been considerable controversy over its applicability. GP requires the explicit quantification of goal levels and preference ratings of the goals. However, some objectives and their values are not easily quantified. For example, improving wildlife habitat quality or increasing outdoor recreation opportunity in public parks can be objectives of park management, but these objectives defy easy quantification.

Many natural resource management problems are concerned with incommensurable objectives. There may be no satisfactory way to specify goal levels of the objectives. Instead, decision makers' perceptions of the range of choice and feasibility have conventionally been used. Goal levels specified in this way often lead to an inferior or dominated solution, which is not on the boundary of the feasible solution space. Another problem in GP is setting the goal preference weights. The conventional GP model applies cardinal weights to the deviation variables. But many GP problems have goals which are unrelated to each other and have no objective measurement of the trade-off among the goals.

Application to Natural Resource Management Problems

Since Field (1973) first discussed GP in the forestry literature, it has been applied to a substantial number of forest resource management problems. Bell (1976) and Arp and Lavigne (1982) applied it to forest land-use planning. Rustagi (1976), Kao and Brodie (1979), and Field, Dress and Fortson (1980) used GP for timber production and harvest scheduling. Schuler and Meadows (1975), Steuer and Schuler (1979), and Chang and Buongiorno (1981) applied GP to multiple-use forestry. Bottoms and Bartlett (1975) applied GP to range management. Outdoor recreation applications were found in Romesburg (1974) and Rudra (1977). Methodological improvements and alternative approaches of GP have also been discussed in Hotvedt, Leuschner and Buhyoff (1982), Walker (1985), and Mendoza (1986).

The following is a review of GP application to forestry in the context of multiple-use management. The discussion focuses on how GP has been applied to natural resource management problems in the context of multiple-use and how the conventional GP problems, as stated, above have been dealt with.

As shown on Table 1, the objectives most frequently dealt with in the applications are timber production, wildlife and range management, and outdoor recreation. However, the goals and the units used for each objective are quite different among the applications. In timber production

Table 1. GP applications to multiple-use forest resource management.

		Objectives of multiple-use forestry			
Author	Situation	Timber Production	Wildlife and Range	Outdoor Recreation	Others
Schuler & Meadows (1975)	Actual	Yes	Yes	Yes	No
Bottoms & Bartlett (1975)	Hypothetical	Yes	Yes	Yes	Yes
Bell(1976)	Hypothetical	Yes	Yes	Yes	Yes
Rudra (1977)	Hypothetical	Yes	No	Yes	Yes
Steuer & Schuler (1979)	Actual	Yes	Yes	Yes	No
Chang & Buongiorno (1981)	Hypothetical	Yes	No	Yes	Yes
Arp & Lavigne (1982)	Actual	Yes	Yes	Yes	No

objectives, Schuler and Meadows (1975) used saw timber and pulpwood of softwood and hardwood as goals. Arp and Lavigne(1982) set merchantable and non-merchantable volume goals. Chang and Buongiorno (1981) employed area as a timber management goal. Bottoms and Bartlett (1975) used specific species volume for the goals. For wildlife and range management objectives, all authors used grazing goals except Arp and Lavigne (1982) who used deer population levels.

For the outdoor recreation management objective, each author selected one or more outdoor recreation activities as goals. They all used visitor day as a unit of measure for the goals. Table 2 provides more details.

It is clear from Tables 1 and 2 that while timber production has well-defined goals and units of measure, goals and units for wildlife and range management, and outdoor recreation objectives are unclear. As it is difficult to quantify the wildlife and range management objectives, more quantifiable ones are preferably selected for goals. But they do not always reflect the actual management objectives as clearly as in timber production goals.

Most of the GP applications seem to ignore these extrinsic problems. GP also has intrinsic problems in application. These include determining coefficients for input and output production functions, setting target levels for goal constraints, and setting preferences among deviation variables (Cohon and Marks, 1975; Dykstra, 1984; Leuschner, 1984). Attempts to address these problems are discussed below.

Table 2. Goals and units used in GP applications to multiple-use forest resource management.

Authors	Timber Production		Wildlife & Range		Outdoor Recreation	
	Goals	Units	Goals	Units	Goals	Units
Schuler & Meadows (1975)	Saw timber Pulpwood	ft^3 ft^3	Grazing	AUM	Dispersed recreation Hunting	v.d.[a] v.d.
Bottoms & Bartlett (1975)	Timber harvest	MBF	Grazing	AUM	Camping	v.d.
Bell(1976)	Timber production	MBF	Forage	lb	Dispersed recreation	v.d.
Rudra (1977)	Permissible cut	n.d.[b]			Permissible visitor load in summer and winter	n.d.
Steuer & Schuler (1979)	Timber production	ft^3	Grazing	AUM	Dispersed recreation Hunting	v.d. v.d.
Chang & Buongiorno (1981)	Timber management area for growing stock	acre			Campground Snowmobiling	v.d. v.d.
Arp & Lavigne (1982)	Merchant-able volume	m^3/ha	Deer population	deer/ha	Recreation capability (disperse & developed)	v.d.

Note. [a] v.d. : visitor day

[b] n.d. : not defined

1. Coefficients of Input and Output Production Function

This is a problem in GP as well as in LP. In land-use planning applications (Bell, 1976; Schuler and Meadows, 1975), unit land productivity has been applied based upon the assumption that unit lands are homogeneous and have same productivity level for various products of goals. Arp and Lavigne (1982) used Dane, Meador and White's (1977) land capability index for outdoor recreation and their own assumptions for wildlife population based upon sex ratio, birth rate and mortality. Bottoms and Bartlett (1975) used subjective judgement to estimate coefficients. However, these coefficients seem still to have been determined in an arbitrary manner.

2. Target Levels

Target levels have been traditionally determined by decision makers' subjective judgement. In Schuler and Meadows (1975), the planning team determined the target levels based upon the users' demand for the goals. Bell (1976) suggested that current biological output or arbitrarily low levels be used as initial targets and then modified according to public opinion and manager's subjective judgement. Arp and Lavigne (1982) and Bottoms and Bartlett (1975) also relied upon subjective judgement. Chang and Buongiorno (1980) started with tentative goal levels and found optimal goal levels in an interactive way. The tentative goal levels were subjectively devised. However, subjective judgement often leads to inferior solution. Zeleny (1981) argued that target levels of goals should be outputs rather than inputs to GP. GP structurally requires _a priori_ specification of target level. Walker (1985) found that this problem could be improved efficiently by introducing feasible and optimal policy spaces. The feasible space for each goal is determined by formulating a pair of LP problems and the optimal policy space is determined by using GP where the goal attainment levels are set to optimal values. This approach, however, exhibits some computational burden (Mendoza, 1986). Mendoza (1986) suggested a method to reduce the burden.

3. Preference Structure

The structure of priority rankings and weightings needs to be established to reflect the relative importance of the various goals. One widely known approach of ranking is preemptive or lexicographic orderings of the objectives. That is, the fulfillment of the goals with high priority is immeasurably more desirable to the fulfillment of any other set of goals with lower priority. Applications of this method appear in forestry literature (Arp and Lavigne, 1982; Bell, 1976; Chang and Buongiorno, 1981). In spite of its wide use, the preemptive ordering has been criticized for its weakness. Dyer, Hof, Kelly, Crim and Alward (1979) questioned the use of preemptive ordering, since it implied that unit deviations from higher ranking goal target levels were infinitely more undesirable than unit deviations from lower ranking goal target levels. For the same reason, Mendoza (1986, 1987) also identified the possibility of generating a dominated or inefficient solution.

The deviation variables, $\mathbf{D^+}$ and $\mathbf{D^-}$ in equation (3), are weighted according to the relative importance of each goal as expressed by the cardinal weights, $\mathbf{W^+}$ and $\mathbf{W^-}$.

In multiple-use forestry literature, Arp and Lavigne (1982) and Chang and Buongiorno (1981) used cardinal weighting for their GP applications. The difficulty of specifying weights or priorities from a practical standpoint has been recognized and reported in various literature (Chang and Buongiorno, 1981; Hotvedt et al., 1982; Steuer, 1976; Steuer and Schuler, 1979; Zeleny, 1982). Steuer and Schuler (1979) used an interactive weighting procedure to identify the most acceptable solution with the aid of a filtering device.

Buongiorno and Gilless (1987) suggested that a relative importance of deviating by one percentage point from the respective goals could be used for assigning values to the weights. Mendoza (1987) stated that weights and priorities are indicative of the decision makers' value judgement about the relative importance of objectives or goals. Determining these weights or priorities before the analysis can be too difficult or even arbitrary due to lack of information or sufficient knowledge of the intricacies of these values and the decision environment. Table 3 is a summary of the approaches to the various problems in GP application to multiple-use forestry.

Table 3. Approaches to the problems of GP application to multiple-use forest resource management.

Authors	Coefficients of input and output functions	Target Levels	Preference Structure: Weights	Preference Structure: Priorities
Schuler & Meadows (1975)	Alternative acreage allocation based upon unit level	Subjective judgement by planning team and users'demands	Cardinal weights based upon market value ratio	Preemptive ordinal ranking
Bottoms & Bartlett (1975)	Subjective judgement	Varying subjective judgement	Not defined	Varying ordinal rankings
Bell(1976)	Potential average outputs based on alternative input levels	Current biological output figures, arbitrarily low level and then modify by public opinion or manager's input	Relative values for alternative outcomes through Churchman-Ackoff technique	Preemptive ordinal ranking
Rudra(1977)	Not defined	Not defined	Not defined	Varying weighted priorities
Steuer & Schuler(1979)	Alternative acreage allocation based on unit level	Subjective judgement by planning team & users' demands	Interactive change of weights with	Ordinal ranking filtering device
Chang & Boungiorno (1981)	Not defined	Interactive searching from tentative goal levels by subjective judgement	Cardinal weights for same priority	Preemptive ordinal ranking
Arp & Lavigne (1982)	Land capability based on Dane <u>et</u> <u>al</u>. (1977) for outdoor recreation and assumptions for wildlife population	Annual allowable cut for timber and subjective judgement for others	Cardinal weighting	Ordinal ranking

JUDGEMENT-BASED MODELS

Systems Approach

As discussed in earlier, natural resource management problems involve the study of complex bio-physical and socio-economical systems. Mathematical programming is frequently insufficient to handle these management problems because many qualitative variables are often associated with the problems. This characteristic becomes more prominent as the system becomes more complex.

Actual problems in natural resource management involve a multiplicity of competing variables, presenting a complexity of behavior that may dwarf resource managers' capacities for comprehending the problems. Consequently, decisions may be made in truncated spaces by sharply reducing the variables to the quantifiables (Kane, 1972). Mathematical programming concentrates its attention upon those variables which can be readily quantified, and tends to exclude the qualitative variables. For example, merchantable volume, harvest area, recreation visitor day, and grazing area are readily quantifiable variables. However, subjective or emotional notions in natural resource management, such as wildlife viewing opportunity, outdoor recreation opportunity, accessibility to the park, aesthetic quality, and amenity in the park, are soft variables and are seldom included within the mathematical model. Moreover, the relationships among these and the numerical variables are often poorly understood. But qualitative variables may still exercise an important role in understanding the problem being addressed. Integrated resource management problems require a holistic approach by which the resource manager can see the problem in the context of the broad picture of the systems he is concerned with. Therefore, it is important to extract and make use of the soft variables rather than discard them entirely.

Kane (1972) noticed the above problems and developed a subjective judgement-based KSIM model, which has the capacity of enlarging the scope of resource managers' understanding of the system.

KSIM Model

The KSIM model was developed by using structural dynamics based upon causality between variables. It stressed geometric linkage rather than refining arithmetic estimates of future probabilities as the mathematical model does. It can handle data of subjective estimates as well as of highly precise physical measurements. Because of its nature, it is available to a broader range of application.

Causality and its perception are fundamental to human understanding of processes and systems. Causality is the notion of an interaction between two objects in which one assumes a dependency role relative to the other (Burns and Marcy, 1979). A change on the part of any one object is a cause that produces an effect on the objects that interact with it. From the point of causality, a system can be thought of as a collection of objects that interact. The KSIM model bases its structure on a cross-impact matrix drawn up by causality. KSIM requires a minimum of three specifications: a set of variables, interactions between any two pairs of them, and a set of initial conditions of each variable. Variables and their initial conditions can be specified by brainstorming techniques. The cross-impact matrix can consist of interactions of all pairs of variables.

Figure 1 shows the hypothetical causal model and associated cross-impact matrix.

Once a particular interaction matrix and initial values have been selected, the future can be forecasted by the KSIM simulation algorithm. Following is the KSIM simulation algorithm and its properties from Kane (1972) and Kane, Vertinsky and Thompson (1973).

$$X_i(t+\Delta t)=X_i(t)^{\varnothing i(t)} \tag{7}$$

Where:

$0 < X_i(t) < 1$; $i = 1,2,\ldots,n \quad t \geq 0$

t is time step.

$$\varnothing_i(t) = \frac{1+\frac{\Delta t}{2}\sum_{j=1}^{m}[|a_{ij}+B_{ij}| - (a_{ij}+B_{ij})]X_j(t)}{1+\frac{\Delta t}{2}\sum_{j=1}^{m}[|a_{ij}+B_{ij}| + (a_{ij}+B_{ij})]X_j(t)} \tag{8}$$

m is the number of column variables.

a_{ij} is the strength of the long-term "L"

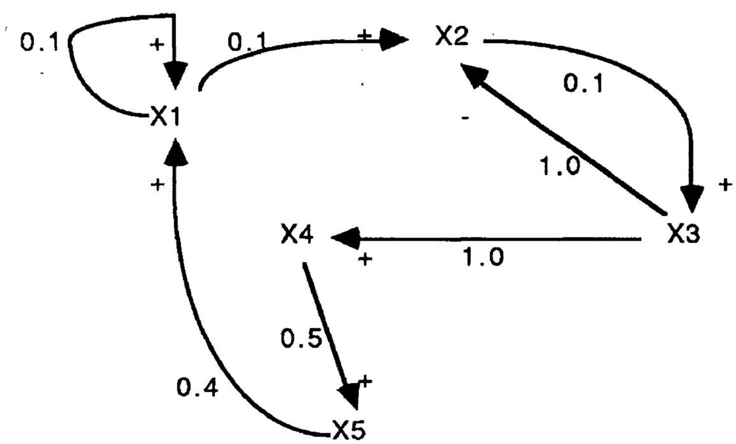
$$B_{ij} = b_{ij}\frac{dX_j(t)}{dt} \tag{9}$$

b_{ij} is the strength of the short-term "S" numerical impact for the variables related in cell row i column j.

X_j is the normalized level of the column variable j.

Equation (8) can be rewritten in the following form:

$$\varnothing_i(t) = \frac{1+\Delta t \ |\text{sum of negative impacts on } X_i|}{1+\Delta t \ |\text{sum of positive impacts on } X_i|} \tag{10}$$



	X1	X2	X3	X4	X5
X1	0.1				0.4
X2	0.1		-0.1		
X3		0.1			
X4			1.0		
X5				0.5	

Xn = variables.

Figure 1. Hypothetical causal model and associated cross-impact matrix (from Burns and Marcy, 1979).

1. System variables are bounded. It is now recognized that any variable of human significance cannot increase indefinitely. There must be distinct limits. In an appropriate set of units, these can always be set to one and zero.

2. From equations (7) and (8) if negative impacts are greater than positive ones, $\varnothing_i(t)>1$ and X_i decreases. If positive impacts are greater than the negatives, $\varnothing_i(t)<1$ and X_i increases. If positive and negative impacts are equal, $\varnothing_i(t)=1$ and X_i remains unchanged.

3. From equation (9), it is clear that if $x_i \rightarrow 0$ or 1

   then $\frac{dX_i(t)}{dt} \rightarrow 0$.

4. Considering X_j in the system of differential equation (9) individually, it is seen that, as it increases or decreases, the magnitude of the impact of X_j upon any X_i increases or decreases.

5. Equation (9) also holds because system behavior is modeled through coefficients, each of which describes the binary interaction of X_j upon X_i.

As discussed above, the KSIM simulation model is a holistic approach to comprehending a complex system which includes non numerical variables. It emphasizes the structural relations of variables and their dynamics rather than numerical prediction. It also gives the users insight into geometric concepts such as connections between variables, the directions of forces, and the threshold and saturation of variables. However, KSIM focuses on model structure rather than on the evaluation of the results from the simulation.

Expansion of KSIM Model

The KSIM model was modified and expanded by Bonnicksen and Becker (1983) and Bonnicksen (1985). Bonnicksen (1985) developed a participatory decision analysis technique called Initial Decision Analysis (IDA) based upon Kane's (1972) KSIM. He also strengthened the analytical power of the model by adding an evaluation process to KSIM. Bonnicksen (1987) made a series of modifications and improvements to his early work. Recently, IDA has been developed as a commercial micro-computer program named EZ-IMPACT (Bonnicksen, 1987).

IDA Model

The IDA model is a judgement-based participatory systems modelling and decision analysis technique. This model employed the KSIM algorithm for model structure, but it has strengthened the planning and evaluation processes to make it more applicable to actual situations. KSIM emphasized the model's function as a learning tool for decision-making so that the holistic concepts and the dynamics of complex feedback structures could be understood by users (Kane et al., 1973). IDA also includes those heuristic features in the model, but it tends to orient itself more towards problem-solving (Bonnicksen, 1987). The IDA process has three main parts - the planning phase, the simulation phase, and the evaluation phase. Bonnicksen (1985) describes each phase as follows: The planning phase focuses on identifying the problem; developing goals, objectives, and alternatives; and designing the bio-social systems model. The planning phase can result in either a complete product, such as an increased understanding of the problem and identification of the most important areas for research, or it can provide a foundation for the simulation phase of IDA. The simulation phase utilizes the bio-social systems model to conduct policy experiments so that consequences can be anticipated prior to implementing a policy. The evaluation phase uses the results of policy experiments to help refine policy portfolios (Bonnicksen, 1985). Figure 2 is the simplified process of IDA model.

Both the KSIM and IDA models are structured by a cross-impact matrix based upon subjective judgement. To obtain as precise a subjective judgement as possible, both models require joint efforts of people from the various disciplines through a workshop or panel.

The IDA model shares most of the same properties as the KSIM model, but IDA has more features. The most significant difference between IDA and KSIM is the evaluation process, which increases the analytical power in the model. In the evaluation process of IDA, each interest group selects its desired level of selected variables as objectives. Based upon the objectives and the simulated results, satisfaction level is determined by the three satisficing algorithms (as shown in Appendix I).

The IDA model is good for integrated resource management problems because it can handle the soft variables by using normalized values. IDA normalizes the value of each variable as a percentage of that variable's maximum possible value. The normalization provides uniform units of measures, i.e. percentage. The uniform units of measures can significantly improve the manager's capability to handle complex problems.

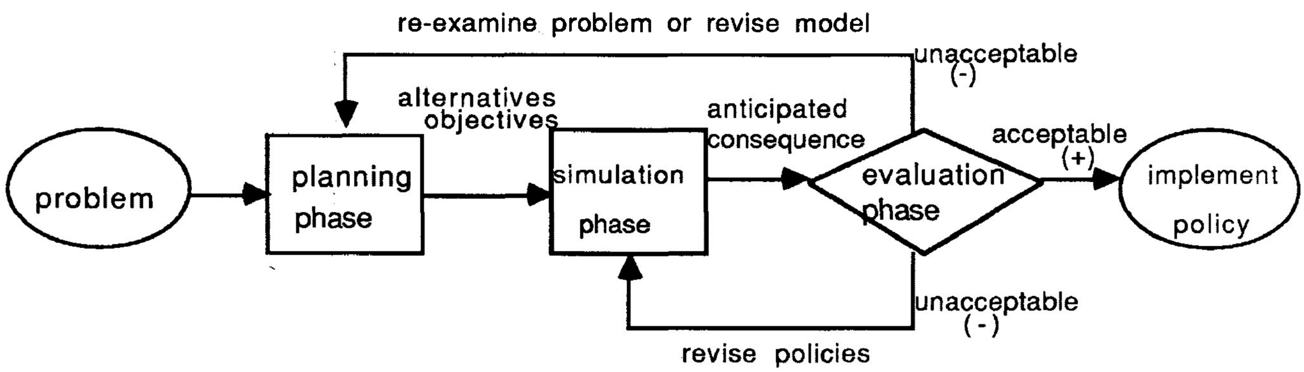


Figure 2. Simplified representation of phases in IDA process (from Bonnicksen, 1985).

Another feature of IDA is the refinement of the original model. Refinement is adjusting the original estimates of the strength of the impacts in the matrix so that all of the impacts interact to produce a trend for each variable which approximates that variable's expected trend (Bonnicksen, 1985, 1987). Through the refinement, subjective judgement can be reasonably improved. The refinement is based upon the assumption that existing knowledge about specific relationships is often less well developed than knowledge about the actual or likely trends that result from those relationships. This nature of the IDA model enables the resource manager to handle effectively complex integrated resource management problems, that involve qualitative objectives and a variety of units of measure.

LINKING MATHEMATICAL AND JUDGEMENT-BASED MODELS

A resource management problem includes many bio-physical and socio-economical variables. Some are readily quantifiable and some are not. Quantifiable variables can be used by mathematical models as a tool for solving a problem. However, today's resource managers are confronted with rapid changes, conflicts and complexities (Bonnicksen, 1985). Problems consist of many interrelated variables including qualitative ones. Therefore, reliance on quantifiable variables only might lead to overlooking important aspects of the problems. Even if variables are readily quantifiable, it may not be easy to quantify them accurately and in time required for decision-making. Judgement-based models might fill the gap between mathematical models and reality. The model's holistic approach might help the resource manager envisage the problem in a wider context than mathematical programming can reflect. Because judgement-based models utilize the readily available knowledge and experience of experts, it can save a resource manager's time. Linking the two modelling approaches may enable complex resource management problems to be handled more effectively than employing only one of the methods.

METHOD

The previous chapters discussed and reviewed characteristics of modern resource management problems and some popular methods of approaching them. This chapter describes a method of combining mathematical programming and the judgement-based modelling approach to resolve complex resource management problems. To explain the steps followed, this chapter discusses the general approach used. The following chapter covers the specific method used for the resource management problem studied.

The aim of the approach introduced here is to achieve two important objectives of integrated resource management planning problems: the quantitative optimality for the various objectives and the harmonization of conflicts between the various interest groups. The process of linking these two methods involves the following 5 steps:

1. pre-select hard variables
2. determine feasible decision spaces by LP
3. develop a resource policy by IDA.
4. determine target levels and weights for GP application.
5. apply GP for optimality.

Three different analytical procedures are linked together to produce a methodological improvement in the decision making process. The LP is used to determine the feasible policy space to assist in the IDA judgement process, and to determine the weights for the GP application. The IDA is used for two main purposes: first, to develop a resource policy for resolving conflicts that might exist between interest groups; second, to improve the determination of target levels and weights for GP application. Finally, the GP is used for its original purpose, to achieve optimality of multiple objectives using the results of the IDA process. Figure 3 is a schematic of the linking process.

PRE-SELECTING HARD VARIABLES

The resource management problem addressed is identified by both hard and soft variables. Hard variables are readily quantifiable, while soft variables are not readily or easily quantifiable. Variables used are those necessary to achieve the objectives identified in integrated resource management problems. The variables, particularly the pre-selected variables, function differently at each phase of this process. These variables are dependent variables of the objective function in LP problems, system components and management objectives in the IDA model, and goals in the goal programming problem.

In this study, merchantable volume harvested (MVH), scenic beauty (SB) and winter browse availability (WBA) were pre-selected as the three representative variables related to the three main integrated resource management planning objectives for this study; timber, outdoor recreation, and wildlife.

The three variables, MVH, SB, and WBA, were estimated based upon common variable predictors of forest stand characteristics; such as, stand age, basal area, site class and stocking level. Thus, quantification and prediction of

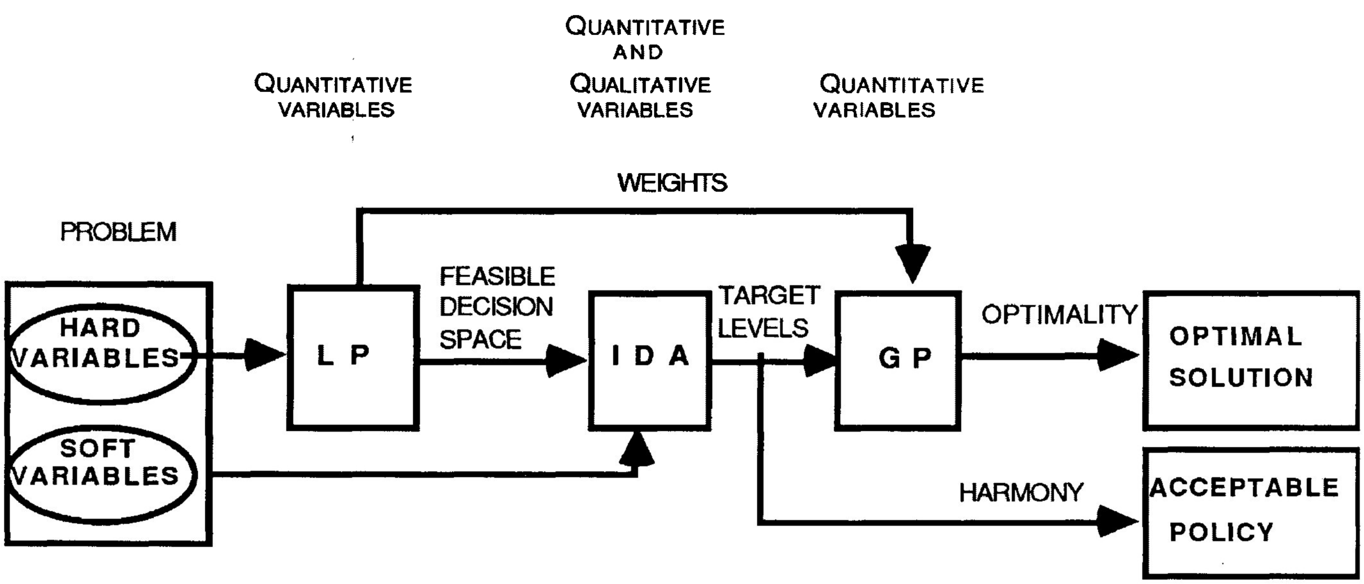


Figure 3. Process of linking mathematical model and judgement-based model.

changes in these variables over time were possible by applying multiple linear regression.

DETERMINING FEASIBLE POLICY SPACES

Linear programming is applied to determine the feasible policy spaces of the pre-selected variables. A feasible policy space is the interval between the two LP solutions: the simple optimal level and the worst feasible level. The simple optimal level is the objective level attained as a result of maximizing the objective function of a LP problem. The worst feasible level is the objective level attained as a result of minimizing the objective function of a LP problem (Walker, 1985). The interval between the simple optimal and worst feasible levels is the feasible policy space.

This feasible policy space also implies that it is a decision space within which some trade-off can take place between objective attainment levels. For a variable with given physical and operational constraints, the simple optimal level indicates a maximum attainment level while the worst feasible level indicates a minimum attainment level. Therefore, a management decision for the variable may occur between these two levels. Likewise, the expected and desired changes in a variable for the IDA process may be determined within this feasible policy space.

DEVELOPING A RESOURCE POLICY

The IDA process is applied by using a workshop to develop resource policies. Workshop participants include experts from disciplines involved with the resource management problems. IDA has three main phases: planning, policy experiment, and evaluation phases. Each phase involves four or five steps as shown in Figure 4. The steps in each phase are as follows:

Planning Phase

The planning phase is mainly for model construction. Model construction includes the determination of variables, trends of the changes of variables, and relationships between variables.

Variables and Trends

The workshop identifies problems to be addressed, and develops objectives to solve these problems. Variables are determined to obtain the objectives. The candidate variables are screened to a reduced set of parsimonious variables.

For example, the variables selected by the workshop for this study were moose density (MD), moose viewing opportunity (MVO), accessibility (ACC), cutting area (CA), employment (EMP), cost (CO), number of local park users (NPUL) and number of tourist park users (NPUT). Trends of each variable were estimated, after choosing the variables for the model. The trends included maximum increase, expected increase, and external impact of a variable over a certain time period under current policy. These three trend terms are important terminology in IDA model application that require explanation. Definitions of these terms, from Bonnicksen (1987), and examples are in the next three paragraphs.

The maximum increase is the maximum feasible percentage increase for a variable over the simulated time period. For

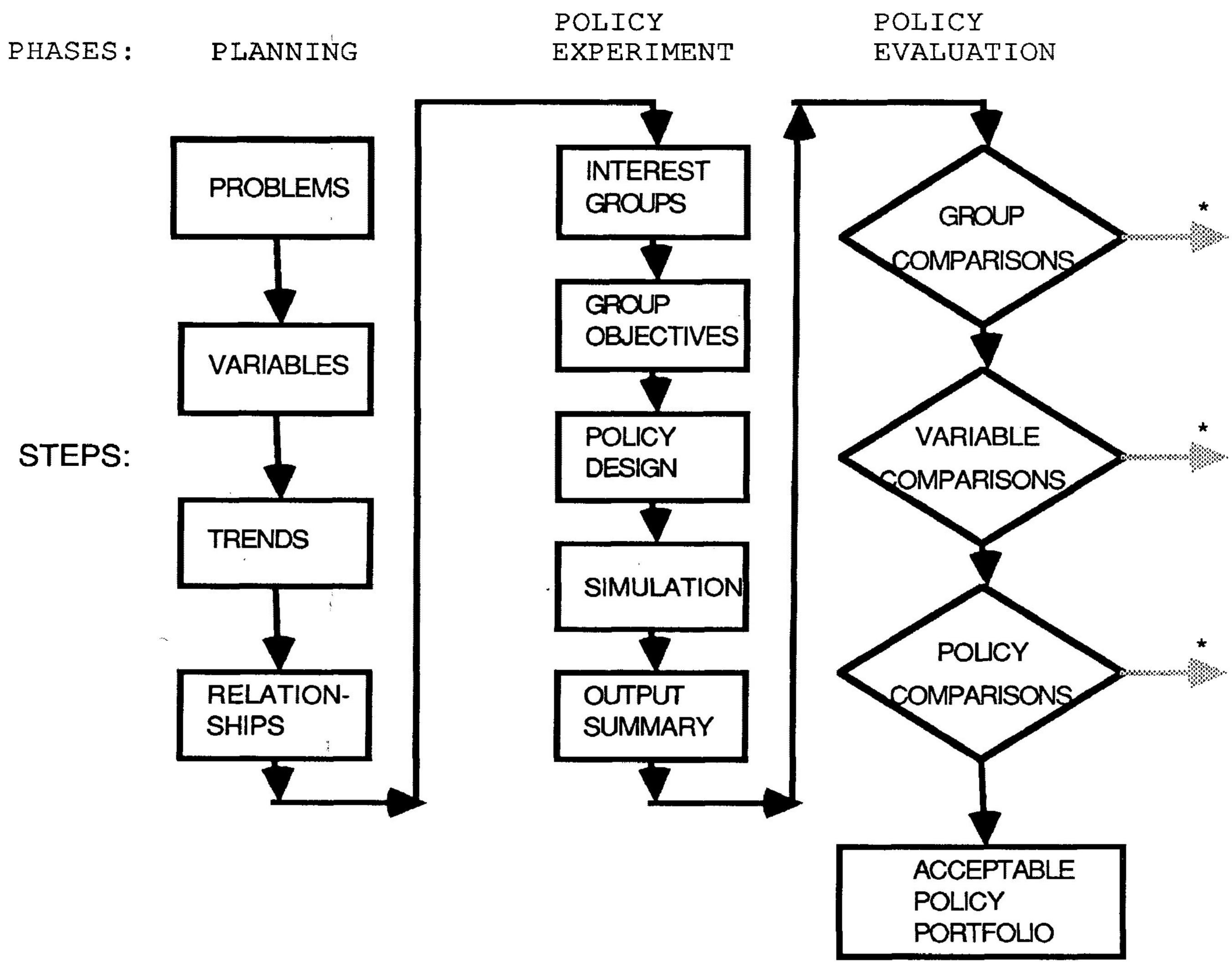


Figure 4. IDA workshop process

* The lightly shaded arrows indicate that the workshop can return to any earlier stages to make necessary modifications.

example, the Sibley Provincial Park vegetation management plan (McNicol, McAlister and Bretschneider, 1986) has a wildlife management objective of increasing MD from approximately 0.5 to 3.0 per square kilometre over a 10-year period. From this statement, MD can be taken as a variable for IDA model construction. The density, 3.0 per square kilometre, is considered as the maximum possible increase for the given period. Thus, maximum percentage increase is 600. This maximum can be adjusted by using the average judgement of participants in a workshop.

The expected change represents the percentage change in a variable that is likely to occur under current policies during the simulated time period. Both the maximum increase and the expected change are expressed as a percentage change from the beginning of the time period. For example, an expected change in MD of minus 16 percent indicates that the MD would drop by 16 percent over the simulated time period under the current policy.

The external impacts account for variables that are not represented in the model, but which influence the model from outside (e.g. demographic, economic, ecological, technological, political or cultural impacts). These external impacts represent the estimated percentage of expected changes in each variable that can be attributed to such outside influences. For example, if the external impact on MD is 43 percent of the total expected change, then the three variables related to changes in MD, that is, MVH, WBA and MD, explain 57 percent of the expected change.

Relationships

The next step in the model construction is the estimation of the relationships among variables in order to construct a cross impact matrix. In the arrays, all variables are presented both across the columns and down the rows. Each cell entry of the matrix requires information such as the existence of a relationship, the type of impact, the direction of the impact, the strength of the impact, and the constraint of the impact. The following five points, from Bonnicksen (1987), describe these relationships, along with examples from the study workshop.

1. Existence of relationship

A relationship is considered present in any given cell if a column variable is hypothesized to have an impact on a row variable. For example, cutting an area causes an increase of MVH, a decrease of SB, and provides more favorable habitat conditions for an increased moose population. A higher MD could increase MVO, which in turn increases the number of park users. From this piece of information, the existence of relationships are hypothesized between CA and MVH, SB, and MD; and MD and MVO, and the number of park users.

2. Type of impact

Once a relationship is considered to be present, the impact type, long or short-term impacts, are determined. A long-term impact existed if a column variable exerts a continual influence on a row variable, even if the column variable remains constant. A short-term impact exists if a column variable only influences a row variable when the column variable changes, and the impact is directly proportional to the amount of change that occurs in the column variable at each time simulation step. Thus, for a short-term impact, the row variable is unchanged if the column variable remains constant. For example, if a relationship exists between MD and WBA and MVO, the MD, even if it remains constant, has a continuing influence on the decrease of WBA because of the utilization of browse by moose. Thus, the type of impact that exists between MD and WBA is long term. On the other hand, if more cutting occurs, more MVH and less SB are expected. Harvest of merchantable volume and degradation of SB occurs only when cutting takes place. The relationships between CA, and MVH and SB are directly proportional. Thus, this type of impact is short term.

3. Direction of impact

If the row variables changes in the same direction as a column variable (i.e., if the column variable increases, and the row variable also increases), then a positive impact exists. If, on the other hand, the row variable changes in a direction opposite to that of the column variable (i.e., if the column variable increases, the row variable decreases), then a negative impact exists. For example, more cutting increases harvested merchantable volume, but decreases SB. Thus, the CA has a positive impact on MVH, but a negative impact on SB.

4. Strength of impact

The strength of the impact is determined by workshop members as relative assessments of the effects of a variable's change. The following values are entered according to the strength.

Strong impact : 3
Moderate impact : 2

Weak impact : 1

For example, harvesting merchantable volume can have a strong impact on WBA, SB and CA, a moderate impact on MD, MVO and EMP, while it may have a weak impact on CO and NPUL.

5. Constraint on impact

Constraint on impact is the final item required to define the relationship. If a constraint exists, it indicates the direction a column variable must be moving to have an impact on a row variable. If a column variable can only impact the row variable when the column variable is going up, the "UP" constraint is entered. If a column variable can only impact the row variable when the column variable is going down, "DN" constraint is entered. If column and low variables are closely correlated with each other, "C" constraint is entered. For example, if MVO is highly correlated to MD, the "C" constraint can be applied to the MD's impact on MVO.

Introducing Feasible Policy Space

During the model construction, the pre-selected quantitative variables used for the LP application and their feasible policy spaces are introduced to the workshop participants. As the simple optimal level is interpreted as the maximum attainable level, it is used to determine the maximum increase percentage for a variable as follows:

Maximum increase (%) =

$$\frac{\text{Simple optimal level - Present year's yield level}}{\text{Present year's yield level}} \times 100\% \qquad (11)$$

Thus, the expected change can be determined within the given feasible policy space in a more precise and objective manner. The subjective judgement of the workshop participants can be assisted and improved by introducing the feasible policy space.

Policy Experiment Phase

The policy experiment phase is the procedure of designing policy alternatives and predicting the results of their implementation by means of simulation.

The policy experiment phase includes determining interest groups and their objectives, and designing and simulating policy alternatives over a certain planning period.

Interest groups are those who would be affected in one way or another as a result of a policy implementation. The workshop selects representatives of interest groups. In this study, a naturalist group, a tourist group, a local public group, a nearby town called Pass Lake, and the Ontario Ministry of Natural Resources were selected as representatives.

Group objectives are expressed by means of desired changes in variables over the simulated period. Desired changes are expressed in a qualitative manner; such as, not down, don't care, up to the maximum. For example, a naturalist group can desire no changes in MVH, WBA, SB, MD and CA for the next 10 years. On the other hand, they may desire a percentage increase in MVO and ACC. This group may not be interested in whether EMP, CO, NPUL and NPUT are going up or down.

Designing policy alternatives requires setting the desired percentage change of each target variable over the planning period. The desired changes in target variables for a policy alternative changes the impacts in the cross-impact matrix of the original model and causes corresponding changes in all of the other variables in the matrix during the simulation.

For example, the naturalist group may design a policy to meet their objectives of no changes from the current policy for all variables except for a percentage increase in MVO and ACC. Because this naturalist policy expects little change in most variables, the trends of the variables over the simulated period and the final values expected will be almost the same as those of the current policy. On the other hand, other policies, which desire changes in most of the variables will cause many changes in those variables during the simulation. As a result, trends, final values, and difference from both initial and expected values will be different from those of the current policy.

Policy Evaluation Phase

The policy evaluation is a procedure of comparing the results of the policy experiment with the current policy as well as alternative policy. The policy experiment results indicate the performance of a policy in terms of attainment and satisfaction levels obtained by a given policy. The final value, and the difference from initial and expected values as a result of policy implementation are used as indicators for the attainment level.

The other performance indicator, satisfaction level, is a percentage measurement of the achievement level of a group's objectives. Comparisons of the policy experiment are made by the achieved satisfaction levels by 1) groups, 2) variables, and 3) policies as shown in Figure 4. The group comparison shows each group's expected total satisfaction level achieved as a result of implementing a policy alternative. The variable comparison shows the expected satisfaction levels obtained for a variable for a group, for each policy alternative. The policy comparison shows the expected satisfaction levels obtained by all groups as a result of implementing each policy alternative. The comparison is made by three mathematical satisficing algorithms as shown in Appendix I.

The policy comparison suggests which policy alternative is superior to another. The end product of the IDA process is the most acceptable policy to all group, in other words, a policy which can bring the highest degree of harmony among the groups. As the policy is expressed in terms of desired changes in target variables, the desired changes can be applied to determine target levels for goal programming.

DETERMINING TARGET LEVELS AND WEIGHTS

Target Levels

Once the most acceptable policy is developed, the next step involves goal programming of the pre-selected variables with the improved target levels and weights. As discussed in the literature review, the determinations of target levels and weights are the most critical factors in the successful application of goal programming; however, there is no unambiguous and objective way of determining these value. Usually, a subjective judgement has been applied as shown in Table 3. This study partly addressed a methodology for improving the determination of target levels and weights.

The IDA process produces the most acceptable policy alternative. This policy alternative is expressed by desired changes in target variables. The desired change is interpreted as a target or a goal anticipated to be obtained through that policy. Therefore, the desired changes of the most acceptable policy can be directly applied to target levels for goal programming. As IDA is a judgement-based modelling approach (Bonnicksen, 1987), each step of the process relies on the workshop participant's subjective judgement. However, the entire process can be made more or less objective by a varied composition of workshop participants. In addition, the possibility that any one individual may unduly influence the results is significantly reduced by averaging participants' subjective judgement (Bonnicksen, 1985). In this study, the workshop participant's subjective judgements for the pre-selected variables were assisted and narrowed down to the feasible policy space determined by the initial LP solutions. By using the results of the IDA process for the target levels of goal programming, the objectivity of the goal programming application was improved.

Weights

Weights of the pre-selected variables are required for the application of goal programming, particularly, for the objective function. In this study, the feasible policy spaces as determined by LP were used in the process of determining weights. The feasible policy spaces indicates the range of a variable's attainment levels, given the physical and operational constraints. The range implies the magnitude of a variable's possible change. Given the same unit of forest land, the magnitude of a variable's possible change is disproportionally related to the variable's weights. The inverse of the feasible policy space can be used for the weights. Therefore, the larger the feasible policy space, the smaller the weight used. The smaller the feasible policy space, the larger the weight used.

APPLYING GOAL PROGRAMMING FOR OPTIMALITY

Goal Programming can be applied for an optimal allocation of the forest land for multiple objectives. The linked LP and IDA methods provide improved target level and weight determination. Thus, improved target level and weight can methodologically enhance the solution of goal programming application. In addition, the use of the LP solutions can assist and improve the workshop participants' judgement for IDA model application.

With the above procedure, the advantages of two important modelling approaches can be used, to achieve the objectives of this study.

APPLICATION OF METHOD AND DISCUSSION

STUDY AREA

Sibley Provincial Park was selected as the study area for this research. This park is located approximately 40 km east of Thunder Bay, Ontario, Canada (see Figure 5). It is 244.4 km^2 in size and is designated as a natural-environment park in accordance with the Ontario Provincial Parks classification system (McNicol et al.; 1986). The park was considered appropriate for this study because of the multiple use activities and the possible conflicting uses.

The goal for the park is to protect its natural and cultural resources in order to provide a wide variety of compatible high quality recreational and tourism opportunities within a natural environment that has educational, scientific, and recreational significance (Anon., 1980). McNicol et al. (1986:1) said "the various goals of the park can be achieved through an integrated approach which considers all elements of the park's natural resources, and existing and potential benefits they provide for outdoor recreation, tourism, education and research". These various goals, however, frequently bring about contradictory management objectives in both development and protection.

Several studies of the park users (Anon., 1984; Moor, 1973) showed that the wildlife viewing opportunity is one of

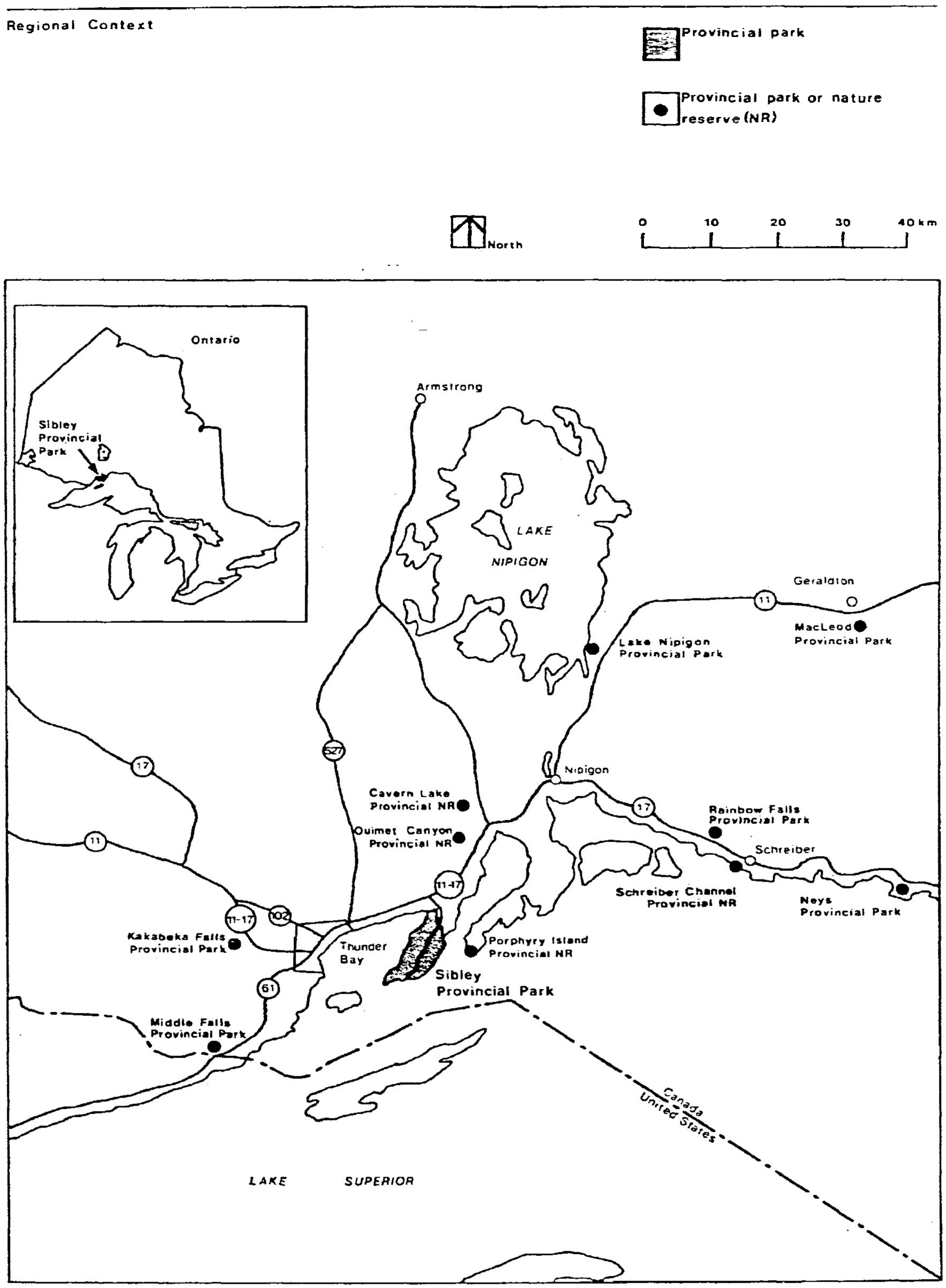


Figure 5. Location of Sibley Provincial Park (from Anon., 1987).

the most important activities. Therefore, it is important for the park's management strategy to ensure the continuation of quality viewing opportunities of wildlife in the park. To maintain wildlife viewing opportunities, development in the park should be minimized and over-use of the park prevented.

A recent concern is that the moose (Alces alces andersoni) population in the park is decreasing because 90% of the forest stands in the park are mature or over-mature. Some studies make recommendations to improve the situation (McNicol et al., 1986; Nisbet, 1981; Stone, 1981, 1982). McNicol et al. (1986) suggest that cuttings in selected mature and over-mature stands in the natural environment zones should take place to improve the variety of wildlife habitats and to maintain the forest in various successional stages.

The park is divided into 6 zones, each with a designated purpose: wilderness, historical, access, development, nature reserve, and natural environment. Figure 6 shows the boundary and zoning of the park. Though commercial depletion of forest resources is not allowed in the park, some form of timber harvesting can take place in the natural environment (NE) zones and nature reserve (NR) zones.

In NE zones, forest management is allowed to create a variety of wildlife habitats and to maintain a forest which is diverse both in age and tree species (Anon., 1980). In NR zones, which are set apart to maintain special conditions or features, some form of management is allowed (Anon., 1980). Although cutting does not take place in the park presently, this study assumes that cutting can take place in NE and NR zones.

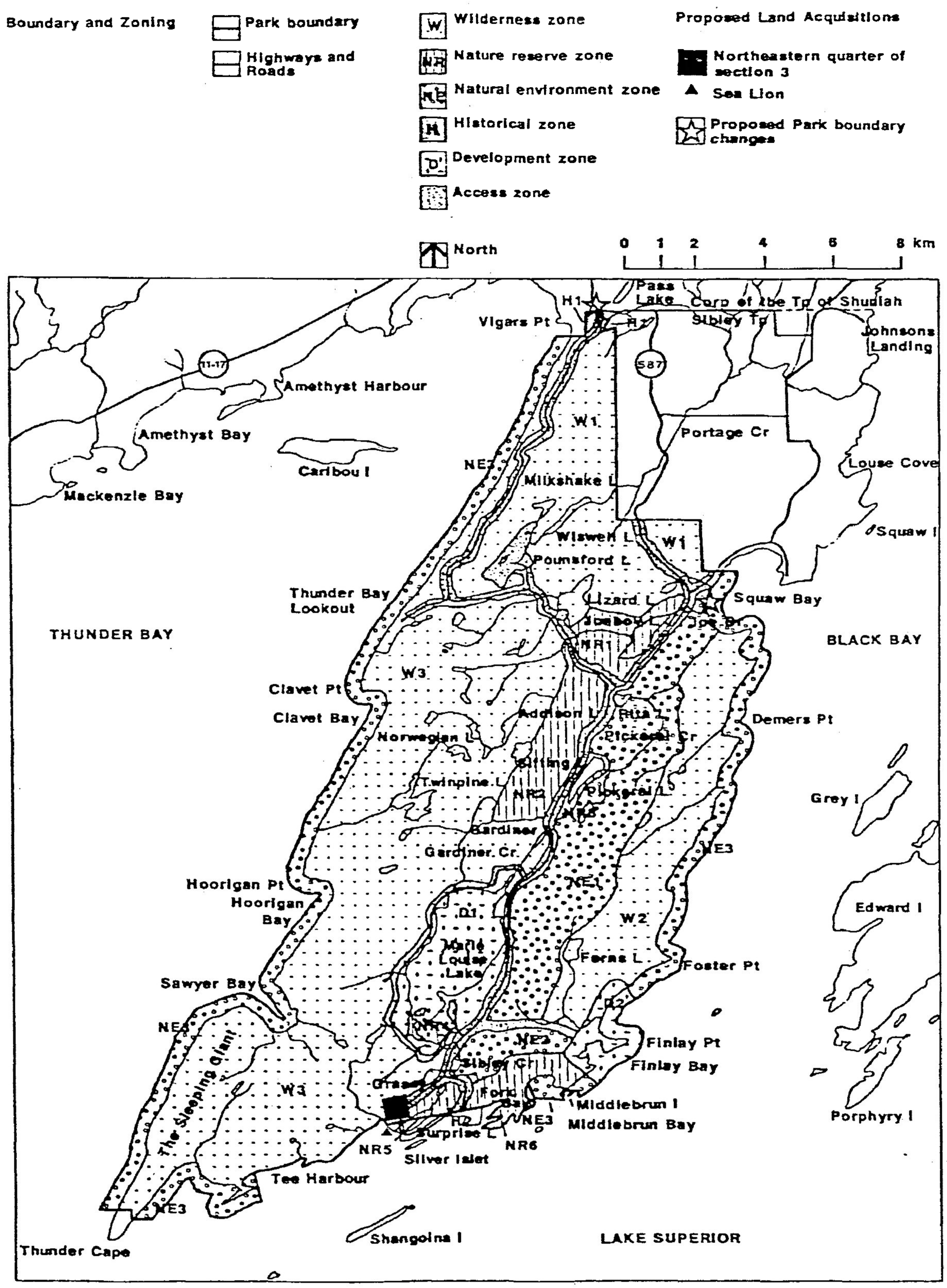


Figure 6. Sibley Provincial Park boundary and zoning (from Anon., 1987).

DATA COLLECTION

Stone (1981) conducted a combined timber and browse survey in NE zones 1 and 2, and NR zones 1 and 2 in the park. The survey examined selected species' winter browse production levels for moose and white-tailed deer (Odocoileus virginianus), and utilization by moose. The forest stand listings for NE1 and 2, and NR 1 and 2 from Stone's (1981) report were used as the primary source of data for predicting the yield of the quantifiable variables; merchantable volume harvested, winter browse availability and forest scenic beauty. The forest stand listings surveyed in 1981 are shown in Appendix II. The data were updated to 1988 (Appendix III).

BASIC ASSUMPTIONS

The following assumptions were considered for this study.

- planning horizon : 10 years (1988-1997)
- base year : 1988
- planning period : 5 years
- treatment tactics for each stand:
  - Alternative 1: no management
  - Alternative 2: removal of 2.5% basal area over 5 years (approximately 5% removal over 10 years)
  - Alternative 3: removal of 12.5% basal area over 5 years (approximately 25% removal over 10 years)
  - Alternative 4: removal of 25% basal area over 5 years (approximately 50% removal over 10 years)

PREDICTION MODELS

Several prediction models were used to predict each variable's yield level over the planning horizon and to estimate the average yearly yield levels for LP application. Readily available models were applied in most of the cases, except for winter browse availability prediction. A prediction model for the winter browse availability had to be derived for this study based upon the survey data of the study area. The prediction models used in this study are as follows.

Merchantable Volume and Basal Area

Various equations in Plonski's yield tables (Payandeh, 1973) were used according to the site class and species studied. For species not covered in the Plonski's tables, such as cedar (Thuja occidentalis L.) and balsam fir (Abies balsamea L.), the black spruce (Picea mariana) equation was used.

Forest Scenic Beauty

Hull (1984) developed a forest scenic beauty model based upon forest stand characteristics. The term scenic beauty is the perception of visual aesthetic quality in the natural environment. Therefore, a beautiful landscape is considered as more scenic than an ugly landscape. According to the scenic beauty assessments by Hull (1984), the most preferred scene is a scene containing short grass and a split rail fence in the foreground, and rolling hills in the background. The most preferred scene is set at 100. In contrast, the least scenic site is set at 0, that scene being a roadside view of a recent clear cut (Hull, 1984).

Hull (1984) states that the scenic beauty of forest scenes ranged from 35 to 85. In general, the scenic beauty increases as stand age increases and stand density decreases. The following scenic beauty prediction model was used for this study. The original model of Hull (1984), and Hull and Buhyoff (1986) was modified for metric measurements.

$$SB(BA) = 5.663-17.799BA/AGE+16.148LN(4.356*BA)$$

where;

SB(BA) = scenic beauty of basal area;
BA = basal area per hectare in square meters;
AGE = stand age in years;
LN = natural logarithm

Winter Browse Availability

A prediction model was developed for winter browse availability based upon Stone's (1981) survey data. Stone (1981) surveyed the NE1 and 2 and NR 1 and 2 zones for moose browse. Stems with a browsable twig between the height of 0.691 m (2.0 ft) and 3.048 m (10 ft) were recorded as potential browse stem. The following 11 species were tallied for the browse species:

white birch	[*Betula papyrifera* Marsh],
balsam fir	[*Abies balsamea* (L.) Mill],
mountain ash	[*Sorbus* L.],
willows	[*Salix* L.],
maples	[*Acer* L.],
dog wood	[*Cornus stolonifera* Michx.],
cherries	[*Prunus* L.],
juneberries	[*Amelanchier* L.],
poplar	[*Populus* L.],

hazel	[*Corylus cornuta* March],
green alder	[*Alnus crispa* (Ait.) Pursh],
speckled alder	[*Alnus rugosa* (Du Roi) Spreng],
cedar	[*Thuja occidentalis* L.].

The number of potential browse stems in each stand are shown on Appendix II.

A multiple linear regression model was derived based upon the data. Stand characteristics were used as predictor variables for the model. An SPSSX packaged program on the VAX 780 computer facilities at Lakehead University was used for deriving the multiple linear regression model. The backward method was used to build up the multiple linear equation. Following is the prediction model.

$$WBA = 12.533 + 0.00029\ AGE - 1.743\ SC - 7.688\ CE - 8.296\ B$$

Where;

WBA = 1000 winter browse stems per hectare;
AGE = stand age squared;
SC = stand site class;
CE = arc sine($\sqrt{CER*STK}$);
CER = cedar ratio in a stand;
B = arc sine($\sqrt{BR*STK}$);
BR = balsam fir ratio in a stand;
STK = stand stocking level.

The model explained approximately 41% of the variation in winter browse availability, and was statistically significant at 0.0001 level of significance (Tables 4 and 5).

A few extreme cases of the original data were modified, as indicated below, to permit their use in the prediction model.

Table 4. Analysis of variance.

ANOVA				
SOURCE	DF	MEAN SQUARE	R SQUARE	F[a]
Regression	4	144.513	0.413	8.603
Error	49	16.797		

[a] F is significant at 0.0001

Table 5. Parameter statistics.

Regressor	Coefficient Estimate	Standard Estimate	Standard Error	t
SC	- 1.742636	- 0.254680	0.800521	- 2.177
CE	- 7.668245	- 0.441750	1.958684	- 3.915
AGE	0.000287	0.456241	0.000070	4.079
B	- 8.295651	- 0.282717	3.518091	- 2.358
CONSTANT	12.533273		2.534874	4.944

* All coefficients are significant at 0.034.

1. The stand recorded as barren and scattered was considered as 5 years old in stand age and 10% in stocking level.
2. Two stands with stocking level of 1.2 were modified to 1.0.
3. Of the 97 stands, four site class x stands were made site class 1, and one site class 4 stand was made for site class 3. This was necessary as the prediction model could use only site classes 1,2, and 3.

CALCULATION OF AVERAGE YEARLY YIELD

The average yearly yield of each variable under 4 different treatment alternatives for the 10-year planning horizon was estimated for the LP application. They were estimated by averaging the two 5-year planning periods' yields that could be attained by the treatment alternatives described previously under the heading of basic assumptions. Table 6 shows the treatment scheme throughout the planning horizon.

Basal Area and Stocking Level

As basal area and stocking level were used to predict the quantifiable variables, their changes over time were predicted. Basal area was predicted by using Plonski's normal basal area prediction models (Payandeh, 1973), and was adjusted for the amount of basal area removed by the treatment alternatives. Over the short time projection of this study (10 years) it was assumed that no growth in basal area occurred. Reductions in the initial basal area were made in the middle year of both 5-year planning periods. Table 7 shows the calculation of basal area.

Table 6. Treatment Scheme. (unit:%)

Alternatives	1st 5-year period 1988 1990 1992	2nd 5-year period 1993 1995 1997
1	0	0
2	2.5	2.5
3	12.5	12.5
4	25.0	25.0

Table 7. Basal area calculation.

	1st 5-year period	2nd 5-year period
Alternative 1	N.B.A.[a]*1*STK[b]	N.B.A.*1*STK
Alternative 2	N.B.A.*(1-0.025)*STK	N.B.A.*(1-0.025)^2*STK
Alternative 3	N.B.A.*(1-0.125)*STK	N.B.A.*(1-0.125)^2*STK
Alternative 4	N.B.A.*(1-0.25)*STK	N.B.A.*(1-0.25)^2*STK

[a] N.B.A. = Normal basal area predicted
[b] STK= initial stocking level

Average Yield

The average yearly yield of each period was estimated as follows. To calculate scenic beauty and winter browse availability, the average yearly yield was estimated by averaging the yield of the first and last years of the 5-year planning period. To determine the merchantable volume harvested per year during a period, the difference between the merchantable volume stock of alternative 1 (no management), and one of the other alternatives, was divided by 5 years.

Once the average yield of each period was estimated, the average yearly yield for the planning horizon was estimated by averaging the yield of both periods. Traditionally, the amount of cutting on the area may be evenly spread over the planning period to attain a sustained yield, but for this study it was assumed that only one cutting would took place in the middle year of the planning period.

Tables 8, 9 and 10 show the calculation process. The numbers in the table represent matrices of yield attained by different treatment alternatives in a year. The first part of the number is the year when the yield is predicted. The second part of the number represents the alternative number. The three columns under the heading of yield predicted in Tables 8 and 9 are matrices of each stand's yield levels of MVH, SB and WBA, predicted for the different treatment alternatives. For example, 88.1 is a matrix that shows the predicted values of MVH, SB and WBA in 97 stands in NE and NR zones in the year of 1988 under the treatment alternative 1. The age class component is an aggregation of the stands with the same initial age class.

Table 8. Average yearly yield calculation - 1st 5-year period.

Alt.[a]	Yield predicted (MVH,SB,WBA)			Average yearly yield		
	1988	1990	1992	MVH	SB	WBA
1	88.1[b]	90.1	92.1	$\{\frac{1}{5}(90.1-90.1)$,	$\frac{1}{2}(92.1+88.1)$,	$\frac{1}{2}(92.1+88.1)\}$= 1.1[c]
2	88.2[d]	90.2	92.2	$\{\frac{1}{5}(90.1-90.2)$,	$\frac{1}{2}(92.2+88.2)$,	$\frac{1}{2}(92.2+88.2)\}$= 1.2
3	88.3[d]	90.3	92.3	$\{\frac{1}{5}(90.1-90.3)$,	$\frac{1}{2}(92.3+88.3)$,	$\frac{1}{2}(92.3+88.3)\}$= 1.3
4	88.4[d]	90.4	92.4	$\{\frac{1}{5}(90.1-90.4)$,	$\frac{1}{2}(92.4+88.4)$,	$\frac{1}{2}(92.4+88.4)\}$= 1.4

[a] Alt. is treatment alternative number.
[b] 88.1 is a matrix of yield predicted by treatment alternative 1 for MVH, SB and WBA in 1988.
[c] 1.1 is a matrix of average yearly yield expected by alternative 1 for the 1st 5-year period. It consists of average yearly merchantable volume harvested, average yearly scenic beauty and average winter browse availability.
[d] As no cutting takes place in 1988, 88.2, 88.3, 88.4 are same as 88.1.

Table 9. Average yearly yield calculation - 2nd 5-year period.

Alt.[a]	Yield predicted (MVH,SB,WBA)			Average yearly yield		
	1993	1995	1997	MVH	SB	WBA
1	93.1[b]	95.1	97.1	$\{\frac{1}{5}(95.1-95.1)$,	$\frac{1}{2}(97.1+93.1)$,	$\frac{1}{2}(97.1+93.1)\}$= 2.1[c]
2	93.2	95.2	97.2	$\{\frac{1}{5}(95.1-95.2)$,	$\frac{1}{2}(97.2+93.2)$,	$\frac{1}{2}(97.2+93.2)\}$= 2.2
3	93.3	95.3	97.3	$\{\frac{1}{5}(95.1-95.3)$,	$\frac{1}{2}(97.3+93.3)$,	$\frac{1}{2}(97.3+93.3)\}$= 2.3
4	93.4	95.4	97.4	$\{\frac{1}{5}(95.1-95.4)$,	$\frac{1}{2}(97.4+93.4)$,	$\frac{1}{2}(97.4+93.4)\}$= 2.4

[a] Alt. is treatment alternative number.
[b] 93.1 is a matrix of yield predicted by treatment alternative 1 for MVH,SB and WBA in 1993.
[c] 2.1 is a matrix of average yearly yield expected by alternative 1 for the 2nd 5-year period. It consists of average yearly merchantable volume harvested, average yearly scenic beauty and average winter browse availability.

Table 10. Average yearly yield for the planning horizon.

$$\text{Alternative 1} = \frac{1}{2}(1.1+2.1)$$

$$\text{Alternative 2} = \frac{1}{2}(1.2+2.2)$$

$$\text{Alternative 3} = \frac{1}{2}(1.3+2.3)$$

$$\text{Alternative 4} = \frac{1}{2}(1.4+2.4)$$

Table 11. Age class compartments and areas.

Compartment No.	Age Class (yrs.)	Area (Ha)	
		NE	NR
1	10-14	170	24
2	20-24	89	0
3	55-59	171	0
4	75-79	201	0
5	80-84	290	214
6	85-89	644	60
7	90-94	100	0
8	95-99	260	0
9	100-104	84	0
10	105-109	56	38
11	115-119	0	414
12	125-129	34	74
13	135-139	37	0
14	140-144	28	7
15	145-149	32	234
16	155-159	0	5
17	160-164	67	0
18	165-169	183	29
19	180+	2	0
TOTAL		2448	1099

Table 11 shows the age class compartments and areas. The yield of each age class compartment is presented by NE and NR zones in Appendices IV and V. These appendices also show the zone's average yearly yield predicted for each variable that would be expected under different treatment alternatives.

LINEAR PROGRAMMING APPLICATION

Problem Formulation

The maximum and minimum limits that a variable could attain by certain treatment alternative under the relevant physical and operational constraints were calculated to determine the decision space of each variable. A linear programming technique, part of the alternative approach to goal programming (Walker, 1985) was used for this purpose. For the LP problem formulation, a total of 152 decision variables (combination of 2 zones, 19 age class compartments, and 4 treatment alternatives) were needed. Each variable indicated the area in hectares to be assigned to a particular treatment alternative. The following is the LP problem formulation used.

Maximize and minimize Z

$$Z_V = \sum_h \sum_i \sum_j A_{hij} V_{hij} \qquad (12)$$

$$Z_S = \sum_h \sum_i \sum_j A_{hij} S_{hij} \qquad (13)$$

$$Z_B = \sum_h \sum_i \sum_j A_{hij} B_{hij} \qquad (14)$$

$h=1,2.\ i=1,2,\ldots 19.\ \ j=1,2,3,4.$

Subject to

$$\sum_j A_{11j} = 170$$

$$\sum_j A_{12j} = 89$$

.

. Area of compartments in NE zones

.

$$\sum_j A_{119j} = 2$$

$$\sum_j A_{21j} = 24 \qquad (15)$$

$$\sum_j A_{22j} = 0$$

.

. Area of compartments in NR zones

.

$$\sum_j A_{219j} = 0$$

$$\sum_h \sum_i \sum_j A_{hij}B_{hij} \geq 24{,}105{,}180 \qquad (16)$$

$$\sum_i \sum_j A_{1ij}S_{1ij} \geq 149{,}071 \qquad (17)$$

$$\sum_i \sum_j A_{2ij}S_{2ij} \geq 74{,}383 \qquad (18)$$

$$A_{hij} \geq 0 \qquad (19)$$

Where

Z_V = total expected merchantable volume harvested in NE and NR zones in cubic metres per year.

Z_S = total expected forest scenic beauty level of NE and NR zones per year.

Z_B = total winter browse availability of NE and NR zones per year.

A_{hij}= area in hectares of zone h and compartment i assigned to treatment alternative j.

V_{hij}= merchantable volume harvested in cubic metres per hectare per year from compartment i, zone h under treatment alternative j.

S_{hij}= Scenic beauty level per hectare per year of compartment i,zone h under treatment alternative j.

B_{hij}= winter browse availability in stems per hectare per year from compartment i, zone h under treatment alternative j.

A pair of LP problems was formulated for each objective, to maximize and minimize each Z value with all constraints considered. Equations (12), (13), and (14) are objective functions and Equations from (15) to (19) are constraints. Equations in (15) are maximum area constraints for NE zones (A_{1ij}) and NR zones(A_{2ij}). Equations (16) to (18) are operational constraints for the park's management: minimum yearly level of each objective to be maintained the park's management purposes. The winter browse availability constraint (Equation 16) was needed to maintain the minimum winter food supply per year for the moose in the park. Ninety percent of the 1988 level was assumed as the minimum level to maintain throughout the planning horizon (Table 12). The minimum scenic beauty maintenance constraints (Equations 17 and 18) were treated differently in NE and NR zones according to the park's zone management strategy. The park's vegetation management plan (McNicol _et al_., 1986) says that aesthetic value is more important in NR zones than in NE zones partly because of the perpetuation of a representative sample of red pine (_Pinus resinosa_) and white pine (_Pinus strobus_). To maintain the minimum scenic beauty level,90% and 95% of the present year's (1988) scenic beauty level were applied to NE and NR zones respectively (Table 12). Appendix III shows each variable's yield levels in each stand and objective in 1988. Table 12 shows the total, and average values of the constraints on the variables for LP application. Equation (19) is a non-negativity constraint to ensure that all variables are assigned non-negative values.

Linear Programming Solution

The above LP problems were solved by using the XMP (Marsten, 1986) packaged program installed on an IBM-PC AT

Table 12. 1988 average yield predicted.

Objectives	Zones NE	Zones NR	Total	Constraints for LP application
Merchantable volume(m^3/ha/yr)	264,666 (108.12)	140,396 (127.75)	405,063 114.20)	-------
Scenic beauty level(/ha/yr)	165,635 (67.66)	78,299 (71.25)	243,933 (68.77)	149,071[a] 74,383[b]
Winter browse availability (stems/ha/yr)	17,333,346 (7,080)	9,450,187 (8,599)	26,783,533 (7,551)	24,105,180[c]

[a] 90% of 1988 scenic beauty level of NE zones.
[b] 95% of 1988 scenic beauty level of NR zones.
[c] 90% of 1988 winter browse availability in total area.

Table 13. LP solutions.

Objective (Units[a])	Simple Optimal Level	Worst Feasible Level	Feasible Policy Space
Merchantable volume harvested (m^3/ha/yr)	28,844 (8.13)[b]	0 (0)	28,844 (8.13)
Scenic beauty level(/ha/yr)	245,933 (69.34)	233,280 (65.77)	12,653 (3.57)
Winter browse availability (stems/ha/yr)	50,492,227 (14,235)	30,576,417 (8,620)	19,915,810 (5,615)

[a] The units are applicable to the values inside the brackets.
[b] Values inside the bracket are average value per hectare while the ones without brackets are values for the total area.

computer at Lakehead University. Table 13 shows the LP solutions and the decision space for each objective. All of these values indicate the space that each variable can feasibly attain as a maximum, under the simple optimal level heading, or as a minimum, under the worst feasible level heading, given all the physical and operational constraints set for this problem.

The feasible policy spaces were calculated by subtracting the worst feasible level from the simple optimal level (Table 13).

APPLICATION OF INITIAL DECISION ANALYSIS

Planning

Workshop

An IDA workshop was held for two days at Lakehead University on May 12 and 18, 1988. The participants of the workshop were a unit forester, a wildlife biologist, and a park supervisor from the Ontario Ministry of Natural Resources' Thunder Bay District Office and 5 faculty members from the Schools of Forestry and Outdoor Recreation of Lakehead University.

The workshop constructed a model on the 1st day and designed and experimented with policies on the 2nd day. The workshop took the same steps as shown in Figure 4. All the steps in the workshop were assisted by IDA computer program's commercial version called EZ-IMPACT (Bonnicksen, 1987). The program was installed and run on an IBM-PC AT computer at Lakehead University.

Data for the cross-impact matrix were determined by discussion among the workshop participants. The most agreeable value to all workshop participants was entered instead of the more time-consuming process of averaging the individual estimation.

Model Construction

The IDA model structure and process, and the problems in the study area and the park, were presented to the workshop participants. The most important activity of the model construction session was identifying variables relevant to the problem. The variables in the model functioned as indicators that significantly affected the attainment level achievable by a policy. In addition to the variables, units of measure and their trends were determined, based upon the identified problems and objectives. The following problems and objectives, as described in the park's vegetation management plan (Anon., 1986), were discussed:

1. improving wildlife habitat
2. improving wildlife viewing opportunity
3. perpetuate aesthetic values of the park.

At this point, the three variables pre-selected for LP application, in an earlier stage, were introduced in the variable list. Besides these three variables, the workshop selected 8 more variables based upon the objectives of the park management. Each variable's trend was also determined by averaging trend estimates of all participants. Table 14 shows the selected variables and their trends. Table 15 shows the cross-impact matrix constructed.

Table 14. Variable list and trend.

No.	Variable Name[a]	Unit of Measure	Maximum Increase (%)	Expected Change (%)	External Impact (%Exp.)
1	MVH	m3/ha/yr	9999.0	0.0	0.0
2	WBA	stems/ha/yr	88.5	7.0	34.0
3	SB	/ha/yr	1.0	1.0	25.8
4	MD	moose/km2	343.0	-16.0	43.0
5	MVO	moose/visit	110.0	24.0	19.0
6	ACC	km/ha/yr	31.0	25.0	22.0
7	CA	ha/yr	573.5	6.8	30.0
8	EMP	person/yr	121.7	-60.0	67.5
9	CO	$/yr	9999.0	15.0	20.8
10	NPUL	v.d./yr[b]	1698.0	12.5	30.0
11	NPUT	v.d./yr	1753.0	12.5	38.3

[a] NVH=merchantable volume harvested, WBA=winter browse availability SB=scenic beauty, MD=moose density, MVO=moose viewing opportunity ACC=accessibility, CA=cutting area, EMP=employment, CO=cost, NPUL=number of park user(local), NPUT=number of park user(tourist)

[b] v.d./yr = visitor day/year

Table 15. Cross impact matrix (original model).

Var.	MVH[a]	WBA	SB	MD	MVO	ACC	CA	EMP	CO	NPUL	NPUT
MVH	.	.	.	.	.		$+S_3$[b]	.	.	.	.
WBA	$+S_3$	.	.	$-L_3$	.	$+S_2$	$+S_3$	.	.	.	.
SB	$-S_3$	.	.	.	.	$+S_3$	$-S_3$	.	.	.	.
MD	$+S_2$	$+L_3$	.	$+L_1$	.	.	.	.	.	.	.
MVO	$+S_2$	$+L_3$	.	$+L_3$	.	$+S_3$	$+S_3$	.	.	.	.
ACC	.	.	.	.	.	.	$+S_3$	.	.	$+S_1$	$+S_1$
CA	$+S_3$	.	.	.	.	.	.	.	.	.	.
EMP	$+S_2$	.	.	.	.	$+S_1$	$+S_2$	.	.	$+S_1$	$+S_1$
CO	$+S_1$	$+S_1$	.	.	.	$+S_2$	$+S_2$	.	.	$+S_2$	$+S_2$
NPUL	$-S_1$	.	$+S_3$	$+S_3$	$+S_3$	$+S_2$	$-S_3$	.	.	.	.
NPUT	.	.	$+S_3$	$+S_3$	$+L_3$	$+S_2$	.	.	.	.	.

[a] NVH=merchantable volume harvested, WBA=winter browse availability SB=scenic beauty, MD=moose density, MVO=moose viewing opportunity ACC=accessibility, CA=cutting area, EMP=employment, CO=cost, NPUL=number of park user(local), NPUT=number of park user(tourist)

[b] Plus(+) signs represent positive impact, minus(-) signs negative impact, S short term impact and L long term impact. The subscript represents the strength of the impact.

For the maximum increase of the three pre-selected variables, the LP solutions were used. The simple optimal solution in Table 13 was considered as the maximum level that was feasibly attainable under the given constraints. Thus, the maximum increase of the variables in Table 13 was calculated as follows using Equation (11):

$$MVH = \frac{8.13 - C}{C} \times 100\ \% \approx 9999\ \% \qquad (C < 0.1)$$

$$SB = \frac{69.34 - 68.77}{68.77} \times 100\ \% \approx 1.0\ \%$$

$$WBA = \frac{14235 - 7551}{7551} \times 100\ \% = 88.51\ \%$$

The first value in the numerators were from the simple optimal levels in Table 13. The second value in the numerators and the denominator were present average yield levels from Table 12 under the total heading. As no commercial depletion took place in the park at the time of this study, the present value of the merchantable volume harvested was zero and the maximum increase(%) could not be solved by the Equation (11). Thus, very little cutting, less than 0.1 m^3/ha, was assumed to take place in the park currently and the maximum acceptable value by EZ-IMPACT program, 9999%, was used.

The maximum increase percentages were predetermined without the help of the workshop participants judgement. The information in Table 13 was given to the workshop participants so that they could use it for their estimation for the expected changes and the policy design at a later process of the workshop.

Refinement

IDA requires the original model to be refined for simulation. Refining a model involves adjusting the original estimates of the strength of the impacts in the matrix so that all of the impacts interact to produce a trend for each variable which approximates that variable's expected trend (i.e., the trend defined by the line that connects the "initial value" and the "expected value" of a variable (Bonnicksen, 1987). All of the other characteristics of the impacts described in the matrix remain unchanged. The refinement process continues until the 'final value' of all variables fall within plus and minus 4% of the maximum units of their "expected values". The external and internal impacts of the original model of this study were successfully refined after 5 and 52 iterations respectively. Table 16 shows the refined model. Only the strength of the impact are presented in the table.

Table 16. Refined model.

Var.	MVH	WBA	SB	MD	MVO	ACC	CA	EMP	CO	NPUL	NPUT
MVH	.	.	.	.	.	.	3.00[a]	.	.	.	.
WBA	21.96	.	.	-0.41	.	14.64	21.96	.	.	.	.
SB	-3.00	.	.	.	.	3.00	-3.00	.	.	.	.
MD	0.00	0.00	.	0.00	.	.	.	.	.	.	.
MVO	0.01	0.02	.	0.02	.	0.02	0.02	.	.	.	.
ACC	.	.	.	.	.	.	44.17	.	.	0.01	14.72
CA	3.00	.	.	.	.	.	.	.	.	.	.
EMP	0.00	.	.	.	.	0.00	0.00	.	.	6685.50	0.00
CO	0.14	1.12	.	.	.	0.29	0.29	.	.	0.82	0.29
NPUL	-15.58	.	0.19	0.19	0.19	0.13	-46.74	.	.	.	.
NPUT	.	.	0.002	0.002	0.002	0.001	.	.	.	.	.

a The values are the refined strength of the impact. The other characteristics of the impact remain unchanged.

Policy Experiment

Interest Groups and Objectives

The workshop selected the following groups as interest groups who would be significantly affected as a result of a policy implementation in the park.

1. Naturalist
2. Tourist
3. Local Public
4. Pass Lake
5. Ontario Ministry of Natural Resources.

The naturalist group represented those concerned about the protection of fauna and flora in the park. The tourist group was the park-user group from outside the Thunder Bay district. The local public consisted mainly of citizens of the Thunder Bay District, and those who were concerned about most of the issues in the park. Pass Lake was a community at the entrance of the park that considered employment opportunities as dependent upon the park's policy. The Ontario Ministry of Natural Resources was the local authority responsible for the park's management and policy implementation. All groups were considered equally important and were given the same weight of one.

One or two workshop participants represented each interest group and set the group's objectives as outlined in Table 17. The group's objectives were either expressed qualitatively, such as not up, not down, no change or don't care or quantitatively. The quantitative expression included the direction and the amount of desired changes.

Table 17. Objectives of each group.

No.	Var.	Natural	Tourist	LocalPub	PassLake	OMNR
		Groups				
1	MVH	No change	Don't care	Don't care	Not Down	Up Max 9999%
2	WBA	No change	Don't care	Don't care	Not Down	Up Max 89%
3	SB	No change	Up Max 0%	Up Max 0%	Not Down	Up Max 0%
4	MD	No change	Up Max 343%	Up 100%	Up 100%	Up Max 343%
5	MVO	Up 20%	Up Max 110%	Up 100%	Up Max 110%	Up Max 110%
6	ACC	Up 20%	Up Max 31%	Up 25%	Up Max 31%	Up 10%
7	CA	No change	Not Up	Down 100%	Up Max 574%	Up Max 574%
8	EMP	Don't care	Don't care	Not down	Up Max 122%	Up Max 122%
9	CO	Don't care	Don't care	Not up	Up Max 9999%	No change
10	NPUL	Not up	Not up	Not down	Up Max 1695%	Up 500%
11	NPUT	Not up	Up Max 1753%	Don't care	Up Max 1753%	Up 500%

Var = Variables. Natural = Naturalist. LocalPub = Local public.
PassLake = Pass Lake. OMNR = Ontario Ministry of Natural Resources.

NVH=merchantable volume harvested, WBA=winter browse availability,
SB=scenic beauty, MD=moose density, MVO=moose viewing opportunity,
ACC=accessibility, CA=cutting area, EMP=employment, CO=cost,
NPUL=number of park user(local), NPUT=number of park user(tourist).

Table 18. Groups' policy.

Var.	Maximum Increase (%)	% change desired				
		Natural	Tourist	LocalPub	PassLake	OMNR
MVH	9999.0	-	-	-	-	1000.0
WBA	88.5	-	-	-	-	88.5
SB	1.0	-	1.0	1.0	-	1.0
MD	343.0	-	343.0	300.0	100.0	200.0
MVO	110.0	30.0	110.0	110.0	110.0	100.0
ACC	31.0	30.0	31.0	20.0	31.0	25.0
CA	573.5	-	6.8	-	573.0	200.0
EMP	121.7	-	12.5	20.0	121.0	121.0
CO	9999.0	-	1753.0	-	9999.0	0.0
NPUL	1698.0	-	-	200.0	1698.0	1000.0
NPUT	1753.0	-	-	-	1753.0	1000.0

Var = Variables. Natural = Naturalist. LocalPub = Local public.
PassLake = Pass Lake. OMNR = Ontario Ministry of Natural Resources.

NVH=merchantable volume harvested, WBA=winter browse availability,
SB=scenic beauty, MD=moose density, MVO=moose viewing opportunity,
ACC=accessibility, CA=cutting area, EMP=employment, CO=cost,
NPUL=number of park user(local), NPUT=number of park user(tourist).

Policy Design and Simulation

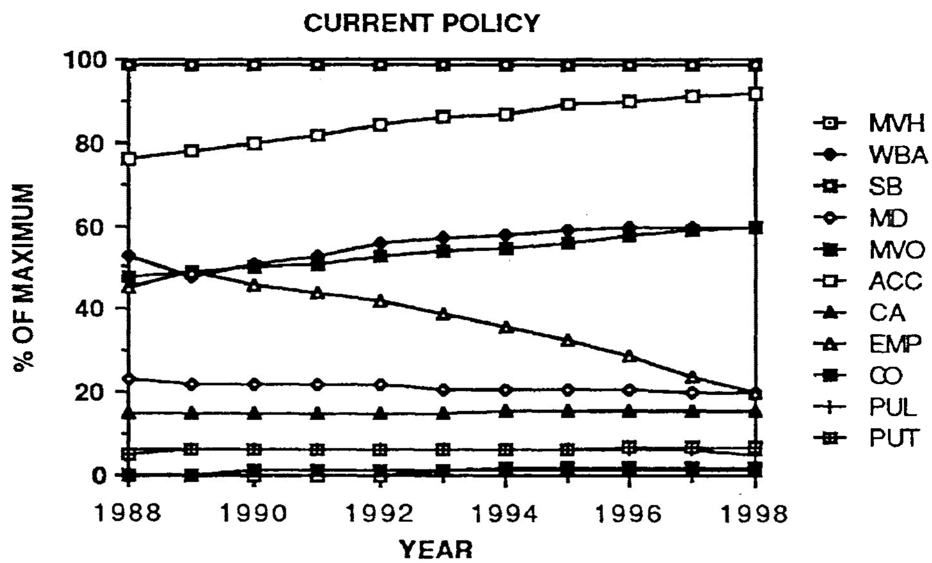
The policy experiment was performed by forcing a given target variable up, or down, a desired percentage over the specified time period. Each representative was asked to design a policy for his group's interest. Table 18 shows each group's policy by the desired change in certain variables. Each policy was simulated for 10 years. The simulation computed the resulting change in each variable (final value). This resulting change was compared with the present situation (initial value). The simulation result was presented in terms of such various policy performance indicators as trend over time, final value, and difference from initial and expected values. Appendices VI and VII show the simulation results. They are summarized graphically in Figures 7, 8, 9, and 10.

Discussion of Simulation Results

The results of the policy experiment indicated the performance of each policy. Trends of the variable's change over time, attainment levels and group's satisfaction levels were used as indicators for performance. The performance of a policy was interpreted differently by different indicators. For example, one policy, which demonstrated high performance in terms of the attainment level, might not always bring a high satisfaction level depending upon the group's objectives. Consequently, the line graphs in Figure 7 and the bar charts in Figures 8, 9, 10, and 11 show the possible outcome by a policy implementation. Also, they imply the possible impact of other policies on the variables of concern to one interest group. Through this process, an interest group could gain more understanding of their own and other problems. This increased their willingness for the flexibility necessary for a compromise with others.

Figure 7.a, 7.b and 7.c show the trends produced by implementing policies. It shows how each variable changed over the planning horizon. As shown in Figures 7.a, 7.b and 7.c, the naturalist's policy, which concentrated on preservation, has similar trends as the current policy. Tourist, and local public's policies had the same high achievement in moose density and moose-viewing opportunity, reflecting the park's most important activities by users. However, these two polices were designed with too much emphasis on the park-user-related variables, with little concern for the remaining variables. For example, these policies expect high performance in MVO, MD and ACC. However, WBA, which affects MD, and consequently, MVO, was left in natural growth rather than being accelerated by cutting. According to the original model, MD has a long-term negative impact on WBA. Thus, the winter browse obtained from natural growth by these two policies would not be sufficient for a rapidly increasing moose population.

Policies of Pass Lake, and the OMNR were multiple-use policies as most of the variables obtained high level of achievements. The Pass Lake policy desired a high achievement in employment, that was indicated by the increased merchantable timber harvested. In addition, the increase in park-user was expected to increase employment. This policy, in comparison with the others, required more expenditure. On the other hand, the OMNR policy had most of the variables increase over the simulation period, while it maintained the current cost and cutting area. In general, Pass Lake's policy was orientated towards social variables while the OMNR's was more concerned with biological variables. Figure 8 shows the final values produced as an implementation of each policy. This figure presents the



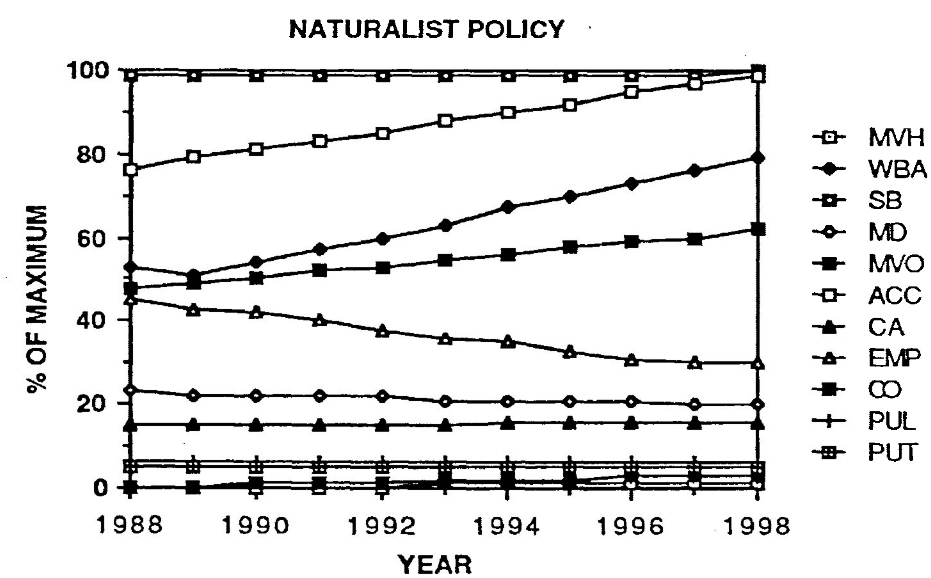
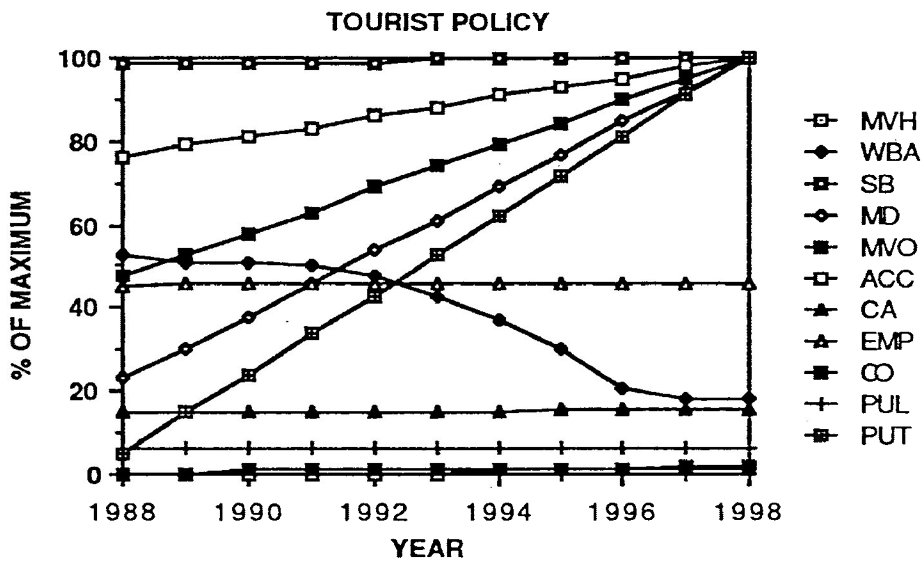


Figure 7.a. Trends of variables (1988-1998).



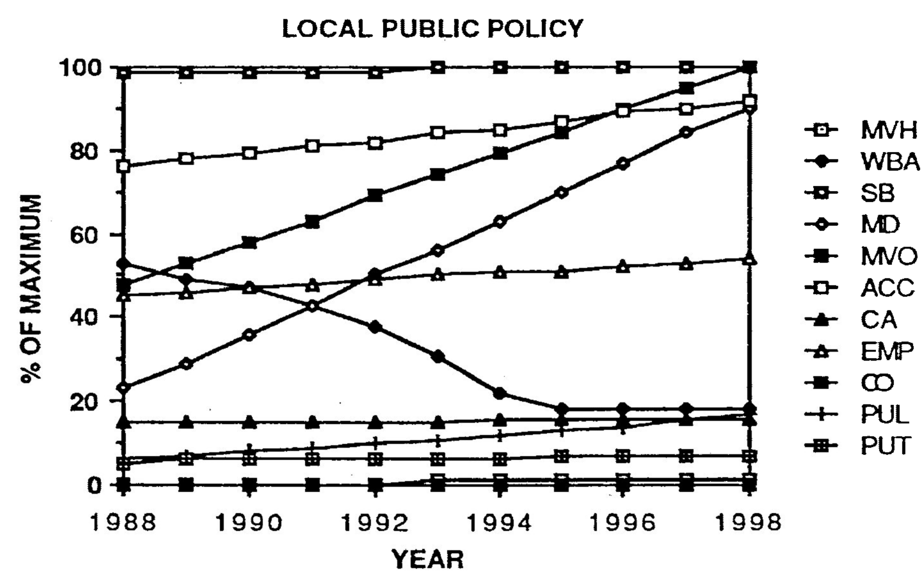
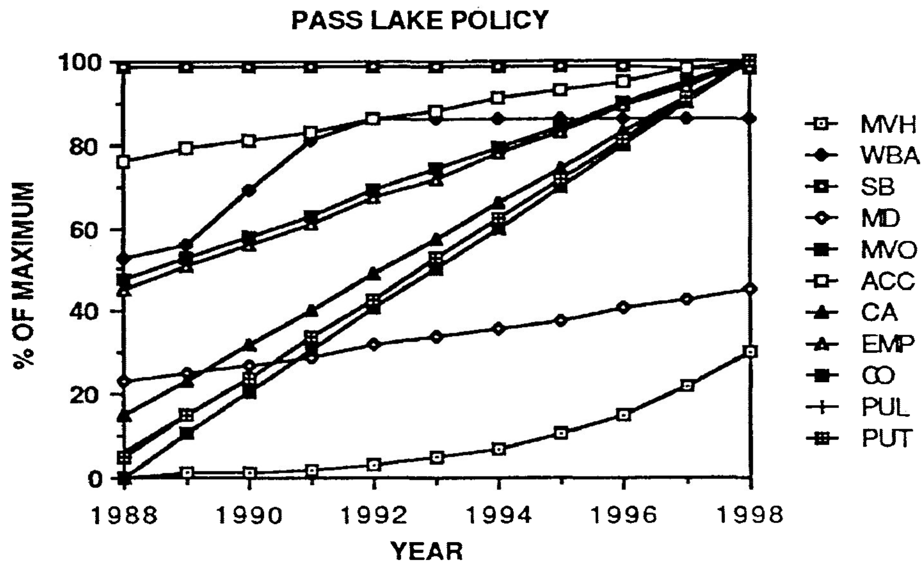


Figure 7.b. Trends of variables (1988-1998).



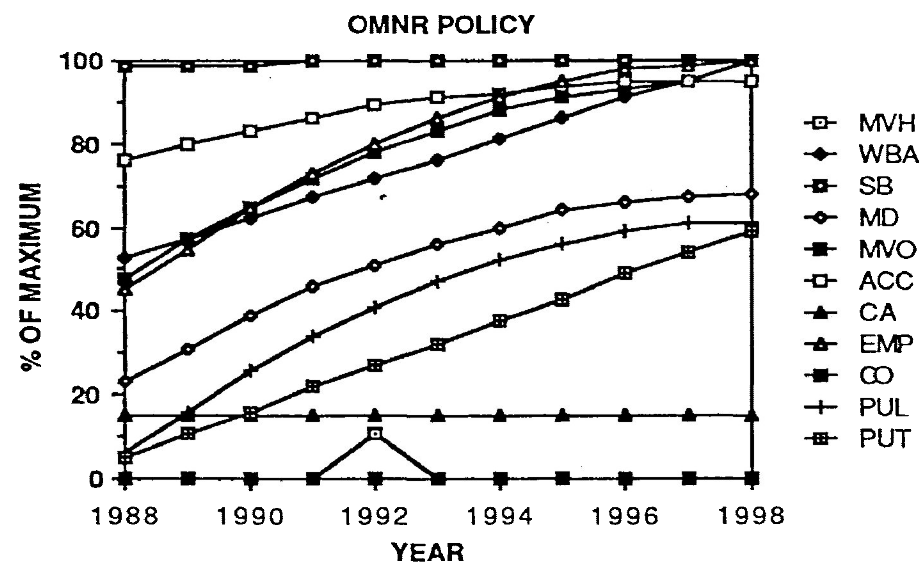


Figure 7.c. Trends of variables (1988-1998).

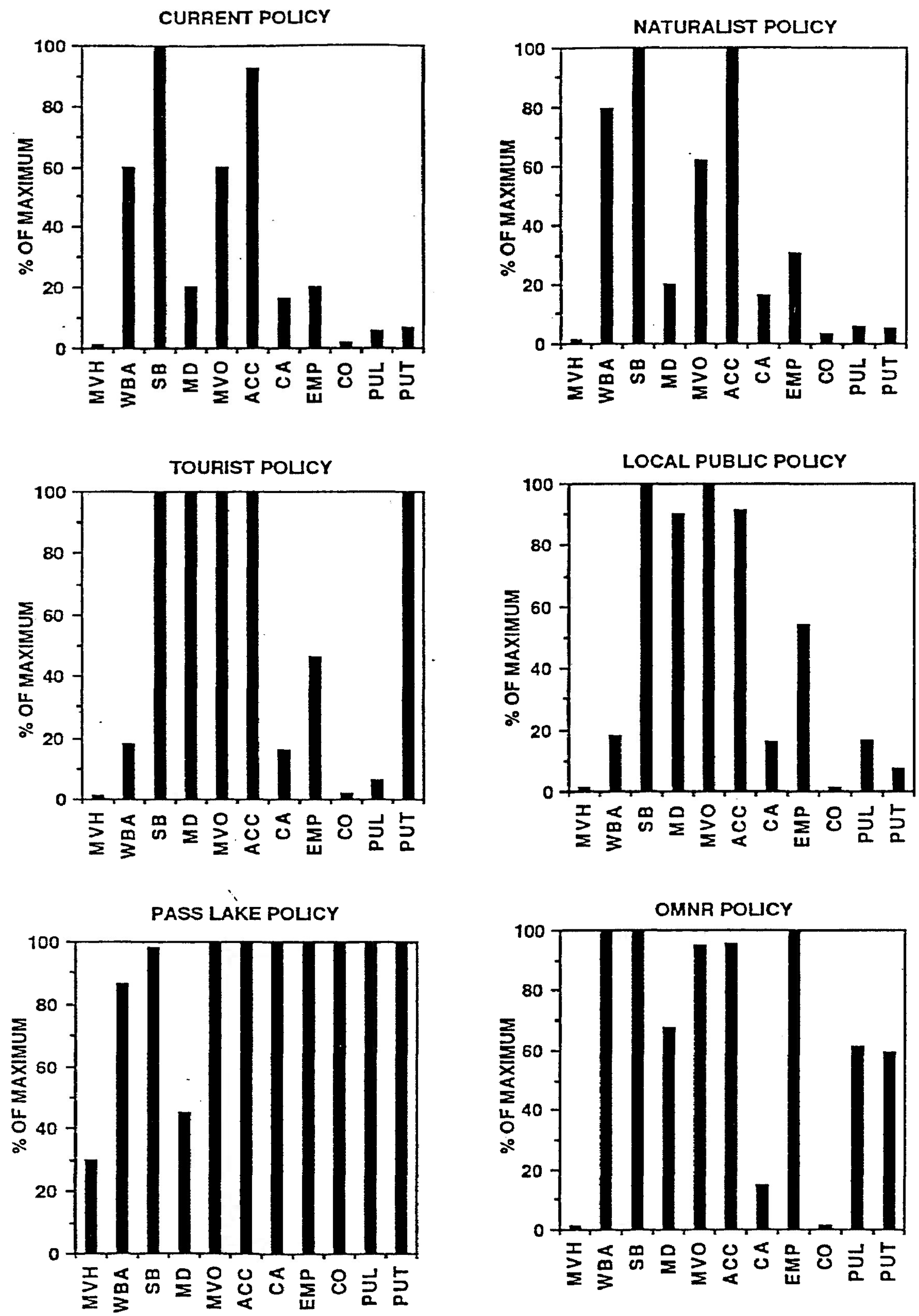


Figure 8. Final value.

values in terms of the percentage of maximum possible value. The Pass Lake and OMNR policies produced overall high attainment levels in comparison with other policies. As shown by these figures, similar results are achieved by two different policies; the current and naturalist policies, the tourist and local public policies, and the Pass Lake and OMNR policies.

Figures 9 and 10 show the percentage change from the initial and expected values respectively. They are presented in terms of percentage of possible difference from those values. The percentage of possible difference is the percentage of one value's differences from the final value and 100% (Appendix VI). Figure 9 shows that the Pass Lake and OMNR policies produced the biggest changes from the present situation for 10 and 8 out of 11 variables respectively. The Pass Lake policy achieved 100% of maximum possible change in MVO, ACC, EMP, PUL and PUT. This achievement caused a decrease in SB, and 100% change in CA and CO.

The last indicator for the policy performance was the difference from the expected value. Figure 10 shows this difference in terms of percentage of possible, which is the percentage of the expected value's differences from the final value and 100%. It shows results similar to Figure 9. Appendix VI provides more details about the percentage changes from the initial and expected values.

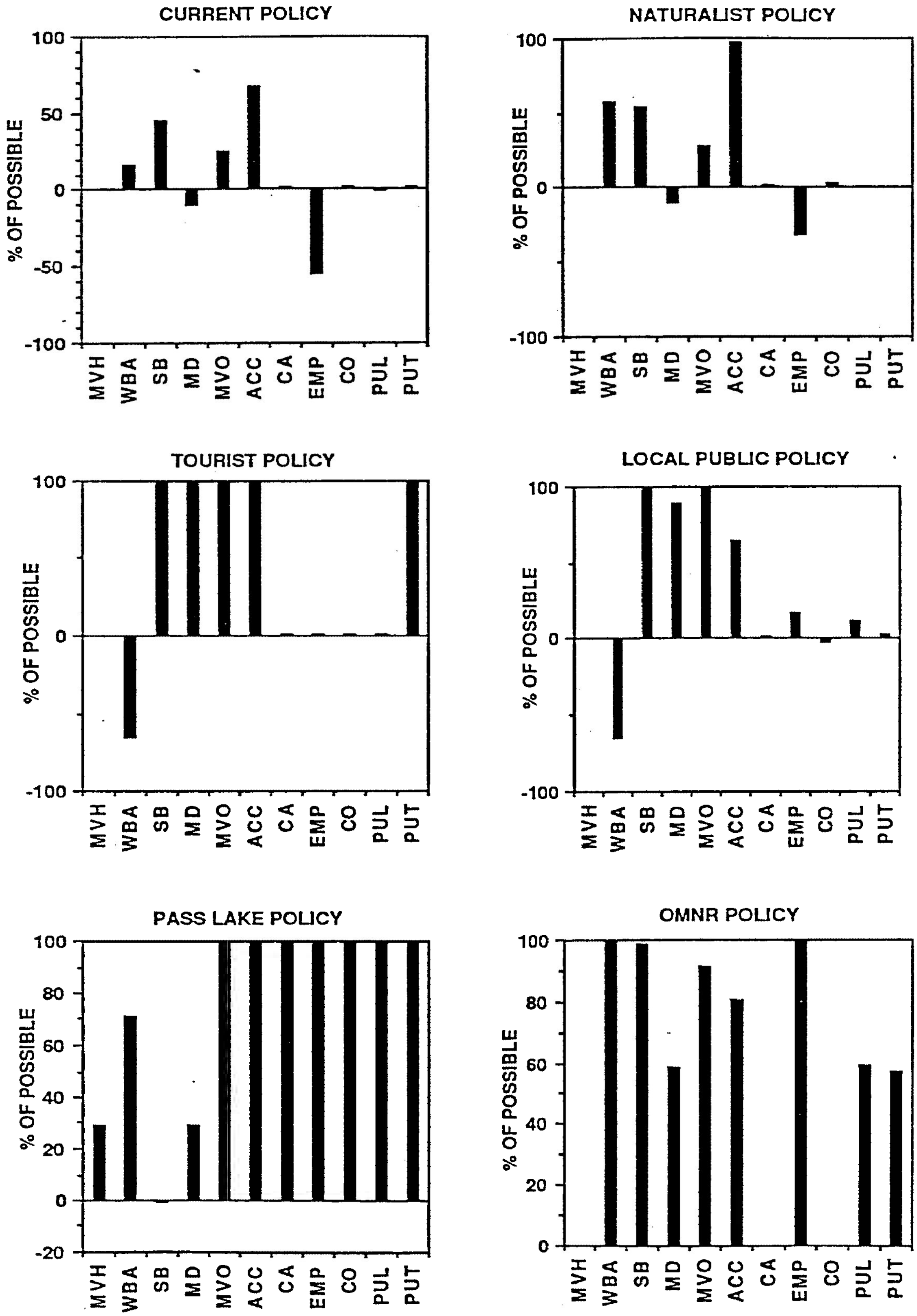


Figure 9. Difference from initial value.

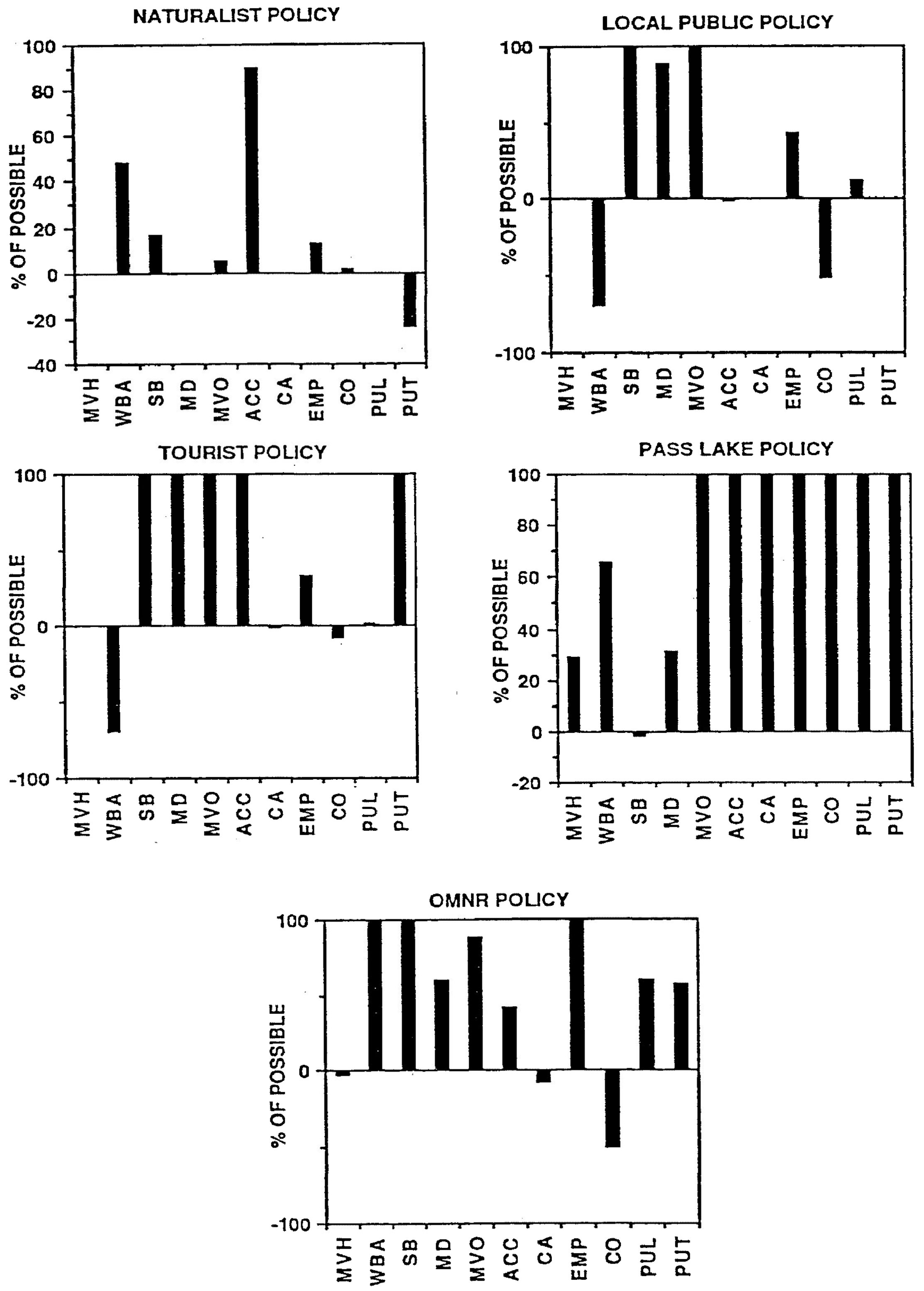


Figure 10. Difference from expected value.

Policy Evaluation and Discussion

Policy evaluation is a process to assess how well the results of each experiment satisfy the objectives of particular interest groups (Bonnicksen, 1987). As shown in Figures 7 to 10, the Pass Lake and OMNR's policies achieve overall higher performance than the others in terms of attainment level. However, the performance in terms of satisfaction level achieved by a policy is still required for policy evaluation. The satisfaction is defined as the degree to which the level of a variable at the end of a simulation matches the desired level (the objective) for that variable, and it is measured as a percentage between 0 and 100 (Bonnicksen, 1985). The satisfaction levels achieved by variables, groups and policies are discussed as follows.

Variable Comparisons

The levels of satisfaction of each group's objectives, for each variable as a result of a policy experiment are presented in Appendix VIII. This information enabled the participants to evaluate how much a particular variable's objective was satisfied by a group as a result of a policy implementation. For example, the naturalist group was satisfied 100% with MVH, while the OMNR was least satisfied (10%) with the same variable's attainment level (Appendix VIII). Ninety percent satisfaction was achieved for the naturalist group by naturalist policy, but only 42% by the OMNR policy (Appendix VIII).

Group Comparisons

The EZ-IMPACT also produced the satisfaction level achieved for an interest group as a result of a certain policy implementation. Figure 11 shows the satisfaction levels of group objectives achieved by each policy. As seen in Figure 11, each group shows different satisfaction levels under different policies. For example, the naturalist group was most satisfied with preservation-oriented current and naturalist policies, but they were least satisfied with other polices involved with cutting or development. Each group showed the highest satisfaction levels under its own policy, but the OMNR policy provided most groups with relatively high satisfaction. More detailed information on this is shown in Appendix VII.

Policy Comparisons

In the previous section, policy performance as indicated by the satisfaction achieved for a variable and a group as a result of policy implementation was discussed. This section discusses another performance indicator: the satisfaction level achieved for all groups. The IDA compared policy performance based upon the satisfaction levels achieved for all groups as a result of policy implementation. The IDA used three mathematical satisficing algorithms for the policy comparison as shown on Appendix I. The result of the policy comparison are presented in Table 19.

As shown in Table 19, the best policy by the "maximin" solution is the employment-oriented policy of Pass Lake group. The best policy by this rule maximized total minimum level of satisfaction. In other words, implementation of this policy would hurt all groups the least.

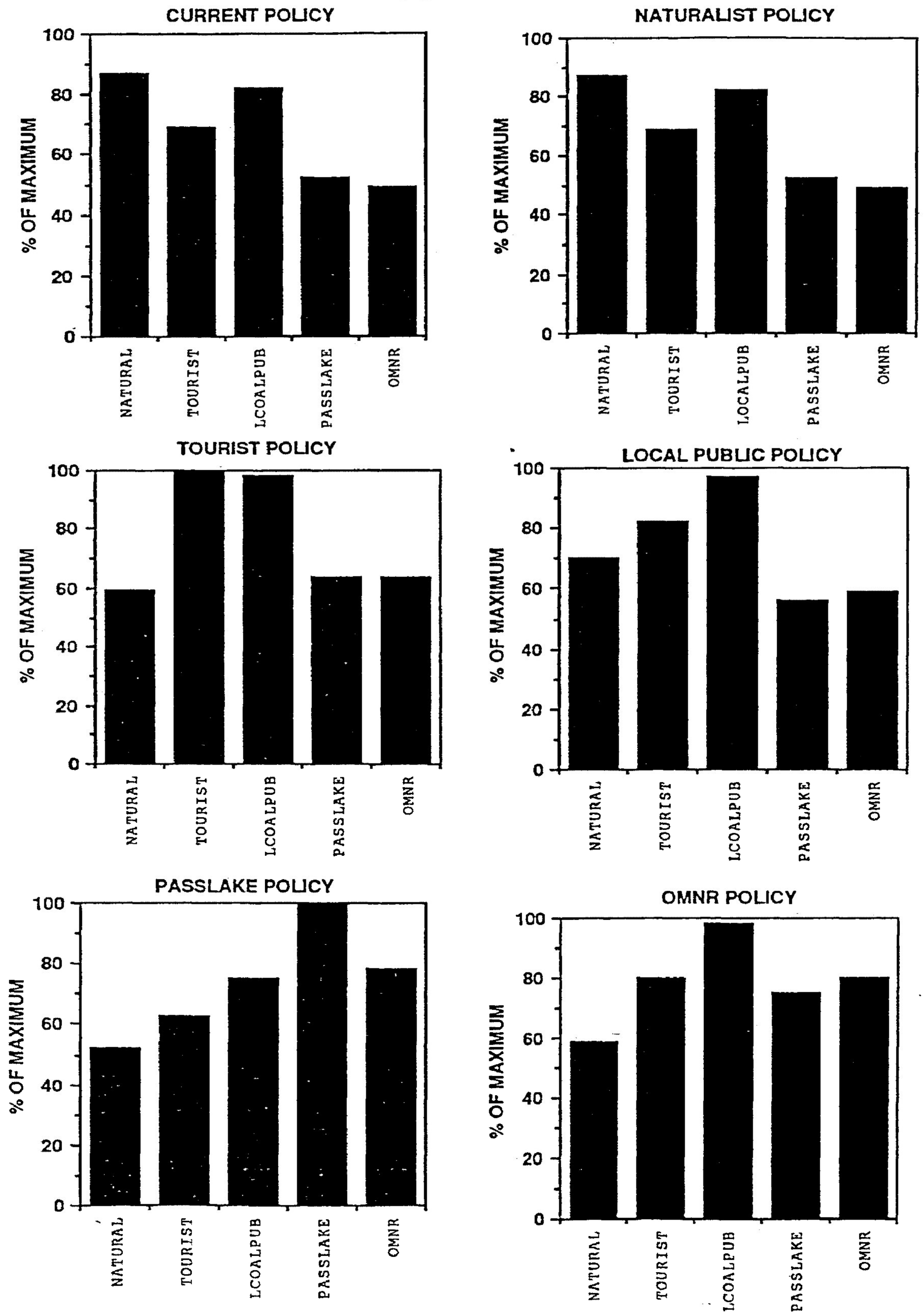


Figure 11. Satisfaction of group objectives.

Table 19. Satisfaction achieved by policies.

Policy	Maximin (% of max.)	Maximax (% of max.)	Minimax (%)
Current	30.9	65.1	[99.0][c]
Natural	30.4	65.8	99.0
Tourist	26.4	74.3	100.0
LocalPub	29.0	70.8	99.0
PassLake	[45.6][a]	75.4	100.0
OMNR	39.5	[77.7][b]	99.9

[a] Maximin solution:policy maximizes total weighted minimum satisfaction (the non-competitive non-compensatory case).

[b] Maxmax solution:policy maximizes total weighted satisfaction (the non-competitive and competitive compensatory case).

[c] Minimax solution:policy minimizes dissatisfaction for any one group (the competitive and non-compensatory case).

The best policy by the "maximax" rule was the OMNR's policy. The best policy by this rule maximized the total level of satisfaction. Therefore, implementation of this policy would bring the highest total satisfaction level to all interest groups.

The third policy, solved by the "minimax" solution, was the least hurtful policy for any one group. The best policy by this rule minimized maximum interest group dissatisfaction. The solutions by this rule showed all the policies to be similar.

Because of the limited time, the workshop focused on policy evaluation rather than the variable and group comparisons. Although not used in this study, the variable and group comparisons contained useful information that could be used for further policy experiments (see Appendices VII and VIII). Though each policy was designed based upon each group's desires and concerns, such desires and concerns were not fully reflected in the outcome of the policy experiments and required some modifications in the earlier stages of the model construction.

For example, the policy experiment outcome showed little difference between the current and naturalist polices. This implied that the naturalist group might need to modify its policy to better reflect their interests. Similar relationship existed between the tourist and local public policies. Obviously, these two groups shared common interests; therefore, the development of one combined policy might be appropriate. These two polices also showed some discrepancies by increasing the MD up to the maximum or near maximum, while the WBA decreased. This discrepancy might be eliminated by going back to the earlier stages of the IDA process, modifying the model or re-designing the policies.

GOAL PROGRAMMING APPLICATION

The three different solution rules selected three different policies as the superior one. Pass Lake's policy was superior to the others by the "maximin" rule, which maximized the total interest group's minimum satisfaction. OMNR's policy was superior to the others by the "maximax" rule, which maximized the total interest group's satisfaction. However, the policy alternatives were within 1% of difference each other by the "minimax solutions". The policy alternative that would finally be selected for implementation was considered to be as a political decision. However, the OMNR's policy was selected for the last procedure of this study, the goal programming application. This policy was designed in such a way that desired changes were noted for all pre-selected variables, while other policies restricted themselves to changes in only some of the variables. The information on the OMNR's policy was used to determine target levels for the goal programming application to the three pre-selected variables. Table 20 shows the target levels for the three pre-selected variables.

The feasible policy spaces, determined earlier by LP, were used to choose the weights for each objective variable. As the feasible policy space was the range of possible change of the variable over 10-year planning horizon, the range indicated the relative importance of each variable. The larger the space was, the less important one unit of the change in the variable was. Furthermore, all the value of decision spaces were commonly expressed on a per hectare basis, the objectivity of the weight determination was improved. The inverse of feasible policy space was assigned to the weight of each variable for GP application as shown in Table 21.

Table 20. Target levels determined by IDA solution.

variables (units)	changes in percentage: maximum possible increase	changes in percentage: desired increase by OMNR	changes in units: maximum possible increase	changes in units: desired increase by OMNR
Merchantable volume harvested (m^3/ha/yr)	9999%	1000%	28,844	2,884[a]
Scenic beauty (/ha/yr)	1%	1%	245,933	245,933
Winter browse availability (stems/ha/yr)	88.5%	88.5%	50,492,227	50,492,227

[a] $2{,}884 = 28{,}844 \times \frac{1000}{9999}$

Table 21. Weight of each variable.

variables (units)	feasible policy space (Table 13)	weights
Merchantable volume harvested (m^3/ha/yr)	8.13	0.1230[a]
Scenic beauty (/ha/yr)	3.57	0.2801[b]
Winter browse availability (stems/ha/yr)	5,615	0.0002[c]

[a] $0.123 = \frac{1}{8.13}$

[b] $0.2801 = \frac{1}{3.57}$

[c] $0.0002 = \frac{1}{5615}$

Goal Programming Formulation

The goal programming problem was formulated as follows based upon the target levels and weights as determined earlier. The same Equations from (15) to (19) for LP formulation were used for the constraints from (24) to (28).

Minimize

$$Z = 0.1230D_1^+ + 0.1230D_1^- + 0.2801D_2^+ + 0.2801D_2^- + 0.0002D_3^+ + 0.0002D_3^- \quad (20)$$

Subject to

$$Z_V = \sum_h \sum_i \sum_j A_{hij}V_{hij} - D_1^+ + D_1^- = 2,884 \quad (21)$$

$$Z_S = \sum_h \sum_i \sum_j A_{hij}S_{hij} - D_2^+ + D_2^- = 245,933 \quad (22)$$

$$Z_B = \sum_h \sum_i \sum_j A_{hij}B_{hij} - D_3^+ + D_3^- = 50,492,227 \quad (23)$$

$$\sum_j A_{11j} = 170$$
$$\sum_j A_{12j} = 89$$
$$\vdots \qquad \text{Area of compartments in NE zones}$$
$$\sum_j A_{119j} = 2$$
$$\sum_j A_{21j} = 24 \quad (24)$$
$$\sum_j A_{22j} = 0$$
$$\vdots \qquad \text{Area of compartments in NR zones}$$
$$\sum_j A_{219j} = 0$$

$$\sum_h \sum_i \sum_j A_{hij}B_{hij} \geq 24,105,180 \quad (25)$$

$$\sum_i \sum_j A_{1ij}S_{1ij} \geq 149,071 \quad (26)$$

$$\sum_{i}\sum_{j} A_{2ij}S_{2ij} \geq 74{,}383 \tag{27}$$

$$A_{hij} \geq 0 \qquad D_k^+ \; D_k^- \geq 0 \tag{28}$$

$h=1,2.\ i=1,2,\ldots 19.\ \ j=1,2,3,4.\ \ k=1,2,3.$

Where

D_1^+ = positive deviation from the merchantable volume harvested goal (i.e. overachievement);

D_1^- = negative deviation from the merchantable volume harvested goal (i.e. underachievement);

D_2^+ = positive deviation from the scenic beauty goal (i.e. overachievement);

D_2^- = negative deviation from the scenic beauty goal (i.e.underachievement);

D_3^+ = positive deviation from the winter browse availability goal (i.e. overachievement);

D_3^- = negative deviation from the winter browse availability goal (i.e. underachievement);

Z_V = total expected merchantable volume harvested in NE and NR zones in cubic metres per year;

Z_S = total expected forest scenic beauty level of NE and NR zones per year;

Z_B = total winter browse availability of NE and NR zones per year;

A_{hij} = area in hectares of zone h and compartment i assigned to treatment alternative j;

V_{hij} = merchantable volume harvested in cubic metres per hectare per year from compartment i, zone h under treatment alternative j;

S_{hij} = Scenic beauty level per hectare per year of compartment i, zone h under treatment alternative j;

B_{hij} = winter browse availability in stems per hectare per year from compartment i, zone h under treatment alternative j.

Goal Programming Solutions

The goal programming problem was solved by using the XMP (Marsten, 1986) packaged program installed on the IBM-PC AT computer at Lakehead University. The goal programming solutions in Table 22 show the optimal attainment level for each variable if the OMNR's policy were implemented. Table 23 shows what alternative should be assigned to each age class compartment to obtain the attainment levels as in Table 22. The solutions for all objectives were found as close to target levels as possible. The solutions were interpreted from two aspects that this study pursued from the beginning. First, the solutions were optimal attainment levels for the pre-selected quantitative variables when the OMNR's policy would be implemented. Second, the optimal allocation of the study area, as a result of the goal programming application, implied the possibility that higher satisfaction levels could be achieved in comparison with other policies and, consequently, less conflicts among the interest groups would be expected.

Table 22. GP solutions.

Objective (Units)	Target Levels	Solutions	Average Yield (/ha)
Merchantable volume harvested (m^3/yr)	2,884	2,884	0.81
Scenic beauty level(/yr)	245,933	245,291	69.15
Winter browse availability (stems/yr)	50,492,227	47,973,498	13,525

Table 23. Age class compartments assigned by cutting alternatives.

Compartment No.	Age Class (yrs.)	N E Area (ha)	N E Alternative	N R Area (ha)	N R Alternative No.
1	10-14	170	1	24	1
2	20-24	89	1	0	-
3	55-59	171	1	0	-
4	75-79	201	2	0	-
5	80-84	290	2	214	1
6	85-89	644	1	60	3
7	90-94	100	1	0	-
8	95-99	260	1	0	-
9	100-104	84	1	0	-
10	105-109	56	1	38	1
11	115-119	0	-	414	1
12	125-129	34	4	74	1
13	135-139	37	1	0	-
14	140-144	28	1	7	1
15	145-149	32	1	234(38,196)[a]	2,3
16	155-159	0	-	5	1
17	160-164	67	1	0	-
18	165-169	183	1	29	1
19	180+	2	1	0	-
	TOTAL	2448		1099	

[a] 69 hectares is assigned for alternative 2 and 165 hectares is assigned for alternative 3.

CONCLUSIONS AND SUGGESTED RESEARCH

As our society places more demands on the forest, a larger number of interest groups will become involved in forest resource management problems. Modern resource management problem are characterized by the conflicting and competitive demands for the uses of forest resources. The social and bio-physical aspects require more attention to handle the problem of harmonizing the various uses of the forest.

This study attempted to handle the complex resource management problem from both bio-physical and social aspects. This study also looked at an approach encompassing the various problems that occur on forest land. The analytical tool developed for this purpose, used two different modelling approaches: quantitative modelling with linear and goal programming, and judgement-based modelling with the IDA model. The two types of models were linked to allow the advantages of each model to complement the other model. Through this approach, quantitative optimality and social harmony were achieved. These two achievements could not be obtained readily by application of a single method.

Besides the above, the following advantages can be expected through this approach.

First, the goal programming solution was substantially improved by the enhanced target levels and weight determinations. The target levels were objectively determined by linking the initial LP solution and the result of IDA process. This approach suggested that determination of the weights for the variables could partly be improved based upon the feasible policy spaces. Buongiorno and Gilless (1987) suggests working with relative deviation from goals for assigning values to weights regardless of the units of goals. However, in this study, feasible decision spaces were used for determining relative importance of each objective variable. Furthermore, as the decision spaces had a common unit in their expressions, per hectare in this study, objectivity of the weights determined based upon the relative importance of variables were improved.

Second, this approach took advantage of the features of both models. The mathematical model is widely employed for optimizing scarce resources, but the optimality does not necessarily mean that the resource management problem has been solved. As all aspects of modern society become increasingly more related with each other, no single group can monopolize the forest's resources without considering other groups. Harmonizing the interest groups is a problem that a resource manager must consider. The judgement-based model, IDA, pursued the achievement of harmony among the involved interest groups through the satisfaction level achieved by a policy. The IDA solution was also improved by LP. The decision spaces suggested by the initial LP solution assisted the workshop participant's subjective judgement and improved the model's construction. Consequently, a better representation of the actual problem and simulation results, can be expected through IDA model.

Third, qualitative management objectives could be handled by this approach. The IDA model is relatively flexible and can handle qualitative variables. The resource manager can introduce these variables during their decision making. The model constructed with those qualitative variables may have more power of representation of real world problems. Consequently, the manager's capability to understand and handle the problem can be significantly improved.

Lastly, as this approach required various experts to share their knowledge in developing policies, the team effort approach should be more favorable than policies developed by an individual.

Despite the above advantages, further studies still need to be carried out to improve the outcome. The following areas of study are suggested for future research.

1. A comparison of the solutions between this approach and any single approach is required to confirm the advantages.

2. More generalization and simplification of the approach is required to promote wider range of application. Developing a computer program for the entire process of the approach may meet this requirement, as well as making it easier for use by resource managers and interest groups.

3. A cost-effective and time-saving policy developing approach was suggested in this study. A comparison of this approach with the class environmental assessment process for timber management is encouraged in order to study all aspects of developing resource policy.

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APPENDICES

APPENDIX I

MATHEMATICAL SATISFICING ALGORITHMS

1. Maximin solution: Policy maximizes total minimum satisfaction for all groups (the non-competitive non-compensatory case).

Maximin = Maximum of SS_k

Where:

SS_k is the percentage (between o and 100) of the maximum possible weighted satisfaction of objectives produced by the least satisfied objective for each variable, for policy k, and SS is expressed as

$$SS = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} W_i M_{ij}}{\sum_{i=1}^{m} W_i}$$

M_{ij} is the minimum level of satisfaction (pct. of max. units) produced for any group by variable j, and the group affected is i.

W_i is the weight of affected group i and $1.0 \leq W \leq 9.9$.

m is the number of affected groups, $1 \leq m \leq 15$.

n is the number of variables for which all groups did not assign the "Don't Care" objective and $1 \leq n \leq 39$.

k is the policy.
i is the group.
j is the variable.

2. Maximax solution: Policy maximizes total satisfaction for all groups (the non-competitive and competitive compensatory cases).

Maximax = Maximum of SS_k

Where:

SS_k is the percentage (between 0 and 100) of the possible weighted satisfaction of objectives produced for all groups by all variables, for policy k, and SS is expressed as

$$SS = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} W_i S_{ij}}{\sum_{i=1}^{m} W_i (n - d_i)}$$

S_{ij} is the satisfaction (pct. of Max. units) produced for group i by variable j. S=0 if the objective is "Don't Care."

W_i is the weight of group i, and $1.0 \leq W \leq 9.9$.

m is the number of groups, $1 \leq m \leq 15$.

n is the number of variables for which all groups did not assign the "Don't Care" objective and $1 \leq n \leq 39$.

d_i is the number of variables assigned the "Don't Care" objective by group i.

k is the policy.

i is the group.

j is the variable.

3. Minimax solution: Policy minimizes dissatisfaction for any one group (the competitive and non-compensatory case).

Minimax = Minimum of [Maximum of $(100 - S_{ij})_k$]

Where:

S_{ij} is the satisfaction of the objective (Pct. of Max. units) for group i variable j.

k is the policy.

i is the group.

j is the variable. (from Bonnicksen, 1987)

APPENDIX II

FOREST STAND LISTINGS - 1981

ST NO	B	Bw	Ce	Pj	Po	Pr	Pw	Sb	Sw	L[f]	AGE yrs	HT[a] m	STK[b] %	SC[c]	AREA[d] ha	BROWSE[e] stem/ha
NE1[g]																
1	2	1	7								91	15	0.4	2	69	6614
2	1		6					3					B&S[h]	3	73	2343
3			9					1			91	10	1.2	3	3	4102
4			8					2			91	7	1	3	17	
5	4		1					5			91	10	0.7	3	7	1436
6	1	1	7					1			133	12	0.5	3	5	
7	1	1	7					1			88	12	0.6	2	20	2237
8			6					4			88	11	0.7	3	3	3828
9	1	1	6					1	1		133	14	1	2	5	
10	2	2	6								133	14	0.6	2	18	14493
11	3	1	2		1			1	2		78	17	0.2	1	247	9391

[a] HT=Height
[b] STK=Stocking level
[c] SC=Stand site class.
[d] AREA=Stand area
[e] BROWSE=Potential winter browse stems per hectare.
[f] B=Balsam Fir (Abies balsamea (L.) Mill.)
Bw=White Birch (Betula papyrifera March.)
Ce= Eastern White Cedar (Thuja occidentalis L.)
Pj= Jack Pine (Pinus banksiana Lamb.)
Po= Trembling Aspen or Poplar spp.(Populus tremuloides Michx. or Populus spp.)
Pr= Red Pine (Pinus resinosa Ait.)
Pw= White Pine (Pinus strobus L.)
Sb= Black Spruce (Picea mariana (Mill.) B.S.P.)
Sw= White Spruce (Picea glauca (Moench) Voss)
L= Tamarack (Larix laricina (DuRoi) K.Koch.)
[g] NE1= Natural environment zone 1
[h] B&S= Barren and scattered.

Appendix II. (Continued)

ST	SPECIES	COMPOSITION									AGE	HT	STK	SC	AREA	BROWSE
NO	B	Bw	Ce	Pj	Po	Pr	Pw	Sb	Sw	L	yrs	m	%		ha	stem/ha
12	1	1	3					5			80	14	0.7	1	10	
13	1		6					3			91	12	0.6	2	69	1786
14	1	2	6					1			91	12	0.3	2	10	
15	1		8					1			91	14	0.5	2	3	
16		1	8					1			98	15	0.9	2	15	10665
17	1		6					2		1	98	15	0.5	2	33	6915
18	2	3	2				2		1		90	23	0.4	1	28	820
19											17	5	1	1	89	16243
20	2	2	3					1	1		80	13	0.4	2	23	3076
21	5	1					3		1		50	12	0.7	1	21	6563
22	5	2	3								73	15	0.4	1	17	6973
23	1	1	6					2			153	14	0.7	3	47	2461
24			10										B&S	2	13	
25	2	1	5						2		128	16	0.7	2	37	957
26		1			8			1			68	18	0.9	3	23	4102
27	3	2	1		1			3			83	13	0.9	2	15	
28	1	2	1		4			1	1		73	22	1	3	96	5025
29			9					1			74	14	0.5	1	24	
30	5	4	1								73	19	0.6	x	13	4512
31	1	2					6		1		219	24	0.2	2	2	27346
32	1				1			8			98	12	0.5	3	8	
33	5	2	1		1				1		73	14	0.5	1	69	10602
34	6	1							3		73	15	0.5	1	28	9727
35	1		8					1			73	12	0.8	2	43	2133
36		5			2			2	1		68	21	1	1	33	
37			4					6			83	13	0.4	2	51	
38	1	1			5				3		69	19	0.9	3	61	4624
39	2	1	5		1				1		138	18	0.5	1	32	9639
40	1	1	5					3			94	12	0.3	2	84	3555
41	5		2		3						80	16	0.4	1	6	
42	4	5	1								85	20	1.2	2	6	9024
43	1	3			5				1		79	23	0.8	2	81	6071
44	1				7				2		79	20	0.8	3	13	3555
45			4					6			88	11	B&S	3	6	
46			4					6			88	11	0.6	3	25	
47	1	5			2			2			68	23	0.9	x	69	
48	3	3			3				1		68	21	0.5	1	4	
49		4			4			2			68	21	0.4	1	11	
50								10					B&S	2	14	
51	2	2			5				1		79	22	0.8	3	89	5646
52	1	1			6				2		78	23	0.5	2	7	4512
53			5		2			3			158	15	0.4	3	4	8204
54	1	2	4					3			158	15	0.9	3	148	6768
55	2	1			6				1		79	20	1	2	5	
56	4	3			1			2			122	18	1	1	34	
57	2	2			5			1			79	20	1	3	39	
58			4		4				2				B&S	3	10	
NE2[i]																
1	1	3	2		4						79	23	0.6	2	5	
2	2	6			1				1		79	18	0.9	2	36	2110
3	2	2			6						50	16	0.3	3	114	10899

[i] NE2=Natural environment zone 2.

Appendix II. (Continued)

ST	SPECIES	COMPOSITION									AGE	HT	STK	SC	AREA	BROWSE
NO	B	Bw	Ce	Pj	Po	Pr	Pw	Sb	Sw	L	yrs	m	%		ha	stem/ha
4	4	3			1			2			83	14	0.6	2	14	
5					10								B&S	3	18	
6		4			6						50	16	0.8	3	19	
7					10								B&S	1	38	
8			7					3			158	12	0.4	3	2	
9	2	1	4					3			158	15	1	2	29	
10	1	3	1		5						79	16	1	4	25	
11	4	1	1		2				2		50	16	1	2	17	
12	2	3	4		1						83	14	0.9	2	14	
13	2	1	2		5						79	19	0.7	3	58	7383
14	2		5					3			157	15	0.9	2	20	
15													B&S	2	4	
NR1[j]																
1	2	4	2		1				1		108	19	0.4	2	100	
2			6					4			98	11	0.6	3	6	
3	2	2	6								78	19	0.5	x	60	7657
4	3	4				1	1		1		149	20	0.7	2	5	
5		10											B&S	2	24	
6		1	5		2			2			99	12	0.4	2	32	
7	2	1	5				1		1		130	18	0.5	1	77	6116
8	3	3	3				1				109	18	0.2	1	6	
9	1		8					1			109	14	0.5	2	17	1641
10	2	1	6					1			109	18	0.5	1	28	1641
NR2[k]																
1	2	2	3		1		1		1		108	18	0.3	1	132	17638
2	1	2						6	1		108	14	0.5	2	7	19689
3	3	4	1				2				108	19	0.6	2	15	8204
4	1	2	7								133	12	0.5	3	7	
5	1	1	1		1	3	3				162	23	0.5	2	29	9516
6	3	2	2				1		2		108	20	0.5	x	109	6125
7	3	1	1					5			75	12	0.4	2	40	
8	1	1	7			1					75	14	0.4	1	32	4102
9					9				1		75	18	0.8	3	2	12360
10	1	2	4				2	1			77	13	0.5	2	63	7032
11	1	1	3				4		1		141	23	0.6	2	64	11719
12	3		4				3				118	16	0.6	2	51	4758
13	2	1	2				4		1		141	25	0.6	2	170	6733
14	3		5				1		1		118	17	0.6	1	23	2256

[j] NR1=Natura reserve zone 1.
[k] NR2=Nature reserve zone 2.

APPENDIX III

1988 YIELD LEVELS PREDICTED

STAND				SPECIES							
NO.	AGE	AREA	STK[a]	COMPO.[b]		SC[c]	BA[d]	WG[e]	MV[f]	SB[g]	WBA[h]
	yr	ha	%	B	CE		m2		m3	/ha	st/ha
NE1											
1	98	69	0.4	2	7	2	14.20	Ce	55.77	69.69	5177.56
2	12	73	0.1	1	6	3	0.00	Ce	0.00	0.00	4617.19
3	98	3	1	0	9	3	30.22	Ce	71.99	78.98	511.48
4	98	17	1	0	8	3	30.22	Ce	71.99	78.98	1599.54
5	98	7	0.7	4	1	3	21.15	Sb	50.40	74.86	3410.11
6	140	5	0.5	1	7	3	17.87	Ce	67.05	73.71	6262.90
7	95	20	0.6	1	7	2	21.03	Ce	79.44	74.67	4204.92
8	95	3	0.7	0	6	3	20.78	Ce	45.82	74.53	4514.90
9	140	5	1	1	6	2	40.90	Ce	212.78	84.15	5267.32
10	140	18	0.6	2	6	2	24.54	Ce	127.67	77.98	6861.99
11	85	247	0.2	3	2	1	7.37	B	39.04	60.14	9288.25
12	87	10	0.7	1	3	1	25.98	Ce	140.23	76.71	7113.42
13	98	69	0.6	1	6	2	21.29	Ce	83.66	74.94	4844.81
14	98	10	0.3	1	6	2	10.65	Ce	41.83	65.69	7028.24
15	98	3	0.5	1	8	2	17.75	Ce	69.71	72.65	4710.87
16	105	15	0.9	0	8	2	32.83	Ce	139.19	80.24	4475.05
17	105	33	0.5	1	6	2	18.24	Ce	77.33	73.22	5928.71
18	97	28	0.4	2	2	1	15.59	Bw	90.66	70.92	8940.83
19	24	89	1	0	0	1	13.66	Sw	0.00	61.51	10957.04
20	87	23	0.4	2	3	2	13.51	Ce	44.75	68.70	6150.59
21	57	21	0.7	5	0	1	22.22	B	75.56	72.56	6480.41
22	80	17	0.4	5	3	1	14.47	B	72.72	69.36	6087.09
23	160	47	0.7	1	6	3	26.31	Ce	106.54	79.30	7100.29
24	12	13	0.1	0	10	2	0.00	Ce	0.00	0.00	6621.58
25	135	37	0.7	2	5	2	28.19	Ce	144.12	79.63	6296.52

[a] STK=stocking.
[b] SPECIES COMPO.=species composition.
[c] SC=site class.
[d] BA=basal area.
[e] WG=working group.
[f] MV= gross merchantable volume.
[g] SB=scenic beauty.
[h] WBA=winter browse availability.

Appendix III. (Continued)

STAND				SPECIES							
NO.	AGE	AREA	STK	COMPO.		SC	BA	WG	MV	SB	WBA
	yr	ha	%	B	CE		m2		m3	/ha	st/ha
26	75	23	0.9	0	0	3	25.77	Po	189.15	75.78	8935.25
27	90	15	0.9	3	1	2	30.85	B	107.91	78.70	4526.68
28	80	96	1	1	1	3	29.08	Po	220.74	77.38	4023.57
29	81	24	0.5	0	9	1	18.16	Ce	92.27	72.25	7054.30
30	80	13	0.6	5	1	1	21.71	B	109.08	74.30	5939.73
31	226	2	0.2	1	0	2	8.40	Pw	96.42	63.13	22681.86
32	105	8	0.5	1	0	3	15.68	Sb	42.90	71.21	8630.39
33	80	69	0.5	5	1	1	18.09	B	90.90	72.16	6572.99
34	80	28	0.5	6	0	1	18.09	B	90.90	72.16	7837.31
35	80	43	0.8	1	8	2	26.04	Ce	73.18	76.27	1413.57
36	75	33	1	0	0	1	38.98	Bw	190.61	79.33	12421.25
37	90	51	0.4	0	4	2	13.71	Sb	47.96	68.99	8240.49
38	76	61	0.9	1	0	3	25.86	Po	191.13	75.89	6451.31
39	145	32	0.5	2	5	1	20.85	Ce	155.21	75.91	10203.05
40	101	84	0.3	1	5	2	10.78	Ce	43.84	65.92	7511.54
41	87	6	0.4	5	2	1	14.85	B	80.13	69.95	6939.74
42	92	6	1.2	4	1	2	29.94	Bw	171.85	78.52	2439.37
43	86	81	0.8	1	0	2	27.17	Po	269.05	77.13	8812.91
44	86	13	0.8	1	0	3	23.64	Po	185.76	75.61	7069.91
45	95	6	0.1	0	4	3	2.97	Sb	6.55	46.45	8377.24
46	95	25	0.6	0	4	3	17.81	Sb	39.27	72.59	5995.44
47	75	69	0.9	1	0	1	35.08	Bw	171.55	78.55	9893.52
48	75	4	0.5	3	0	1	19.49	Bw	95.30	72.76	9121.94
49	75	11	0.4	0	0	1	14.04	Po	146.75	68.76	12421.25
50	12	14	0.1	0	0	2	0.00	Sb	0.00	0.00	9088.76
51	86	89	0.8	2	0	3	23.64	Po	185.76	75.61	6034.90
52	85	7	0.5	1	0	2	16.93	Po	167.17	71.56	9271.39
53	165	4	0.4	0	5	3	15.19	Ce	62.42	71.72	11644.00
54	165	148	0.9	1	4	3	34.19	Ce	140.44	82.77	7737.15
55	86	5	1	2	0	2	40.80	Po	336.31	80.87	7345.42
56	129	34	1	4	0	1	40.81	B	285.90	83.69	9935.46
57	86	39	1	2	0	3	29.55	Po	232.20	77.99	5602.42
58	12	10	0.1	0	4	3	0.00	Po	0.00	0.00	5801.75
NE2											
1	86	5	0.6	1	2	2	20.38	Po	201.79	73.89	6426.36
2	86	36	0.9	2	0	2	22.14	Bw	123.91	74.86	7556.96
3	57	114	0.3	2	0	3	7.91	Po	48.35	60.35	6193.22
4	90	14	0.6	4	0	2	20.56	B	71.94	74.18	7148.67
5	12	18	0.1	0	0	3	0.00	Po	0.00	0.00	7345.76
6	57	19	0.8	0	0	3	21.10	Po	128.94	72.08	8246.21
7	12	38	0.1	0	0	1	0.28	Po	0.00	8.45	10831.76
8	165	2	0.4	0	7	3	15.19	Ce	62.42	71.72	10923.58
9	165	29	1	2	4	2	44.36	Ce	242.41	85.88	7845.40
10	86	25	1	1	1	4	29.55	Po	232.20	77.99	2569.41
11	57	17	1	4	1	2	27.13	B	0.00	74.25	1841.60
12	90	14	0.9	2	4	2	30.85	Ce	107.91	78.70	2826.75
13	86	58	0.7	2	2	3	20.69	Po	162.54	74.07	3326.69
14	164	20	0.9	2	5	2	39.79	Ce	217.22	84.59	7573.56
15	12	4	0.1	0	0	2	0.00	Sb	0.00	0.00	9088.76
NR1											
1	115	100	0.4	2	2	2	10.38	Bw	64.10	65.60	8304.47

Appendix III. (Continued)

S T A N D NO.	AGE yr	AREA ha	STK %	SPECIES COMPO. B	CE	SC	BA m2	WG	MV m3	SB /ha	WBA st/ha
2	105	6	0.6	0	6	3	18.82	Ce	51.48	73.63	5566.88
3	85	60	0.5	2	6	1	18.43	Ce	97.59	72.62	5771.33
4	156	5	0.7	3	0	2	18.90	Bw	126.46	74.73	12155.26
5	12	24	0.1	0	0	2	0.00	Bw	0.00	0.00	9088.76
6	106	32	0.4	0	5	2	14.64	Ce	62.68	70.30	8750.19
7	137	77	0.5	2	5	1	20.64	Ce	149.29	75.63	9548.81
8	116	6	0.2	3	3	1	7.98	Ce	52.64	61.74	10741.68
9	116	17	0.5	1	8	2	18.96	Ce	87.87	74.03	5827.95
10	116	28	0.5	2	6	1	19.96	Ce	131.60	74.71	7578.32
NR2											
1	115	132	0.3	2	3	1	11.95	Ce	78.40	67.63	10235.88
2	115	7	0.5	1	0	2	18.89	Sb	86.97	73.96	11011.39
3	115	15	0.6	3	1	2	15.57	Bw	96.15	71.35	7349.79
4	140	7	0.5	1	7	3	17.87	Ce	67.05	73.71	6262.90
5	169	29	0.5	1	1	2	20.99	Pr	192.08	76.37	13729.59
6	115	109	0.5	3	2	1	19.92	B	130.67	74.65	8858.75
7	82	40	0.4	3	1	2	13.17	Sb	39.03	68.20	6518.31
8	82	32	0.4	1	7	1	14.59	Ce	74.90	69.54	6793.83
9	82	2	0.8	0	0	3	23.40	Po	179.76	75.26	9253.96
10	84	63	0.5	1	4	2	16.64	Ce	51.72	71.30	5667.13
11	148	64	0.6	1	3	2	24.53	Pw	247.30	78.15	9986.45
12	125	51	0.6	3	4	2	23.42	Ce	114.52	77.02	6017.56
13	148	170	0.6	2	2	2	22.42	Po	249.50	76.95	9752.03
14	125	23	0.6	3	5	1	24.33	Ce	167.53	77.50	7241.69

		MV	SB	WBA
TOTAL		405063	243933	26783533
AVERAGE		114.2	68.772	7551.038
TOTAL	NE	264666	165635	17333346
TOTAL	NR	140396	78299	9450187
AVERAGE	NE	108.12	67.661	7080.615
AVERAGE	NR	127.75	71.245	8598.896

APPENDIX IV

AVERAGE YEARLY YIELDS - NE ZONES

Age	MVH (M3/HA)[a]				SB(/HA)[b]				WBA(ST/HA)[c]			
Class[d]	1[e]	2[e]	3[e]	4[e]	1	2	3	4	1	2	3	4
1	0	0	0	0	5.74	5.65	5.28	4.76	7032	7050	7125	7222
2	0	0	0	0	64.69	64.57	63.93	62.75	11029	11029	11029	11029
3	0	0.46	2.23	4.27	65.16	64.85	63.47	61.41	6182	6220	6374	6569
4	0	1.40	6.78	12.97	77.37	77.12	76.02	74.28	9483	9505	9594	9708
5	0	1.04	5.03	9.61	74.88	74.59	73.31	71.36	5287	5375	5723	6158
6	0	1.03	4.99	9.54	69.96	69.64	68.23	66.13	7644	7693	7893	8150
7	0	0.62	3.00	5.74	73.53	73.22	71.85	69.80	6669	6737	7011	7358
8	0	0.54	2.61	4.98	72.50	72.17	70.73	68.61	16560	16829	17751	18656
9	0	0.35	1.69	3.24	66.24	65.88	64.30	62.02	7784	7843	8080	8383
10	0	0.71	3.42	6.54	75.18	74.85	73.45	71.36	6208	6303	6670	7116
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	2.19	10.58	20.22	83.94	83.67	82.44	80.57	10281	10365	10699	11112
13	0	1.11	5.36	10.25	79.92	79.60	78.20	76.12	6658	6770	7218	7782
14	0	1.01	4.90	9.37	78.60	78.27	76.84	74.72	6844	6959	7413	7980
15	0	1.18	5.71	10.92	76.06	75.71	74.20	72.00	10590	10680	11042	11502
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	1.06	5.14	9.83	81.11	80.79	79.35	77.23	7671	7788	8254	8834
18	0	1.17	5.67	10.84	83.13	82.81	81.42	79.35	8314	8421	8847	9382
19	0	0.72	3.49	6.68	63.17	62.77	61.09	58.67	23281	23295	23356	23434

[a] MVH=Merchantable volume harvested in m^3 per hectare.
[b] SB= Scenic beauty level per hectare.
[c] WBA= Winter browse availability in stems per hectare.
[d] Age Class = Age class compartment as on Table 11.
[e] Treatment alternatives.

APPENDIX V

AVERAGE YEARLY YIELDS - NR ZONES

Age Class[d]	MVH (M3/HA)[a] 1[e]	2[e]	3[e]	4[e]	SB (/HA)[b] 1	2	3	4	WBA (ST/HA)[c] 1	2	3	4
1	0	0	0	0	0	0	0	0	9129	9129	9129	9129
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0.70	3.40	6.50	72.39	72.05	70.59	68.43	7701	7777	8085	8478
6	0	0.77	3.74	7.16	72.99	72.67	71.28	69.21	6002	6099	6490	6984
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0.49	2.34	4.48	71.16	70.81	69.31	67.10	8533	8584	8792	9054
11	0	0.72	3.46	6.62	70.08	69.73	68.19	65.95	9271	9338	9607	9952
12	0	1.01	4.89	9.34	77.44	77.11	75.67	73.56	6733	6838	7261	7796
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0.52	2.50	4.79	73.95	73.60	72.06	69.82	6637	6731	7107	7579
15	0	1.87	9.05	17.31	77.41	77.06	75.57	73.39	10211	10284	10580	10958
16	0	0.95	4.60	8.79	74.84	74.48	72.93	70.68	12571	12625	12840	13113
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	1.44	6.95	13.29	76.39	76.03	74.49	72.24	14180	14225	14412	14652
19	0	0	0	0	0	0	0	0	0	0	0	0

[a] MVH=Merchantable volume harvested.
[b] SB= Scenic beauty level per hectare.
[c] WBA= Winter browse availability in stems per hectare.
[d] Age Class = Age class compartment as on Table 11.
[e] Treatment alternatives.

APPENDIX VI

POLICY EXPERIMENT OUTPUT SUMMARY

POLICY EXPERIMENTED: Current

TIME PERIOD: 10 years, beginning May 1988.

Variable		Values (% of maximum)			Difference from Initial Value		Difference from Expected Value	
No.	Name	Initial	Final	Expected	(%)[a]	(% of psbl)[b]	(%)[c]	(% of psbl)[d]
1	MVH	1.0	1.0	1.0	2.6	0.0	0.0	0.0
2	WBA	52.7	59.8	59.8	13.4	14.9	0.0	0.0
3	SB	99.0	99.4	99.4	0.4	43.6	0.0	0.0
4	MD	22.6	20.2	20.2	-10.3	-10.3	0.0	0.0
5	MVO	47.6	59.9	59.9	25.8	23.4	0.0	0.0
6	ACC	76.3	92.2	92.2	20.8	67.1	0.0	0.0
7	CA	14.8	16.1	16.1	8.6	1.5	0.0	0.0
8	EMP	45.1	20.0	20.0	-55.6	-55.6	0.0	0.0
9	CO	1.0	2.0	2.0	100.1	1.0	0.0	0.0
10	NPUL	5.6	5.5	5.5	-1.3	-1.3	0.0	0.0
11	NPUT	5.4	7.0	7.0	29.8	1.7	0.0	0.0

[a] Difference from initial value(%)

$$= \frac{\text{Final value} - \text{Initial value}}{\text{Initial value}} \times 100\%$$

[b] Difference from initial value(% of possible)

$$= \frac{\text{Final value} - \text{Initial value}}{100 - \text{Initial value}} \times 100\%$$

[c] Difference from expected value(%)

$$= \frac{\text{Final value} - \text{Expected value}}{\text{Expected value}} \times 100\%$$

[d] Difference from expected value(% of possible)

$$= \frac{\text{Final value} - \text{Expected value}}{100 - \text{Expected value}} \times 100\%$$

POLICY EXPERIMENTED: Naturalist

TIME PERIOD: 10 years, beginning May 1988.

Variable		Values (% of maximum)			Difference from Initial Value		Difference from Expected Value	
No.	Name	Initial	Final	Expected	(%)	(% of psbl)	(%)	(% of psbl)
1	MVH	1.0	1.0	1.0	2.6	0.0	0.0	0.0
2	WBA	52.7	79.4	59.8	50.5	56.3	32.7	48.6
3	SB	90.0	99.5	99.4	0.5	52.7	0.0	16.3
4	MD	22.6	20.3	20.2	-10.3	-10.3	0.0	0.0
5	MVO	47.6	61.9	59.9	30.0	27.3	3.3	5.0
6	ACC	76.3	99.2	92.2	30.0	96.8	7.6	90.2
7	CA	14.8	16.1	16.1	8.6	1.5	0.0	0.0
8	EMP	45.1	30.4	20.0	-32.5	-32.5	52.0	13.0
9	CO	1.0	3.5	2.0	251.3	2.5	75.6	1.5
10	NPUL	5.6	5.6	5.5	0.0	0.0	1.4	0.0
11	NPUT	5.4	5.4	7.0	0.0	0.0	-23.0	-23.0

POLICY EXPERIMENTED: Tourist

TIME PERIOD: 10 years, beginning May 1988.

Variable		Values (% of maximum)			Difference from Initial Value		Difference from Expected Value	
No.	Name	Initial	Final	Expected	(%)	(% of psbl)	(%)	(% of psbl)
1	MVH	1.0	1.0	1.0	2.1	0.0	-0.6	-0.6
2	WBA	52.7	17.9	59.8	-66.0	-66.0	-70.0	-70.0
3	SB	99.0	100.0	99.4	1.0	99.0	0.6	98.2
4	MD	22.6	100.0	20.2	343.0	100.0	393.8	100.0
5	MVO	47.6	100.0	59.9	110.0	100.0	66.9	100.0
6	ACC	76.3	100.0	92.2	31.0	100.0	8.4	99.9
7	CA	14.8	15.9	16.1	6.8	1.2	-1.7	-1.7
8	EMP	45.1	46.0	20.0	2.0	1.7	129.8	32.5
9	CO	1.0	1.8	2.0	83.8	0.8	-8.1	-8.1
10	NPUL	5.6	6.3	5.5	12.5	0.7	14.0	0.8
11	NPUT	5.4	100.0	7.0	1752.8	100.0	1327.1	100.0

POLICY EXPERIMENTED: Local Public

TIME PERIOD: 10 years, beginning May 1988.

Variable		Values (% of maximum)			Difference from Initial Value		Difference from Expected Value	
No.	Name	Initial	Final	Expected	(%)	(% of psbl)	(%)	(% of psbl)
1	MVH	1.0	1.0	1.0	2.6	0.0	0.0	0.0
2	WBA	52.7	17.9	59.8	-66.0	-66.0	-70.0	-70.0
3	SB	99.0	100.0	99.4	1.0	99.0	0.6	98.2
4	MD	22.6	90.3	20.2	300.0	87.5	345.9	87.8
5	MVO	47.6	100.0	59.9	110.0	100.0	66.9	100.0
6	ACC	76.3	91.6	92.2	20.0	64.5	-0.7	-0.7
7	CA	14.8	16.1	16.1	8.6	1.5	0.0	0.0
8	EMP	45.1	54.1	20.0	20.0	16.4	170.3	42.6
9	CO	1.0	1.0	2.0	-2.8	-2.8	-51.4	-51.4
10	NPUL	5.6	16.7	5.5	200.0	11.8	204.0	11.8
11	NPUT	5.4	7.1	7.0	32.4	1.9	2.0	0.2

POLICY EXPERIMENTED: Pass Lake

TIME PERIOD: 10 years, beginning May 1988.

Variable		Values (% of maximum)			Difference from Initial Value		Difference from Expected Value	
No.	Name	Initial	Final	Expected	(%)	(% of psbl)	(%)	(% of psbl)
1	MVH	1.0	29.7	1.0	2900.1	29.0	2823.2	29.0
2	WBA	52.7	86.3	59.8	63.7	71.1	44.4	66.0
3	SB	99.0	98.1	99.4	-0.9	-0.9	-1.3	-1.3
4	MD	22.6	45.1	20.2	100.0	29.2	123.0	31.2
5	MVO	47.6	100.0	59.9	110.0	100.0	66.9	100.0
6	ACC	76.3	100.0	92.2	31.0	100.0	8.4	99.9
7	CA	14.8	99.9	16.1	573.0	99.9	519.5	99.9
8	EMP	45.1	99.7	20.0	121.0	99.4	397.8	99.6
9	CO	1.0	100.0	2.0	9998.0	100.0	4945.9	100.0
10	NPUL	5.6	100.0	5.5	1697.8	100.0	1722.1	100.0
11	NPUT	5.4	100.0	7.0	1752.8	100.0	1327.1	100.0

POLICY EXPERIMENTED: OMNR

TIME PERIOD: 10 years, beginning May 1988.

Variable		Values (% of maximum)			Difference from			
					Initial Value		Expected Value	
No.	Name	Initial	Final	Expected	(%)	(% of psbl)	(%)	(% of psbl)
1	MVH	1.0	1.0	1.0	-0.0	-0.0	-2.6	-2.6
2	WBA	52.7	99.9	59.8	89.5	99.9	67.1	99.9
3	SB	99.0	100.0	99.4	1.0	99.0	0.6	98.2
4	MD	22.6	67.7	20.2	200.0	58.3	234.4	59.5
5	MVO	47.6	95.2	59.9	100.0	90.9	59.0	88.1
6	ACC	76.3	95.4	92.2	25.0	80.6	3.5	41.2
7	CA	14.8	14.8	16.1	-0.0	-0.0	-7.9	-7.9
8	EMP	45.1	99.7	20.0	121.0	99.4	397.8	99.6
9	CO	1.0	1.0	2.0	0.0	0.0	-50.0	-50.0
10	NPUL	5.6	61.2	5.5	1000.0	58.9	1014.8	58.9
11	NPUT	5.4	59.4	7.0	1000.0	57.0	747.3	56.3

APPENDIX VII

SATISFACTION OF GROUP OBJECTIVES

Experiment: Current

Group	Total Satisfaction (% of max.)[a]	Highest Dissatisfaction (%)	Highest Dissatisfaction (Variables)	Dif. from Initial Val (%)	Objective
Natural	92	44	SB	0.4	No Change
Tourist	68	93	NPUT	29.8	Up Max.1753%
LocalPub	79	56	MD	-10.3	Up 100%
			EMP	-55.6	Not Down
PassLake	50	98	CO	100.1	Up Max.9999%
OMNR	47	99	MVH	2.6	Up Max.9999%

Experiment: Naturalist

Group	Total Satisfaction (% of max.)	Highest Dissatisfaction (%)	Highest Dissatisfaction (Variables)	Dif. from Initial Val (%)	Objective
Natural	87	56	WBA	50.5	No Change
Tourist	69	95	NPUT	0.0	Up Max.1753%
LocalPub	82	55	MD	-10.3	Up 100%
PassLake	52	97	CO	251.3	Up Max.9999%
OMNR	49	99	MVH	2.6	Up Max.9999%

[a] Maximum excludes variables assigned 'Don't Care'.

Experiment: Tourist

Group	Total Satisfaction (% of max.)	Highest Dissatisfaction (%)	Highest Dissatisfaction (Variables)	Dif. from Initial Val (%)	Objective
Natural	59	100	MD	343.0	No Change
			NPUT	1752.8	Not Up
Tourist	100	1	CA	6.8	No Up
LocalPub	98	16	CA	6.8	Down 100%
PassLake	64	98	CO	83.8	Up Max.9999%
OMNR	64	99	MVH	2.1	Up Max.9999%

Experiment: Local Public

Group	Total Satisfaction (% of max.)	Highest Dissatisfaction (%)	Highest Dissatisfaction (Variables)	Dif. from Initial Val (%)	Objective
Natural	70	99	SB	1.0	No Change
Tourist	82	93	NPUT	32.4	Up Max.1758%
LocalPub	97	16	CA	8.6	Down 100%
PassLake	56	99	CO	-2.8	Up Max.9999%
OMNR	59	99	MVH	2.6	Up Max.9999%

Experiment:Pass Lake

Group	Total Satisfaction (% of max.)	Highest Dissatisfaction (%)	Highest Dissatisfaction (Variables)	Dif. from Initial Val (%)	Objective
Natural	52	100	CA	573.0	No Change
			NPUL	1697.8	Not Up
			NPUT	1752.8	Not Up
Tourist	63	100	CA	573.0	Not Up
			NPUL	1697.8	Not UP
LocalPub	75	100	CA	573.0	Down 100%
			CO	9998.0	Not Up
PassLake	100	0	SB	-0.9	Not Down
			MD	100.0	Up 100%
			MVO	110.0	Up Max. 110%
			ACC	31.0	Up Max.31%
			CA	573.0	Up Max.574%
			EMP	121.0	Up Max.122%
			CO	9998.0	Up Max.99999%
			NPUL	1697.8	Up Max.1698%
			NPUT	1752.8	Up Max.1753%
OMNR	78	100	CO	9998.0	No Change

Experiment: OMNR

Group	Total Satisfaction (% of max.)	Highest Dissatisfaction (%)	Highest Dissatisfaction (Variables)	Dif. from Initial Val (%)	Objective
Natural	59	100	WBA	89.5	No Change
Tourist	80	59	NPUL	1000.0	Not Up
LocalPub	98	15	CA	0.0	Down 100%
PassLake	75	99	CO	0.0	Up Max.9999%
OMNR	80	99	MVH	-0.0	Up Max.9999%

APPENDIX VIII

VARIABLE COMPARISONS

Experiment: Current

Satisfaction of objectives for each variables

	Variable (% of objective satisfied)										
Group	MVH	WBA	SB	MD	MVO	ACC	CA	EMP	CO	NPUL	NPUT
Natural	100	85	56	90	100	100	98	D/C[a]	D/C	100	98
Tourist	D/C	D/C	99	20	60	92	98	D/C	D/C	100	7
LocalPub	D/C	D/C	99	45	63	97	84	44	99	99	D/C
PassLake	100	100	100	45	60	92	16	20	2	5	7
OMNR	1	60	99	20	60	100	16	20	99	16	22

Experiment: Naturalist

Satisfaction of objectives for each variables

	Variable (% of objective satisfied)										
Group	MVH	WBA	SB	MD	MVO	ACC	CA	EMP	CO	NPUL	NPUT
Natural	100	44	56	90	100	100	98	D/C	D/C	100	98
Tourist	D/C	D/C	99	20	60	92	98	D/C	D/C	100	7
LocalPub	D/C	D/C	99	45	63	97	84	44	99	99	D/C
PassLake	100	100	100	45	60	92	16	20	2	5	7
OMNR	1	60	99	20	60	100	16	20	99	16	22

[a] D/C = Don't Care

Experiment: Tourist

Satisfaction of objectives for each variables

	Variable (% of objective satisfied)										
Group	MVH	WBA	SB	MD	MVO	ACC	CA	EMP	CO	NPUL	NPUT
Natural	100	34	1	0	100	100	99	D/C	D/C	99	0
Tourist	D/C	D/C	100	100	100	100	99	D/C	D/C	99	100
LocalPub	D/C	D/C	100	100	100	100	84	100	99	100	D/C
PassLake	100	34	100	100	100	100	16	46	2	6	100
OMNR	1	18	100	100	100	100	16	46	99	19	100

Experiment: Local Public

Satisfaction of objectives for each variables

	Variable (% of objective satisfied)										
Group	MVH	WBA	SB	MD	MVO	ACC	CA	EMP	CO	NPUL	NPUT
Natural	100	34	1	13	100	100	98	D/C	D/C	88	98
Tourist	D/C	D/C	100	90	100	92	98	D/C	D/C	88	7
LocalPub	D/C	D/C	100	100	100	97	84	100	100	100	D/C
PassLake	100	34	100	100	100	92	16	54	0	17	7
OMNR	1	18	100	90	100	100	16	54	97	50	22

Experiment: Pass Lake

Satisfaction of objectives for each variables

	Variable (% of objective satisfied)										
Group	MVH	WBA	SB	MD	MVO	ACC	CA	EMP	CO	NPUL	NPUT
Natural	71	29	99	71	100	100	0	D/C	D/C	0	0
Tourist	D/C	D/C	98	45	100	100	0	D/C	D/C	0	100
LocalPub	D/C	D/C	98	100	100	100	0	100	0	100	D/C
PassLake	100	100	99	100	100	100	100	100	100	100	100
OMNR	31	86	98	45	100	100	100	100	0	100	100

Experiment: OMNR

Satisfaction of objectives for each variables

	Variable (% of objective satisfied)										
Group	MVH	WBA	SB	MD	MVO	ACC	CA	EMP	CO	NPUL	NPUT
Natural	100	0	1	42	100	100	100	D/C	D/C	41	43
Tourist	D/C	D/C	100	68	95	95	100	D/C	D/C	41	59
LocalPub	D/C	D/C	100	100	100	100	85	100	100	100	D/C
PassLake	100	100	100	100	95	95	15	100	0	61	59
OMNR	0	100	100	68	95	100	15	100	100	100	100