Optimal Forest Strategies for Addressing Tradeoffs and Uncertainty in Economic Development under Old-Growth Constraints

by

Emina Krcmar[†], Alison J. Eagle[‡] and G. Cornelis van Kooten[‡*]

[†] FEPA Research Unit, University of British Columbia

[‡]Department of Economics, University of Victoria

[*]Corresponding Author: P.O. Box 1700, Stn CSC, Victoria, BC, Canada V8W 2Y2
ph: 250-721-8539; e-mail: kooten@uvic.ca

Selected paper prepared for presentation at the joint Canadian Agricultural Economics Society and American Agricultural Economics Association Annual Meeting, Portland, OR, July 29 – August 1, 2007

Copyright 2007 by E. Krcmar, A.J. Eagle and G.C. van Kooten. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

Abstract

In Canada, governments have historically promoted economic development in rural regions by promoting exploitation of natural resources, particularly forests. Forest resources are an economic development driver in many of the more than 80% of native communities located in forest regions. But forests also provide aboriginal people with cultural and spiritual values, and non-timber forest amenities (e.g., biodiversity, wildlife harvests for meat and fur, etc.), that are incompatible with timber exploitation. Some cultural and other amenities can only be satisfied by maintaining a certain amount of timber in an old-growth state. In that case, resource constraints might be too onerous to satisfy development needs. We employ compromise programming and fuzzy programming to identify forest management strategies that best compromise between development and other objectives, applying our models to an aboriginal community in northern Alberta. In addition to describing how mathematical programming techniques can be applied to regional development and forest management, we conclude from the analysis that no management strategy is able to satisfy all of the technical, environmental and social/cultural constraints and, at the same time, offer aboriginal peoples forest-based economic development. Nonetheless, we demonstrate that extant forest management policies can be improved upon.

Keywords: forest-dependent aboriginal communities; boreal forest; compromise and fuzzy programming; sustainability and uncertainty

JEL Categories: R11, Q23, Q01, C61

Optimal Forest Strategies for Addressing Tradeoffs and Uncertainty in Economic Development under Old-Growth Constraints

Introduction

Alberta forest policy requires sustained yield management, which is implemented using harvest levels and growth rates as indicators. The sustained yield policy requires that harvest levels not exceed average timber growth (annual harvests equal mean annual increment); but it also implies maximizing cumulative harvest volume (because it is related to total employment), while maintaining an even flow of harvests (in order to maintain employment and regional economic stability) over some planning horizon. While this might be considered a decent rule of thumb, the five-year planning period militates against this practical approach to sustainability, partly because the planning period does not coincide with the forest rotation age and fails to take into account longer term factors affecting forest dynamics. The sustained yield policy flies in the face of uncertainty regarding growth and yield, natural disturbances (fire, disease and insect infestations), price volatility, climate change, and even shifts in forest policies themselves.

In Canada, many aboriginal people live in forest-dependent communities. They are subject to provincial forest policies that are short-sighted to say the least. Yet, the well being of aboriginal people spans a much longer period of time than that considered in forest management plans. In this paper, we focus on the consequences of this for the Little Red River Cree Nation (LRRCN) of northern Alberta, a forest-dependent community seeking to use forest resources as a springboard for economic development. We assume that the goal of the LRRCN is to develop and implement a forest management strategy that will ensure the community's economic sustainability, while preserving a forest landscape with features critical to cultural values and on-going traditional use of the forest. In this regard, preservation of old-growth forest is integral to

First Nations' beliefs: "The value First Nations people place on old-growth forests often reflects the fact that old growth is crucial to their continued existence. Old growth is inextricably bound to the culture of First Nations and this fact has to be recognized in management decisions, as there is simply no replacement for old growth forest for many aspects of First Nations culture" (Walkem 1994, p.3). But maintaining old growth is also a special consideration of management because of its contribution to biodiversity (Spies and Franklin 1996; Burton et al. 1999).

Aboriginal peoples have historically occupied portions of the Lower Peace River region in north-central Alberta and used these lands to support their culture and livelihood. Treaty No. 8 (1899) affirmed their right to use the resources within their historical area; the forest resources were legally meant to sustain traditional vocations and way-of-life. As part of this mandate, LRRCN was able to form its own forest management company, Little Red River Forestry (LRRF), and a company holding timber quota that can be sold to forest companies (Askee Development Corporation). In 1995, the LRRCN and the neighboring Tall Cree First Nation entered into a cooperative management planning agreement with the Alberta Government and Tolko Industries Ltd. (MOU 1996). In addition to the agreements with Tolko, a volume agreement was later signed between LRRCN and Footner Forest Products Ltd. (MOU 1999) to supply deciduous fiber to an oriented strand board (OSB) mill. Under these agreements, the companies compensate LRRF for the costs of harvesting and reforestation (although only coniferous stands are replanted as deciduous stands are left to regenerate naturally). As the quota holder for LRRCN, Askee Development Corporation also receives stumpage fees for harvested timber, with payments linked to product prices in a manner similar to that used by the Alberta Government to establish stumpage rates. However, the Alberta Government also collects stumpage on volumes harvested under these tenures so aboriginal people do not collect all of the resource rent.

Arguably, the federal and provincial governments may not lived up to the Treaty 8 obligations, as aboriginal people do not have access to the timber resources on all Treaty 8 lands. Rather, they are relegated to Forest Management Unit F23 (see Figure 1) and some other smaller parcels. Are these adequate to support the aboriginal community, as seems to be required under the Treaty? To examine the resource constraints facing LRRCN, we focus on management unit F23, for which comprehensive timber resource information is available. Other timber resources in the region are ignored as these are generally spoken for and would not significantly change the analysis in this paper.

The current strategy employed by LRRF to manage F23 was designed to satisfy the co-management agreements between LRRCN, the forest industry and government (MOU 1996, 1999). In this study, we take the aboriginal objectives to be economic development, community stability and employment, although we recognize that these goals are not mutually exclusive. Community stability is represented by even-flow timber supply and little downside variation in employment, while economic development is based on net returns from timber and silvicultural operations. Employment opportunities are found primarily in logging and silviculture, but these could be short term (allocating harvest towards the present) or long term.

To address the potential for economic development in a forest dependent community, we apply methods of multiple-objective decision-making using compromise and fuzzy programming methods. Following Krcmar and van Kooten (2007), we employ two outcomes from compromise programming to construct membership functions to be used in fuzzy programming. This avoids the need to solicit preference information from decision makers. The current research differs from the previous study in our focus on ecological outcomes as represented by the retention of old-growth forests, which are important to aboriginal people (as noted above). We begin in the next section with a formal description of the problem and the mathematical programming models that we use to answer policy questions concerning appropriate development strategies. This is followed by a more detailed discussion of compromise and fuzzy programming, and a section that presents the objective values under various forest management strategies. In essence, these determine the optimal tradeoffs available, with the fuzzy programming model in essence choosing the best compromise that is available. We then examine how employment and forest structure change over time under various management options. Some concluding observations complete the discussion.

Problem Description and Model Formulation

To address the economic, employment and timber supply objectives, we require indicators that provide objective measures for determining the extent to which objectives are satisfied. Thus, the economic measure consists of the net discounted returns to logging and timberland management more generally. For employment, we use both long- and short-term jobs in logging and silviculture (as natives are not currently employed in manufacturing). Long-term employment is measured as the cumulative employment over the entire planning horizon, while the short-term measure constitutes total employment over early periods only. Short-term employment will inevitably take precedence over long-term employment, although the latter better indicates the ability of a small community to survive on the timber resource base, assuming that non-forest related economic opportunities gravitate to larger centers.

The timber supply objective addresses concerns relate to providing adequate fiber for mills and satisfying contractual obligations with the Province and industry. This objective is typically accomplished through even-flow harvest over time. We couple even-flow harvest to the objective of maximizing cumulative harvest volume over the planning horizon, because this drives fiber supply as high as possible (thereby also enhancing employment in logging).

To examine the ability of local timber resources to support a sustainable economic base and perhaps economic development in forest-dependent native communities, we construct several strategic forest planning models. We used a 200-year planning horizon (2005 to 2205) divided into twenty decades, chosen according to the strategic planning practices in Canada. Specifically, we formulate models to determine harvest schedules that seek to achieve:

1. An economic objective of maximizing the cumulative discounted net returns from forestry;
2. Long- and short-term social objectives expressed as maximizing potential cumulative employment in forest operations over the (a) entire planning horizon and (b) first several periods;
3. Timber supply objectives that are formulated in terms of maximizing cumulative harvest volume over the planning horizon and minimizing maximum deviation of softwood and hardwood harvest flow; and
4. Ecological objectives expressed as preserving a certain amount of old growth over the whole planning horizon.

The harvest flow requirements address concerns related to adequate timber supply for mills, and thereby jobs and community stability. The output generated by employment in various forest activities is provided in Table 1. This relation between activities and jobs is assumed to remain unchanged over the planning horizon, which implies that we err on the side of higher employment as technological change will undoubtedly impact the relationships in Table 1.

There are two general approaches for defining targets on preservation of old-growth forests: One is to calculate the expected proportion of old growth based on the annual incidence of natural disturbance, especially fire; the other is to utilize the pattern present in the existing forest. We define old-growth targets using the latter approach. The extant proportions of old coniferous and deciduous forests in the study region are 34.6% and 6.8%, respectively, where old growth is defined as forests older than 100 years. Based on the initial inventory patterns and expected near-future regulations, we set the targets for preserving old coniferous and deciduous forests at 18% and 6% of their respective harvest areas. The timber management area comprises 42.5% of coniferous forest and 57.5% of deciduous forest. So an old growth target of 11.1% is calculated as a weighted average of the 18% and 6% targets for old coniferous and deciduous growth.

Harvest scheduling decisions are addressed in a non-spatial manner using model elements defined as follows. Forest attributes are aggregated into management strata, where a stratum m is defined by a combination of tree species, density, height and age. Let M denote the set of management strata, T the number of planning periods, $TS < T$ the number of periods considered for short-term employment, and $M_g \subset M$, $g \in G = \{conif, decid\}$ a partition of M by the coniferous and deciduous forest types g. We also introduce a set $M_g^{OG} \subset M$ that contains old growth strata of type g. The index sets, M_g and M_g^{OG}, allow us to address constraints and objectives specific to coniferous and deciduous old-growth forest types.

A decision variable $x = x_{mt}$ represents a forest management strategy expressed as the area (in ha) of stratum m harvested in period t. Denote the merchantable volume from a ha of stratum m harvested in period t by v_{mt}, the net discounted revenue per ha of stratum m in period t by nv_{mt}, and employment generated by harvesting a ha of stratum m in period t by e_{mt}. Let A_g be the area (ha) of forest type *g* available for harvest, $Vol_{g,t}(x) = \sum_{m \in M_g} v_{m,t} x_{m,t}$ the harvest volume (m^3) of type *g* in period *t*, and $OG_{g,t}(x) = \sum_{m \in M_g^{OG}} x_{m,t}$ the area (ha) of old forest of type *g* in period *t*. The conservation requirements are expressed in terms of a proportion of old growth relative to the total harvest area by forest type. A parameter ω_g denotes targets on the proportion of old growth of type *g* in each period over the planning horizon.

The objective functions can then be stated as:

Discounted net revenue from timber: $$N(x) = \sum_{m \in M} \sum_{t=1}^{T} nv_{mt}\, x_{mt}$$

Cumulative volume: $$V(x) = \sum_{m \in M} \sum_{t=1}^{T} v_{mt}\, x_{mt}$$

Long-term employment: $$EL(x) = \sum_{m \in M} \sum_{t=1}^{T} e_{mt}\, x_{mt}$$

Short-term employment: $$ES(x) = \sum_{m \in M} \sum_{t=1}^{TS} e_{mt}\, x_{mt}$$

Maximum harvest flow deviation: $$D_g(x) = \max_t |Vol_{g,t+1}(x) - Vol_{g\,t}(x)|,\ g \in G$$

Maximum old growth target deviation: $$OGd_g(x) = \max_t [\omega_g - OG_{g\,t}(x)],\ g \in G\,.$$

Here $Vol_{g\,t}(x) = \sum_{m \in M_g} v_{mt}\, x_{mt}$ is the volume of type *g* harvested in period *t* and $D_g(x)$ is maximum absolute difference between harvest volumes in subsequent periods. In the case of even flow, this difference is zero; in all other management strategies, it reflects variations in timber supply over time. If stability of timber supply is one of the management goals, $D_g(x)$ is to be minimized. Also, $OG_{g\,t}(x) = (100/A_g) \sum_{m \in M_g^{OG}} x_{m\,t}$ is the percent of old growth of type *g* preserved in period *t* and $OGd_g(x)$ is the maximum difference between the old-growth target and current old-growth values. If the old-growth targets are met, these differences are non-positive. Since preserving old growth is set up as an objective, $OGd_g(x)$ is to be minimized.

The multiple objective linear programming (MOLP) model can then be written as:

(N) Max $N(x)$
(V) Max $V(x)$
(EL) Max $EL(x)$
(ES) Max $ES(x)$
(D) Min $D_g(x)$, $g \in G$
(OGd) Min $OGd_g(x)$, $g \in G$
subject to $x \in F$

The feasible set F consists of all the technical constraints on land availability, forest management and silvicultural investment options, the initial and terminal timber inventories, and the non-negativity constraints.

Methods for Solving Multiple Objective Decision-making Problems

Unlike single objective programming where there is one best objective value, the solution to a multiple objective programming problem constitutes a set of vectors in the objective space, each of which represents different tradeoffs among the objectives. A feasible forest management strategy $x \in F$ is evaluated in terms of the MOLP model objectives or strategy outcomes, $f_q(x)$, $q \in Q$ = {N,V,EL,ES,DF, DOG}, where $f_N(x) = N(x)$, $f_V(x) = V(x)$, $f_{EL}(x) = EL(x)$, $f_{ES}(x) = ES(x)$, $f_D(x) = D_g(x)$ and $f_{OGd}(x) = OGd_g(x)$; it is highly unlikely that there exists a single management strategy that achieves the optimum value for each of the MOLP model's objectives.

Our approach combines compromise programming, which does not require any preference information, and fuzzy goal programming, which does require a priori articulation of preference information in cardinal form. In compromise programming, solutions are obtained by using the best possible outcome for each objective (the 'ideal') as a reference point. Compromise solutions are obtained by assuming decision makers' risk attitudes vary from risk neutral to highly risk averse, but there is a separate compromise solution for each assumption about risk attitude. Fuzzy goal programming, on the other hand, assumes that objectives need to be satisfied, but the extent to which any and all objectives are satisfied for a given management strategy is not known with certainty. The decision maker's preferences are needed to determine which strategy is somehow 'best'. The advantage of our approach is that the results of compromise programming can be used to construct the fuzzy preference function, thereby enabling one to obtain a 'true' compromise solution without the need to elicit preferences.

Compromise Programming

A widely applicable approach for solving multiple objective programming problems is distance metric optimization (Jones and Tamiz 2003). The distance metric framework was introduced in the context of compromise programming (Yu 1973) and includes several well-known methods, such as goal programming and the reference point method (Wierzbicki 1999; Romero et al. 1998). This approach seeks management strategies that minimize a distance metric between the achieved levels of objectives and a reference point in the objective space. The solution techniques differ in how they define the reference point and distance metric.

The compromise solutions to a multiple objective programming problem are found by minimizing the distance between the current objective vector and the ideal vector. The distance is formulated in terms of a metric in the objective space. In order to minimize a distance related to an L_π norm, all objective components have to be of the same dimension or dimension free. Rescaling could be done in different ways and it is often achieved by dividing the objective increment $f_q^* - f_q(x)$ by $f_q^* - f_{q*}$, where f_{q*} is the ideal value or upper bound of the objective q and f_{q*} is its nadir value or lower bound. Finding an exact nadir value may be difficult and it is usually approximated. In the case of maximizing the non-negative objectives $f_q(x)$, f_{q*} could be set to zero $f_{q*} = 0$, $q \in \{N, V, EL, ES\}$.

A family of L_π metrics that evaluate distances between points in the objectives space is $L_\pi(w,x) = \{\sum_{q\in Q} [w_q d_q(x)]^\pi\}^{1/\pi}$, $1 \le \pi \le \infty$, where $w_q > 0$, $\sum_{q\in Q} w_q = 1$, are weights representing relative importance of objectives, and $d_q(x) = \frac{f_q^* - f_q(x)}{f_q^*}$, $q \in Q$, is the normalized distance between the current and the best objective value, $f_q^* = \max_{x\in F} f_q(x)$, $q \in Q$. A solution x to the program

$$(CP_\pi, w) \qquad \min_{x\in F} L_\pi(w,x)$$

is referred to as the 'weighted compromise' solution to the MOLP model with respect to w and π. If all weights are equal, the solution is called the 'neutral compromise' solution. The choice of a distance parameter π ($1 \le \pi \le \infty$) expresses decision makers' attitudes toward simultaneous attainment of multiple objectives: $\pi=1$ represents a risk-neutral decision maker and $\pi=\infty$ a decision maker with extremely low risk tolerance (Ballestero 1997). For $\pi=1$, the problem becomes

$$(CP_1) \qquad \min_{x\in F} L_1(x) = \min \sum_{q\in Q} d_q(x)$$

and the solution algorithm searches for a strategy to minimize the weighted sum of $d_q(x)$. We refer to (CP_1) as the 'compromise min sum' or 'average' program. The associated strategy is referred to as the 'average strategy.'

As π increases, more weight is put on the largest $d_q(x)$. Ultimately, the largest distance completely dominates and, for $\pi=\infty$, becomes:

(CP$_\infty$) $$\min_{x\in F} L_\infty(x) = \min_{x\in F} \max_{q\in Q} d_q(x).$$

If $\lambda = \max_{q\in Q} d_q(x)$, then the program (CP$_\infty$) could be rewritten as:

min λ

(CP$_\infty$) subject to

$$d_q(x) = \frac{f_q^* - f_q(x)}{f_q^*} \le \lambda,\ q \in Q$$

$$x \in F$$

The solution in this case balances all objectives in terms of their normalized distances from the best values. We refer to (CP$_\infty$) as the 'compromise min max' or 'balanced' program, with an associated strategy called a 'balanced strategy.'

The metric L_π has an important practical feature for both $\pi=1$ and $\pi=\infty$, namely, that the model's linearity is preserved. This is important given the size and complexity of the programming model. However, the linearity assumption is not restricting because solutions for (CP$_\pi$) ($1<\pi<\infty$) lie between the solutions for (CP$_1$) and (CP$_\infty$).

The solutions of the compromise program (CP$_\pi$) are affected not only by the choice of parameter π, but also by the normalization method used for distance calculation. Solutions of (CP$_\pi$) with equal weighting coefficients are neutral compromise strategies with the corresponding outcomes located somewhere in the middle of the Pareto-optimal frontier. These solutions serve only to eliminate obviously bad strategies and are typically used as a starting point in a search for an acceptable solution.

Fuzzy Programming

In compromise programming, the application of the ideal as a reference point avoids having to determine the decision maker's preferences, thus providing objectivity to the solution process. The drawback is that it likely result in outcomes far from the desired targets. Different approaches have been suggested to fix this problem. The most widely used multiple objective decision making technique is goal programming, which requires information about desired objective targets. The preferred solution is defined as the one that minimizes a combined deviation from the set of targets. A difficulty with defining the targets is that they are not known exactly. In addition to this vagueness of the targets originating in the decision maker's preferences, there is an uncertainty resulting from environmental, economic and social conditions. Factors that may affect the targets include: (i) growth and yield as a function of weather, climate change and soil conditions; (ii) natural disturbances; (iii) forest policy changes (e.g., a shift from sustained yield to sustainable forest management); (iv) market conditions in the form of demand for forest products and likely fluctuating prices; (v) distribution between softwood and hardwood harvest and subsequent consequences for employment in silviculture and logging; and (vi) technological changes over the short and long terms. Not all of these factors affect each of the objective values and targets, but several of them contribute to imprecision of outcomes and goals.

In this paper, the vague targets are quantified using fuzzy numbers. A vague financial target related to timber benefits can be represented by the fuzzy number $N(x)$ whose satisfaction, or membership $\mu_{N(x)}$, is represented by a non-decreasing linear function:

$$\mu_{N(x)} = \begin{cases} 1, & if \quad N(x) > N_2 \\ \dfrac{N(x) - N_1}{N_2 - N_1}, & if \quad N_1 \le N(x) \le N_2 \\ 0, & if \quad N(x) < N_1 \end{cases}$$

Complete satisfaction of the economic target ($\mu_{N(x)} = 1$) occurs when $N(x)$ is greater than N_2, while satisfaction is less than 1 ($0 \le \mu_{N(x)} < 1$) when values are below N_2. There is no satisfaction whatsoever ($\mu_{N(x)} = 0$) if $N(x)$ is lower than N_1. The fuzzy number $N(x)$ is shown in Figure 1.

We represent a vague target of the maximum allowable deviation of harvests between periods by the fuzzy number $D(x)$ whose satisfaction (or membership) $\mu_{D(x)}$ is represented by a non-increasing linear function:

$$\mu_{D(x)} = \begin{cases} 1, & if \quad D(x) < D_1 \\ \dfrac{D_2 - D(x)}{D_2 - D_1}, & if \quad D_1 \le D(x) \le D_2 \\ 0, & if \quad D(x) > D_2 \end{cases}$$

The membership function for maximum allowable deviations in harvest, $D(x)$, is provided in Figure 2. Complete satisfaction ($\mu_{D(x)} = 1$) occurs when $D(x)$ is less than D_1, while satisfaction is below 1 when values are greater than D_1. There is no satisfaction at all ($\mu_{D(x)} = 0$) when $D(x)$ is greater than D_2.

We also assume that respective membership functions $\mu_V(x)$, $\mu_E(x)$ and $\mu_{E3}(x)$ of $V(x)$, $EL(x)$ and $ES(x)$ are linear and non-decreasing between V_1 and V_2, EL_1 and EL_2, and ES_1 and ES_2, respectively. With respect to old growth, we assume that the fuzzy number $\mu_{OG(x)}$ of $OGd(x)$ is linear and non-increasing between OGd_1 and OGd_2.

Combining the Compromise and Fuzzy Programming Approaches

To implement our mathematical programming approach, we define the objective targets using the outcomes of two compromise strategies. Denote by $f_q^{avg} = f_q(x^{avg})$ and $f_q^{bal} = f_q(x^{bal})$, $q \in Q$, outcomes of the average and balanced strategies, obtained as the solutions to the programs (CP_1) and (CP_∞), respectively. Denote further $f_q^1 = \min\{f_q^{avg}, f_q^{bal}\}$ and $f_q^2 = \max\{f_q^{avg}, f_q^{bal}\}$, $q \in Q$. Then, for example, the fuzzy goal for net present value will be determined as follows:

$$N_1 = \min\{N^{avg}, N^{bal}\} \text{ and } N_2 = \max\{N^{avg}, N^{bal}\}.$$

The novelty of this approach is the application of the two compromise outcomes for constructing the fuzzy goals or membership functions. The results from the fuzzy programming component of the model then determinethe final strategy whose outcomes are bounded by the average and balanced compromise outcomes.

Zimmermann (1978) was the first to use the max-min operator to solve multiple objective programming problems by maximizing minimum satisfaction over the set of feasible strategies:

$$\max\{\min[\mu_{N(x)}, \mu_{V(x)}, \mu_{E(x)}, \mu_{E3(x)}, \mu_{Dfl(x)}, \mu_{Dog(x)}]\} \text{ subject to } x \in F$$

Denote by $\alpha = \min[\mu_{N(x)}, \mu_{V(x)}, \mu_{E(x)}, \mu_{E3(x)}, \mu_{Dfl(x)}, \mu_{Dog(x)}]\}$ the overall satisfaction level of a strategy *x*. The fuzzy strategy *x* and its satisfaction are found by solving the following linear program:

Max α
Subject to:

(FGP)

$$\mu_{N(x)} = \frac{N(x) - N_1}{N_2 - N_1} \geq \alpha$$

$$\mu_{V(x)} = \frac{V(x) - V_1}{V_2 - V_1} \geq \alpha$$

$$\mu_{E(x)} = \frac{EL(x) - EL_1}{EL_2 - EL_1} \geq \alpha$$

$$\mu_{E3(x)} = \frac{ES(x) - ES_1}{ES_2 - ES_1} \geq \alpha$$

$$\mu_{D(x)} = \frac{D_2 - D(x)}{D_2 - D_1} \geq \alpha$$

$$\mu_{OGd(x)} = \frac{OGd_2 - OGd(x)}{OGd_2 - OGd_1} \geq \alpha$$

$$x \in F$$

Model Outcomes

The compromise model is implemented by minimizing $L_\pi(x)$ for π=1 and π=∞ over the set of feasible management alternatives. By examining only the π=1 and π=∞ solutions, we identify the entire set of preferred compromise management strategies.

Basic Strategies

The MOLP model is first solved for each of the objectives separately with all constraints that define the feasible set *F* in place, thereby enabling us to determine f_q^* for all $q \in Q$. That is, we optimize each objective function individually over the set of feasible strategies *F* and then compute the values of the remaining objectives for that solution. This is done using a series of linear programs coded in GAMS and solved using the CPLEX solver (Brooke et al. 1998). We refer to the outcomes of these programs as the optimal or 'ideal' objective values for the 'basic strategies.' They are indicated in bold along the main diagonal in Table 2. Each row of Table 2 consists of values of the individual objectives calculated for the corresponding basic strategy. Short-term employment refers to the cumulative employment over the first 30 years (three periods) of the planning horizon. The (D) strategy is obtained by maximizing the cumulative volume $V(x)$ under constraints of even-flow of both the softwood and hardwood harvests, thus providing the highest possible even-flow harvests over the horizon.

It is clear from Table 2 that the objectives conflict, including notably between attaining high net present value and cumulative harvest volume. For example, in order to attain the maximum net present value of C$0.605 billion, cumulative volume drops to 125.9 million m^3 while at the same time harvest flow deviates up to 17.8 million m^3 between consecutive periods. The strategy of maximizing short-term employment leads to the worst values for cumulative volume and long-term employment, plus it generates the highest deviation from even-flow harvest. In order to generate 6.139 million hours of employment over the first three periods, cumulative volume drops to 120.453 million m^3 relative to its ideal value of 154.835 million m^3 and long-term employment to its lowest value of 14.158 million hours, while leading to a 27.12 million m^3 difference between consecutive-period harvests.

The even-flow objective conflicts most with the financial and short-term employment objectives. Even-flow of harvest over the planning horizon is attainable only at huge financial costs and sacrifice in cumulative volume and both long- and short-term employment. The cost of the even-flow strategy calculated relative to the ideal net present value (N) of that strategy is C$0.358 billion, while the sacrifices of cumulative volume, long- and short-term employment amount to 22.7 million m^3 and 3.3 and 3.9 million hours, respectively.

Not surprisingly, the relation between preserving old growth and other objectives is asymmetric. Satisfaction of the old-growth target reduces the net present value, cumulative volume, and long- and short-term employment by 15.5%, 8.3%, 12.8% and 14.1%, respectively. On the other hand, achieving optimal net present value, cumulative volume, and long- and short-term employment implies large deviations (100%) from the old-growth target. This implies, however, that old-growth targets are realistically attainable.

Alternative Strategies: Compromise and Fuzzy Programming Outcomes

Since none of the management strategies that optimize a single objective function is acceptable, we seek a resolution to conflicts among multiple objectives by solving the (CP_π) program for π=1 and π=∞, depending on whether the L_1 (average) or L_∞ (balanced) metric is used. Outcomes of the 'average' and 'balanced' management strategies are provided in Table 3, along with the corresponding distance measures.

Under the average strategy, objectives attain between 74% and 100% of their corresponding best values. For the average strategy, net present value is 74% of its best possible value, while there is no deviation from the old-growth target (100% of its ideal). The outcomes of the balanced strategy range between 82% and 86% of the ideal. The net present value, cumulative volume, short-term employment and maximum harvest flow deviation objectives are 'balanced' for this strategy, but this balance constrains the remaining two objectives.

Outcomes to the fuzzy strategy are provided in Table 4 along with the fuzzy goals. The fuzzy strategy might be considered an improvement over the average ('min sum') and balanced ('min max') strategies of compromise programming simply because it provides an indication as to the level of satisfaction of the objectives, and does not require the elicitation of decision maker preferences. The level of satisfaction is 0.575, or, rather, the fuzzy strategy leads to a solution that has a membership value of 0.575 in the set 'all objectives have been optimized'. This is not a resounding level of satisfaction and is, rather, indicative of the difficulty in balancing these conflicting objectives.

The fuzzy strategy increases net discounted revenues (that can be used to fund economic development) over the average strategy but slightly less than under the balanced strategy. The sacrifice in terms of the old-growth target is very small – it achieves 91% of its ideal or best possible value. Short-term employment attains some 80% of its best possible value, while other objectives achieve more that 85% of their ideal values.

Dynamic Profile of Model Outcomes

Objective values are not always an adequate indicator of the usefulness of any given forest management strategy. Rather, it is helpful to examine the profile of outcomes over time. Here again, we expect the fuzzy strategy to provide the better option for decision makers, but we compare it to the two compromise strategies to determine if this is indeed the case.

Harvest Flow

Consider first annual harvests per period assuming that decision makers focus on only one objective at a time. As indicated in Figure 3, depending on which objective is chosen, harvests will be constant over time (minimize deviation of harvests between decades), take place almost entirely in the first thirty years of the planning horizon (maximize short-term employment), or assume a pattern of significant fluctuation over time (other objectives). In all cases except even-flow, harvests are projected to cease for a significant period beginning as early as the fourth decade. Cessation of harvests is avoided in the even-flow case only because harvest levels are depressingly low from an economic development point of view. Can a compromise or fuzzy strategy lead to outcomes that avoid this possibility?

Harvest levels for the compromise and fuzzy strategies are provided in Figure 4. The good news is that, even though harvest levels in each of the first decades are declining, the compromise and fuzzy strategies are able to delay total cessation of harvests to at least the fifth decade, while maintaining harvest levels above that under the current even-flow regime for at least thirty years. This suggests that, while a downfall in timber harvests is unavoidable, harvest levels might be sufficiently high that they could be relied upon as a driver of economic development for perhaps 20 to 30 years, after which the local economy must be diversified if the aboriginal community is to survive. This conclusion is reinforced by the models' projections concerning employment.

Employment Opportunities

Employment consists of jobs in both logging and silviculture, but not in processing because training levels and travel distances to mill locations are too great for LRRCN members. Employment in logging and silviculture are provided in Figures 5 and 6. Annual employment is lowest under the current even-flow management regime (Figure 5); it is so low compared to any of the other scenarios that this option is immediately ruled out. Employment is likewise unacceptably low if an attempt is made to maximize wealth or, with the exception of the first period, to maximize total harvest volume. Not surprisingly, the single-objective options that lead to the greatest employment per year are those that maximize long-term or short-term employment, with the former leading to the highest consistent levels of employment and the latter to the highest employment in the first several decades (with subsequent employment becoming insignificance during decades four through six before rising again thereafter).

The compromise and fuzzy solutions (Figure 6) provide reasonable alternatives to the single objective strategies, with the employment in each case following a similar pattern over time. Of the three, the average compromise strategy likely proves to be the 'best' option. Regardless of which is preferred, it is clear that, based on levels of employment over time, the multiple-objective compromise and fuzzy strategies are clearly preferred as employment never falls below 100,000 hours per year and, in the average compromise case, not even below about 200,000. Yet, based on a work week of about 35 hours, this implies that there are only some 110-125 full-time equivalent jobs in the forestry sector (excluding processing). Even assuming an unrealistically high multiplier of 2.5, since many indirect and induced jobs would be generated in the larger centers of the Province (see Natural Resources Canada 2006, p.30), this would lead to a maximum of some 300 jobs, perhaps sufficient to support a community of 1500 individuals.

Again, it is clear that employment in excess of 300,000 hours per year might be achieved in the early decades, suggesting that even a community of as many as 2500 might be supported by forest sector employment. However, this cannot continue and, unless economic diversification occurs, the future looks rather bleak if the First Nation hopes to support a community of 5000 or more people on the basis of forestry activities. In this regard, our conclusion is not too different from that of Leake et al. (2006) who find forest resource dependence to be an impediment to economic development.

Ecological Outcomes

When analyzing development strategies for an aboriginal forest-dependent community, it is necessary to balance the financial, timber and employment outcomes against ecological impacts. We use the distribution of old-growth forest over time as a proxy for ecological impacts. The old growth deviations obtained under different management strategies (presented in

Tables 2, 3 and 4) provide information about maximum deviations from the old-growth target. More detailed insights are obtained by analyzing old growth over time for different strategies. For each of the several management strategies, the distribution of old forest over time is plotted in Figures 7 and 8. The area of old-growth forest disappears entirely after the initial period under the management strategies that maximize discounted net revenue, cumulative volume or long-term employment. Under the short-term employment strategy, the amount of old growth remains near the target amount. It is interesting that Alberta's current sustained-yield forest policy (which requires even-flow harvest) does not preserve old growth in the long run. After the seventh decade, the amount of old growth drops below the target and never recovers (Figure 7).

The distribution of old-growth forest over time under alternative strategies is provided in Figure 8. A deep plunge in the relative area of old growth in the second period is followed by 'equilibrium' for the three strategies. The balanced and fuzzy strategies provide a stable level of old growth, but below the target amount. In contrast, the amount of old growth under the average strategy is at or above the target over the entire planning horizon. The alternatives strategies provide multiple socio-economic benefits, while at the same time making possible preservation of old forests over time.

Discussion and Conclusions

In this study, we sought to determine whether the forest resources available to one aboriginal forest-dependent community were sufficient to enable the community to develop or, at minimum, retain an economic base for its members. Treaty 8 obligations appear to require that the community have such rights, including forest resources that satisfy cultural needs (for which we used proportion of old-growth forest as a proxy measure).

We also looked at the use of compromise and fuzzy programming methods for analyzing conflicting objectives. The programming methods that we use are highly appropriate for the problem at hand. They indicate that not all objectives can be satisfied and, indeed, that the conflict among objectives is so great that, on a 0 to 1 scale, they can only be satisfied to a degree less than 0.6.

Strategies that rely on intensive harvest activities at the beginning of the horizon may enable the First Nation to achieve high financial returns without sacrificing future use of forest resources. For example, sustainable management with a lax harvest flow regime offers an opportunity for greater financial returns at the beginning of the planning horizon, which could be diverted for building technical and professional capacity to be used by current and future generations. Nonetheless, while this study sought to provide the best possible strategies that might be available for a timber-dependent aboriginal community in northern Canada, no management strategy is able to satisfy all of the technical, environmental and social/cultural constraints and, at the same time, offer aboriginal peoples forest-based economic development. Indeed, even if environmental and socio-cultural constraints were relaxed, economic development based on timber resources would not be possible without significant reductions in the population to be supported.

Acknowledgement

The authors wish to thank Dave Cole, Stephanie Grocholski and Ron Laframboise of the Little Red River Forestry (LRRF), who provided useful insights and data during an on-site visit and numerous telephone calls. Remaining errors are ours. We also want to thank SFM for funding support.

References

Ballestero, E., 1997. "Selecting the CP Metric: A Risk Aversion Approach." *European Journal of Operational Research* 97: 593-596.

Brooke, A., D. Kendrick, A. Meeraus and R. Raman, 1998. *GAMS. A User's Guide*. Washington, DC: GAMS Development Corporation.

Burton, P., D. Kneeshaw and D. Coates, 1999. "Managing Forest Harvesting to Maintain Old Growth in Boreal and Sub-boreal Forests." *The Forestry Chronicle* 75: 623-631.

Jones, D.F. and M. Tamiz, 2003. "Analysis of Trends in Distance Metric Optimization Modeling for Operations Research and Soft Computing." In T. Tanino, T. Tanaka and M. Inuiguchi (eds.) *Multi-objective Programming and Goal-Programming*. New York NY: Springer-Verlag. pp.19-26.

Krcmar, E. and G.C. van Kooten, 2007. Economic Development Prospects of Forest-Dependent Communities: Analyzing Tradeoffs using a Compromise-Fuzzy Programming Framework. REPA Working Paper 2007-03. Victoria: Department of Economics.

Krcmar, E., G.C. van Kooten and I. Vertinsky, 2005. "Managing Forests for Multiple Tradeoffs: Compromising On Timber, Carbon Uptake and Biodiversity Objectives." *Ecological Modelling* 185: 451-468.

Leake, N., W.L. Adamowicz and P.C. Boxall, 2006. "An Econometric Analysis of the Effects of Forest Dependence on the Economic Well-Being of Canadian Communities." *Forest Science* 52(5): 595-604.

MOU (Memorandum of Understanding), 1996. Little Red River Cree Nation – Tall Cree Nation and the Government of Alberta Cooperative Management Agreement. Albertat Department of Aboriginal Affairs, Edmonton, Canada.

MOU (Memorandum of Understanding), 1999. Little Red River Cree Nation – Tall Cree Nation and the Government of Alberta Cooperative Management Agreement. Alberta Department of Aboriginal Affairs, Edmonton, Canada.

Natural Resources Canada, 2006. *The State of Canada's Forests 2005-2006. Forest Industry Competitiveness*. Ottawa: Canadian Forest Service, Natural Resources Canada.

Romero, C., M. Tamiz, and D.F. Jones, 1998. "Goal Programming, Compromise Programming and Reference Point Method Formulations: Linkages and Utility Interpretations." *Journal of the Operational Research Society* 49: 986-991.

Spies, T.A. and J.F. Franklin, 1996. "The Diversity and Maintenance of Old-growth Forests." In Szaro, R.C. and D.W. Johnston (eds.) *Biodiversity in Managed Landscapes*. Oxford University Press, Oxford. UK, 296-314.

Walkem, A., 1994. *First Nations and Old Growth Values*. Spence's Bridge, BC: Cook's Ferry Band.

Wierzbicki, A.P., 1999. "Reference Point Approaches." In T. Gal, T.J. Stewart and T. Hanne, (eds.) *Multicriteria Decision Making: Advances in MCDM Models, Algorithms, Theory and Applications*. Dordrecht, NL: Kluwer Academic Publishers. pp. 9.1-9.39.

Yu, P.L., 1973. "A Class of Solutions for Group Decision Problems." *Management Science* 19: 936-946.

Zimmermann, H.-J., 1978. "Fuzzy Programming and Linear Programming with Several Objective Functions." *Fuzzy Sets and Systems* 1: 45-55.

Table 1: Output Generated by Employment in Various Forest Management Activities[a]

Logging	Output	Planting & Silviculture[b]	Output
Felling	50 m^3/hr	Tree planting	0.1 ha/hr
Skidding	48 m^3/hr	Stand tending	0.1 ha/hr
Delimbing	46 m^3/hr	Site preparation	1.0 ha/hr
Loading	100 m^3/hr		

[a] Includes employment in all categories: operators, administration and supervision.
[b] Assumes 2000 trees per ha.

Table 2: Outcomes of the Basic Strategies[a]

	Basic management strategies					
Objective values	(N)	(V)	(E)	(E3)	(D)	(OG)
NPV (10^6 \$)	**605.829**	462.388	483.907	382.925	247.858	512.049
	(100%)	(76.3%)	(79.9%)	(63.2%)	(40.9%)	(84.5%)
Volume (10^6 m^3)	125.949	**154.835**	154.565	108.195	132.128	141.921
	(81.3%)	**(100%)**	(99.8%)	(69.9%)	(85.3%)	(91.7%)
Long-term employment (10^6 hrs)	17.018	18.693	**19.117**	12.958	15.795	16.665
	(89.0%)	(97.8%)	**(100%)**	(67.8%)	(82.6%)	(87.2%)
Short-term employment (10^6 hrs)	5.472	5.066	5.426	**6.139**	2.258	5.275
	(89.1%)	(82.5%)	(88.4%)	**(100%)**	(36.8%)	(85.9%)
Max flow dev. (10^6 m^3)	17.836	26.697	25.779	27.138	**0**	22.848
	(34.3%)	(1.6%)	(5%)	(0%)	**(100%)**	(15.8%)
Max OG dev. (%)[b]	11.1	11.1	11.1	11.1	8.6	**0**
	(0%)	(0%)	(0%)	(0%)	(22.4%)	**(100%)**

[a] Best objective values are given in bold.
[b] OG target is 11.1% .

Table 3: Outcomes of the Compromise Strategies

	Compromise management strategies			
	Average (min Sum)		Balanced (min Max)	
Objective values	Outcome	% of ideal	Outcome	% of ideal
NPV (10^6 $)	447.465	73.9	494.202	81.6
Volume (10^6 m^3)	137.761	89.0	126.306	81.6
Long-term employment (10^6 hrs)	16.961	88.7	16.371	85.6
Short-term employment (10^6 hrs)	4.752	77.4	5.008	81.6
Max flow dev. (10^6 m^3)	2.695	90.1	4.997	81.6
Max OG dev. (%)	0	100.0	2.25	83.9

Table 4: Fuzzy Goals and Outcomes of the Fuzzy Strategy

	Membership Function Limits		**Fuzzy strategy**	
Objectives	worst	best	outcomes	% of ideal
NPV (10^6 $)	447.465	494.202	474.344	78.3
Volume (10^6 m^3)	126.306	137.761	132.894	85.8
Long-term employment (10^6 hrs)	16.371	16.961	16.713	87.4
Short-term employment (10^6 hrs)	4.752	5.008	4.899	79.8
Max flow deviation (10^6 m^3)	4.997	2.695	3.673	86.5
Max OG dev. (%)	2.25	0	1	91.0

Figure 1: The study area (in green) relative to the Province of Alberta

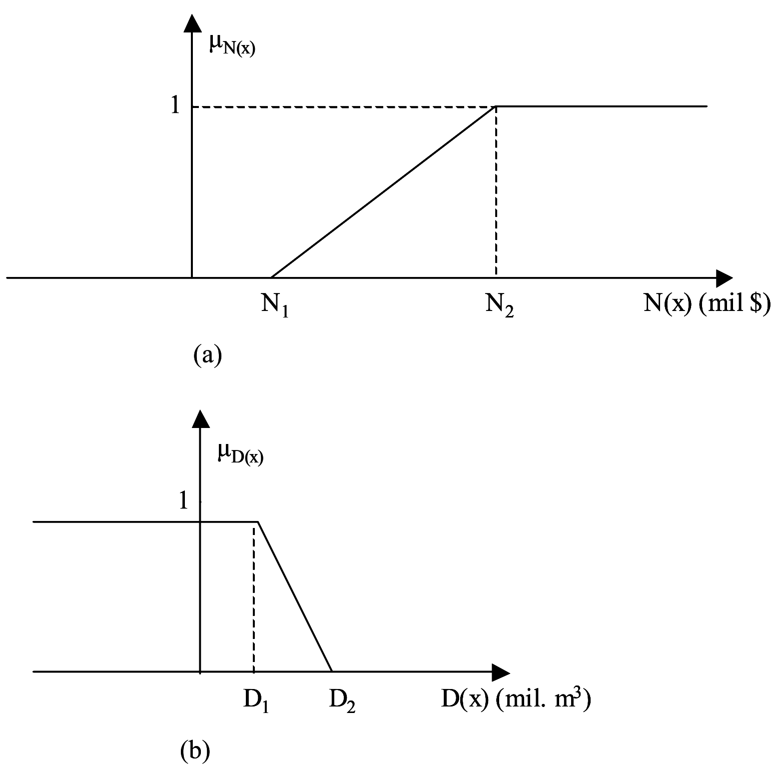

Figure 2: Membership function for (a) net discount returns, N(x); and (b) deviation in between period harvests, D(x).

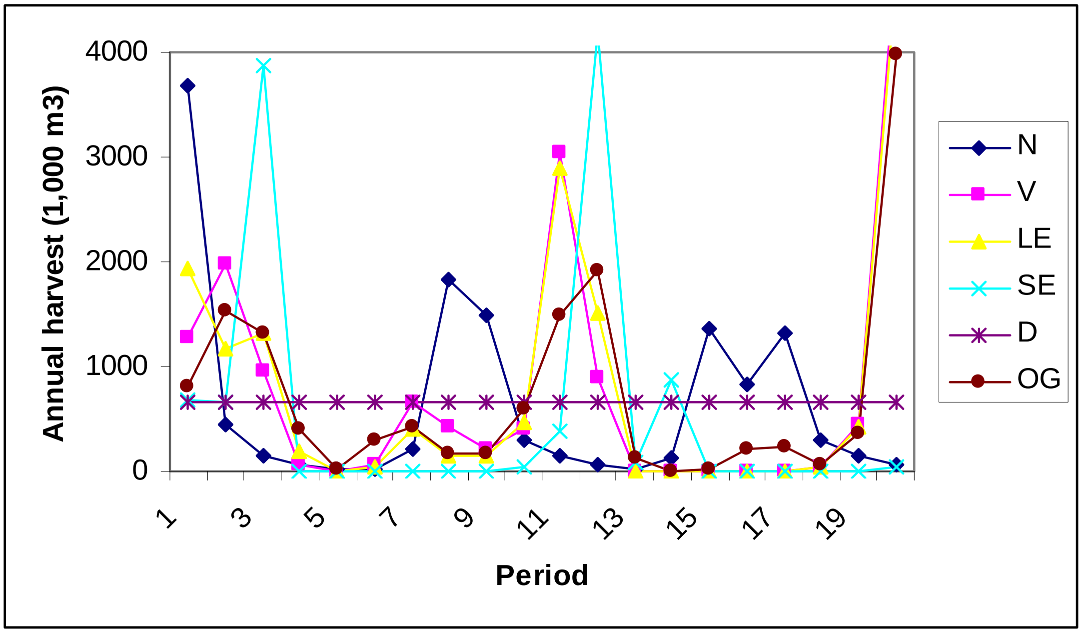

Figure 3: Harvest flow over the planning horizon for basic management strategies

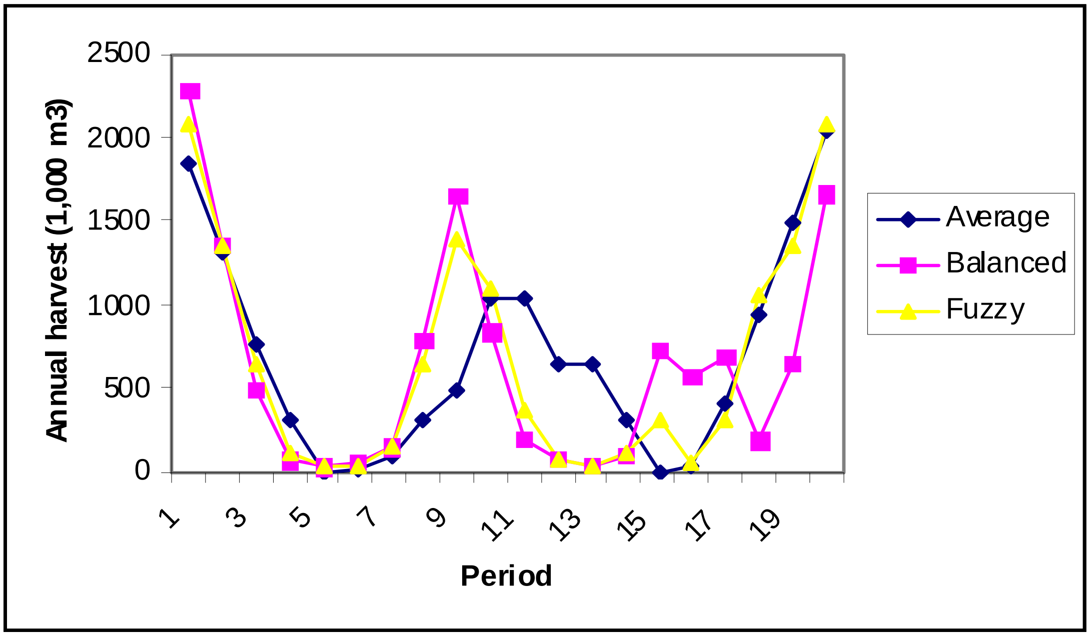

Figure 4: Harvest flow the planning horizon for alternative management strategies

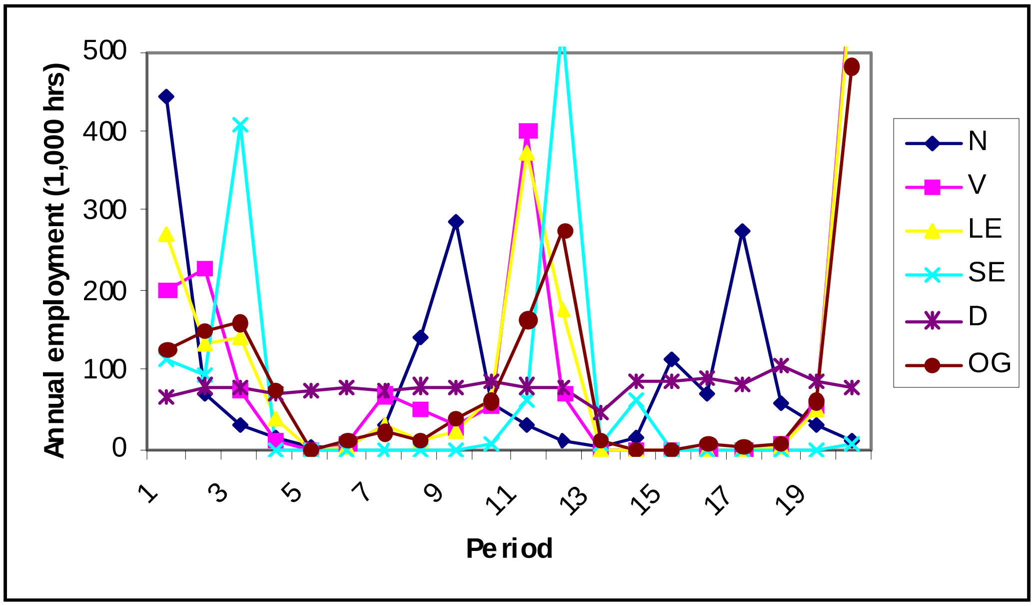

Figure 5: Employment over the planning horizon for basic management strategies

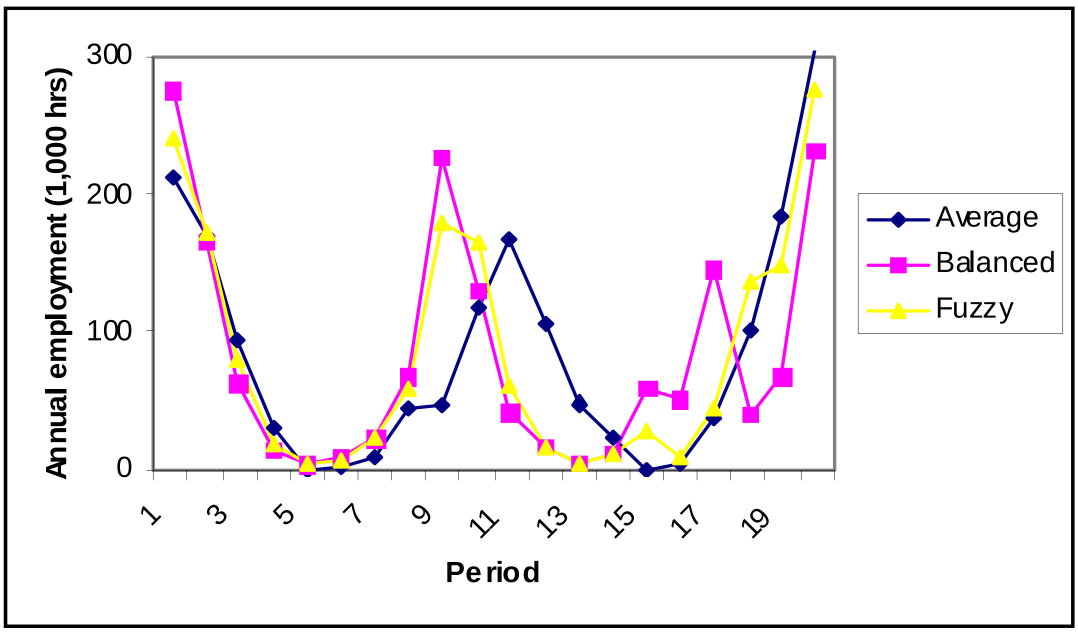

Figure 6: Employment over the planning horizon for alternative management strategies

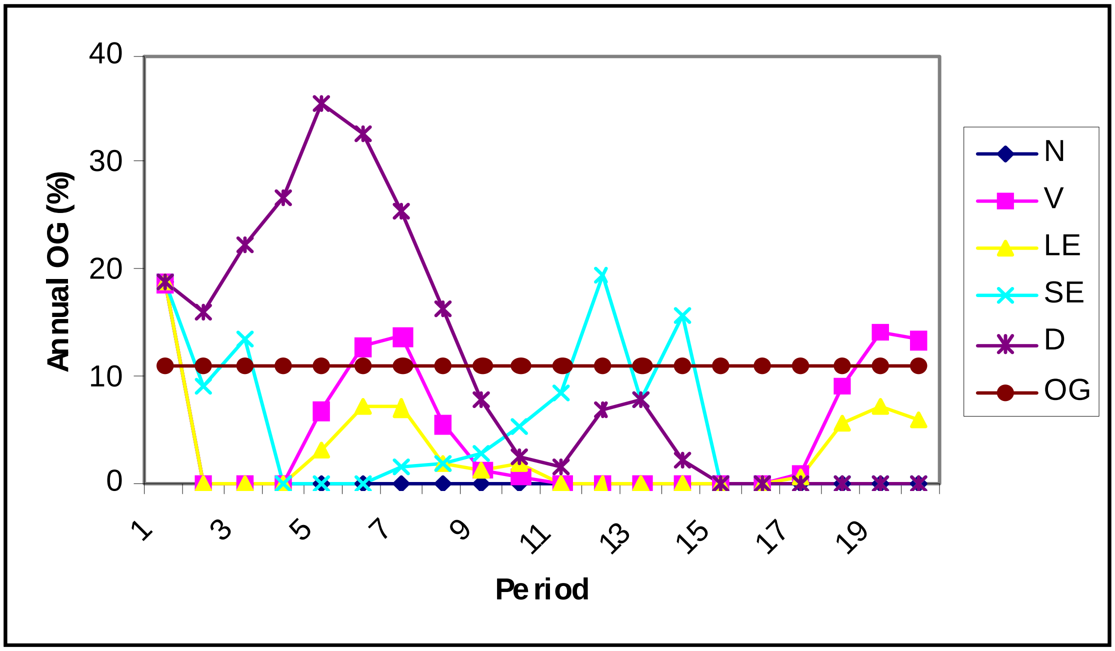

Figure 7: Old growth over the planning horizon for basic management strategies

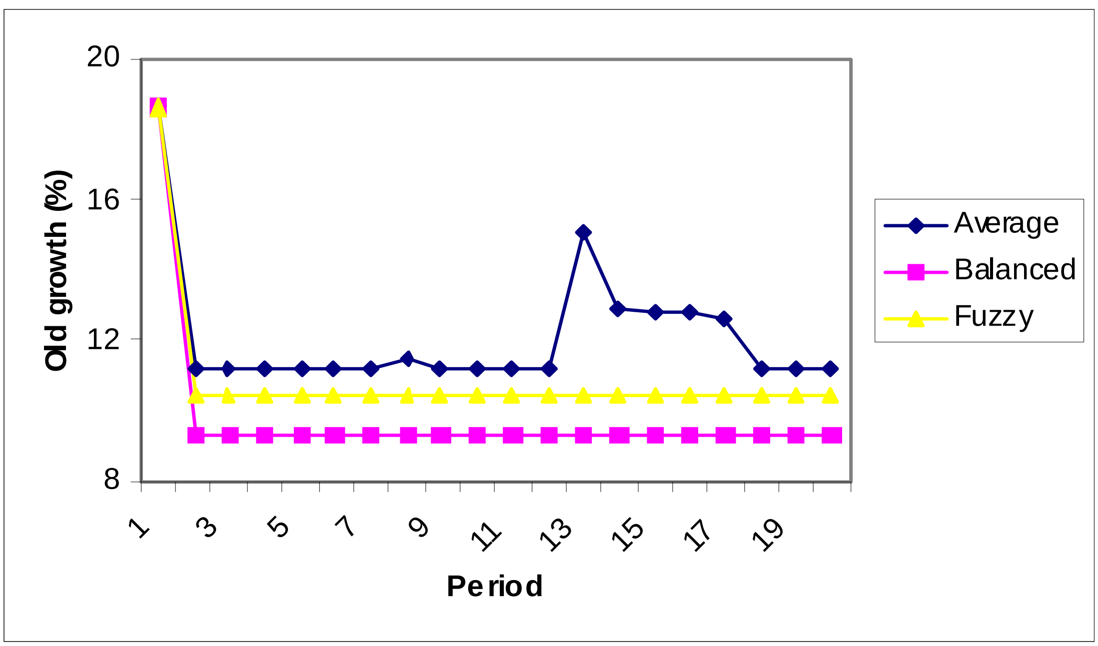

Figure 8: Old growth over the planning horizon for alternative strategies