ALLOCATION OF OUTDOOR RECREATION ACROSS A MINE WASTE SECTION

by

CLAYTON KARL ROUSE

B.Sc.(Agr.), The University of British Columbia, 1981

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

Department of Resource Management Science

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

September 1983

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Resource Management Science

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

Date September 9, 1983

ABSTRACT

The objective of this thesis was to test multi-attribute utility analysis as a method to help a planner allocate outdoor recreational activities across a mine waste section. The mine waste examined was a hypothetical 10 km x 10 km section. The physical features of the mine waste resemble the coal mine waste of the Elk River Valley in southeastern British Columbia. Nine activities were chosen for examination. These were trailbiking, four-wheel driving, snowmobiling, downhill skiing, cross-country skiing, snowshoeing, hiking, horseback riding and recreational vehicle camping. The activities were grouped into sixteen land uses. A resident of the Elk River Valley was chosen to represent the interests of each activity user group. These interests were described as preferences for attributes of the mine waste. Multi-attribute utility analysis was used to develop the nine representatives' preference structures for the mine waste attributes. The results of the analysis were used to develop an objective function which measured how well a recreation plan for the mine waste satisfied the user groups' interests. A computer program was developed to evaluate the objective function. Using this program, a recreation land use plan was produced for the hypothetical mine waste section which maximized the value of the objective function.

Two limitations of the multi-attribute utility analysis were identified in this study. The first was the large time commitment required by user groups to structure their preferences for the mine waste attributes. This resulted in user groups becoming tired with the preference assessment procedure. The

second limitation was that the assessed preferences did not take into account the cost to the user groups of obtaining each attribute level. These two factors may influence user groups' preference structures for the mine waste attributes.

Accepting these limitations, multi-attribute utility analysis in this study was successful in breaking the large outdoor recreation planning problem into smaller problems where user groups' objectives and associated attributes were identified. The analysis enabled user groups to systematically articulate and understand their preferences for each of the attributes. Using this information, a planner was able to isolate agreements and differences in the preferences of the user groups, which provided a firm basis on which to begin a process of conflict resolution. A planner is then able to incorporate these results with other information on the mine waste development area to develop a feasible outdoor recreation land use plan.

Thesis Supervisor

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

Figure | Page

ACKNOWLEDGEMENT

I gratefully acknowledge my great debt to my committee for their support in making this thesis possible.

I am very grateful to Dr. L.M. Lavkulich, my thesis supervisor, for his guidance, advice and resources made available to me throughout this thesis. I am also very grateful to Dr. A.D. Chambers for his guidance and advice throughout the study. I express my gratitude to Dr. A.H.J. Dorcey for his guidance during the thesis and helpful suggestions towards making it a success. I also express sincere appreciation to Dr. R. Hilborn for introducing me to the methods used in this thesis and his patience, availability and devotion to the study.

Aside from my committee, I would like to express my gratitude to Mr. John Flinn who faithfully assisted with the computer programming in this thesis and to Mrs. Joyce Hollands for her support and advice. I would like to express my appreciation to the residents of the Elk River Valley, B.C., who participated in the assessments in this study for their patience and interest. I am also very grateful to Dr. J. Dick and Ms. L. Bailey of the Planning Branch, Ministry of Environment in Victoria, B.C., for their time and resources. Finally, I would like to thank the personnel of the companies, clubs, associations, agencies and interest groups, too numerous to mention here, who made information available to me during this thesis.

CHAPTER 1

STATEMENT OF THE PROBLEM

1.1 Introduction

While an extraordinary amount of technical data and information has been compiled on the biological reclamation of surface mined lands, there has been little effort in Canada to analyse the existing information in relation to other land uses.

Surface mining temporarily alters the topography of an area, displacing all vegetation and leaving the area in long, successive parallel ridges or piles of fractured rock and soil material. This land base can be utilized for both motorized and non-motorized outdoor recreational activities. On natural areas, ecological damage from motorized recreation can be extensive (Baldwin and Stoddard 1973, Bury et. al. 1976, Geological Society of America 1977, Webb et. al. 1977, Sheridan 1979); however, mine waste has already been drastically disturbed and ecological damage by motorized recreation is minimal except that caused by dust, noise and vehicle exhaust fumes. Non-motorized recreational activities such as cross-country skiing, hiking, horseback riding and snowshoeing may also be conducted on the mine waste base, for such areas usually offer challenging terrain and are very often located in mountainous regions which afford spectacular views. Many surface mined areas in the United States have been developed for off-road vehicle use, camping, picnicking and other recreational activities (Higgins 1973, O'Neill 1973, Timmons 1973, U.S.D.A. 1973).

When planning a mine waste area for outdoor recreation, a planner must decide where to locate various recreational activities. He must incorporate into his decision, information on factors such as cost of development, projected use of the mine waste, adjacent development projects, ownership, environmental impacts from development and recreational user groups' interests.

This thesis is concerned with how a planner develops a recreation plan which satisfies the most recreational user groups' interests. It is assumed in this study that a user group's interests can be described by its preferences for attributes of the mine waste.

In this thesis, a decision maker is defined as a representative of a recreational user group, whose preference structure for mine waste attributes is assumed to be representative of the user group.

A planner will almost always find that although a decision maker prefers one course of action when one mine waste attribute such as slope is considered, he will prefer another course of action when a different attribute is considered. Seldom is one course of action preferred for every attribute. A planner, therefore, must find a method to analyse these attribute tradeoffs to develop the recreation plan.

There are two main sets of methods for addressing the attribute tradeoff issue. One set requires a decision maker to informally weigh tradeoffs in his mind. The other set of methods requires a decision maker to formalize explicitly his preference structure for attributes and uses this to evaluate attribute tradeoffs.

To date, formal methods have not been extensively applied to mine waste recreation areas. In this study, the formal method of multi-attribute utility analysis developed by Keeney and Raiffa (1976) is used to address the tradeoff issue between mine waste attributes. There are nine recreational activities examined in this study. The activities are grouped into 16 land uses. The mine waste examined in this study is a hypothetical 10 km x 10 km section. The physical features of the mine waste resemble the coal mine waste of the Elk River Valley in south-eastern British Columbia. The 10 km x 10 km section is divided into 100 grid squares. Each grid square is assigned one recreation land use. The mine waste section is illustrated in Figure 1.

The Elk River Valley, illustrated in Figure 2, has characteristically hot summers and mild to severe winters with heavy snowfall at elevations near 2300 metres (B.C. Research 1976; 1980). There are currently three surface coal mining companies actively operating in the study area. These are B.C. Coal Limited, Fording Coal Limited and Crowsnest Resources Limited. Three towns in the Valley accomodate the mines' employees and their families. These are Fernie, Sparwood and Elkford. The waste rock from these coal mines has present and future outdoor recreation potential, and for this reason, the Elk River Valley was chosen for study.

There are 9 decision makers in this study. Each decision maker is a resident of the Elk River Valley who frequently participates in one of the outdoor activities examined in this study. Multi-attribute utility analysis is used to assess preference structures of these decision makers for attributes of the mine waste in this study. The results of the analysis are used in a computer program to help a planner best allocate outdoor recreation activities to the mine waste section.

1.2 Objective of the Study

The objective of this study is to test multi-attribute utility analysis as a method to help a planner best allocate outdoor recreational activities across a mine waste section.

1.3 Organization of the Study

The study is divided into two parts:

(i) Part 1 - Multi-attribute utility analysis;

(ii) Part 2 - Maximization of the objective function developed from multi-attribute utility analysis in Part 1.

Part 1 begins with a literature review of multi-attribute utility analysis development and applications. An overview of Keeney and Raiffa's (1976) multi-attribute utility analysis methodology used in this study is then presented. The methodology of the multi-attribute utility analysis is then presented starting with a discussion of how the recreational activities were chosen for this study, followed by discussions on choice of the recreational activity attributes and determination of their numerical ranges. The methodology for assessing attribute utility functions is then presented, followed by discussions of the assessment procedure's assumptions, the strengths and weaknesses of the procedure itself and on decision makers' attitudes towards risk. The methodology for verifying independence properties of attributes is then presented, followed by the methodology for assessing attribute scaling constants. A discussion of the strengths and weaknesses of the scaling constant assessment prodecure is then presented followed by methodologies for choosing a multi-attribute utility function and development of an equation to scale the activities. Part 1 is concluded by a presentation and discussion of the results of multi-attribute utility analysis in this study.

Part 2 of the study consists of using a computer program, which evaluates the objective function developed in Part 1, to maximize the objective function value of alternative recreation plans on the hypothetical mine waste section. Part 2 begins with an introduction to the methodology to evaluate the objective function followed by a methodology to group the recreational activities examined in this study into land uses. A more detailed discussion on bounding the mine waste section is then presented, followed by methodologies to calculate attribute levels from the mine waste section. A discussion of the methodology for evaluating the mine waste section is then presented. Part 2 is concluded by a presentation of the results of the mine waste recreation plan evaluation, followed by a discussion of the results.

Fig. 1. Mine waste section examined in this study.

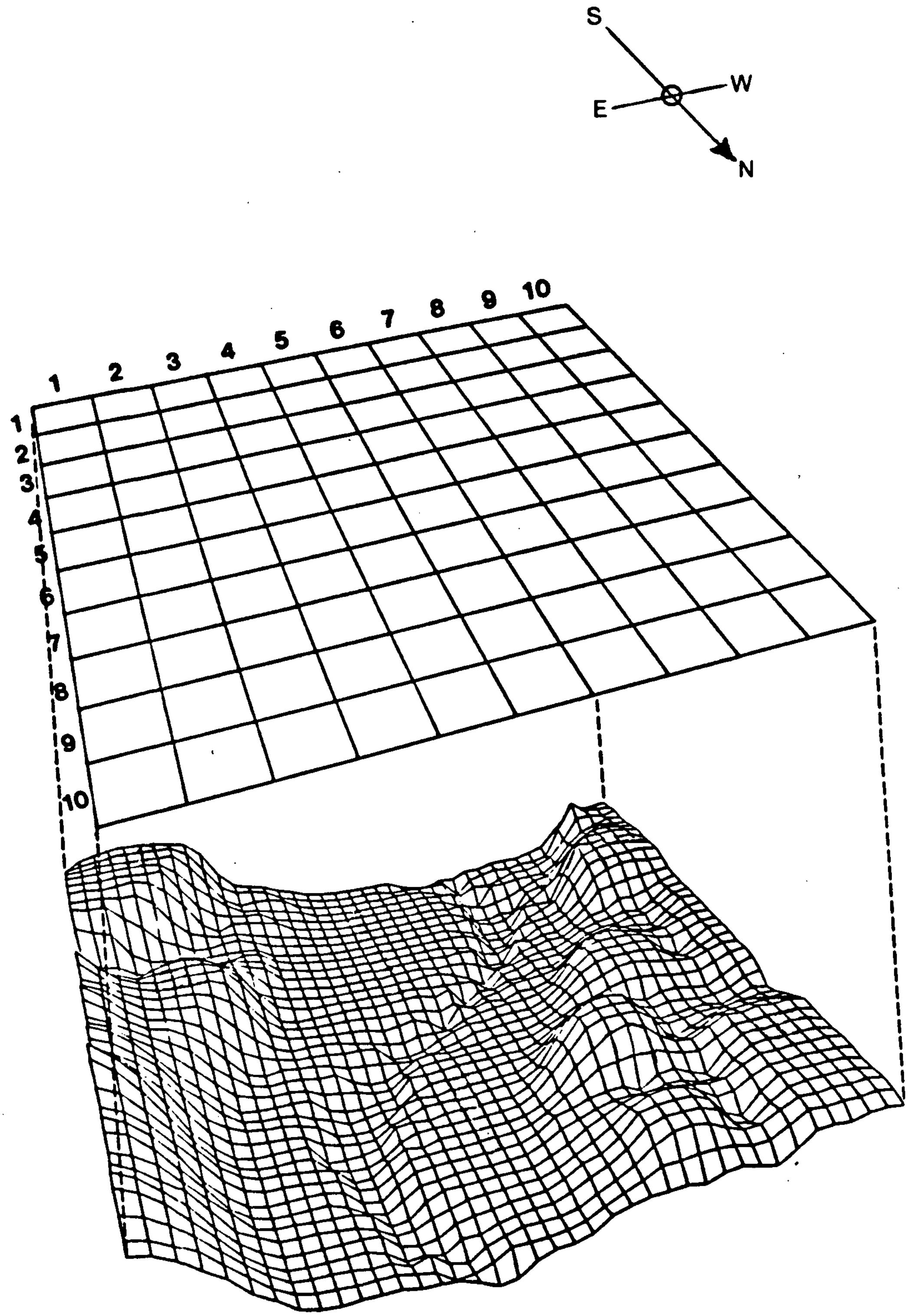
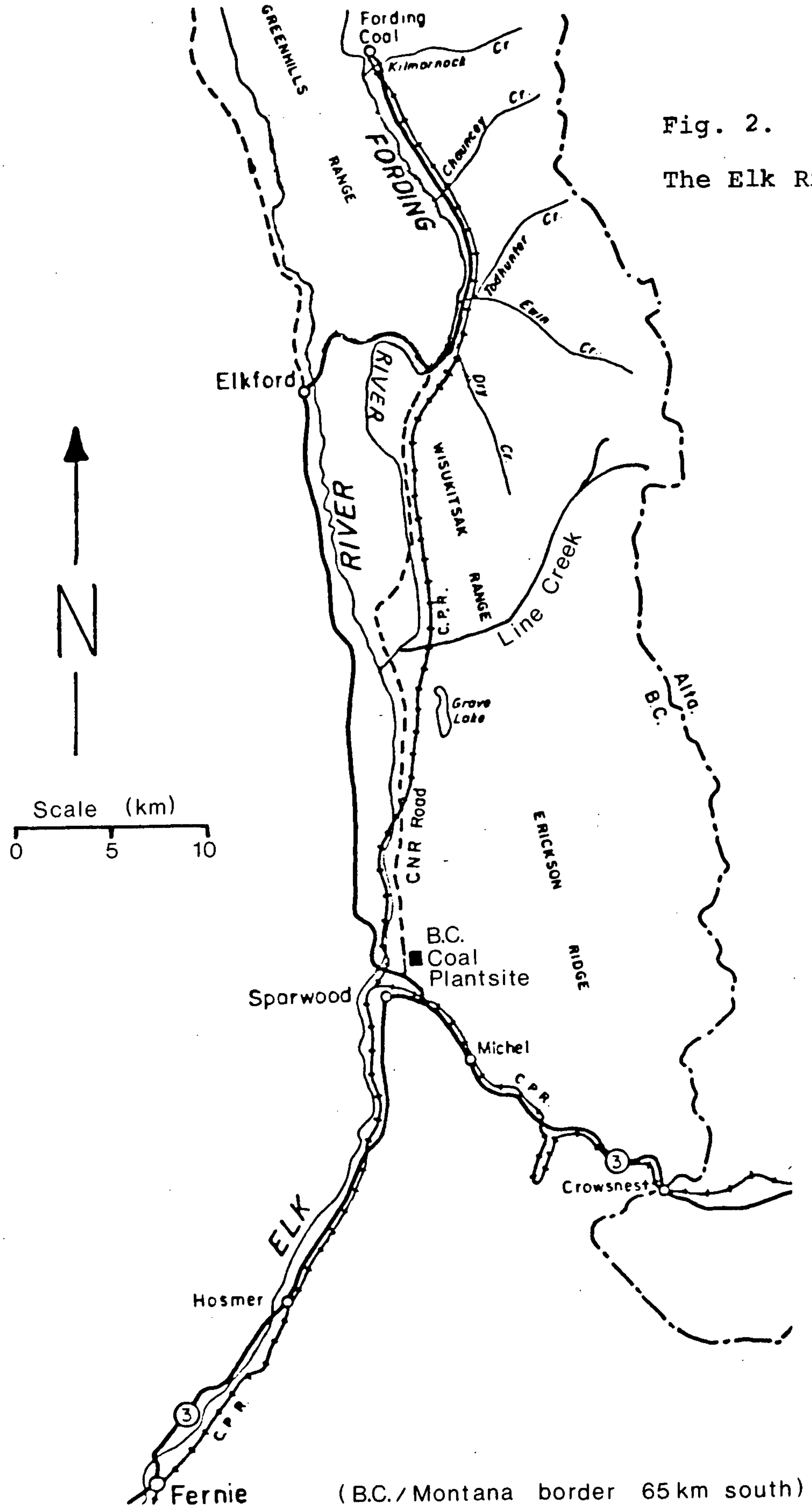


Fig. 2.

The Elk River Valley.



CHAPTER 2

METHODOLOGY - PART 1

Multi-Attribute Utility Analysis

2.1 Literature Review of Multi-Attribute Utility Analysis Development and Applications

The use of utility theories in decision problem analysis has become popular in recent years (Fishburn 1966). Among these theories, the von Neumann-Morgenstern (1947) expected utility theory is one of the more popular theories (Fishburn 1964, Larsson 1977). Ramsey (1931, as cited by MacCrimmon and Larsson 1975) and later von Neumann and Morgenstern (1947) developed a set of assumptions or axioms of "rational behaviour" that, when satisfied by a decision maker, would make it possible to empirically assess a utility function for him. Furthermore, von Neumann and Morgenstern showed that if the assumptions were accepted, a decision maker would be compelled to choose the maximization of expected utility as the decision criterion in risky situations (Fishburn 1964).

In recent times, multi-attribute utility models or functions based on the von Neumann-Morgenstern axioms have been developed and used to assess the utility of alternative courses of action with multiple attributes (Lee 1971, Keeney 1972a, Huber 1974). Keeney and Raiffa (1976) have developed a multi-attribute utility analysis based on the axioms. This multi-attribute utility analysis has been successfully applied in research studies on water resource project evaluation (Shih and Dean undated, as cited by Morris 1971), analysing patient management decisions as applied to cleft palate (Krischer 1974), forest pest management (Bell 1975, as cited by Keeney and Raiffa 1976), salmon management on the Skeena River (Hilborn and Walters 1977), siting energy facilities (Keeney 1980) and determining salmon coho policy in Oregon (Walker 1982).

Practical applications of the multi-attribute utility analysis have been conducted in developing the major airport facilities of the Mexico City metropolitan area (Keeney 1973), structuring corporate preferences for multiple objectives (Keeney 1975), evaluating environmental impacts at proposed nuclear power plant sites (Keeney and Robillard 1977) and for evaluating proposed pump storage facilities for power generation (Keeney 1979).

Keeney and Raiffa's multi-attribute utility analysis is used in this study.

2.2 Overview of Multi-Attribute Utility Analysis

Multi-attribute utility analysis in this study is composed of the following steps:

(i) Choice of the recreational activities;
(ii) Choice of recreational activity attributes;
(iii) Determination of numerical ranges of the attributes;
(iv) Assessment of attribute utility functions;
(v) Verification of independence properties of attributes;
(vi) Assessment of scaling constants for the attributes;
(vii) Choice of a multi-attribute utility function;
(viii) Development of an equation to scale the recreational activities.

2.3 Choice of Recreational Activities

In 1980, the Ministry of Environment Planning Branch conducted a study to determine current levels of participation in land and water-based recreational activities by Southeast Coal Block residents (Nessman and Bailey 1981). The following land-based recreational activities were identified in their study:

(i) Trailbiking (TB)
(ii) Four-Wheel Driving (4x4)
(iii) Snowmobiling (SNOW)
(iv) Downhill Skiing (DOWN)
(v) Cross-Country Skiing (X-C)
(vi) Snowshoeing (SHOE)
(vii) Hiking (HIKE)
(viii) Horseback Riding (HORSE)
(ix) Summer Motorized Camping (CAMP)

This classification is used in this study.

2.4 Choice of Recreational Activity Attributes

An attribute is a characteristic or property that contributes to the success or failure of a recreatonal activity (Holloway 1979). When discussing attributes, Keeney and Raiffa (1976) state the following:

> *An attribute should be both comprehensive and measurable. An attribute is comprehensive if, by knowing the level of an attribute in a particular situation, the decision maker has a clear understanding of the extent that the associated objective is achieved. An attribute is measurable if it is reasonable both (a) to obtain a probability distribution for each alternative over the possible levels of the attribute - or in extreme cases to assign a point value - and (b) to assess the decision maker's preferences for different possible levels of the attribute, for example, in terms of a utility function or, in some circumstances, a rank ordering.*

Attributes which are both comprehensive and measurable chosen for the nine recreational activities are presented and discussed in Appendix 1.

2.5 Determination of Numerical Ranges for the Attributes

After the attributes have been chosen, the numerical ranges for them are assessed. This is accomplished by assessing the highest and lowest possible values of the attributes that a decision maker will encounter on the mine waste area.

The range of travel time for all the attributes was chosen to be between 0 and 4 hours. The 10 km x 10 km grid section allows a maximum travel time of 23.6 minutes to and from any area within the section; however, the location of the town can be outside the section and from the author's experience in the Elk River Valley, 4 hours would be the maximum travel time the residents of the Elk River Valley would drive to a recreational area within the Valley.

The range of length of trail was chosen to be between 0 and 20 km because 20 km is very close to the trail length for 9 grid squares (18.4 km) which is the maximum number of grid squares the objective function algorithm in Part 2 will examine at any one time to calculate trail distance.

The range of average slope of an area was chosen to be between 0 and 50 percent for all the activities except for four-wheel driving and downhill skiing which have slope ranges between 0 and 60 percent and 0 and 120 percent respectively. Although some average slopes encountered in the Elk River Valley are in excess of 120 percent, the chosen maximum slope values are realistic limiting values for the activities; therefore, any values of slope over these maximum values are assumed to have a corresponding utility of zero.

The average winter snow depth of the Elk River Valley ranges from 0 to 244 cm or 8 feet. These ranges were chosen for the winter activities.

The ranges of distance to a drinking water source for the activities hiking and camping were chosen to be between 0 and 10 km because 10 km is the maximum length or width of the 10 km x 10 km grid section.

2.6 Assessment of Attribute Utility Functions

In this study a recreational activity is composed of several attributes. An alternative is defined as an amount of an attribute. For example, the range of an attribute X may be from 0 to 10. An alternative may be any level from 0 to 10. for instance, 6 or 7. An outcome is defined as a choice among several alternatives. For example, assume a decision maker is faced with a gamble where he has a chance of receiving alternatives 0 or 10 with equal probability. Whichever alternative he receives, 0 or 10, is the outcome of the gamble.

The von Neumann-Morgenstern expected utility theory states that for a given set of alternatives, $(A_o, A_1, A_2 \ldots A_n)$, with preference rankings $A_o \prec A_1 \prec A_2 \prec A_n$, a decision maker can specify a probability p such that the following outcomes are indifferent:

(i) Certain outcome (receive A_i for sure)

(ii) Risky outcome (a) a $p(A_i)$ probability of receiving A_n (best possible alternative)

(b) a $1-p(A_i)$ probability of receiving A_o (worst possible alternative)

where $U(A_n) = 1$ and $U(A_o) = 0$ U = utility.

The choice between the outcomes can be represented by Figure 3.

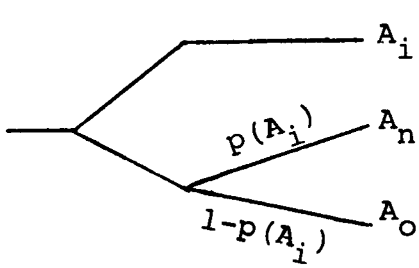


Fig. 3 . Choice between two outcomes.

The expected utility of the risky outcome is

$$pU(A_n) + 1\text{-}pU(A_o).$$

If the outcomes are indifferent, the utility of the certain outcome is equal to the expected utility of the risky outcome. The choice between the two outcomes is called a lottery. The risky outcome is called a gamble. The value A_i where the gamble and the certain outcome are indifferent is called the certainty equivalent of the lottery.

The method used in this study for assessing attribute utility functions is the fixed probability method (Keeney and Raiffa 1976). It is based on the von Neumann-Morgenstern theory. The fixed probability method fixes the values of p and 1-p at 0.5. The expected utility of the gamble is

$$0.5U(A_o) + 0.5U(A_n).$$

Different gambles are set up in lotteries with expected utilities of 0.25, 0.5 and 0.75 and certainty equivalent values are then assessed. The utility function can be drawn by plotting the certainty equivalent values on a graph as illustrated by the example in Figure 4.

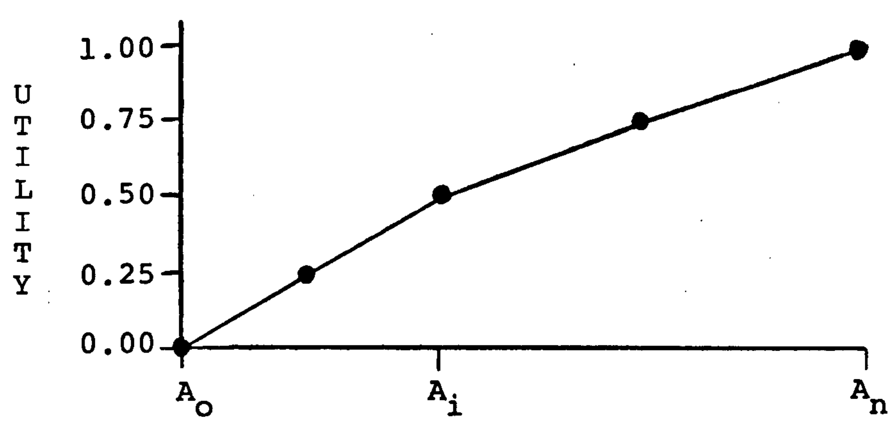


Fig. 4. Graph representing a utility function.

The fixed probability method employs an interview technique based on that used by Keeney (1977b) and Keeney (1980) for assessing decision maker's attribute utility functions.

The interview procedure begins with the assessor familiarizing the decision maker with the terminology and motivation for the assessment. The concept of utility theory should be explained in simple terms so the decision maker realizes the purpose of assessing his preference structure for attributes and is motivated to think hard about his feelings concerning various outcomes (Keeney and Raiffa 1976). An example of dialogue in this study to familiarize the decision maker with the terminology and motivation for the assessment is presented in Appendix 2 for the activity horseback riding.

The next step in the interview procedure is for the assessor to ask the decision maker a series of simple hypothetical questions using the fixed probability method to obtain the decision maker's preferences over attribute levels resulting in a utility function (Keeney 1977b). An example of dialogue used in this study to assess the utility function for the horseback riding attribute travel time is presented in Appendix 3.

2.61 Assumptions of the Assessment Procedure

The fixed probability method of attribute utility function assessment is based on the axioms of the von Neumann-Morgenstern expected utility theory. If a decision maker accepts these assumptions, then it is possible to assign a single real number called a utility in the set of possible outcomes of lotteries involving attribute levels. From these numbers, the expected utility can be calculated for any choice considered by the assumptions. A decision maker is then compelled to prefer the outcome with the highest expected utility and to be indifferent between outcomes with equal expected utilities. The following discussion presents the von Neumann-Morgenstern axioms with corresponding criticisms.

Symbolism

$\succ$ represents "preferred to"

$\prec$ represents "less preferred than"

$\sim$ represents "indifferent to"

$[A_1;A_2]$ represents a 50-50 gamble between alternatives A_1 and A_2

"p" represents a probability between 0 and 1

Assumption 1

For any two alternatives A_1 and A_2, one and only one of the following relations is true:

$$A_1 \succ A_2, \qquad A_2 \succ A_1 \qquad \text{or} \qquad A_1 \sim A_2$$

This assumption implies that any two alternatives are directly comparable. Either one is preferred to the other or the two are equally preferred.

This assumption has been criticized by Lee (1971) on the grounds that realistically, when outcomes are valued about equally, a decision maker believes he prefers A_1 at one moment, A_2 the next moment and shortly thereafter cannot make up his mind. Is he really indifferent between A_1 and A_2? If this is true, then one of these three relations cannot be true unless referring to a moment in time. Because a decision maker cannot demonstrate preference inconsistency in a "moment", the assumption cannot be tested empirically. Many researchers believe this uncertainty is a factor which shapes the utility function and not outside of it. Any increased aversion towards risk will make the utility function more concave; any enjoyment of gambling (risk seeking, discussed in Section 2.63) will make the utility function more convex (Kauder 1965).

Assumption 2

Given the three alternatives, A_1, A_2 and A_3, if

$$A_1 \succ A_2 \quad \text{and} \quad A_2 \succ A_3, \quad \text{then} \quad A_1 \succ A_3.$$

This assumption states that the preference relation ($\succ$) is transitive; if a decision maker prefers A_1 to A_2 and A_2 to A_3, then he will prefer A_1 to A_3.

Luce and Raiffa (1957) state that Assumption 2 can be criticized because it does not conform to behaviour that results when decision makers are presented with a sequence of paired comparisons. Decision makers only have vague likes and dislikes and can err in reporting them; however, when decision makers are made aware of these intransitivities, they will often realign their responses to a transitive ordering.

Assumption 3

$$\text{If } A_1 \succ A_2 \quad \text{then} \quad A_1 \succ \left[pA_1 ; (1-p)A_2 \right]$$

for any p, $0 \angle p \angle 1$.

This assumption states that if A_1 is preferred to A_2, then a decision maker prefers the certain outcome A_1 to a gamble which could give him A_1 at best or might give him a less valued outcome A_2.

Assumption 4

$$\text{If } A_1 \prec A_2 \quad \text{then} \quad A_1 \prec \left[pA_1 ; (1-p)A_2 \right]$$

for any p, $0 \angle p \angle 1$.

This assumption states that if A_1 is less preferred than A_2, a decision maker prefers a gamble which would give him A_1 at worst and possibly the more preferred A_2, to the certain outcome A_1. This is the dual of Assumption 3.

Assumption 5

If $A_1 \succ A_2 \succ A_3$, then there exists a p such that

$$\left[pA_1; (1-p)A_3\right] \succ A_2.$$

This assumption states that if A_1 is preferred to A_2, and A_2 is preferred to A_3, then there is some gamble involving A_1 and A_3 that is preferred to A_2.

Assumption 6

If $A_1 \prec A_2 \prec A_3$, then there exists a p such that

$$\left[pA_1; (1-p)A_3\right] \prec A_2.$$

This assumption states that if A_3 is preferred to A_2, and A_2 is preferred to A_1, then A_2 is preferred to some gamble involving A_1 and A_3. This is the dual of Assumption 5.

Luce and Raiffa (1957) state that although Assumption 5 and Assumption 6 seem realistic, there are examples where they are not universally applicable. They cite an example where most people prefer $1.00 to 1¢ to death, but would one be indifferent between 1¢ and a gamble involving $1.00 and death? The gamble would be preferred if the chance of death was very low, for example 10^{1000}, because of its low probability of occurring. Although these assumptions may not be universally applicable, few applications have extreme alternatives such as death. No extreme alternatives are contained in this study.

Assumption 7

$$\left[pA_1; (1-p)A_2\right] \sim \left[(1-p)A_2; pA_1\right]$$

This assumption states that the arrangement of alternatives in a gamble does not affect their preference.

Assumption 8

If $A_1 \sim A_3$, then $\left[pA_1; (1-p)A_2\right] \sim \left[pA_3; (1-p)A_2\right]$ for any p and A_2.

This assumption states that if A_1 appears in any gamble, and if A_3 is indifferent to A_1, then if A_3 is substituted for A_1 in the gamble, the two gambles will be indifferent.

2.62 Strengths and Weaknesses of the Assessment Procedure

Strengths of the Assessment Procedure

Festinger (1957) showed in his theory of cognitive dissonance, that the more difficulty a decision maker has in making a decision, the greater is the tendency for him to justify the decision by increasing the attractiveness of his decision and by decreasing the attractiveness of the rejected alternatives. In general, decision makers will also avoid information that does not support their decision. These behaviourisms result in less emphasis on objectivity and more partiality in the decision (Festinger 1964). It is therefore desirable to simplify a large decision problem, reducing the number of things a decision maker must keep in perspective at the same time. This will result in reduced cognitive strain on the decision maker and less bias in the decision.

The main strength of multi-attribute utility analysis is that it breaks a large decision problem into smaller problems. The attribute utility function assessment procedure further reduces the problem to choices among attribute levels in simple hypothetical lotteries; therefore, the cognitive strain on the decision maker is greatly reduced.

Another strength of the assessment procedure is that it is based on a utility theory, providing sound procedures for formalizing and integrating judgments and preferences of decision makers. Assumptions of the methodology can also be explicitly stated.

The assessment procedure allows for decision makers' preferences to be integrated into a logical framework so regulatory authorities and other political bodies can fully see where the data came from and how and why the resulting model was constructed.

The assessment procedure results in a numerical assessment which in turn can be used to develop an objective function for a mine waste recreation plan. Because the objective function has a numerical value, it can be evaluated and maximized by computer routines.

Weaknesses of the Assessment Procedure

The main result of the von Neumann-Morgenstern expected utility theory is that decision makers should first choose outcomes in gambles involving attribute levels which have the highest expected utility.

Experiments by Edwards (1953; 1954) showed that decision makers appear to have their own notions of probability such that they will act not in accordance with the true probabilities described by the gamble, but in accordance with their own estimates of the probabilities (Churchman 1961). In these experiments, decision makers preferred gambles with certain combinations of probabilities over other gambles even though their preferred gambles had lower expected values. The assessment procedure used in this study fixes the probabilities in each gamble at 0.5; therefore, preferences for probability combinations are eliminated. The question still remains whether the decision maker's estimates of the probabilities in the gambles (0.5) are in accordance with the true probabilities described by the gamble.

Another weakness of the assessment procedure is that a decision maker is assuming that there is no cost to him from choosing certain attribute levels in the lotteries. For example, a decision maker may place a certain value on a level of an attribute; however, this value may change if he must share the cost of developing the mine waste to obtain this attribute level. The assessment procedure does not take into account cost and other factors which may influence the decision maker's preferences for attribute levels.

Three studies have shown a high correlation between direct assessment of utilities by asking decision makers to directly evaluate items and the Keeney-Raiffa fixed probability method of utility assessment. Von Winterfedlt (1971, as cited by Fischer 1973) conducted a study where decision makers were asked to directly evaluate the attractiveness of hypothetical apartments described by fourteen attributes. Then the decision makers were asked to assess their utility functions for the attributes by the fixed probability method. A mean correlation of R = 0.84 was obtained between the direct assessment and fixed probability methods when the additive utility model was used with the utility functions (Section 2.91). Fischer (1972, cited by Fischer 1973) conducted a study on the attractiveness of cars with eight attributes. A median correlation of R = 0.93 between the direct assessment method and the fixed probability method using the additive utility model was obtained. Fischer (1973, cited by Fischer 1973) in another experiment involving decision makers' preferences for jobs involving three attributes found a median correlation of R = 0.93 between the direct assessment and fixed probability methods using the additive utility model. The results illustrate a good predictiveness of the fixed probability method of actual decision makers' preferences; however, these studies involved simple problems with situations familiar to the decision makers. The weight of empirical evidence using von Neumann-Morgenstern lotteries involving choices among lottery tickets, at various odds, for small amounts of money, concludes that most decision makers choose in a way that is reasonably consistent with the axioms of the theory. They behave as though they were maximizing the expected value of utility as though the utilities of several alternatives can be measured (Edwards 1954, as cited by Simon 1959). When the experiments are extended to more real-life situations, it is not clear that decision makers behave in accordance with the utility axioms. There is some indication that when the choices are simple, where the decision maker can see and remember when he is being consistent, the decision maker will behave as to maximize his expected utility. As the choices become more complicated, he becomes much less consistent (May 1954, as cited by Simon 1959, Davidson and Suppes 1957, as cited by Simon 1959).

The assessment procedure does not take into account the reference effect described by Tversky (1977), whereby attributes are often perceived and evaluated with respect to some reference point or adaptation level, provided by past and present experience. Outcomes that lie above the reference point are perceived as positive; those below negative. Changes in preferences from shifts in the reference point are termed reference effects. The manner in which the problem is presented determines a decision maker's reference point which, in turn, determines a decision maker's utility function. People are more sensitive to negative changes that positive changes and the wording of the question can therefore have an effect on the reference point location. Tversky showed that for attributes involving sensory or perceptual qualities, sensitivity to change in attribute levels decreases as a decision maker moves from his reference level.

Another shortcoming of the assessment procedure is the large time commitment required to complete the assessment. A study by Dennis (1979) showed that if decision makers were not used to the formal procedure required by the assessment, they were reluctant to participate fully in the assessment.

2.63 A Decision Maker's Attitude Toward Risk

The functional form of a decision maker's attribute utility function is determined by his basic attitudes towards risk. The following discussion on risk is condensed from Keeney and Raiffa's (1976) chapter on unidimensional utility theory.

The utility function illustrated in Figure 5 is a straight line utility function for an attribute X with levels ranging from 0 to 10. It is referred to in the following discussion. The expected outcome of a 50-50 gamble is defined as the average of the two reference levels in the gamble. Thus, for a gamble between 0 and 10, the expected outcome is 5. A decision maker's risk premium is defined as the expected outcome of a gamble minus the certainty equivalent of a lottery involving the gamble. It is the amount of an attribute a decision maker is willing to forfeit from the expected outcome to avoid the risks associated with a particular gamble. The utility function in Figure 5 has a risk premium of zero over all levels of attribute X. A decision maker with such a utility function is termed risk neutral or, in other words, he does not prefer to either avoid risks or seek risks associated with the gamble.

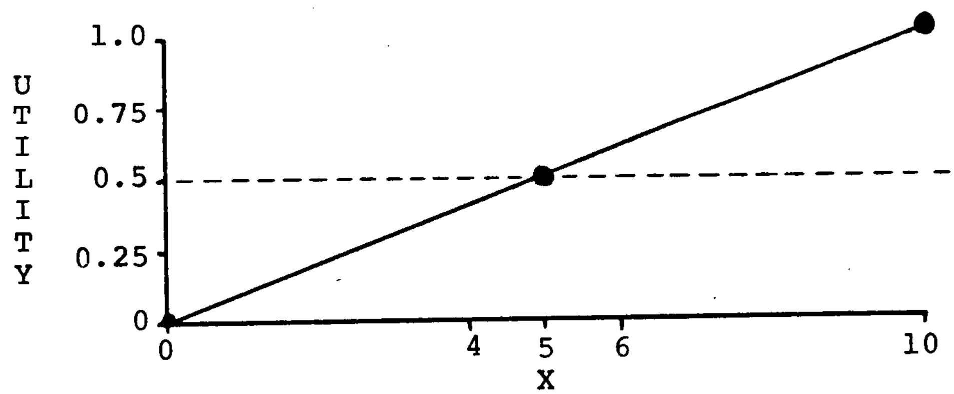


Fig. 5. Attribute utility function illustrating a risk neutral attitude.

If a decision maker's certainty equivalent of a lottery is less than the expected outcome of the gamble, for example a certainty equivalent of 4 in Figure 5, then the risk premium is positive and equal to 1. The decision maker's attitude reflects that he prefers to avoid risks associated with the gamble and is willing to forfeit some amount, in this case 1 unit, of attribute X to avoid accepting the gamble. This attitude is termed risk averse. If a risk premium is positive for all lotteries over the range of X, for increasing and decreasing utility functions, a decision maker is said to be risk averse and his utility function will always be concave as illustrated in Figure 6.

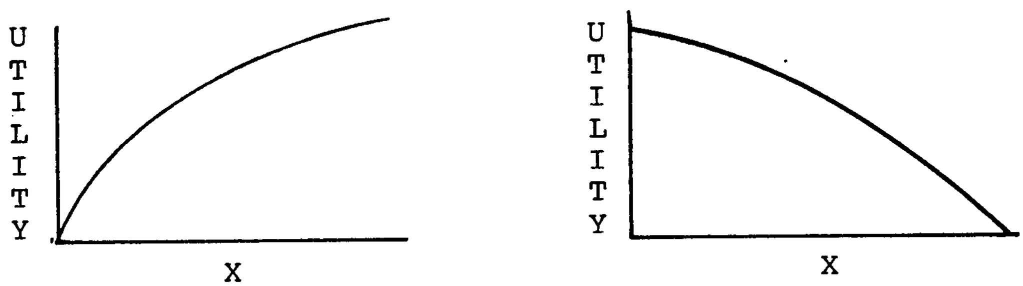


Fig. 6. Concave increasing and decreasing utility functions indicating a risk averse attitude.

A decision maker is increasingly risk averse if (1) he is risk averse, and (2) his risk premium for any lottery increases as the reference levels of the attribute in the lottery increase. The risk premium a decision maker is willing to pay to avoid the gamble increases with increasing reference values in the gamble. His utility function becomes more concave as X increases.

A decision maker is decreasingly risk averse if (1) he is risk averse and (2) his risk premium for any lottery decreases as the reference levels of the attribute in the lottery increase. The risk premium a decision maker is willing to pay to avoid the lottery decreases with increasing reference values in the gamble.

His utility function becomes less concave as X increases.

If a decision maker's certainty equivalent of a lottery is greater than the expected outcome of the gamble, for example a certainty equivalent of 6 in Figure 5 , then the risk premium is negative, equal to -1. The decision maker's attitude reflects that he prefers to take risks associated with the gamble and is not willing to forfeit units of attribute X to avoid these risks. This attitude is termed risk seeking. If a decision maker's risk premium is negative for all lotteries over the range of X, for increasing and decreasing utility functions, he is said to be risk seeking and his utility function will be convex as illustrated in Figure 7.

Fig. 7. Convex increasing and decreasing utility functions indicating a risk seeking attitude.

A decision maker is increasingly risk seeking if (1) he is risk seeking and (2) his risk premium for any lottery decreases as the reference levels of the attribute in the lottery increase. The risk premium a decision maker is willing to pay to avoid the gamble decreases with increasing reference values in the gamble. His utility function becomes more convex as X increases.

A decision maker is decreasingly risk seeking if (1) he is risk seeking and (2) his risk premium for any lottery increases as the reference levels of the attribute in the lottery increase. The risk premium a decision maker is willing to pay to avoid the gamble increases with increasing reference values in the gamble. His utility function becomes less convex as X increases.

2.7 Verification of Independence Properties of Attributes

Multi-attribute utility functions are valid only when certain independence properties concerning attributes are true (Keeney 1974; 1977a; 1977b, Keeney and Raiffa 1976). The independence properties of concern to this methodology are utility independence, preferential independence and additive independence.

2.71 Utility Independence

Keeney (1970; 1972a; 1974; 1977a) and Keeney and Raiffa (1976) showed that given the set of attributes (X_1, X_2,... X_n), then X_1 is utility independent of the other attributes if the preference order for lotteries over X_1, given the other attribute levels are fixed, does not depend on the level where those attributes are fixed. To test for utility independence between attributes X_1 and X_2, Figure 8 can be used.

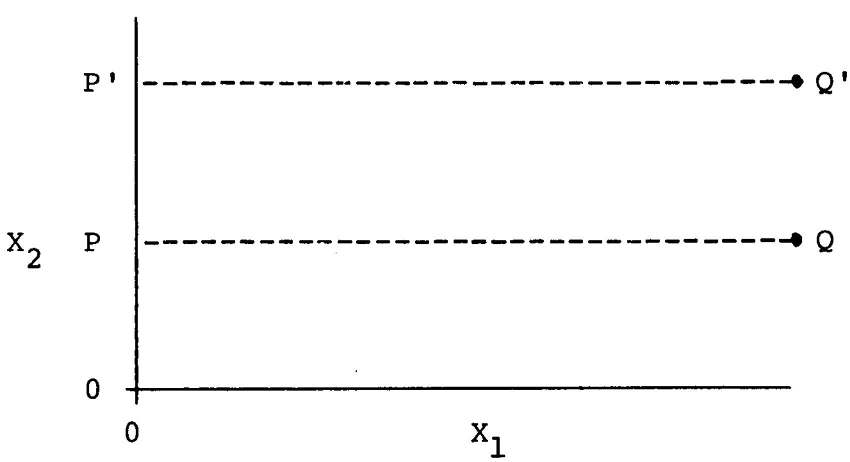


Fig. 8. Graph to test for utility independence between attributes X_1 and X_2.

The attribute X_2 is fixed (eg. at P). Lotteries are then set up between the 50-50 gamble of P and Q and one of the other attribute X_1 levels as illustrated by Figure 9.

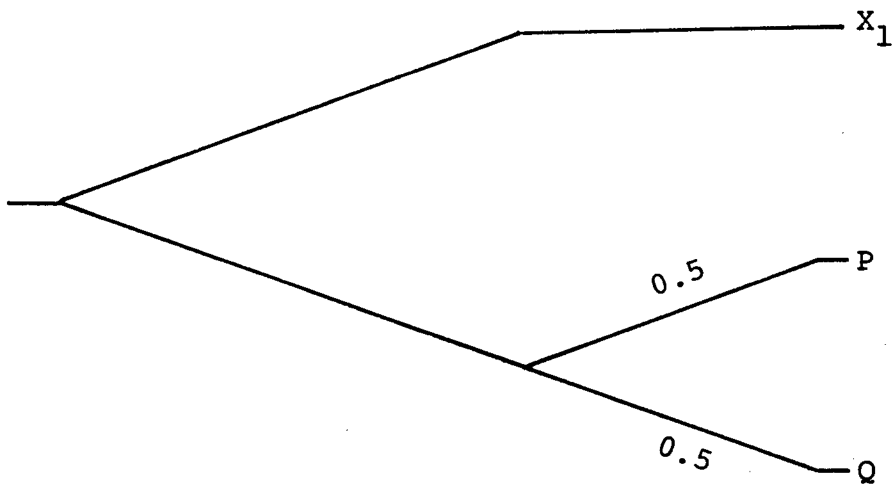


Fig. 9. Lottery between attribute level X_1 and a 50-50 gamble between P and Q.

The levels of X_1 are changed until the level of X_1 is found where the decision maker is indifferent between the two alternatives. The level of X_2 is then fixed at P' and the procedure is repeated. If the decision maker chooses the same level of X_1 to be indifferent between the two alternatives, then X_1 is said to be utility independent of X_2.

An example of dialogue in this study used to verify utility independence between two horseback riding attributes is presented in Appendix 3.

2.72 Preferential Independence

Keeney (1972a; 1974; 1977a) and Keeney and Raiffa (1976) showed that given a set of attributes (X_1, X_2,...X_n), the pair of attributes (X_1,X_2) is said to be preferentially independent of other attributes if value tradeoffs between X_1 and X_2 do not depend on the levels of the other attributes. To test for preferential independence, Figure 10 can be used.

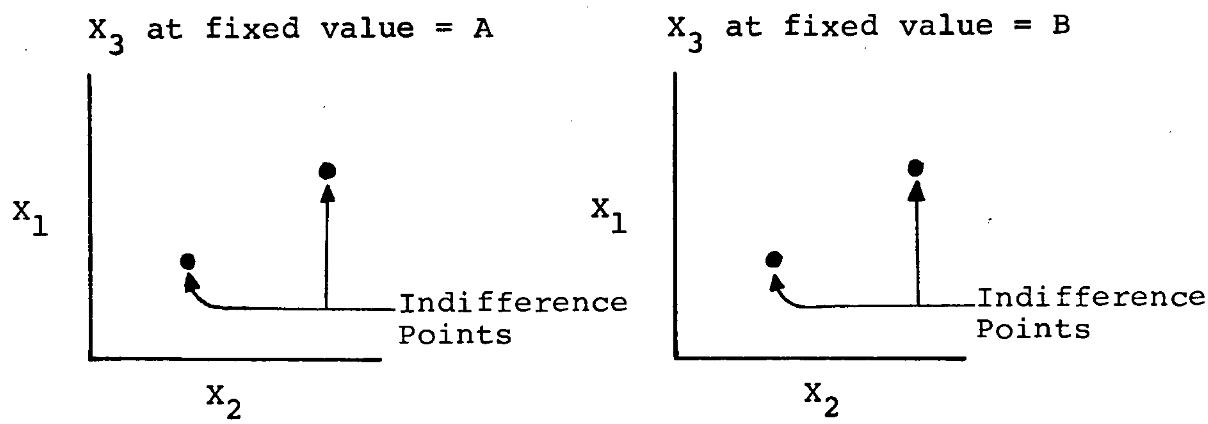


Fig. 10. Graphs to test for preferential independence between the attribute pair (X_1,X_2) and the attribute X_3.

While fixing the level of X_3 at some value A, a point (X_1,X_2) is chosen and the decision maker is asked to choose a level X_2' for a different level of X_1 = X_1' so that he would be indifferent between the two points. X_3 is then fixed at a different level B and the procedure is repeated. If the proportional change in indifference points does not very significantly, then X_1 and X_2 are said to be preferentially independent of X_3. Given the set of attributes (X_1, X_2,...X_n), then X_3 through X_n would be fixed to see if (X_1,X_2) was preferentially independent of X_3 through X_n.

An example of dialogue in this study used to verify preferential independence is presented in Appendix 4 .

2.73 Additive Independence

Attributes X_1 and X_2 are additive independent if the following lotteries are found to be indifferent to a decision maker:

These lotteries must be indifferent over all ranges of X_1 and X_2. (Keeney and Raiffa 1976).

To illustrate, take the attributes travel time and length of trail X_{26} and X_{27}, for the activity horseback riding. The range of travel time is between 0 and 240 minutes. The range of length of trail is between 0 and 20 km. The following lotteries are then set up:

In lottery L_1, the expected value of the gamble is

$$0.5U(240) + 0.5U(0) + 0.5U(0) + 0.5U(20)$$

or $$0.5(0) + 0.5(0) + 0.5(1) + 0.5(1)$$

which is equal to 1.0. Notice that in L_1 there is a 50-50 chance of getting both attributes at their best values and both at their worst values.

In lottery L_2 the expected value of the gamble is

$$0.5U(0) + 0.5U(0) + 0.5U(240) + 0.5U(20)$$

or $$0.5(1) + 0.5(0) + 0.5(0) + 0.5(1)$$

which is equal to 1. Therefore L_1 and L_2 have the same expected value. Notice that in L_2 the decision maker will always receive one attribute at its best level and one at its worst.

If all the attributes for an activity are additive independent, mutual utility independent and preferentially independent then the additive utility function is the appropriate utility function for the activity.

2.8 Assessment of Scaling Constants for the Attributes

To assess the relative importance of each attribute to a recreational activity, scaling constants k_i must be assessed for each attribute X_i.

Scaling constants can be determined by choosing an attribute, for example X_{26}, and examining tradeoffs between X_{26} and the other attributes. From these tradeoffs, equations are developed for scaling constants in terms of other scaling constants. The following example will be used to illustrate the technique (Keeney and Raiffa 1976).
Given the following tradeoff, represented by Figure 11, between attributes X_{26} and X_{27} for the activity horseback riding, the decision maker chooses points A and B to be indifferent.

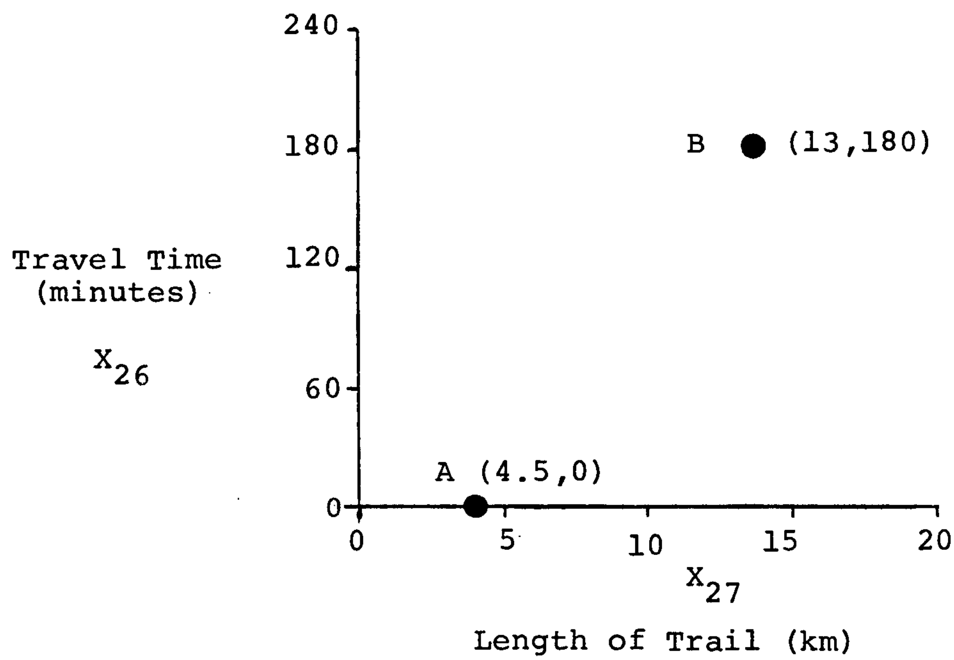


Fig. 11. Tradeoff between attributes X_{26} and X_{27}.

Because points A and B are indifferent, the following equation is true:

$$k_{27}U_{27}(4.5) + k_{26}U_{26}(0) = k_{27}U_{27}(13) + k_{26}U_{26}(180) \qquad (7)$$

From the utility functions for attributes X_{26} and X_{27} in Appendix 5,

$$U_{26}(0) = 1.00 \qquad U_{27}(4.5) = 0.130$$

$$U_{26}(180) = 0.250 \qquad U_{27}(13) = 0.750$$

Substituting into equation (7),

$$k_{27}(0.130) + k_{26}(1.00) = k_{27}(0.750) + k_{26}(0.250)$$

$$k_{26}(0.750) = k_{27}(0.620)$$

therefore, $$k_{26} = 0.827k_{27}$$

This procedure is continued for all the attribute tradeoff combinations.

2.81 Consistency Checks

Before assessing scaling constants for the attributes, the decision maker is asked to rank the attributes in order of importance to the success of the activity in question. Assessed scaling constant values should be consistent with the decision maker's ranking of the attributes.

Several tradeoffs between the attributes should be examined and calculations made to check the ratios of the two scaling constants for each tradeoff. For example, if for one tradeoff between attributes X_{26} and X_{27}, the ratio of scaling constants k_{26}/k_{27} is 0.75, and for another tradeoff, k_{26}/k_{27} is 3.0, then where the ratio is 3.0, the decision maker considers the attribute X_{26} to be 3 times as important as attribute X_{27}, and where the ratio is 0.75, the decision maker considers X_{26} to be 0.75 times as important as X_{27}. From the ratios it is clear that the decision maker is not consistent in his preferences. If the ratios are not reasonably close between the tradeoffs, then a decision maker should be told how he is inconsistent with his assessed attribute utility functions and asked whether he wants to change one of his tradeoffs. If he does not want to change one of his tradeoffs, then other tradeoffs between the same attributes should be conducted to obtain some consistency in the scaling constant ratios.

An example of dialogue in this study used to assess the scaling constants with consistency checks between tradeoffs is presented in Appendix 4.

Another method for checking the decision maker's consistency for attribute preference is to examine the scaling constant equations that do not involve the attribute against which other attributes are traded. From these equations, several values for each scaling constant k_i are assessed. To check for consistency, the scaling constant for the attribute against which other attributes are traded is equated to 1.0 and the other scaling constants are assessed. The different values for an individual scaling constant should not vary significantly. For example, the scaling constant k_{26} for the activity horseback riding is equated to 1.0. The scaling constant k_{28} is expressed in the following equations:

$$k_{28} = k_{26}/0.644 = 1.55$$

$$k_{28} = k_{27}/0.655 = 1.58$$

where $k_{26} = 1.00$ and $k_{27} = 1.03$.

The value 1.63 does not vary significantly from the 1.55 value of k_{28}; therefore, the decision maker is said to be consistent in his relative preference for the attribute X_{28}.

2.82 Evaluating the Scaling Constant Against Which Other Attributes are Traded for the Multiplicative Utility Function

In the course of determining the scaling constant equations, all the attributes are traded off against one attribute, for example X_{26} for the activity horseback riding. Therefore the value of the scaling constant k_{26} is not known.

To determine the value of k_{26}, the decision maker is asked to choose probabilities p and q in the lottery illustrated in Figure 12, so that he is indifferent between the gamble and the certain outcome.

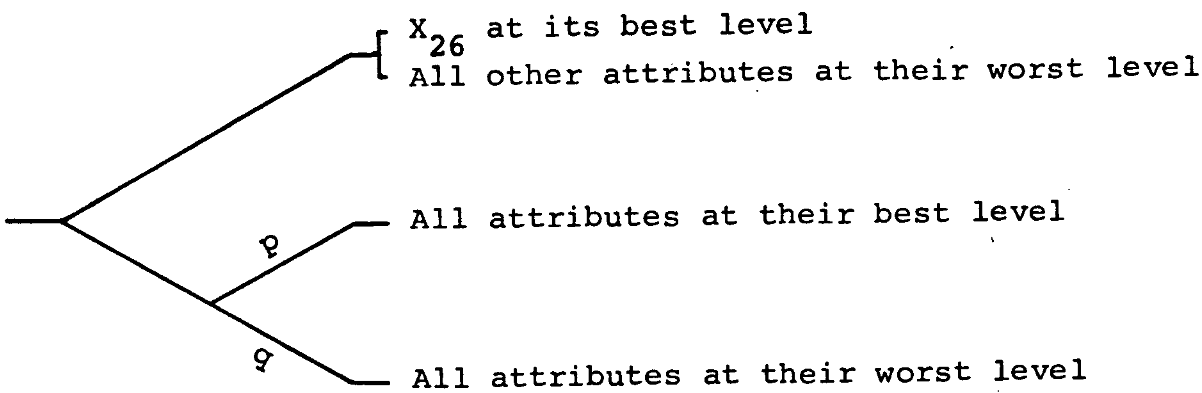


Fig. 12. Lottery to determine k_{26}.

The utility of the attributes at their best level is 1.0. The utility of the attributes at their worst level is 0. Therefore, the expected utility of the gamble is

$$p(1.0) + q(0) = p$$

For example, let p = 0.3 and q = 0.7. The expected utility of the gamble is 0.3 and because the outcomes in the lottery are indifferent, k_{26} = 0.3. k_{26} is then substituted into the other scaling constant equations to determine the other constants.

2.83 Strengths and Weaknesses of the Attribute Scaling Constant Assessment Procedures

Without the scaling constant assessment procedures described in Sections 2.8 to 2.82, a decision maker must keep all the attributes of an activity in perspective at the same time when he is conducting a tradeoff between two of the attributes. The strength of the assessment procedure is that it breaks this large tradeoff problem into several simpler tradeoff problems between two attributes at a time with all other attributes being held constant. This decreases the cognitive strain on the decision maker.

Weaknesses of the Procedures

While conducting consistency checks, the analyst must examine tradeoffs to see if the scaling constants produced are consistent. For every set of tradeoffs he must perform the calculation described by Equation 7 in Section 2.8. This calculation is very time consuming and decision makers may be reluctant to devote the time to complete the assessment. To reduce this time factor in this study, Equation 7 was programmed into a pocket calculator so the analyst only had to enter the four attribute level utility values for each tradeoff to assess the scaling constant.

If scaling constants are not consistent, the analyst must either conduct many tradeoffs until he receives several consistent values or he must prompt the decision maker to be more consistent with his utility functions in the tradeoffs. The criticism in the latter case is that the analyst becomes involved in the attribute tradeoff procedure, which may bias the resulting scaling constant values.

The lottery to determine the unknown scaling constant (Figure 12), for the multiplicative utility function (Section 2.82), requires the decision maker to keep all the attributes in perspective at the same time which increases the cognitive strain on the decision maker; hence, the accuracy of the responses to this lottery may be questionable.

2.9 Choice of a Multi-Attribute Utility Function

MacCrimmon (1973) presented an overview of methods for dealing with multiple objective/multiple attribute decision problems and a method specification chart (Figure 13). Tracing through the chart, the purpose of the decision problem is normative (trying to improve the course of action) rather than descriptive (trying to describe the course of action). A direct assessment of preferences from the fixed probability method described in Section 4.5 is assumed to be valid and reliable. In this study only one decision maker's choices are being considered for each recreational activity. The success of each recreational activity will not solely determined by only the best (Maximax A.3.b) or worst (Maximin A.3.a) attribute. The alternative courses of action (recreational activities) will be chosen from a list, rather than designed.

The tracing results in a choice between five method types. The tradeoff method has the disadvantage of obtaining a decision maker's preferences by directly asking him which may result in the decision maker unable to verbalize his true preferences. Multi-dimensional scaling with ideal points (D.2.a) does not take into account intra-attribute preferences. This study is concerned with a decision maker's preferences between attributes of a recreational activity as well as preferences between varying levels of each attribute. The inter and intra-attribute weighting methods (A.2.b,c, and d) demand numerical inputs representing a decision maker's inter and intra-attribute preferences. Such numerical weighting values derived from Keeney and Raiffa's (1976) fixed probability method have been successfully used in the additive (A.2.b) and multiplicative (A.2.d) weighting models (Keeney 1973; 1975; 1977a; 1979; 1980, Krischer 1974, Hilborn and Walters 1977, Keeney and Robillard 1977, Keeney et. al. 1978, Walker 1982).

These models were chosen for use in this thesis because they have been employed successfully in other multi-attribute decision problems, are part of Keeney and Raiffa's (1976) multi-attribute utility analysis and their results can be used to develop an objective function for a recreation plan which can be used in an optimization algorithm (Fishburn 1968).

Keeney (1974) showed that given the attribute set $(X_1, X_2, \ldots X_n)$, $n \geq 3$, if X_1 is utility independent of $(X_2, \ldots X_n)$, and attribute pairs are preferentially independent of other attributes, then a multi-attribute utility function is either additive if the attributes are also additive independent or multiplicative if the attributes are not additive independent.

Fig. 13. Method specification chart for multiple attribute decision problems (MacCrimmon 1973).

MULTIPLE OBJECTIVE/MULTIPLE ATTRIBUTE DECISION METHODS

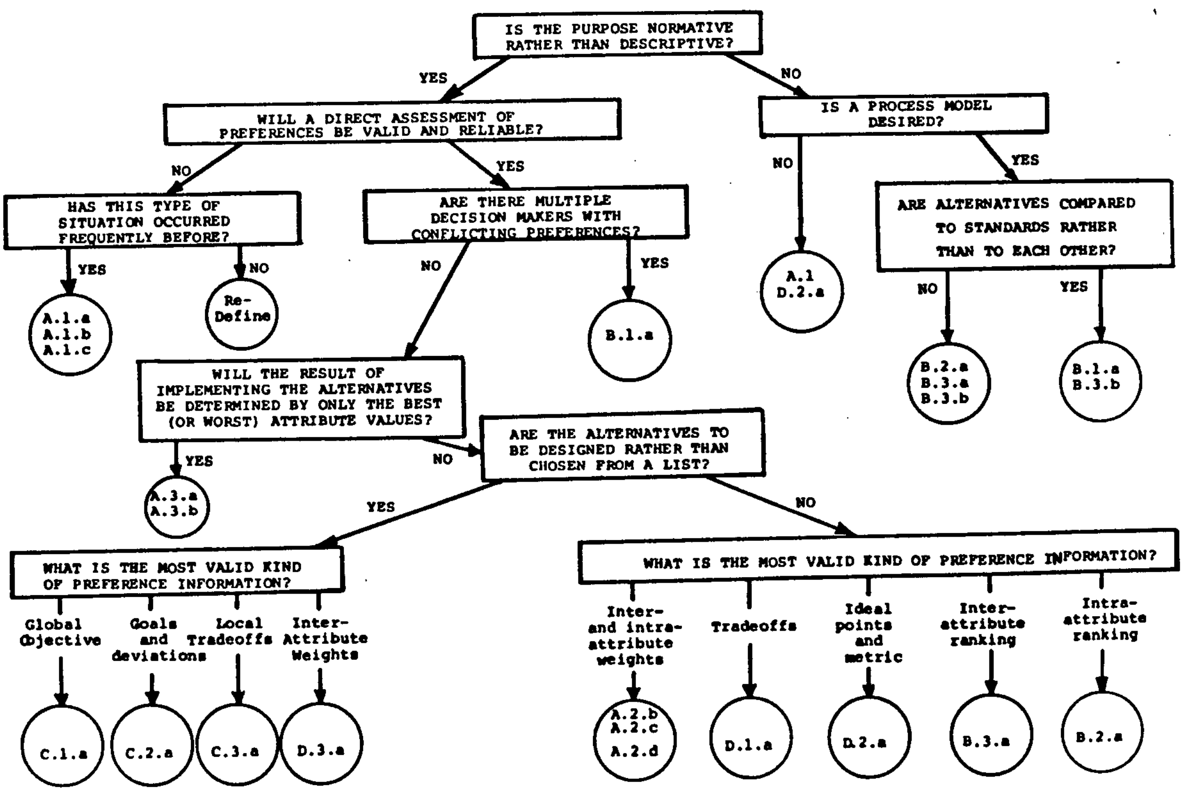
A. WEIGHTING METHODS
   1. Inferred Preference
      a. Linear Regression
      b. Analysis of Variance
      c. Quasi-linear Regression
   2. Directly Assessed Preferences: General Aggregation
      a. Trade-offs
      b. Simple Additive Weighting
      c. Hierarchical Additive Weighting
      d. Quasi-Additive Weighting
   3. Directly Assessed Preferences: Specialized Aggregation
      a. Maximin
      b. Maximax

B. SEQUENTIAL ELIMINATION METHODS
   1. Alternative versus Standard: Comparison Across Attributes
      a. Disjunctive and Conjunctive Constraints
   2. Alternative versus Alternative: Comparison Across Attributes
      a. Dominance
   3. Alternative versus Alternative: Comparison Across Alternatives
      a. Lexicography
      b. Elimination by Aspects

C. MATHEMATICAL PROGRAMMING METHODS
   1. Global Objective Function
      a. Linear Programming
   2. Goals in Constraints
      a. Goal Programming
   3. Local Objectives: Interactive
      a. Interactive, Multi-criterion Programming

D. SPATIAL PROXIMITY METHODS
   1. Iso-preference Graphs
      a. Indifference Map
   2. Ideal Points
      a. Multi-dimensional, non-metric Scaling
   3. Graphical Preferences
      a. Graphical Overlays

METHOD SPECIFICATION CHART



2.91 Additive Utility Function

If attributes $X_1 \ldots X_n$ are found to be additive independent, utility independent and preferentially independent, then the following additive utility function can be used to determine the utility for the activity (Keeney and Raiffa 1976):

$$U(X_1, X_2, \ldots X_n) = \sum_{i=1}^{n} k_i U_i(X_i) \qquad (1)$$

where U and U_i are utility functions scaled from 0 to 1 and k_i are attribute scaling constants $0 \angle k_i \angle 1$, where the scaling constants sum to 1.0.

For example, the following scaling constant equations were assessed for the attributes of horseback riding:

(i) $k_{26} = 0.969k_{27}$

(ii) $k_{26} = 0.644k_{28}$

The $\sum_{i=26}^{28}$ must equal 1.0 for the additive function to be valid. The scaling constants are determined by equating k_{26} to 1.0 and substituting k_{26} into the other scaling constant equations. The resulting scaling constants are the following:

(i) $k_{26} = 1.0$

(ii) $k_{27} = 1.03$

(iii) $k_{28} = 1.55$

The sum of the scaling constants is 3.58.

Scaling to sum to 1.0,

(i) $k_{26} = 1.0/3.58 = 0.279$

(ii) $k_{27} = 0.288$

(iii) $k_{28} = 0.433$

The additive utility function U for the attributes (X_{26}, X_{27}, X_{28}) of the activity horseback riding is the following:

$$U = 0.279U_{26}(X_{26}) + 0.288U_{27}(X_{27}) + 0.433U_{28}(X_{28})$$

where U_i is the utility value of the attribute i at level X_i.

2.92 Multiplicative Utility Function

If attributes $X_1 \ldots X_n$ of an activity are not additive independent but are mutually utility independent and preferentially independent, then the multiplicative utility function is the appropriate utility function to use (Keeney and Raiffa 1976). The multiplicative utility function is illustrated by equation (2):

$$1 + KU(X_1, X_2, \ldots X_n) = \prod_{i=1}^{n} (1 + Kk_i U_i(X_i)) \qquad (2)$$

where U and U_i are utility functions scaled from 0 to 1, k_i are attribute scaling constants $0 < k_i < 1$, K is a non-zero scaling constant, and the $\sum k_i \neq 1.0$.

In order for the multiplicative function to be valid, the scaling constants must not sum to 1.0; therefore, scaling constants are not scaled to 1.0 as in the additive case.
Assume that the following scaling constant equations were assessed for the attributes of horseback riding:

(i) $k_{26} = 0.350k_{27}$

(ii) $k_{26} = 0.400k_{28}$

The scaling constant k_{26} is determined by the method in Section 4.9. The other scaling constants are determined by substituting k_{26} into the equations. The resulting scaling constants are the following (their sum not equal to 1.0):

(i) $k_{26} = 0.300$ (iii) $k_{28} = 0.750$

(ii) $k_{27} = 0.857$

Therefore the multiplicative function U for the attributes (X_{26}, X_{27}, X_{28}) of the activity horseback riding is the following:

$$1 + KU(X_{26},...X_{28}) = \prod_{i=26}^{28} (1 + Kk_i U_i(X_i))$$

or

$$1 + K = \prod_{i=26}^{28} (1 + Kk_i) \qquad \text{(Keeney 1974)} \qquad (3)$$

which implies

$$1 + K = (1 + Kk_{26})(1 + Kk_{27})(1 + Kk_{28}) \qquad (4)$$

or

$$1 = K^2 k_{26}k_{27}k_{28} + K(k_{26}k_{27} + k_{26}k_{28} + k_{27}k_{28}) + (k_{26} + k_{27} + k_{28})$$

In the example

(i) $k_{26} = 0.300$ (ii) $k_{27} = 0.857$ (iii) $k_{28} = 0.750$

Substituting into equation (4),

$$0.193K^2 + 1.13K + 0.910 = 0 \qquad K = -0.964$$

If there are two roots to the equation, $K \geq -1$ is the solution (Keeney 1974).

For the example, K is substituted into equation (3) to yield the following multiplicative utility function for the attributes

$(X_{26},...X_{28})$ of the horseback riding activity:

$$U(X_{26},...X_{28}) = \frac{\prod_{i=26}^{28} (1 - 0.964k_iU_i(X_i)) - 1}{-0.964} \qquad (5)$$

Substituting the k_i values into equation (5), the utility function can be reduced to equation (6):

$$U(X_{26},...X_{28}) = \frac{((1 - 0.289U_{26}(X_{26}))(1 - 0.826U_{27}(X_{27}))(1 - 0.723U_{28}(X_{28}))) - 1}{-0.964} \qquad (6)$$

where U_i is the utility value of the attribute level X_i.

2.10 Development of an Equation to Scale the Recreational Activities

From the multi-attribute utility analysis, decision makers' preferences for each attribute of an activity are assessed and scaled to yield an additive or multiplicative utility function for each activity.

To develop an objective function for a mine waste recreation plan, activities must be scaled as to their relative importance to the residents of the Elk River Valley. If activity utilities are simply added, many mine waste areas may be allocated less preferred activities which may not benefit the majority of the Elk River Valley residents. A scaling system is needed to reflect the residents' preferences for each activity.

Nessman and Bailey (1981) conducted a mail survey of outdoor recreation participation in the study area. Data for the percentage of households participating in each recreational activity considered in this study were collected. These data are the only available recent data on outdoor recreation participation in the study area. They were used in this study to indicate the relative importance of the activities to the residents of the Elk River Valley. The percentages were scaled between 0 and 1 and both are presented in Table 1. The scaling factors were then used to develop the objective function presented in Figure 14 for an outdoor recreation plan on the mine waste section in this study.

This scaling system for activities does not take into account changes in preferences for activities over time. The system would have to be updated regularly as people with varying preferences for activities migrate to and leave the Elk River Valley

Recreational Activity	% Households Participating	Scaling Constants
Trailbiking	14.8	$\frac{14.8}{320.6} = 0.046$
Four-Wheel Driving	35.7	0.111
Snowmobiling	26.8	0.084
Downhill Skiing	42.8	0.133
Cross-Country Skiing	26.5	0.087
Snowshoeing	20.6	0.064
Hiking	46.8	0.146
Horseback Riding	25.1	0.078
Summer Camping	81.5	0.254
	320.6	1.00

Table 1. Data for percentage households participating in recreational activities of the Elk River Valley and their scaling constants.

$$
\begin{aligned}
U_{plan} = {} & 0.046\ U_{TB} + 0.111\ U_{4x4} + 0.084\ U_{SNOW} \\
& + 0.133\ U_{DOWN} + 0.087\ U_{X-C} + 0.064\ U_{SHOE} \\
& + 0.146\ U_{HIKE} + 0.078\ U_{HORSE} + 0.254\ U_{CAMP}
\end{aligned}
$$

Fig. 14. Objective function to determine the utility of a land use plan with outdoor recreational activities.

CHAPTER 3

RESULTS AND DISCUSSION - PART 1

Multi-Attribute Utility Analysis

Results

(i) In the course of assessing attribute utility functions, mutual utility independence and preferential independence were verified between all the attributes;

(ii) Assessed attribute utility functions for the recreational activities are presented in Appendix 5;

(iii) Attribute tradeoffs and the assessed scaling constant equations are presented in Appendix 6;

(iv) Improper interview questions resulted from the assessor's incomplete understanding of the additive independence lottery presented in Section 2.73, at the time of the interviews; therefore, additive independence was not established between the attributes and a proper selection of utility equations could not be obtained. To demonstrate the analysis and evaluation of the mine waste, the attributes were assumed to be additive independent and the additive utility model used. The additive utility functions for the recreational activities are presented in Appendix 7;

(v) The relative importance of each attribute of an activity to a decision maker is presented in Appendix 8.

Discussion

The multi-attribute utility analysis for each decision maker took, on average, two hours to complete. More time would have been useful to recheck decision makers' answers to interview questions; however, two hours was the maximum any decision maker in this study was willing to devote to the analysis.

The following observations were noted during the assessment of decision makers' attribute utility functions:

(i) At the beginning of the assessment, decision makers' answers to the lotteries contradicted themselves. Decision makers would answer in accordance with what they thought the analyst wanted as an answer from the tone of analyst's question. The analyst pointed out the contradiction which clarified the assessment procedure for the decision makers and this result was not encountered again during the assessment;

(ii) Decision makers would begin to lose interest in the assessment due to the repetitive nature of the interview questions and would begin to answer the questions without thinking hard about the hypothetical situations posed by the lotteries, answering very quickly. At this stage the analyst must try to restore the decision maker's interest in the lotteries by putting enthusiasm and emphasis into the interview questions. It is noted that the decision makers in this study did not have a vested interest in the resulting recreation plan. It would seem logical to predict that a decision maker who would use the resulting plan would be more attentive during the assessment because of this vested interest.

The attribute scaling constant assessments were all conducted later in the interview because the procedure uses the assessed utility functions. About half way through the scaling constant assessment, decision makers became tired and would respond very quickly to tradeoffs without thinking hard about what they were saying. To get the decision maker to think hard about each tradeoff, the analyst would repeat the decision maker's responses to the decision maker, to verify that the response was one in which the decision maker really believed.

For all the questions in the multi-attribute utility analysis, it is essential that the analyst remain impartial in the phraseology of the questions. Decision makers are very quick to change their responses if the analyst words the interview question in such a way that the decision maker thinks a certain response would be preferred by the analyst.

The average slope of a mine waste area in the Elk River Valley proved to be the most important attribute to the decision makers for all the activities which had slope as an attribute, except for snowshoeing.

The attribute utility functions were drawn as straight lines between assessed certainty equivalent points for ease of calculation of utility values for the objective function, maximized in Part 2.

CHAPTER 4

METHODOLOGY - PART 2

Maximization of the Objective Function

4.1 Introduction

The intent in this study was to use a computer optimization routine to produce a recreation plan which would maximize the objective function developed in Part 1. The objective function is non-linear. Activities are grouped into 16 land uses as discussed in Section 1.1. Land uses 1 - 16 are INTEGERS; therefore, an INTEGER optimization routine must be used for for non-linear functions. At the present time, there is little software available at the University of British Columbia for such optimization. The software that is available is relatively new, will not guarantee successful solutions and is extremely expensive to use.

Since an optimization routine was not available, an algorithm called NLP.S (a filename) which evaluates the objective function value of a recreation plan within the 10 km x 10 km mine waste section was developed. The algorithm is presented in Appendix 9, explained in Appendix 10 and summarized by a flowchart in Appendix 11. The procedure for using it is presented in Appendix 12.

4.2 Grouping the Recreational Activities into Land Uses

Many of the mine waste areas are desirable for both summer and winter recreational activities. Many of the roads in the

Elk River Valley, which are easily travelled during the dry summer months, become blocked with deep snow from late fall to early summer. As a result, these areas are only accessible to snowmobilers, snowshoers and cross-country skiers. The first division of the activities is therefore between summer and winter activities.

Serious incompatability exists between the summer motorized activities trailbiking and four-wheel driving and the non-motorized activities hiking, horseback riding and camping. Trailbikes and four-wheel drive vehicles create noise and safety hazards from using the same roads and areas as hikers, horseback riders and campers (Brewer and Fulton 1974; as cited by Brander 1974). Hikers and horseback riders also conflict with trailbikes and four-wheel drive vehicles by impeding the traffic of these off-road vehicles (Chilman 1979).

Incompatability also exists between the winter motorized activity snowmobiling and the non-motorized activities cross-country skiing and snowshoeing. Lund and Williams (1974) state that snowmobiles leave the trail in a condition that is not satisfactory for cross-country skiers. Cross-country skiers and snowshoers cannot tolerate the noise from snowmobiles and may be endangered by speeding snowmobiles (Hoene undated, Selles 1973, Allan 1975, Jubenville 1978). When cross-country skiers or snowshoers use the same trail as snowmobilers, they impede snowmobile traffic (Allan 1975), and decrease enjoyment for the snowmobiler because the snowmobiler is constantly worried about striking a cross-country skier or snowshoer (Lund and Williams 1974).

Zoning by activity is a common technique used to control recreational user group conflict. Conflicting activities are separated spatially, assigning areas for motorized uses that are distinct from areas reserved for non-motorized uses (O'Riordan 1974, McCall and McCall 1977, Jubenville 1978, Knudson 1980). In this study, trailbiking and four-wheel driving are separated from hiking, horseback riding and camping. Snowmobiling is separated from cross-country skiing and snowshoeing.

Minor incompatability exists between trailbikers and four-wheel drivers. One can impede the other's traffic resulting in safety hazards. In this study, trailbiking and four-wheel driving are separated for certain land uses, and because the conflict is minor, and both activities frequently occur together, are grouped for other land uses.

A "no activity" land use was also selected to be a summer or winter land use. A planner wishes to maximize the objective function. Rather than assign a land use with a low utility to a grid square, decreasing the function value for the plan, the planner should have the option of assigning a "no activity" land use to the grid square under examination, which doesn't affect the objective function value of the plan.

Land uses composed of both summer and winter activities chosen for analysis in this study are presented in Table 2.

LAND USES

LAND USE #	SUMMER ACTIVITIES	WINTER ACTIVITIES
1	TRAILBIKING	SNOWMOBILING
2	TRAILBIKING	X-C/SNOWSHOEING
3	TRAILBIKING	NO ACTIVITY
4	4X4	SNOWMOBILING
5	4X4	X-C/SNOWSHOEING
6	4X4	NO ACTIVITY
7	TRAILBIKING/4X4	SNOWMOBILING
8	TRAILBIKING/4X4	X-C/SNOWSHOEING
9	TRAILBIKING/4X4	NO ACTIVITY
10	HIKING/HORSEBACK RIDING/CAMPING	SNOWMOBILING
11	HIKING/HORSEBACK RIDING/CAMPING	X-C/SNOWSHOEING
12	HIKING/HORSEBACK RIDING/CAMPING	NO ACTIVITY
13	NO ACTIVITY	SNOWMOBILING
14	NO ACTIVITY	X-C/SNOWSHOEING
15	NO ACTIVITY	NO ACTIVITY
16	NO ACTIVITY	DOWNHILL SKIING

Table 2. Land uses chosen for analysis in this study.

4.3 Bounding of the Study Area to be Evaluated

There is a danger in maximizing the objective function of a mine waste area within a larger area of not examining spillover effects which may have important impacts; however, if the mine waste area to be analysed is not bounded in some way, it will remain hopelessly intractable (Keeney and Raiffa 1976).

It is desirable to examine as large an area as possible without becoming too general in the analysis. The number of variables the non-linear monitor for non-linear optimization routines at the University of B.C. used to run the NLP.S program in this study can examine, is restricted to 100. The mine waste in this study is bounded into a 10 km x 10 km square section. The section is further divided into 100 grid squares, each 1 km x 1 km, and representing one variable or land use. A 10 km x 10 km square section is reasonably large for the study area and detailed results can still be obtained.

4.4 Calculation of Attribute Levels from the 10 km x 10 km Mine Waste Section

4.41 Calculation of Travel Time from Town

The location of a town can be inside or outside the 10 km x 10 km mine waste section. A main highway runs from north to south through the study area. Secondary roads branch east and west off the highway. The total travel time to a grid square from a town is therefore the sum of the highway and secondary road travel times. The speed limit on the highway is 80 km/hour. Average speed is approximately 70 km/hour. Average speed on secondary roads is approximately 40 km/hour. The following relationships were developed for the two travel times:

$$\text{Travel Time on Highway (minutes)} = \frac{(\text{Distance travelled (km)})(70\ \text{km/h})}{60\ \text{minutes}} \quad (1)$$

$$\text{Travel Time on Secondary Roads (minutes)} = \frac{(\text{Distance travelled (km)})(40\ \text{km/h})}{60\ \text{minutes}} \quad (2)$$

Total travel time from town to a grid square = (1) + (2).

In this study, roads running from north to south are assumed to be highways and roads running east to west are assumed to be secondary roads.

4.42 Calculation of Length of Trail

The trail circuit illustrated in Figure 15 was chosen to be characteristic of circuits used by many trailbikers, four-wheel drivers, snowmobilers, cross-country skiers, snowshoers, hikers and horseback riders.

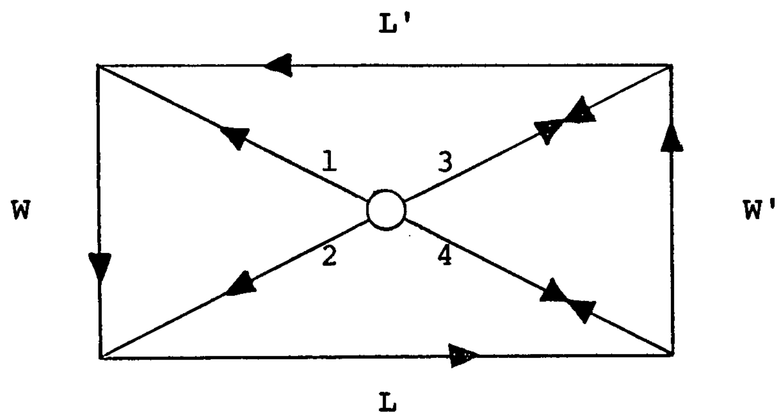


Fig. 15. Trail circuit used by the activities.

This trail circuit was chosen to simplify the complexity of trail patterns for use in the computer model. The spider-web type trail pattern, which this trail pattern closely resembles, is commonly used by trailbikers and snowmobilers (Hetherington 1979). For the other activities, this trail circuit is not unreasonable and offers the following combinations of routes:

(a)	1 W L 4	(g)	3 L' W L 4
(b)	1 W L W' 3	(h)	3 L' W L W' 3
(c)	1 W L W' L' W L 4	(i)	4 W' 3
(d)	2 L 4	(j)	4 W' L' W L 4
(e)	2 L W' 3	(k)	4 W' L' W L W' 3
(f)	2 L W' L' W L 4		

L = length of grid square combination - 200 metres.
W = Width of grid square combination - 400 metres.

The length of trail for the circuit was calculated to be the sum of L + W + L' + W' + 1 + 2 + 3 + 4 and was used in this study as the trail length for a square or rectangular pattern of grid squares. The sum can be reduced to equation 3:

$$\text{Trail length for a square or rectangular pattern of grid squares} = 2L + 2W + 2\sqrt{L^2 + W^2}$$

Table 3 describes trail length in relation to the number of grid squares.

Grid Square Combination (Row x Column)	# Squares	Trail Length (km)
1 x 1	1	4.8
1 x 2	2	8.6
1 x 3	3	12.5
2 x 2	4	11.6
2 x 3	6	15.2
3 x 3	9	18.4

Table 3. Trail length in relation to the number of grid squares.

The algorithm in this study (NLP.S) is limited to only being able to examine one grid square at a time and taking into account 8 grid squares surrounding the examined grid square; therefore, the maximum length of trail that can be calculated by the algorithm is the trail length for 9 grid squares.

From Table 3, 18.4 km of trail is available for 9 grid squares and 4.8 km for 1 grid square. Using these data, a straight line relationship illustrated by Figure 16 and equation

4 were developed between trail length and the number of grid squares.

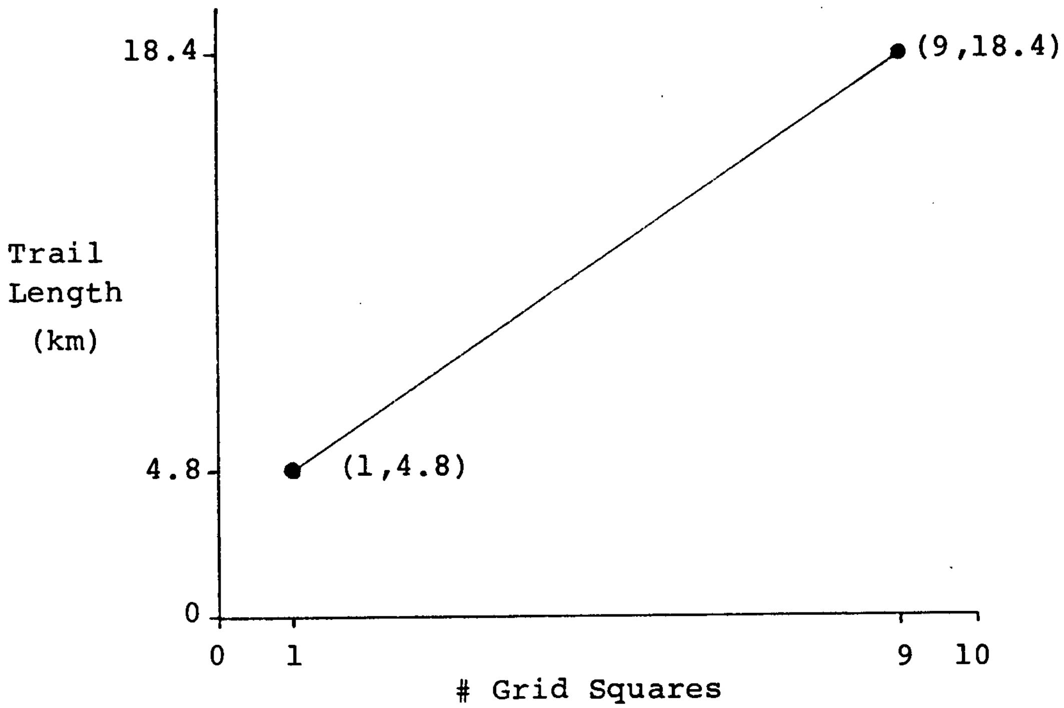


Fig. 16. Trail length in relation to the number of grid squares.

Equation of the line: Trail Length = m(# Grid Squares) + b

Maximum value of trail length = 18.4 = 9m + b

Minimum value of trail length = 4.8 = 1m + b

Subtracting equations, 13.6 = 8m

1.7 = m

3.1 = b

Therefore, Trail Length (km) = 1.7(Nl) + 3.1 (4)

where Nl = number of grid squares (up to 9).

4.43 Calculation of Average Slope and Snow Depth

Average slope and snow depth values are measured for each area represented by a grid square and stored in a file for use later in the program. The values are stored in lines of 10 values, each line representing one row on the grid square. For example the files for slopes and snow depths will have the same format as the files in Figures 17 and 18 respectively.

Line (Row)	
1	050,050,050,050,060,040,010,000,000,060,
2	050,050,050,050,050,045,040,000,000,000,
3	060,065,070,070,060,050,080,090,095,060,
4	070,065,040,030,030,035,055,055,045,050,
5	010,010,000,005,005,000,010,020,030,035,
6	060,040,020,020,025,043,045,045,050,050,
7	090,080,070,080,090,060,070,060,055,050,
8	100,100,090,080,090,050,060,050,045,045,
9	110,120,100,090,080,040,050,040,035,035,
10	130,140,130,120,110,090,080,070,080,045,

Fig. 17. An example of a file with slope values (%).

Line (Row)	
1	183,213,213,213,183,183,152,122,000,152,
2	183,213,213,198,183,152,122,000,122,152,
3	213,213,213,198,152,122,000,122,122,152,
4	213,213,213,183,152,122,000,122,122,152,
5	213,213,213,183,152,122,137,152,168,183,
6	213,213,183,152,122,000,137,168,168,137,
7	183,183,183,169,168,152,152,168,168,183,
8	183,183,152,168,152,137,122,122,122,122,
9	152,152,183,152,152,137,152,168,152,152,
10	183,183,152,168,168,152,137,137,122,122,

Fig. 18. An example of a file with snow depth values (cm).

4.44 Calculation of the Number of Conflicts per Hour Between Activities

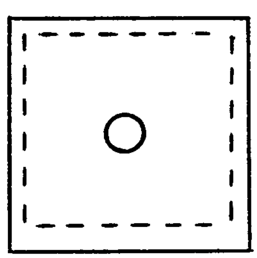
There are three land uses (7, 8 and 9) with conflicting activities. The conflict occurs between trailbiking and four-wheel driving. It is difficult to estimate how many conflicts per hour will occur on a hypothetical mine waste plan; however, four conflicts per hour or 1 conflict every 15 minutes seemed reasonable from the author's experience observing the two activities, for one grid square allocated both activities. This relationship for one grid square is used in the following example to develop an equation (equation 5) which determines the number of conflicts per hour in grid squares.

Example:

Case 1: One square allocated two conflicting activities.

Activity #1 = solid line (———)

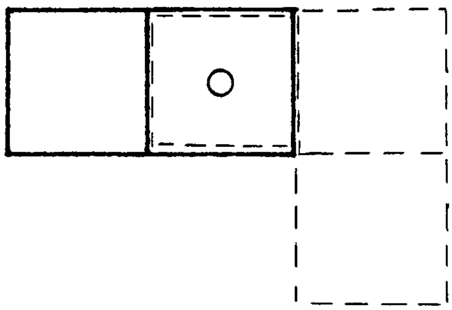
Activity #2 = dashed line (- - - -)



○ = Square under examination.

The number of conflicts in the square under examination is 4 conflicts per hour.

Case 2: Activity #1 allocated 2 contiguous grid squares
Activity #2 allocated 3 contiguous grid squares



O = Square under examination.

A decision maker engaging in Activity #1 will now be inside the square under examination 1/2 of the time. A decision maker engaging in Activity #2 will now be inside the square under examination 1/3 of the time; hence, there will be 1/2 x 1/3 as many conflicts in the square under examination. The number of conflicts per hour is now equal to 4 x 1/2 x 1/3 = 2/3 conflicts per hour for the square under examination. The relationship represented by equation 5 for the number of conflicts per hour in the square being examined is the following:

$$\text{Number of Conflicts per Hour} = \frac{4}{(N1)(N2)} \qquad (5)$$

where N1 = # squares allocated activity #1

N2 = # squares allocated activity #2

Equation 5 is used in the NLP.S algorithm.

4.45 Calculation of the Distance to the Nearest Drinking Water Source

Figure 19 is used in the following discussion to explain the calculation.

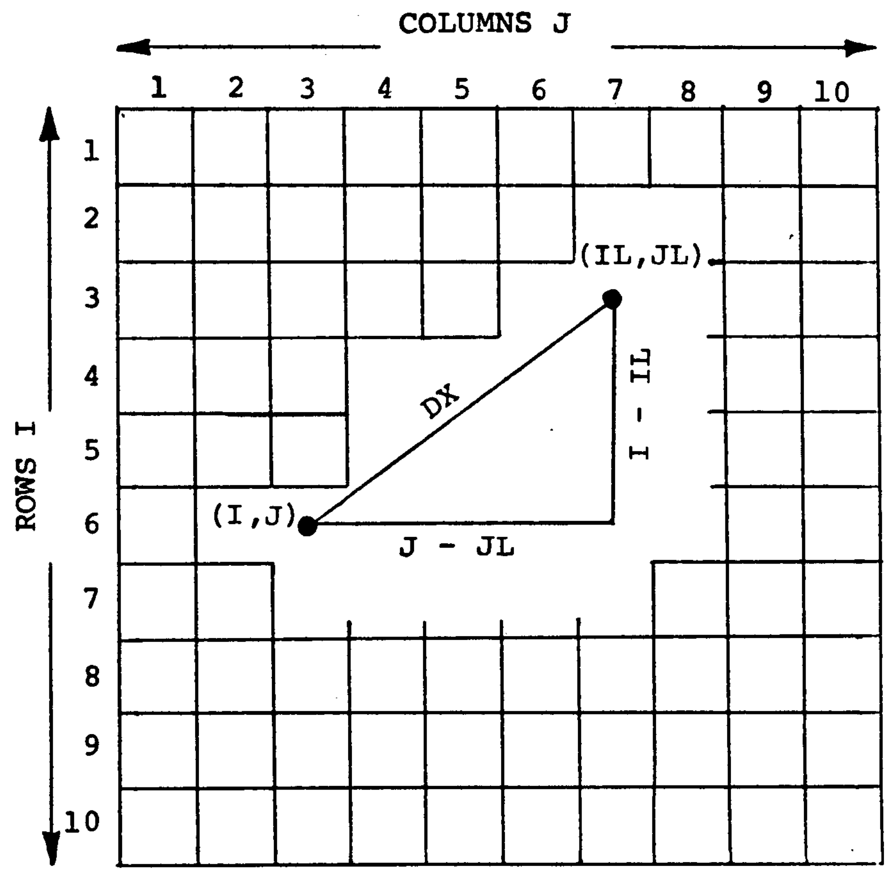


Fig. 19. Land use plan with the square under examination K at I,J coordinates (6,3) and drinking water source at I,J coordinates (3,7).

In Figure 19, (I,J) is the location of square K being examined. (IL,JL) is the location of the drinking water source. DX is the distance from square K to the drinking water source.

The distance DX is calculated by a diagonal from square K to the water source. In Figure 19, I-IL is the vertical length of the right angle triangle formed between square K and the water source. The following equation can therefore be used to calculate DX:

$$DX = \sqrt{(I - IL)^2 + (J - JL)^2}$$

The computer reads the location of the water sources from a file. The squares are numbered from 1 to 100. Square 001 corresponds to the I,J location (1,1); square 100 corresponds to the I,J location (10,10). Whenever a drinking water source is present in a grid square, the number of the square is listed in the file as illustrated by the file in Figure 20.

AN EXAMPLE OF A FILE CONTAINING GRID SQUARES
WHICH HAVE A DRINKING WATER SOURCE

FILE = LAKES

1	007
2	018
3	027
4	037
5	046
6	055
7	064
8	074
9	084
10	095

Fig. 20. An example of a file containing drinking water sources.

The grid square number from 1 to 100 must be converted to an (I,J) location. To illustrate, if square 027 has a drinking water source, then its corresponding (I,J) location is Row 3, Column 7 or (3,7). To determine the I location for grid square 027, the following equation is used:

$$IL = \frac{(LAKES(II) - 1)}{10} + 1$$

where IL = the I location of the water source and where LAKES(II) is the grid square number read by the computer. For the example,

$$IL = \frac{27 - 1}{10} + 1 = \frac{26}{10} = 2.6 + 1$$

The algorithm uses INTEGERS; therefore, all fractions are truncated. Hence IL = 2 + 1 = 3.

To determine the J location for grid square 027, the following equation is used:

$$JL = LAKES(II) - (IL - 1)(10)$$

where JL = the J location of the water source.

For the example, JL = 27 - (3-1)(10) = 27 - 20 = 7.

To calculate the distance DX, let square K be at (6,3). Therefore, I = 6, J = 3, IL = 3, JL = 7.

Hence distance DX is

$$DX = \sqrt{(I - IL)^2 + (J - JL)^2} = \sqrt{(6 - 3)^2 + (3 - 7)^2}$$

$$= \sqrt{3^2 + 4^2} = \sqrt{25} = 5 \text{ km.}$$

4.5 Evaluating the Mine Waste Section

The hypothetical mine waste section to be evaluated in this study is graphically illustrated in Figure 21. Data for the mine waste on average snow depths, average slopes and drinking water source locations are presented in Appendix 15. The town is located at grid square (-20.0,7.0), outside the 10 km x 10 km section.

There are two steps in the evaluation. The first step is to find a starting land use plan to generate a value for the objective function. Since there are 16^{100} possible land use plans, and no optimization routine available at this time, it is desirable to save time by starting with a plan which has a high objective function value. To generate a plan with a high function value, an algorithm called UTILVAL.S was developed which prints utility values for each activity for every grid square. The algorithm is presented in Appendix 16, and the procedure for using it in Appendix 17. The values produced by UTILVAL.S for the mine waste section are presented in Appendix 18. From these values, activities with high utilities are allocated to respective grid squares. Figure 22 illustrates grid squares which produce high utility values for certain activities. These activities can then be grouped into land uses presented in Figure 23. Combinations of these land uses were evaluated and the land use plan presented in Figure 24 had the highest function value of 0.862886567996. This plan was chosen as a starting plan.

The second step in the evaluation is to change land uses in the grid squares with the goal of increasing the value of the objective function. When a land use allocation plan has been generated, where any change in a land use for any grid square, or blocks of grid squares, decreases the function value for the plan, the best land use plan based on decision makers' preferences between attributes and attribute levels has been generated, without an optimization routine.

Fig. 21. Three dimensional representation of the plan evaluated in this study (Town is at row -20.0 and column 7.0 or (-20.0,7.0)).

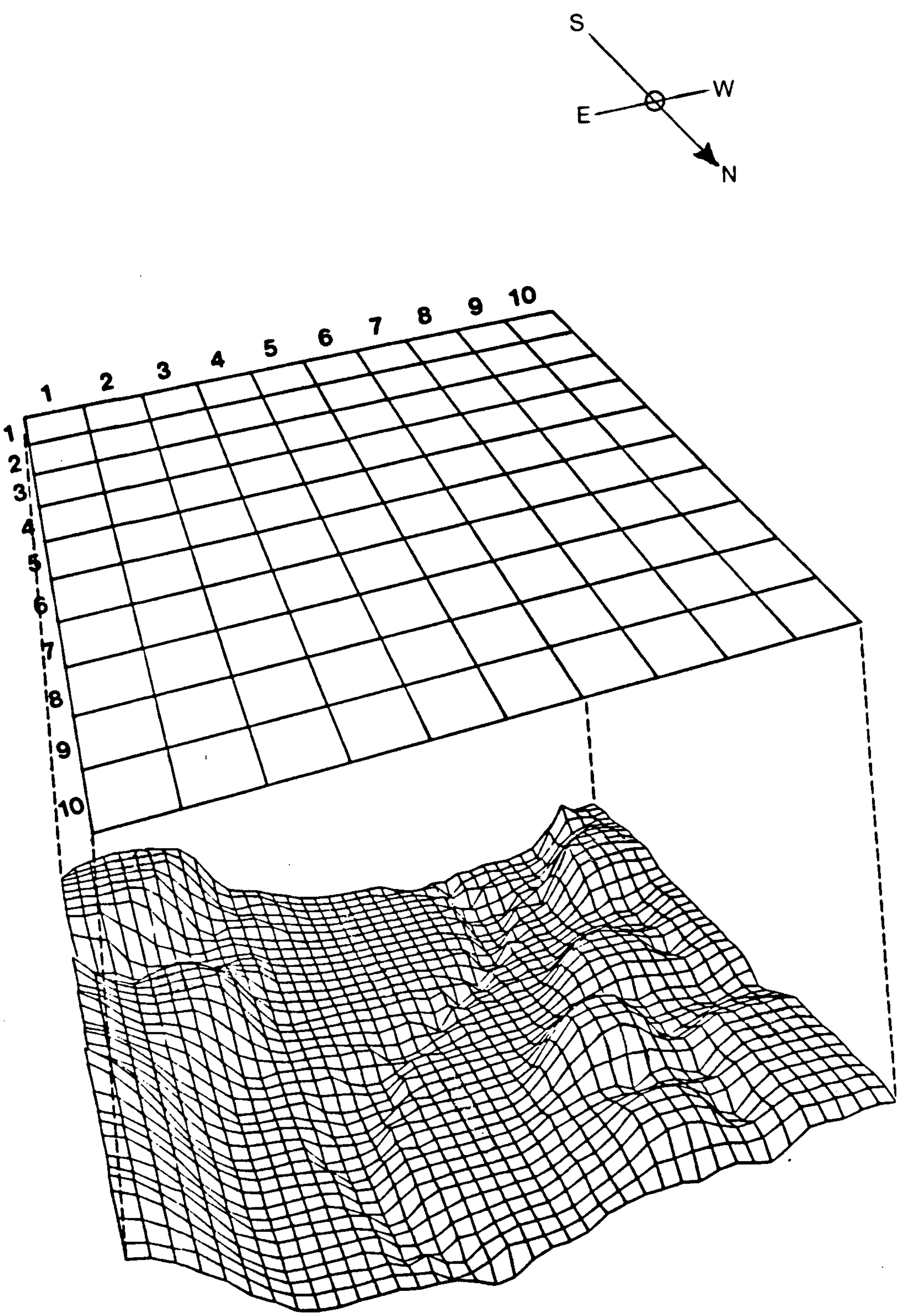


Fig.22. Grid squares with **high** utilities for certain activities.

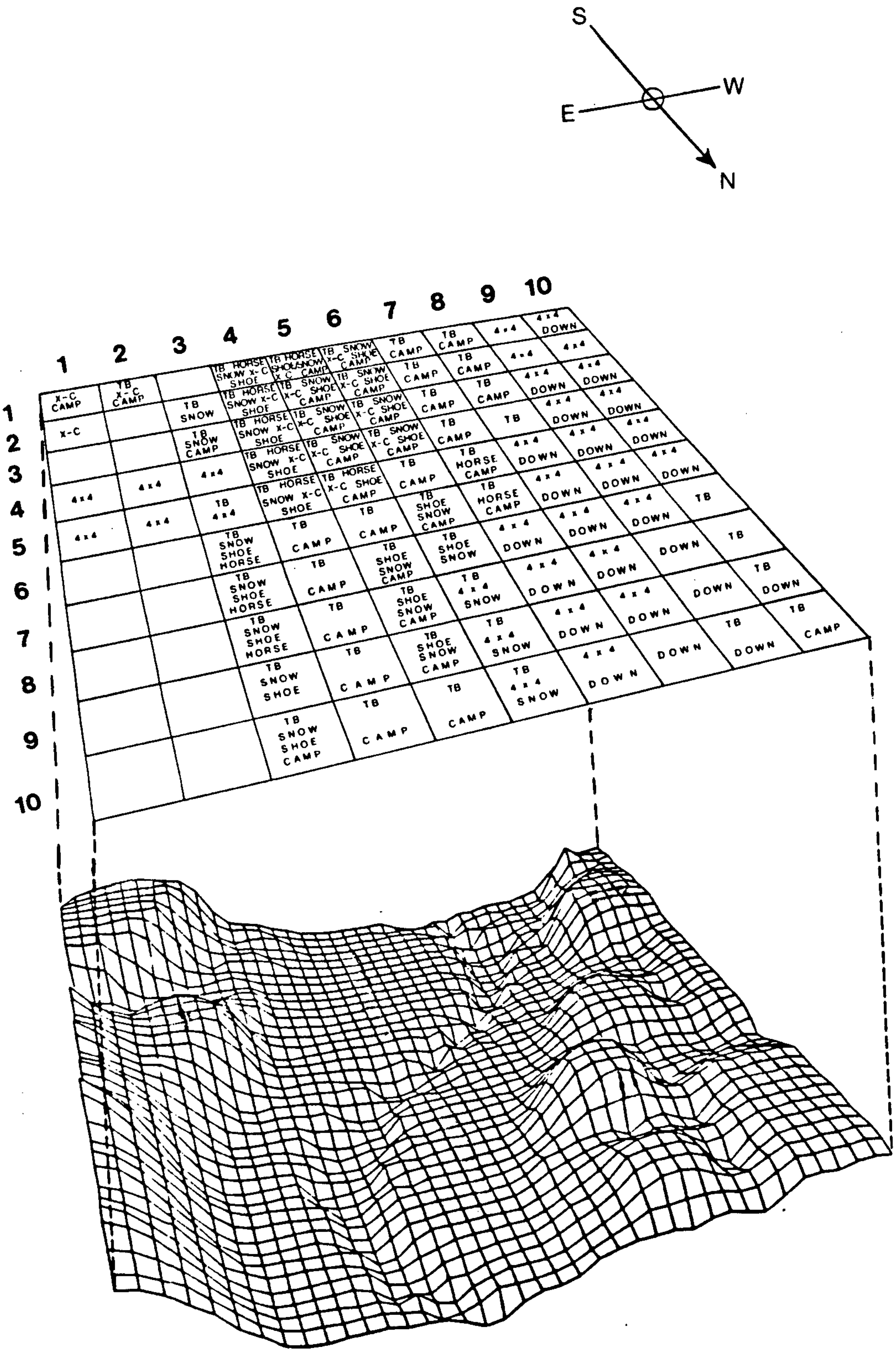
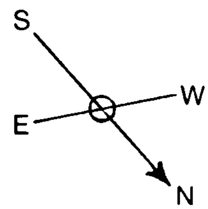


Fig. 23. Land uses resulting from the high utility activities presented in Figure 22.

LAND USE #	SUMMER ACTIVITIES	WINTER ACTIVITIES
1	TRAILBIKING	SNOWMOBILING
2	TRAILBIKING	X-C/SNOWSHOEING
3	TRAILBIKING	NO ACTIVITY
4	4X4	SNOWMOBILING
5	4X4	X-C/SNOWSHOEING
6	4X4	NO ACTIVITY
7	TRAILBIKING/4X4	SNOWMOBILING
8	TRAILBIKING/4X4	X-C/SNOWSHOEING
9	TRAILBIKING/4X4	NO ACTIVITY
10	HIKING/HORSEBACK RIDING/CAMPING	SNOWMOBILING
11	HIKING/HORSEBACK RIDING/CAMPING	X-C/SNOWSHOEING
12	HIKING/HORSEBACK RIDING/CAMPING	NO ACTIVITY
13	NO ACTIVITY	SNOWMOBILING
14	NO ACTIVITY	X-C/SNOWSHOEING
15	NO ACTIVITY	NO ACTIVITY
16	NO ACTIVITY	DOWNHILL SKIING



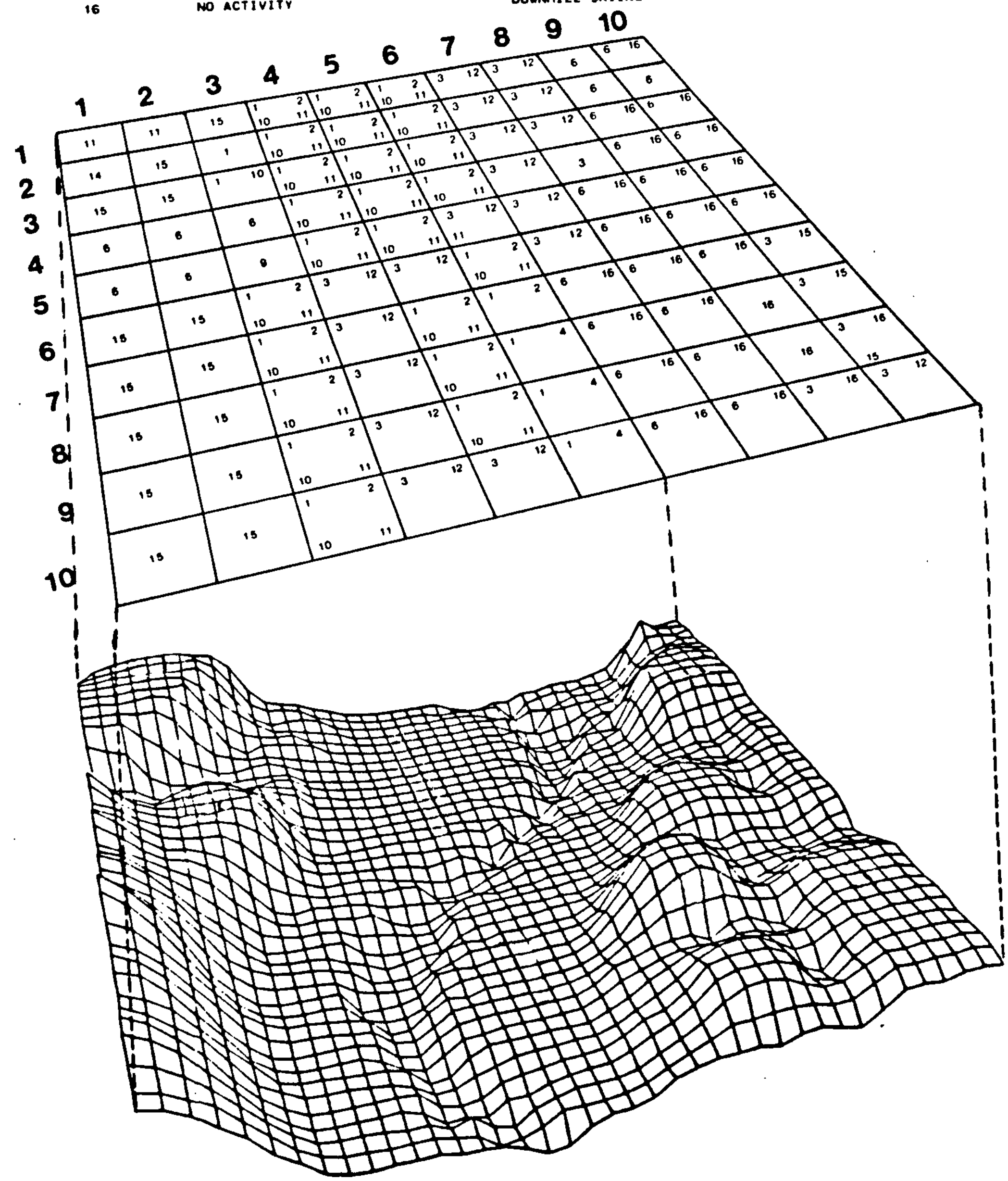
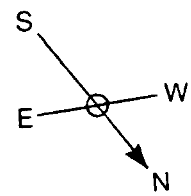


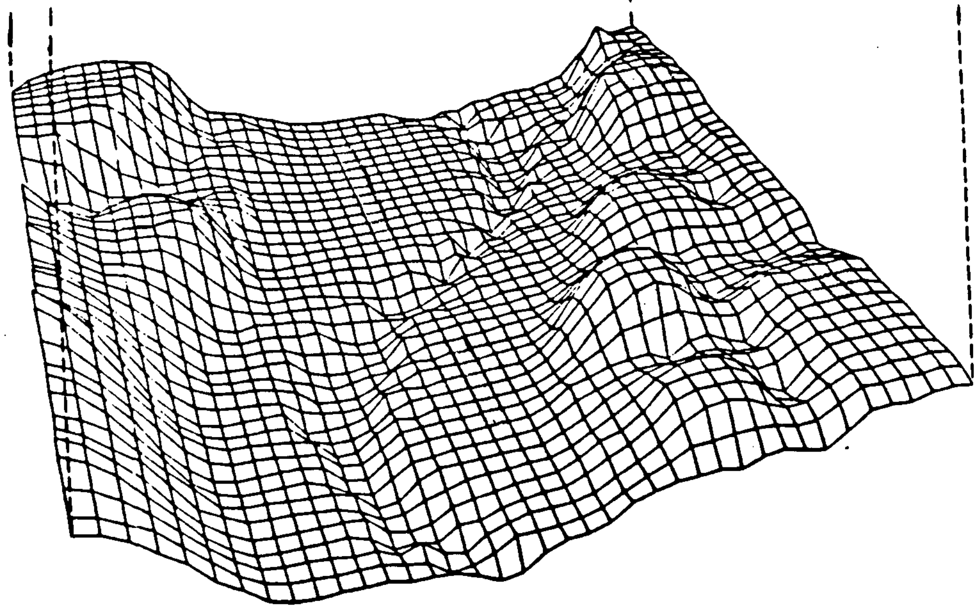
Fig.24. Starting plan for the evaluation.

LAND USE #	SUMMER ACTIVITIES	WINTER ACTIVITIES
1	TRAILBIKING	SNOWMOBILING
2	TRAILBIKING	X-C/SNOWSHOEING
3	TRAILBIKING	NO ACTIVITY
4	4X4	SNOWMOBILING
5	4X4	X-C/SNOWSHOEING
6	4X4	NO ACTIVITY
7	TRAILBIKING/4X4	SNOWMOBILING
8	TRAILBIKING/4X4	X-C/SNOWSHOEING
9	TRAILBIKING/4X4	NO ACTIVITY
10	HIKING/HORSEBACK RIDING/CAMPING	SNOWMOBILING
11	HIKING/HORSEBACK RIDING/CAMPING	X-C/SNOWSHOEING
12	HIKING/HORSEBACK RIDING/CAMPING	NO ACTIVITY
13	NO ACTIVITY	SNOWMOBILING
14	NO ACTIVITY	X-C/SNOWSHOEING
15	NO ACTIVITY	NO ACTIVITY
16	NO ACTIVITY	DOWNHILL SKIING

F = 0.862886567996



	1	2	3	4	5	6	7	8	9	10
1	11	11	15	11	11	11	12	12	6	6
2	14	15	1	11	11	11	12	12	6	6
3	15	15	1	11	11	11	12	12	6	6
4	6	6	6	11	11	11	12	12	6	6
5	6	6	9	11	11	3	3	6	6	6
6	15	15	1	3	3	11	3	6	6	6
7	15	15	1	3	1	1	6	6	6	3
8	15	15	1	3	1	4	6	6	16	3
9	15	15	1	12	1	4	6	6	16	3
10	15	15	2	12	12	4	6	6	3	3



CHAPTER

RESULTS - PART 2

Maximization of the Objective Function

The following land use plans were generated by changing land uses in the starting plan developed in Section 4.5. These land use plans correspond to the 100 grid square section in Figure 21. The top left corner land use corresponds to grid square (1,1); the bottom right corner land use corresponds to grid square (10,10).

The first land use plan presented is the starting plan developed in Section 4.5. The plans that follow the starting plan sequentially increase in objective function value. The symbol "F" represents "objective function value". Each plan presented represents 5 land use changes which increase the function value. For example, the second land use plan presented has a function value of 0.863583195736. Five of its land uses are different than the starting plan.

11	11	15	11	11	11	12	12	6	6
14	15	1	11	11	11	12	12	6	6
15	15	1	11	11	11	12	12	6	6
6	6	6	11	11	11	12	12	6	6
6	6	9	11	11	3	3	6	6	6
15	15	1	3	3	11	3	6	6	6
15	15	1	3	1	1	6	6	6	3
15	15	1	3	1	4	6	6	16	3
15	15	1	12	1	4	6	6	16	3
15	15	2	12	12	4	6	6	3	3

STARTING PLAN

F = 0.862886567996

11	11	15	11	11	11	12	12	6	6
14	15	1	11	11	11	12	12	6	6
15	15	1	11	11	11	12	12	6	6
6	6	6	11	11	11	12	12	6	6
6	6	9	11	11	3	3	6	6	6
15	15	1	3	3	11	3	6	6	6
15	15	1	3	1	1	6	6	6	15
15	15	1	3	1	4	6	6	16	3
15	15	1	3	10	4	6	6	16	15
15	15	2	12	12	4	6	6	15	3

F = 0.863583195736

11	11	15	11	11	11	12	12	6	6
14	15	1	11	11	11	12	12	6	6
15	15	1	11	11	11	12	12	6	6
6	6	6	11	11	11	12	12	6	6
6	6	9	11	11	3	3	6	6	6
15	15	1	3	3	11	3	6	6	6
15	15	1	3	1	1	6	6	6	15
15	15	1	3	1	4	6	6	16	3
15	15	1	12	10	4	6	6	16	15
15	15	2	12	12	4	6	6	15	3

F = 0.863822679413

11	11	15	11	11	11	12	12	6	6
14	15	1	11	11	11	12	12	6	6
15	15	1	11	11	11	12	12	6	6
6	6	6	11	11	11	12	12	6	6
6	6	9	11	11	3	3	6	6	6
15	15	1	3	3	11	3	6	6	6
15	15	1	3	1	1	6	6	6	15
15	15	1	3	1	4	6	6	16	3
15	15	13	12	10	4	6	6	16	15
15	6	12	12	12	4	6	6	15	3

F = 0.864386478268

11	11	15	11	11	11	12	12	6	6
14	15	1	11	11	11	12	12	6	6
15	3	3	11	11	11	12	12	6	6
6	6	6	11	11	11	12	12	6	6
6	6	15	1	11	12	3	6	6	6
15	15	1	3	3	11	3	6	6	6
15	15	1	3	1	1	6	6	6	15
15	15	1	3	1	4	6	6	16	3
15	15	13	12	10	4	6	6	16	15
15	6	12	12	12	4	6	6	15	3

F = 0.866497449359

11	11	15	11	3	14	12	12	6	6
12	15	13	2	11	11	12	12	6	6
15	3	3	11	11	11	12	12	6	6
6	6	6	11	11	11	12	12	6	6
6	6	15	1	11	12	3	6	6	6
15	15	1	3	3	11	3	6	6	6
15	15	1	3	1	1	6	6	6	15
15	15	1	3	1	4	6	6	16	3
15	15	13	12	10	4	6	6	16	15
15	6	12	12	12	4	6	6	15	3

F = 0.870043828838

12	12	15	3	3	14	15	12	6	6
12	15	13	2	11	11	12	12	6	6
15	15	3	11	11	11	12	12	6	6
6	6	6	11	11	11	12	12	6	6
6	6	15	1	11	12	3	6	6	6
15	15	1	3	3	11	3	6	6	6
15	15	1	3	1	1	6	6	6	15
15	15	1	3	1	4	6	6	16	3
15	15	13	12	10	4	6	6	16	15
15	6	12	12	12	4	6	6	15	3

F = 0.873877838249

12	12	15	3	3	14	15	14	6	6
12	15	13	2	11	11	11	15	6	6
15	15	3	11	11	11	12	1	6	6
6	6	6	11	11	11	12	13	6	6
6	6	15	1	11	12	3	6	6	6
15	15	1	3	3	11	3	6	6	6
15	15	1	3	1	1	6	6	6	15
15	15	1	3	1	4	6	6	16	3
15	15	13	12	10	4	6	6	16	15
15	6	12	12	12	4	6	6	15	3

F = 0.878617576695

12	12	15	3	3	14	15	14	6	6
12	15	13	2	11	11	11	15	6	6
15	15	3	11	11	11	12	1	6	6
6	6	6	11	11	11	12	13	6	6
6	6	15	1	11	12	1	6	6	6
15	15	1	3	3	11	1	6	6	6
15	15	1	3	1	1	6	6	6	15
15	15	1	3	1	4	6	6	16	3
15	15	13	12	13	4	6	6	16	15
15	6	12	12	15	6	6	6	15	3

F = 0.879539610232

12	12	15	3	3	14	15	14	6	6
12	15	13	2	11	11	11	15	6	6
15	15	3	11	11	11	12	1	6	6
6	6	6	11	11	11	12	13	6	6
6	6	15	1	11	12	1	6	6	6
15	15	1	3	3	11	1	6	6	6
15	15	1	1	1	1	6	6	6	15
15	15	1	1	1	4	6	6	16	3
15	15	13	15	13	4	6	6	16	15
15	6	15	15	15	6	6	6	15	3

F = 0.880765256587

15	15	15	3	3	14	15	14	6	6
12	15	13	2	11	11	11	15	6	6
15	15	3	11	11	11	12	1	6	6
6	6	6	11	11	11	12	13	6	6
6	6	15	1	10	12	1	6	6	6
15	15	1	3	3	10	1	6	6	6
15	15	1	1	1	1	6	6	6	15
15	15	1	1	1	6	6	6	16	3
15	15	13	13	13	4	6	6	16	15
15	6	15	15	15	6	6	6	15	3

F = 0.881204715644

15	15	15	3	3	14	15	14	6	6
12	15	13	2	11	11	11	15	6	15
15	15	3	11	11	11	12	1	6	6
6	6	6	11	11	11	12	13	6	6
6	6	15	1	10	12	1	6	6	6
15	15	1	3	3	10	1	6	6	6
15	15	1	1	1	1	6	6	6	15
15	15	1	1	1	6	6	6	15	15
15	15	13	13	13	6	6	6	16	15
15	6	15	15	15	6	6	6	15	3

BEST SOLUTION FOUND

F = 0.884954632831

From the evaluation, the final plan generated had an objective function value of 0.884954632831. The plan is graphically presented in Figure 25.

An algorithm called OUTSPLIT.S, presented in Appendix 19, was developed to take a land use plan as in Figure 25, and split the land uses into activity allocations for each grid square. The procedure for using the algorithm is presented in Appendix 20. Figures 26 and 27 illustrate where the activities are allocated in the starting land use plan and final land use plan respectively.

Fig.25. The land use plan with the highest function value.

LAND USE #	SUMMER ACTIVITIES	WINTER ACTIVITIES
1	TRAILBIKING	SNOWMOBILING
2	TRAILBIKING	X-C/SNOWSHOEING
3	TRAILBIKING	NO ACTIVITY
4	4X4	SNOWMOBILING
5	4X4	X-C/SNOWSHOEING
6	4X4	NO ACTIVITY
7	TRAILBIKING/4X4	SNOWMOBILING
8	TRAILBIKING/4X4	X-C/SNOWSHOEING
9	TRAILBIKING/4X4	NO ACTIVITY
10	HIKING/HORSEBACK RIDING/CAMPING	SNOWMOBILING
11	HIKING/HORSEBACK RIDING/CAMPING	X-C/SNOWSHOEING
12	HIKING/HORSEBACK RIDING/CAMPING	NO ACTIVITY
13	NO ACTIVITY	SNOWMOBILING
14	NO ACTIVITY	X-C/SNOWSHOEING
15	NO ACTIVITY	NO ACTIVITY
16	NO ACTIVITY	DOWNHILL SKIING

$F = 0.884954632831$

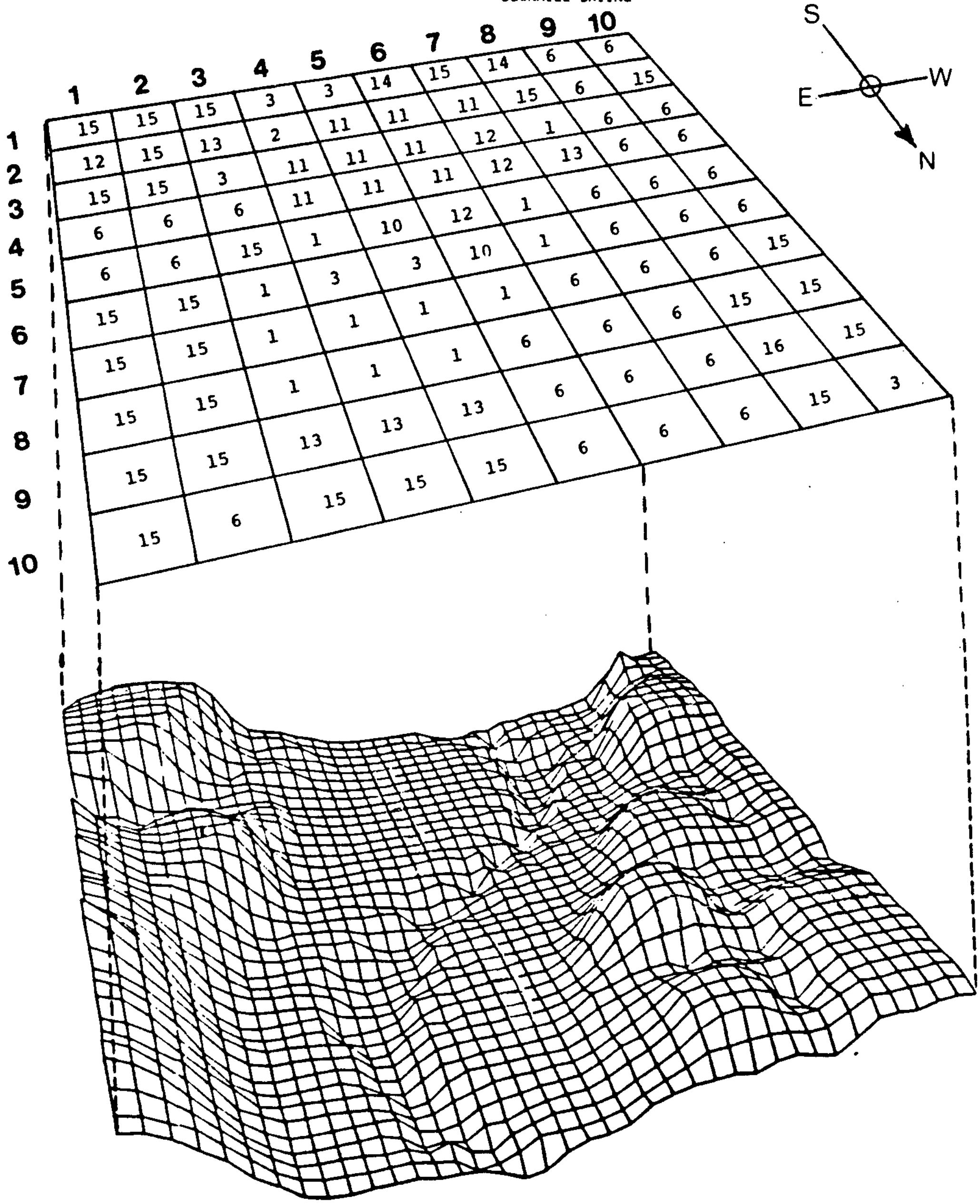


Fig.26. Activity allocations for the starting land use plan.

0 = Activity not allocated to grid square
1 = Activity allocated to grid square

SUMMER ACTIVITIES

Trailbiking

0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	1	1	0	0	0
0	0	1	1	1	0	1	0	0	0
0	0	1	1	1	1	0	0	0	1
0	0	1	1	1	0	0	0	0	1
0	0	1	0	1	0	0	0	0	1
0	0	1	0	0	0	0	0	1	1

4x4s

0	0	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	1	1
1	1	1	0	0	0	0	0	1	1
1	1	1	0	0	0	0	1	1	1
0	0	0	0	0	0	0	1	1	1
0	0	0	0	0	0	1	1	1	0
0	0	0	0	0	1	1	1	0	0
0	0	0	0	0	1	1	1	0	0
0	0	0	0	0	1	1	1	0	0

Hiking/Horseback Riding/Camping

1	1	0	1	1	1	1	1	0	0
0	0	0	1	1	1	1	1	0	0
0	0	0	1	1	1	1	1	0	0
0	0	0	1	1	1	1	1	0	0
0	0	0	1	1	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0
0	0	0	1	1	0	0	0	0	0

WINTER ACTIVITIES

Snowmobiling

0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	0	1	0	1	1	0	0	0	0
0	0	1	0	1	1	0	0	0	0
0	0	1	0	1	1	0	0	0	0
0	0	0	0	0	1	0	0	0	0

Snowshoeing/X-C Skiing

1	1	0	1	1	1	0	0	0	0
1	0	0	1	1	1	0	0	0	0
0	0	0	1	1	1	0	0	0	0
0	0	0	1	1	1	0	0	0	0
0	0	0	1	1	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0

Downhill Skiing

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0

Fig.27. Activity allocations for the best land use plan generated.

0 = Activity not allocated to grid square

1 = Activity allocated to grid square

SUMMER ACTIVITIES

Trailbiking

0	0	0	1	1	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0
0	0	1	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	1	0	0	0
0	0	1	1	1	0	1	0	0	0
0	0	1	1	1	1	0	0	0	0
0	0	1	1	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1

4x4s

0	0	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	1	1
1	1	1	0	0	0	0	0	1	1
1	1	0	0	0	0	0	1	1	1
0	0	0	0	0	0	0	1	1	1
0	0	0	0	0	0	1	1	1	0
0	0	0	0	0	1	1	1	0	0
0	0	0	0	0	1	1	1	0	0
0	1	0	0	0	1	1	1	0	0

Hiking/Horseback Riding/Camping

0	0	0	0	0	0	0	0	0	0
1	0	0	0	1	1	1	0	0	0
0	0	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	0	0
0	0	0	0	1	1	0	0	0	0
0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

WINTER ACTIVITIES

Snowmobiling

0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	1	0	0
0	0	0	1	1	0	1	0	0	0
0	0	1	0	0	1	1	0	0	0
0	0	1	1	1	1	0	0	0	0
0	0	1	1	1	0	0	0	0	0
0	0	1	1	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Snowshoeing/X-C Skiing

0	0	0	0	0	1	0	1	0	0
0	0	0	1	1	1	1	0	0	0
0	0	0	1	1	1	0	0	0	0
0	0	0	1	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Downhill Skiing

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0

CHAPTER 6

DISCUSSION - PART 2

Maximization of the Objective Function

From the starting plan to the final plan, the function value increased by 0.022068064835 or approximately 2.5 percent. The change of any land use or blocks of land uses in the final plan decreased the function value; therefore, the final land use plan is thought to be the best plan generated in the absence of a computer optimization routine.

The "no activity" land use (#15) almost doubled from 14 in the starting plan to 27 in the final plan. This occured because every other land use lowers the average utility value for one or more of the respective activities which in turn lowers the objective function value of the plan. The "no activity" land use does not lower an activity utility.

The number of grid squares allocated trailbiking decreased from 24 in the starting plan to 19 in the final plan. Trail-biking, as expected, was allocated in the final plan to grid squares with slope values of 0 to 30 percent. This slope range corresponds to high utility values for trailbiking and slope is the most important attribute. The locations of trailbiking did not change greatly from the starting plan to the final plan.

The number of grid squares allocated four-wheel driving decreased by 1, from 32 in the starting plan to 31 in the final plan. The locations of four-wheel driving did not change greatly from the starting plan. The four-wheel driving activity, as expected, was restricted to areas with slope values of 35 to 55 percent. These slope values correspond to high utility values for four-wheel driving and slope is the most important attribute.

The final plan did not contain land uses 5, 7, 8 or 9. During the evaluation, land uses 4 and 6 always yielded higher function values than land use 5. This is explained by the conflicting utility values for slope between four-wheel driving and cross-country skiing/snowshoeing. The common attributes of the three activities are travel time, length of trail and slope. The utility functions for travel time and length of trail are similar for the three activities. High slope values have high utility values for four-wheel driving while the reverse is true for cross-country skiing and snowshoeing. Slope is the most important attribute for four-wheel driving and cross-country skiing while not as important to snowshoeing. The conflict created from these opposing utilities for slope results in a decrease in either the four-wheel driving or the cross-country skiing and snowshoeing utilities for a given slope value. Land use 4 represents four-wheel driving and snowmobiling which prefer similar slope values. Land use 6 represents only four-wheel driving. Land uses 4 and 6 will always yield higher objective function values for the plan than land use 5 because they have similar utility functions for slope.

Land uses 7, 8 and 9 were never chosen for the final plan. This is due to the conflict between trailbiking and four-wheel driving. Having the activities together decreases the utility value for both activities. Land uses 1 - 6 separate the two activities and always yield higher objective function values for the plan because the conflict is not present. This result could have been predicted before the evaluation; land uses 7 - 9 were included only for interest.

The number of grid squares allocated snowmobiling increased from 13 in the starting plan to 19 in the final plan. Snowmobiling, as expected, was assigned to grid squares with slope values ranging from 0 to 25 percent and snow depth values ranging from 91 to 122 cm. These ranges correspond to high utility values for these attributes. Some snowmobiling was assigned to grid squares with snow depths of 0 cm which is not logical. Grid squares with snow depths of 0 cm correspond to river locations. A river poses safety hazards to snowmobiling; therefore, modification of the evaluation algorithm is necessary to prevent snowmobiling from being assigned to grid squares with lakes or rivers.

Downhill skiing allocation decreased by 1 grid square from 2 grid squares in the starting plan. It was assigned to the grid square which has a slope value of 60 percent, the most important attribute to downhill skiing a corresponding to a utility of 1.0.

Cross-country skiing and snowshoeing allocations decreased from 19 grid squares in the starting plan to 12 in the final plan. These activities prefer, on average, 67 - 152 cm of snow. These activities were allocated to grid squares with this range of snow depths. Both activities prefer slope values of 0 to 15 percent and as expected, were allocated to squares with these slope values.

Hiking, horseback riding and camping decreased from 28 in the starting plan to 15 in the final plan. They are mainly concentrated around the river which serves as a drinking water source for hiking and camping. Horseback riding prefers slope values of 5 to 20 percent. Camping prefers slope values of 0 to 10 percent. The allocation of the three activities was restricted to grid squares with slope values of 0 percent, corresponding to a utility of 1.0 for camping and a utility value of 0.0 for horseback riding. The reason why these activities were not allocated to grid squares with higher slope values is because the activity camping has the highest scaling factor in the objective function (0.254) while horseback riding has a scaling factor of 0.078. Hiking has a scaling factor of 0.146; therefore, areas with slope values favourable to camping will be chosen for the land uses containing these three activities. The activities were grouped together because of their compatability; in future they should be separated.

CHAPTER 7

SUMMARY AND CONCLUSIONS

In summary, the interests of recreational user groups which will use a mine waste area must be incorporated into a mine waste recreation plan. In this study, a user group's interests are defined as the user group's preferences for mine waste attributes. The mine waste examined in this study was a hypothetical 10 km x 10 km section. The physical features of the mine waste resemble the coal mine waste of the Elk River Valley in southeastern British Columbia. Nine recreational activities were chosen for analysis. These were grouped into 16 land uses. A resident of the Elk River Valley was chosen to represent the interests of each of the activity user groups. Multi-attribute utility analysis was used to develop the nine representatives' preference structures for the mine waste attributes. The results of the analysis were used to develop an objective function which measured how well a recreation plan for the mine waste satisfied the user groups' interests. A computer program was developed to evaluate the objective function. Using this program, a recreation land use plan was produced for the hypothetical mine waste section which maximized the objective function.

In conclusion, a planner in this study is faced with the large problem of satisfying the most recreational user groups' interests in an outdoor recreation plan for mine waste. Multi-attribute utility analysis was employed to address this objective. Two major limitations of the analysis were identified. The first was the large time commitment required by user groups to structure their preferences for mine waste attributes. Given time and budget constraints for a mine waste recreation development project, a planner must seriously consider whether the analysis is justified. Also user groups tend to become tired with the preference assessment procedures. This may affect the shapes of the resulting utility functions. The second limitation was that the assessed preferences did not take into account the cost to the user groups of obtaining each attribute level. This cost may indeed influence the user groups' preferences over attribute levels.

Accepting these limitations, multi-attribute utility analysis is successful in breaking the large outdoor recreation planning problem into smaller problems, where user groups' objectives and associated attributes, indicating the extent that the objectives are achieved, can be identified. The analysis enables user groups to systematically articulate and understand their preferences for each of the attributes. Using this information in a computer program, a planner is able to isolate agreements and differences in the judgments and preferences of the user groups, providing a firm basis on which to facilitate communication between the user groups and the planner, and to begin a constructive process of conflict resolution. The planner can then integrate these results with other information on the mine waste development area to develop a feasible outdoor recreation land use plan.

REFERENCES CITED

Allan, N,J,R, 1975. Man, machine and snow: a study of recreationists' landscape perceptions. Syracruse University, Syracruse, New York.

Arychuk, C., et. al. 1979. Motorized recreation in the Greater Vancouver area. Simon Fraser University report *in* Motorized recreation task force - assessment of potential trailbike sites. Greater Vancouver Regional District: Parks.

Baldwin, M.F., and D.H. Stoddard Jr. 1973. The off-road vehicle and environmental quality (2nd ed.). The Conservation Foundation, Washington, D.C.

Brander, R.B. 1974. Ecological impacts of off-road recreation vehicles *in* Proceedings from workshop outdoor recreation research: applying the results. U.S.D.A. Forest Service general technical report NC-9, St. Paul, Minnesota.

B.C. Research. 1976. Hosmer-Wheeler coal project: stage II environmental assessment. Vancouver, B.C.

B.C. Research. 1980. Greenhills coal project: stage I environmental assessment. Vancouver, B.C.

Brockman, C.F., and L.C. Merriam Jr. 1973. Recreational use of wildlands (2nd ed.). McGraw-Hill Inc., New York.

Bury, R.L., and E. Fillmore. 1975. Motorcycle area design and location: impacts on the recreational experiences of riders and non-riders. Department of Recreation and Parks, Texas A & M University Agricultural Experimental Station.

Bury, R.L., R.C. Wendling, and S.F. McCool. 1976. Off-road recreational vehicles - a research summary 1969 - 1975. Report # MP-1277, Texas A & M University Agricultural Experimental Station.

Canadian Government Office of Tourism, Department of Industry, Trade and Commerce. 1972. Planning Canadian campgrounds. Ottawa, Ontario.

Chilman, K.C. 1979. Profile: the trailbiker. Pages 81-86 *in* Planning for trailbike recreation. U.S.D.I. Heritage Conservation and Recreation Service, Washington, D.C.

Churchman, C.W. 1961. Prediction and optimal decision: philosophical issues of a science of values. Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Dennis, R.L. 1979. The role of modelling: a means for energy/ environment analysis. *In* Goodwin, G.T., and W.D. Rowe (eds.). 1979. Energy risk management. Academic Press Inc., New York, New York.

Edwards, W. 1953. Probability preferences in gambling. Amer. Journal of Psychology 66:349-364.

Edwards, W. 1954. Probability preferences among bets with differing expected values. Amer. Journal of Psychology 67:56-67.

Festinger, L. 1957. A theory of cognitive dissonance. Stanford University Press, Stanford, California.

Festinger, L. 1964. Conflict, decision and dissonance. Stanford University Press, Stanford, California.

Fishburn, P.C. 1964. Decision and value theory. John Wiley & Sons, New York, New York.

______. 1966. A note on recent developments in additive utility theories for multiple-factor situations. Operations Research 14:1143-1148.

______. 1968. Utility theory. Management Science 14(5): 335-378.

Fischer, G.W. 1973. Experimental applications of multi-attribute utility models. *In* Wendt, D., and C. Vlek (eds.). 1975. Utility, probability and human decision making. D. Reidel Publishing Company, Boston, Mass.

Geological Society of America, Committee on Environment and Public Policy. 1977. Impacts of off-road vehicles. Boulder, Colorado.

Helmker, J. 1975. A manual of snowmobiling (2nd ed.). A.S. Barnes & Company, New York, New York.

Hetherington, J.W. 1971. A survey of snowmobile trail facilities. *In* Chubb, M., (ed.). Proceedings of the 1971 snowmobile and off the road vehicle research symposium. Technical report #8, Department of the Interior, Michigan State University.

Higgins, T.W. 1973. Reclaiming surface-mined coal lands for outdoor recreation. *In* Proceedings of regional conference on reclamation of surface-mined land for outdoor recreation. U.S.D.A. Bureau of Outdoor Recreation and Kent State University, Kent, Ohio.

Hilborn, R., and C.J. Walters. 1977. Differing goals of salmon management on the Skeena River. Jour. Fisheries Research Board of Canada, 34(1):64-72.

Hoene, J.V. Undated. Snowmobiles and Noise. International Snowmobile Industry Association.

Holloway, C.A. 1979. Decision making under uncertainty: models and choices. Prentice-Hall Inc., New Jersey.

Huber, G.P. 1974. Multi-attribute utility models: a review of field and field-like studies. Management Science 20(10):1393-1402.

Jubenville, A. 1978. Outdoor recreation management. W.B. Saunders Company, Toronto, Ontario.

Kauder, E. 1965. A history of marginal utility theory. Princeton University Press, Princeton, New Jersey.

Keeney, R.L. 1970. Utility independence and preferences for multi-attributed consequences. Operations Research 19:875-893.

______. 1972. An illustrated procedure for assessing multi-attributed utility functions. Sloan Management Review, 14:37-50.

______. 1973. A decision analysis with multiple objectives; the Mexico City Airport. The Bell Journal of Economics and Management Science 4:101-117.

______. 1974. Multiplicative utility functions. Operations Research 22:22-34.

______. 1975. Examining corporate policy using multi-attribute utility analysis. Sloan Management Review 17:63-76.

______. 1977a. A utility function for examining policy affecting salmon on the Skeena River. Jour. Fisheries Research Board of Canada 34(1):64-72.

______. 1977b. The art of assessing multi-attributed utility functions. Organizational Behaviour and Human Performance 19:267-310.

______. 1979. Evaluation of proposed storage sites. Operations Research 27:48-64.

______. 1980. Siting energy facilities. Academic Press Inc., New York, New York.

Keeney, R.L., and H. Raiffa. 1976. Decisions with multiple objectives: preferences and value tradeoffs. John Wiley & Sons, New York, New York.

Keeney, R.L., and G.A. Robilliard. 1977. Assessing and evaluating environmental impact at proposed nuclear power plant sites. Jour. Env. Econ. and Management 4:153-166.

Knudson, D.M. 1980. Outdoor recreation. MacMillan Publishing Company Inc., New York, New York.

Krischer, J.P. 1974. An analysis of patient management decisions as applied to cleft palate. Unpublished Ph.D. thesis, Center for Research in Computing Technology, Harvard University, Cambridge, Mass.

Kuehn, J.H. 1971. Minnesota's 1970 snowmobile study. *In* Chubb, M., (ed.). Proceedings of the 1971 snowmobile and off the road vehicle research symposium. Technical report #8, Department of the Interior, Michigan State University.

Larsson, S.O. 1977. Studies in utility theory. Unpublished Ph.D. thesis, The University of British Columbia.

Lee, W. 1971. Decision theory and human behaviour. John Wiley & Sons, New York, New York.

Leuschner, W.A. 1970. Skiing in the Great Lake States: the industry and the skier. U.S.D.A. Forest Service Research Paper NC-46, North Central Forest Experiment Station, St. Paul, Minnesota, *in* Recreation symposium proceedings, Northeastern Forest Experiment Station, Forest Service, U.S.D.A., Darby, Pennsylvania.

Luce, D.R. and H. Raiffa. 1957. Games and Decisions. John Wiley & Sons, New York, New York.

Lund, M., and B. Williams. 1974. The snowmobiler's bible. Doubleday & Company Inc., Garden City, New York.

MacCrimmon, K.R. 1973. An overview of multiple objective decision making. *In* Cochrane, J.L., and M. Zeleny (eds.). Multiple criteria decision making. University of South Carolina Press.

MacCrimmon, K.R., and S.O. Larsson. 1975. Utility theory: axioms versus paradoxes. *In* Allais, M., and Hagen, O., (eds.). 1979. Expected utility hypothesis and the Allais paradox. D. Reidel Publishing Company, Boston, Mass.

McCall, J.R., and V.N. McCall. 1977. Outdoor recreation: forest, park and wilderness. Benziger, Bruce and Glencoe Inc., Beverly Hills, California.

Morris, W.T. 1971. Decision analysis. Grid Inc., Columbus, Ohio.

Nessman, E.M., and L.D. Bailey. 1981. Outdoor recreation participation: Southeast Coal Block, 1980. Planning Branch, Ministry of Environment, Victoria, B.C.

Newby, F.L., and W.D. Lilley. 1980. Cross-country skiing trend data: planning for participant needs. *In* Proceedings 1980 national outdoor recreation trends symposium Vol. 2, U.S.D.A. Forest Service, Broomall, Penn., General Technical Report NE-57.

O'Neill, A. 1973. Reclamation for recreation - the national perspective. *In* Proceedings of regional conference on surface-mined land for outdoor recreation. Bureau of Mines, Bureau of Outdoor Recreation and National Recreation and Park Association, Denver, Colorado.

O'Riordan, T. 1974. Back country recreation and public policy. Pages 7-13 *in* Proceedings of the outdoor recreation management conference, University of British Columbia, Vancouver, B.C.

Selles, R. 1973. Report of the all-terrain vehicle study. For the Canadian Parks/Recreation Association.

Sheridan, D. 1979. Off-road vehicles on public land. Council on Environmental Quality, U.S. Government Printing Office, Washington, D.C.

Simon, H.A. 1959. Theories of decision making in economics and behavioural science. American Economic Review 49(1): 253-283. *In* Simon, H.A. 1982. Models of bounded rationality Vol. 2: behavioural economics and business organization. The MIT Press, Cambridge, Mass.

Timmons, B.J. 1973. Reclamation for outdoor recreation in Florida. *In* Proceedings of regional conference on reclamation for recreation. Southeast Regional Office Bureau of Outdoor Recreation, Georgia State University, Bureau of Business and Economic Research and United States Bureau of Mines, Georgia State University, Atlanta, Georgia.

Tversky, A. 1977. On the elicitation of preferences: descriptive and prescriptive considerations. *In* Bell, D.E., R.L. Keeney and H. Raiffa (eds.). Conflicting objectives in decisions. John Wiley & Sons, New York, New York.

U.S.D.A. Bureau of Outdoor Recreation. 1973. Proceedings regional workshop on surface-mined land reclamation for outdoor recreation. Oakland, California.

von Neumann, J., and O. Morgenstern. 1947. Theory of games and economic behaviour (2nd ed.). Princeton University Press, Princeton, New Jersey.

Walker, K.D. 1982. Application of multi-attribute utility analysis in determining coho salmon policy. Unpublished M.Sc. thesis, Oregon State University.

Webb, R., H.C. Ragland, B. Godwin, and D. Jenkins. 1977. The effects of off-road vehicle use on soil and chemical properties. Special Volume - Los Angeles: Southern California Academy of Sciences.

Wells, C. 1979. An outline of the basic criteria needed to develop a trailbike system. *In* U.S.D.I. Heritage Conservation and Recreation Service. Planning for trailbike recreation Part II. Washington, D.C.

APPENDIX

Attributes of the Recreational Activities

ATTRIBUTES OF THE RECREATIONAL ACTIVITIES

Trailbiking

Attributes:

X_1 = Travel time by road to trailbiking area (minutes)
X_2 = Length of trail available for trailbiking (km)
X_3 = Average slope of trailbiking area (%)
X_4 = # Encounters per hour with 4x4s

A study by Wells (1979) showed that when developing a trail-bike system, trailbike access and length of trail must be considered. In this study, access was assumed to be part of any trailbike development and travel time to the area was chosen as a more appropriate attribute.

Studies of trailbike rider preferences have shown that variety of topography is one of the most desired features of a trailbiking area (Bury and Fillmore 1975, Chilman 1979). Average slope was chosen as an attribute to measure the variety of topography on an area of mine waste. The mine waste is composed of uniform material consisting of various sizes of fractured rock and therefore was not used as an attribute to measure the variety of topography.

Incompatability may exist between trailbikes and other recreational uses of a land area (Chilman 1979). Four-wheel drivers are a potential source of motorized conflict with trailbikers in the study area and therefore was chosen as an attribute. The units of conflict were chosen to be the number of encounters per hour with the conflicting activity. An encounter is defined as a single incident where a 4x4 impedes the traffic of a trailbiker.

Four-Wheel Driving

Attributes:

X_5 = Travel time by road to 4x4 area (minutes)
X_6 = Length of road available for 4x4 (km)
X_7 = Average slope of 4x4 area (%)
X_8 = # Encounters per hour with trailbikes

As with trailbiking and other off-road motorized activities, access, length of trail, varied topography and conflicts with other recreational uses of the same land base are attributes that must be considered when planning an area for four-wheel driving (Arychuk et. al. 1979). Therefore, the attributes chosen for the activity four-wheel driving were the same as for trailbiking. An encounter is defined as a single incident where a trailbike impedes the traffic of a four-wheel drive vehicle.

Snowmobiling

Attributes:

X_9 = Travel time by road to snowmobiling area (minutes)
X_{10} = Length of trail available for snowmobiling (km)
X_{11} = Average winter snow depth of snowmobiling area (cm)
X_{12} = Average slope of snowmobiling area (%)

Kuehn (1971), Helmker (1975) and Arychuk et. al. (1979) have shown that access to a snowmobiling area and length of trail are important parameters that contribute to the success of snowmobiling. As with trailbiking, access was assumed to be part of any snowmobiling development and travel time was chosen as a more appropriate attribute. Snow depth and varied topography have been documented as being other important factors for snowmobiling (Hetherington 1971, Arychuk et. al. 1979). Average slope was chosen as an attribute to measure the varying topography of a mine waste area.

Downhill Skiing

Attributes:

X_{13} = Travel time by road to baselift (minutes)
X_{14} = Average slope of skiing area (%)
X_{15} = Average winter snow depth of skiing area (cm)

The time a skier must travel to the baselift of a ski hill has been reported as the most important factor in determining a skier's preference for a ski area for single day trips in the midwestern United States (Leuschner 1970). Newby and Lilley (1980) report similar results. Leuschner (1970) reports that the physical quality of a ski slope is the second most important factor in determining ski area preference in the midwestern United States. The physical quality of a ski slope in this study is described by the attributes average slope and the average winter snow depth of the ski area. As is characteristic of msot downhill skiing areas in British Columbia, it was assumed in this study that any downhill skiing development would be restricted to downhill skiing only; therefore, no attributes describing conflicts were required for this activity.

Cross-Country Skiing

Attributes:

X_{16} = Travel time by road to skiing area (minutes)
X_{17} = Length of trail available for skiing (km)
X_{18} = Average slope of skiing area (%)
X_{19} = Average winter snow depth of skiing area (cm)

Newby and Lilley (1980) report travel distance as being a significant factor in choosing to use a cross-country skiing area. In this study travel time was used as an attribute rather than travel distance because in proctice utility assessment interviews, decision maker's found it easier to estimate how long they would prefer to travel rather than how far.

Cross-country skiers require varied topography (Lund and Williams 1974, Allan 1975) which is represented by the attribute average slope. Length of trail is also a major factor in determining whether to use a ski area (Newby and Lilley 1980). Snow depth will contribute significantly to the quality of a ski area and was therefore chosen as an attribute.

Snowshoeing

Attributes:

X_{20} = Travel time by road to snowshoeing area (minutes)
X_{21} = Length of trail available for snowshoeing (km)
X_{22} = Average winter snow depth of skiing area (cm)
X_{23} = Average slope of skiing area (%)

The attributes for snowshoeing were chosen to be those of cross-country skiing because the activities require similar areas and physical features of the land base.

Hiking

Attributes:

X_{24} = Travel time by road to hiking area (minutes)
X_{25} = Distance of hiking area from a drinking water source (km)

Travel time to a hiking area was chosen as an attribute because a hiker generally considers how long he must travel to an area in deciding whether he will use the area. Distance from a drinking water source was chosen as an attribute because many hikers cannot hike for very long or very far without drinking water.

Horseback Riding

Attributes:

X_{26} = Travel time by road to horseback riding area (minutes)
X_{27} = Length of trail available for horseback riding (km)
X_{28} = Average slope of horseback riding area (%)

Travel time to a horseback riding area was chosen as an attribute because a rider considers how long he must travel to and area when deciding whether to use the area.

Length of trail and slope were chosen as attributes because both help dictate a decision maker's decision whether to use the horseback riding area and both affect the riding experience.

<u>Summer Motorized Camping</u>

Attributes:

X_{29} = Travel time by road to camping area (minutes)
X_{30} = Distance of camping area from a drinking water source (km)
X_{31} = Average slope of camping area (%)

Travel time to a camping area was chosen as an attribute because campers generally have varying preferences for how long it takes them to get to the camping area (Brockman and Merriam 1973).

Drinking water supply is necessary for a successful camping experience (Can. Govt. Office of Tourism 1972, Brockman and Merriam 1973). The slope of the camping area cannot be too great or many recreational vehicles cannot park properly and campers will find it difficult to sleep; therefore, average slope was chosen to be an attribute (Can. Govt. Office of Tourism 1972).

APPENDIX

Dialogue to Familiarize the Decision Maker with the Terminology and Motivation for the Assessment of His Utility Function

DIALOGUE TO FAMILIARIZE THE DECISION MAKER WITH THE TERMINOLOGY AND MOTIVATION FOR THE ASSESSMENT OF HIS UTILITY FUNCTION

Symbolism	Activity
I = Interviewer	Horseback Riding
D = Decision Maker	

I: I'll tell you briefly what I am trying to accomplish in this interview. As you know, much of the land on either side of the Elk Valley is being mined for coal. Some day most of this valley will eventually be mined and there will be quite a large area of mine waste on both sides of the valley.

What is happening now is we are revegetating the waste piles with grasses and other plant species and fertilizing them. However, in the future, these areas may have some demand on them to be used for outdoor recreation such as trailbiking, horseback riding, snowmobiling, camping and other activities. Now assume the valley was make up of mostly mine waste, and the government decided to build a first class horseback riding area on it. Now, as you know, horseback riding has many factors that make it enjoyable or rotten such as a sunny horseback riding area versus a rainy area.

What I want to do is, for a factor like say how long you would travel to get to this horseback area, find your preferences for various lengths of travel time and the same for other factors. Do you understand?

D: Yes, I think so.

I: O.K., I will represent your preferences for various levels of a factor by what we call a utility. (Illustrating) If we have a graph, with the horizontal axis as the factor, say length of trail, the vertical scale will be a utility scale. Utility is just another word for preference. So, the least preferred trail distance will have a value of 0 and the most preferred trail distance will have a value of 1. So, after I ask you questions we will develop your preference relationship for the factors. The resulting curve may have any shape. It may look like this (illustrating) or this or this - that is what I am trying to find out. Do you get the idea behind what I'm trying to do?

D: Yes, I think so.

APPENDIX

Dialogue for Assessing Attribute Utility Functions and Verifying Attribute Utility Independence

DIALOGUE FOR ASSESSING ATTRIBUTE UTILITY FUNCTIONS AND VERIFYING ATTRIBUTE UTILITY INDEPENDENCE

Symbolism	Attribute	Activity
I = Interviewer	Travel Time (X_{26})	Horseback Riding
D = Decision Maker		

I: I would like to ask you questions about hypothetical situations and this is the type of question I will ask you. I'll give you a choice between two alternatives. One will be where the government says they are going to give you this alternative for sure, but you may say you don't like it. If you don't like it, you can then go to arbitration where you may end up with an alternative that is better than their offer or with an alternative that is worse than their offer. In other words, if you don't want their offer, you can go for this 50-50 gamble. What I want to do is pose these choices to you, changing the government's offer until I find the value of what the government will give you where you are indifferent between it and the 50-50 gamble. We'll do it for the factors like travel time, length of trail etc. Do you understand the basic idea?

D: I think so.

I: It will become clearer as we go on. To show you how this works, let's take travel time to a riding area by road. If the government were going to build you a riding area 2 hours from town, you have the option of taking their offer or if you don't like it you have the option of going to arbitration where you may end up with the best travel time which would be right outside your house as you stated earlier or you may end up with having to drive 4 hours. Would you take the government's offer for sure or would you go for a 50-50 gamble between the 4 hours and 0 hours?

D: I'd say if it's a 2 hour drive then that's o.k.

I: Would you go for the gamble or take the government's offer at 2 hours?

D: I would go for the 2 in that case.

I: What if they were going to give you 3 hours for sure?

D: That's getting to be too long. That's starting to get up there.

I: Would you take the chance then?

D: Yes, I would then.

I: What if their offer were 2.5 hours? Would you take it or go to arbitration and try to get 0 or end up with 4 hours travel time?

D: It's hard to say.

I: Would you be indifferent between the two choices when the government's offer is at 2.5?

D: Yes, that's about right.

I: Assume that 2.5 is your indiffernece point where the other factors length of trail and slope are at their best levels. Would you be indiffernet at 2.5 if they were at their worst levels?

D: I guess so.

I: Would it be true to say that your indifference point does not depend on the levels of the other factors?

D: Yes, I guess so. (Verification of utility independence)

I: O.k. If we had another choice here but this time the government offers you an area that takes 3 hours to get to. You can take their offer or go to arbitration where you may end up with 2.5 hours or 4 hours travelling time.

D: I'd try and get it shortened up.

I: Would you go for the gamble then?

D: Yes.

I: What if their choice were say 2.7 hours?

D: Well, 2.7 versus 2.5, - I'd probably be better off with 2.7 for sure.

I: What if they gave you 3 hours for sure?

D: Well, it's one mroe hour to 4 but I may get down to 2.5. I think I'd probably take a chance and try and pull it back to 2.5.

I: What if their offer were 3.5 hours travelling time?

D: For sure I'd take the gamble and try and shorten it.

I: What if their offer were say 3.2 hours?

D: I'd try and get the 2.5.

I: So you would go for the 2.7 for sure but at 3 you would go for the gamble. Would you be indifferent at about 2.8 or 2.9 hours?

D: I'd probably be indifferent at 3.

I: And you would go for the gamble at 3.2?

D: That's right, sure.

I: Does your choice of 3 depend on the levels of the other factors?

D: No, not really. (Verification of utility independence)

I: Now, if the government were going to give you an area 1 hour from town for sure, you could accept their offer or go to arbitration where you could end up with 0 hours travelling time or 2½ hours. Which one would you take?

D: I'd take the 1 hour.

I: What if 1½ hours was their offer?

D: In that case I'd take a chance on arbitration and try to get the 0 hours.

I: So between 1 and 1½ you would be indifferent between the choices?

D: Yes.

I: Would this choice change with varying levels of the other factors?

D: No. (Verification of utility independence)

APPENDIX

Dialogue for Obtaining Attribute Tradeoffs, Consistency Checks and Verifying Attribute Preferential Independence

DIALOGUE FOR OBTAINING ATTRIBUTE TRADEOFFS, CONSISTENCY CHECKS AND VERIFYING ATTRIBUTE PREFERENTIAL INDEPENDENCE

Symbolism

I = Interviewer

D = Decision Maker

Activity

Horseback Riding

The Decision Maker's Ranking of the Attributes

I: Now if you were asked to rank the factors travel time, length of trail and slope, in order of preference to you for horseback riding, how would you rank them?

D: That's travel time, trail length and slope?

I: Yes.

D: I guess slope would be the most limiting factor after a while so I'd say it would be the most important.

I: Then what?

D: I'd say that trail distance would be next. Travel time isn't that important.

Tradeoff #1: Travel Time vs. Length of Trail (X_{26} vs. X_{27})

I: What I would like to do now is find out how to weight each of the factors numerically as to their relative importance to you. We do this by trading off between the factors.

Let's say that the government was going to locate this riding area where you had to drive 0 hours to get it, or right outside your house and with it you would get 4.5 km of trail. How much further would you drove to get 13 km of trail with 20 km as your most preferred distance?

D: I think I'd go about 3 more hours to get 13 because 4.5 isn't very much for a day trip.

I: O.k., if you had to travel 1.5 hours to get an area with 11 km of trail, to get 20 km of trail, how much longer would you drive?

D: Probably another hour.

I: Just a second while I do a quick calculation (consistency check).
(The calculation is to check the ratios of the k scaling constant values from equation (page). For the two pairs of tradeoffs, the ratios should be reasonably close. In this case, k_{26}/k_{27} was 0.827 for the 4.5 km to 13 km tradeoff while k_{26}/k_{27} was 2.50 for the 11 to 20 km tradeoff. The ratios are clearly not very close. To try and bring the ratios closer together, the decision maker is asked to confirm his tradeoffs.)

I: Now you said that you would travel from 0 to 3 hours to go from 4.5 km to 13 km, is that right?

D: Yes.

I: And you would travel one hour more to go from 11 km to 20 km trail length?

D: Yes, between an hour and an hour and a half.

I: So about an hour an a quarter?

D: No, I'd say I'd drive another hour and a half.

I: O.k., let me do a quick calculation (consistency check)

D: (The k_{26}/k_{27} ratio for the 11 km to 20 km tradeoff was lowered to 1.11 which illustrates more consistency between the tradeoffs.)

<u>Testing for Preferential Independence</u>

I: For the tradeoffs we just did between travel time and length of trail - would your answers be influenced by varying slope values?

D: What do you mean?

I: O.k., let's examine a tradeoff we just did. You said that you would travel 0 to 3 hours to go from a 4.5 km to 13 km trail distance. Let's say that the riding area has a 0% slope. Would you sti l drive the 3 hours to go from 4.5 km to 13 km if the slope were 40%?

D: Yes, I think so.

I: So varying slope values don't really influence the tradeoff?

D: No. (This confirms that travel time and length of trail are preferentially independent of slope)

Tradeoff #2: Travel Time vs. Average Slope of Area (X_{26} vs X_{28})

I: Now, if you had to drive 1 hour to get a 20% slope, if 10% slope is your best value, how much longer would you drive to get the 10%?

D: O.k., you said 1 for 20?

I: Yes.

D: Between 10 and 20 isn't that great - I wouldn't consider more than 2 hours.

I: So if you had to travel 2.5 hours to get a 30% slope, how much longer would you drive to get it down to 20%?

D: You said 2.5 for 30?

I: Yes, 2.5 for 30.

D: I'd go up to the 4 hours.

I: O.k., let me do another calculation.

(The ratios of k_{26}/k_{28} were close to each other (0.718 and 0.644 illustrating that the decision maker is consistent in his tradeoffs.)

Testing for Preferential Independence

I: Would length of trail affect how much travel time you would give up for varying slopes?

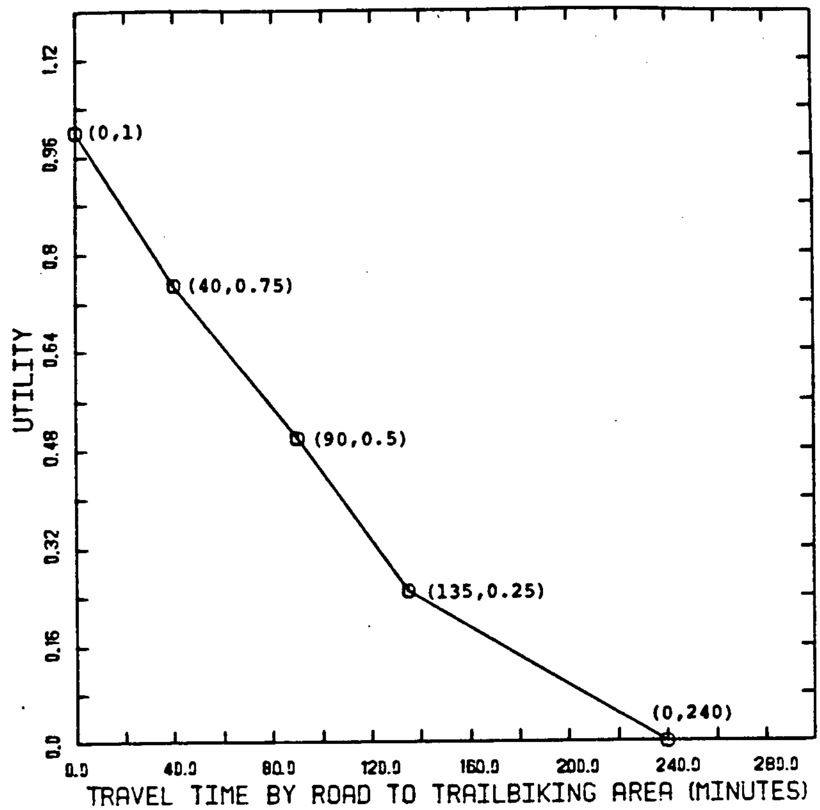
D: No, I don't think so. (Verification of preferential independence of travel time and slope on length of trail.)

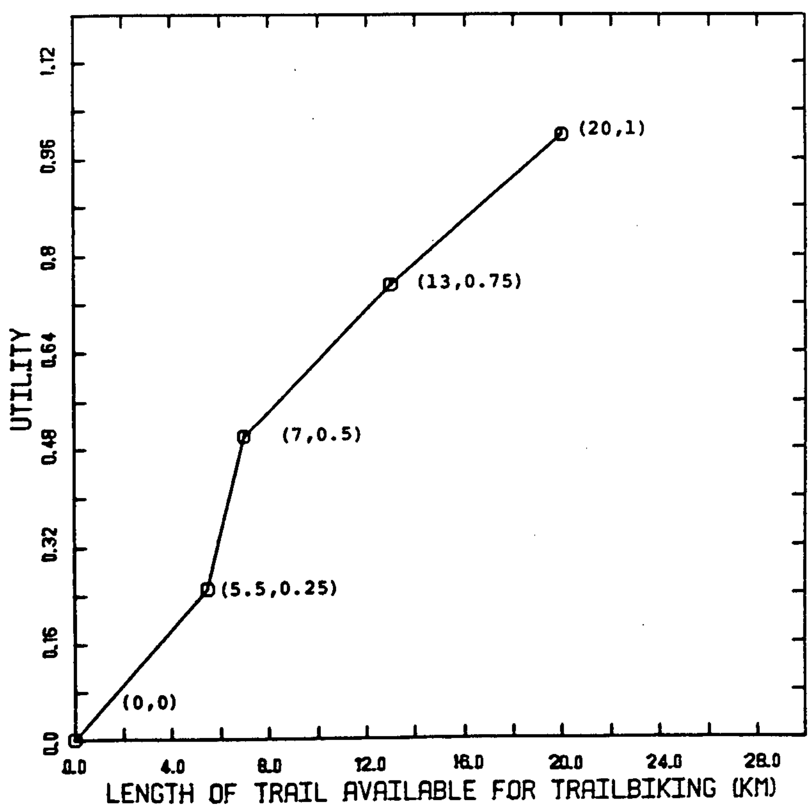
APPENDIX

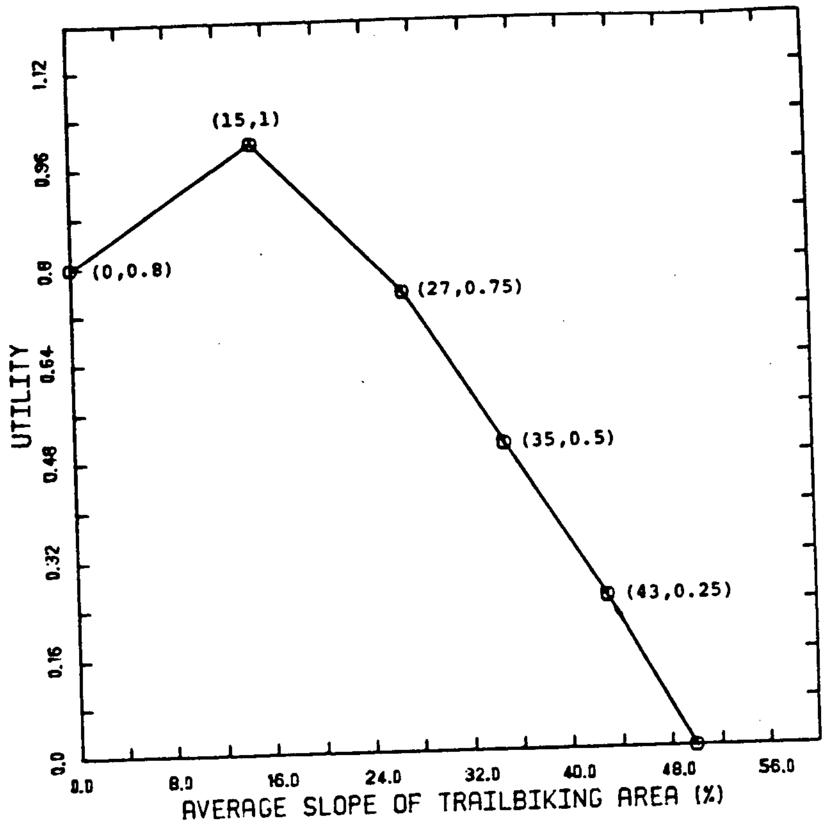
Attribute Utility Functions

ATTRIBUTE UTILITY FUNCTIONS

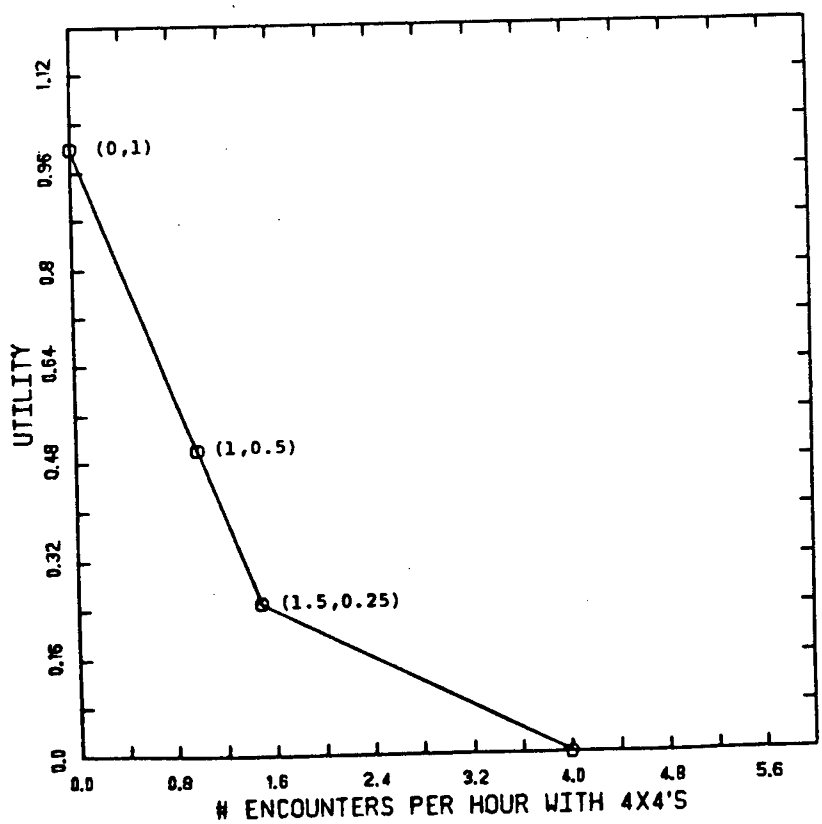
A. .1 Trailbiking





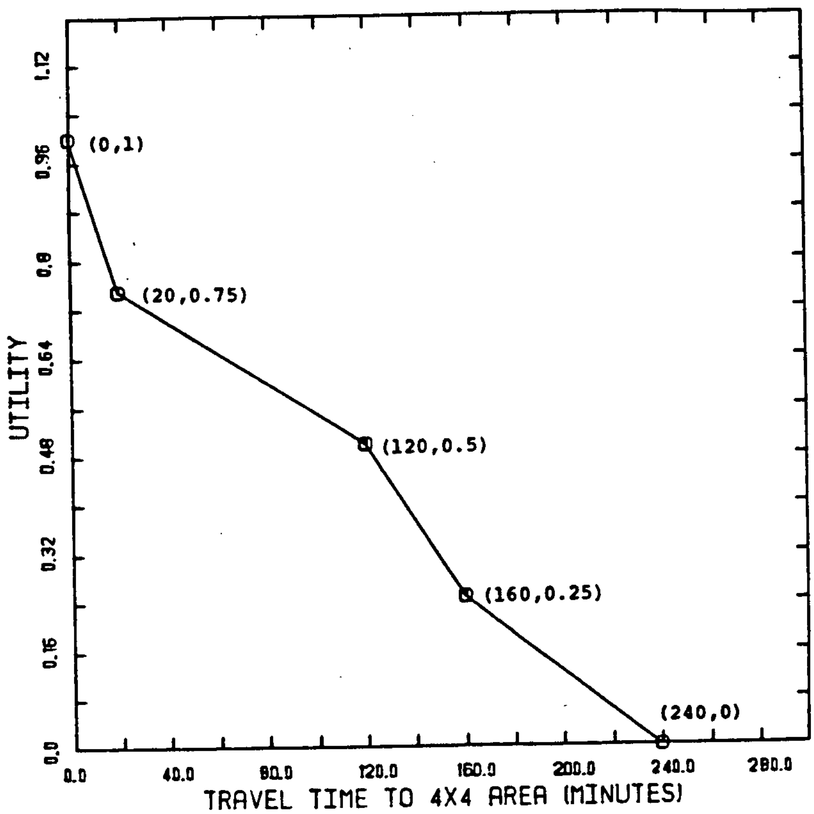


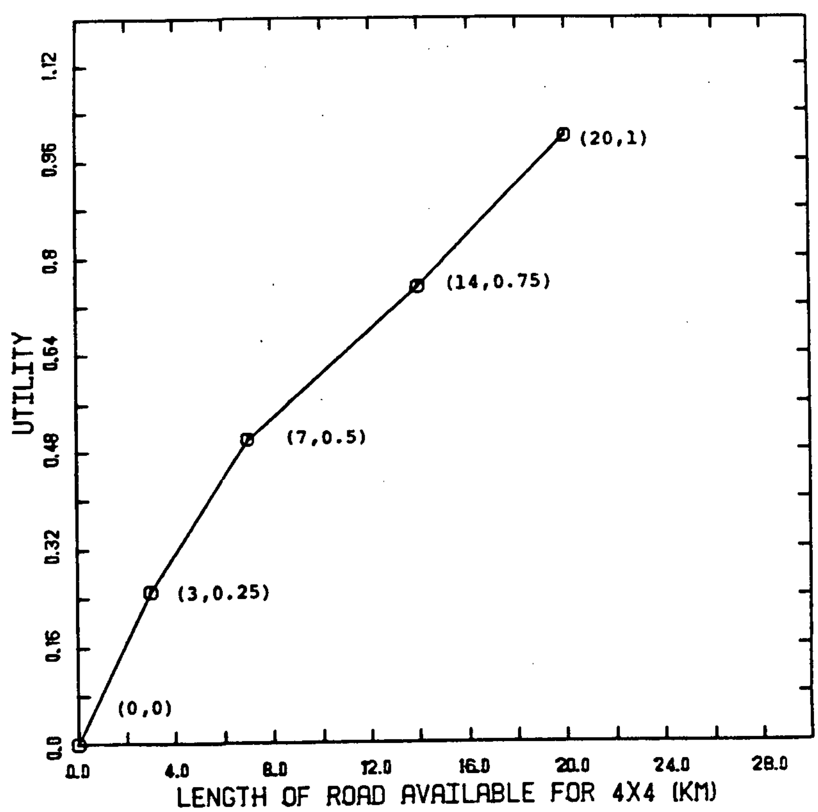
UTILITY
1.12
0.96
0.8
0.64
0.48
0.32
0.16
0.0
(15,1)
(0,0.8)
(27,0.75)
(35,0.5)
(43,0.25)
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
AVERAGE SLOPE OF TRAILBIKING AREA (%)

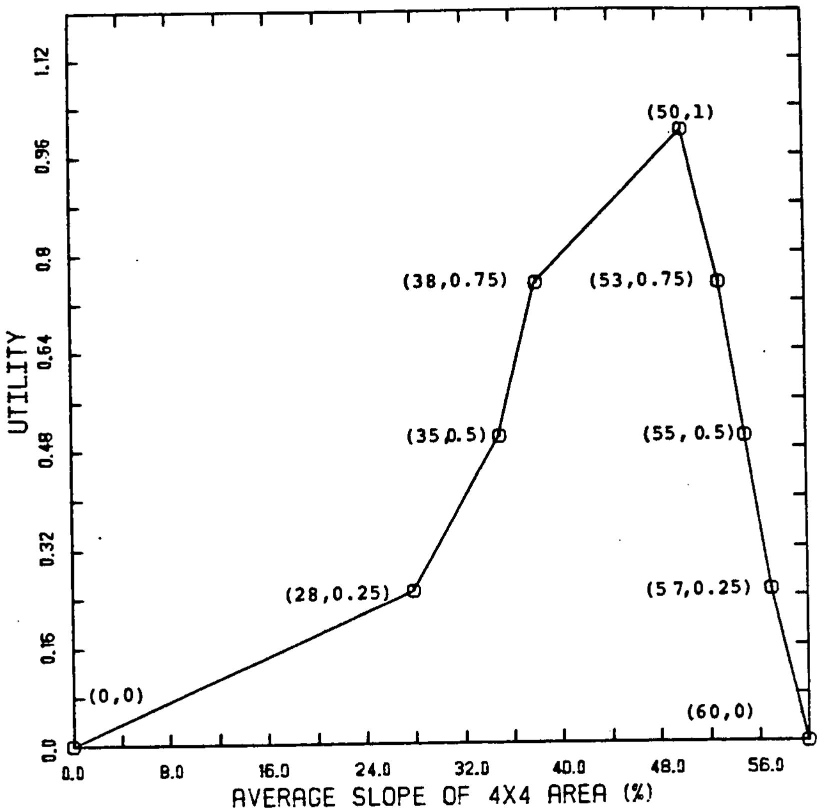


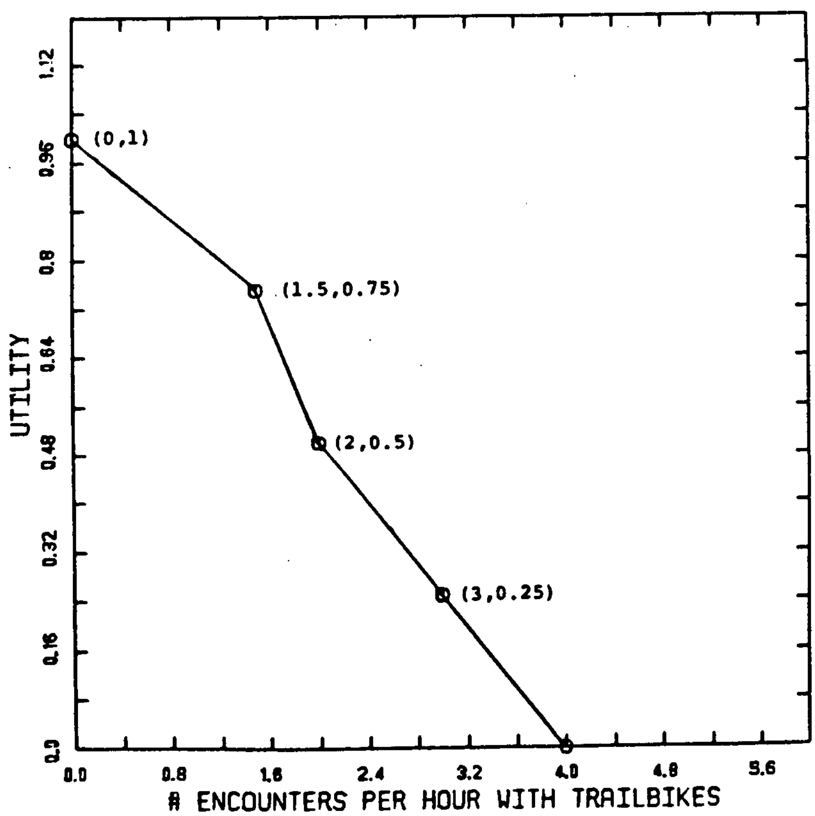
UTILITY
1.12
0.96
0.8
0.64
0.48
0.32
0.16
0.0
(0,1)
(1,0.5)
(1.5,0.25)
0.0
0.8
1.6
2.4
3.2
4.0
4.8
5.6
ENCOUNTERS PER HOUR WITH 4X4'S

A. .2 Four-Wheel Driving

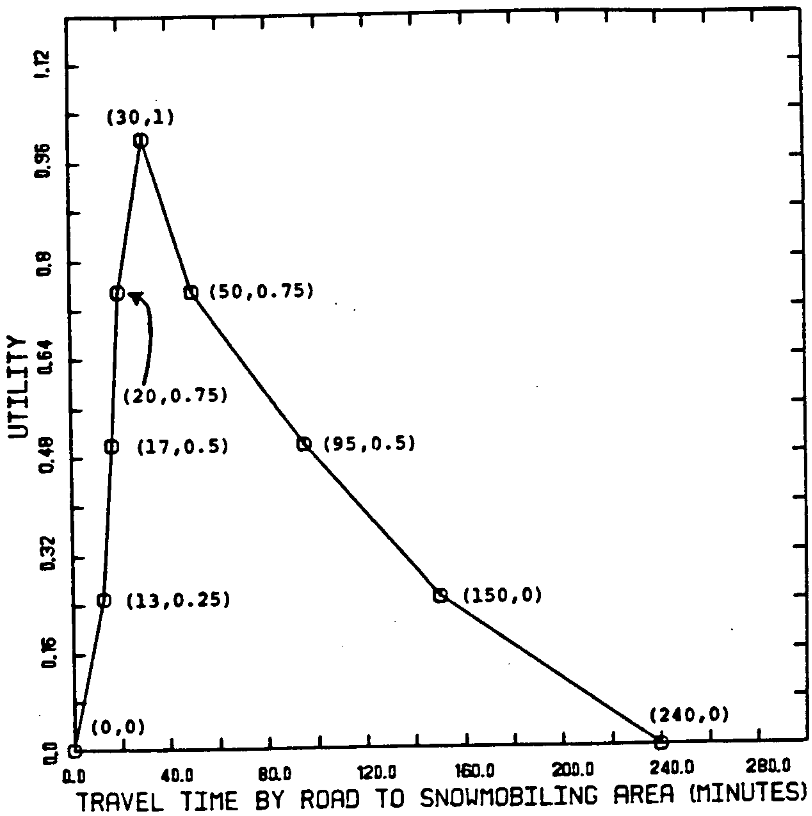


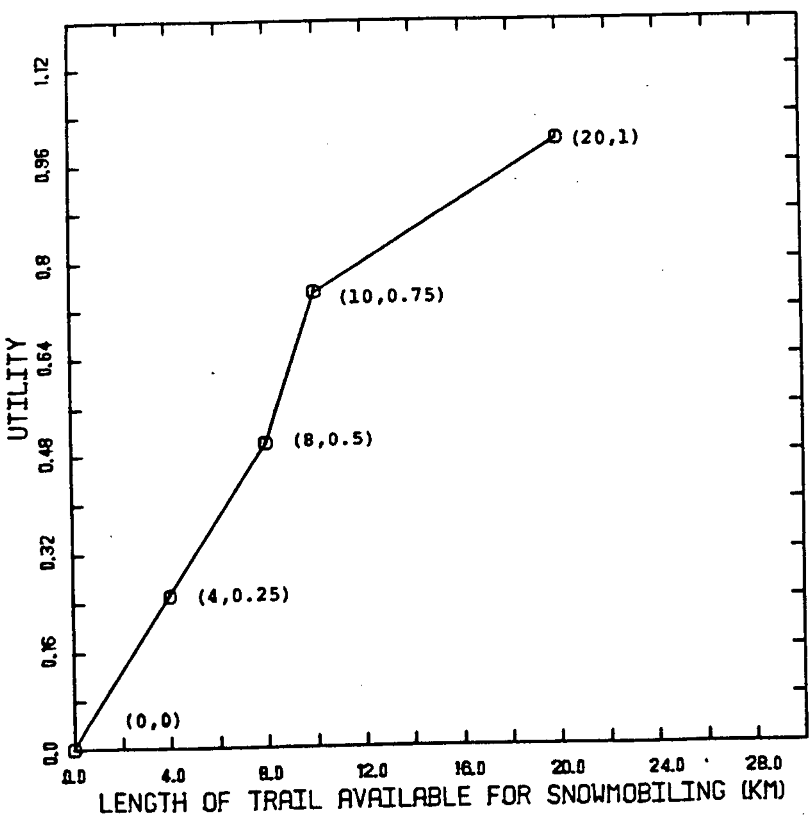


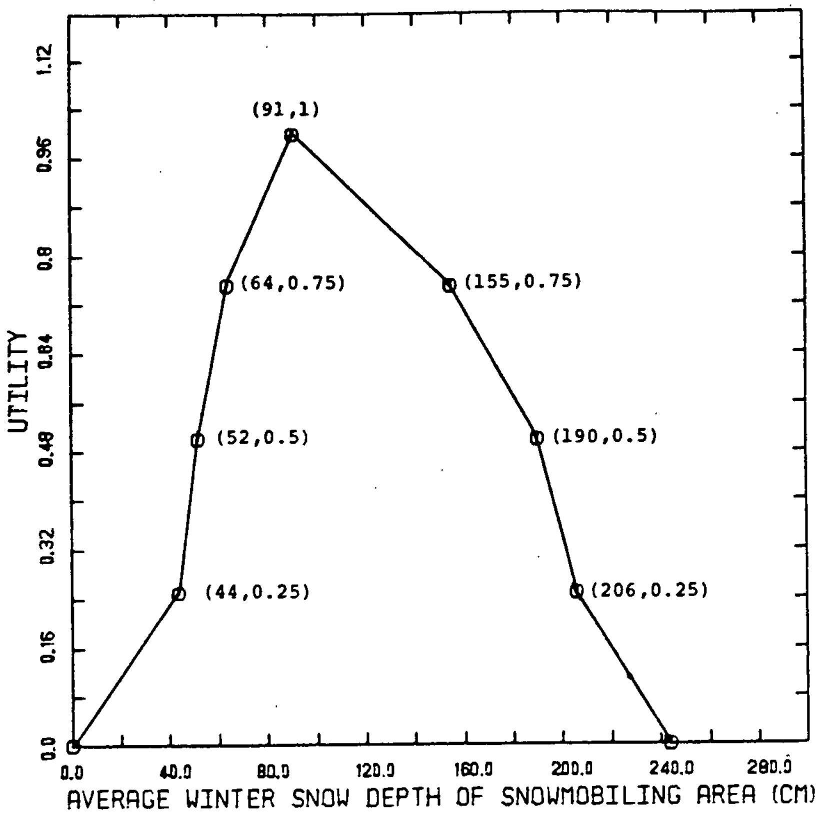

UTILITY
0.0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
AVERAGE SLOPE OF 4X4 AREA (%)
(0,0)
(28,0.25)
(35,0.5)
(38,0.75)
(50,1)
(53,0.75)
(55, 0.5)
(57,0.25)
(60,0)


UTILITY
0.0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
0.0
0.8
1.6
2.4
3.2
4.0
4.8
5.6
ENCOUNTERS PER HOUR WITH TRAILBIKES
(0,1)
(1.5,0.75)
(2,0.5)
(3,0.25)

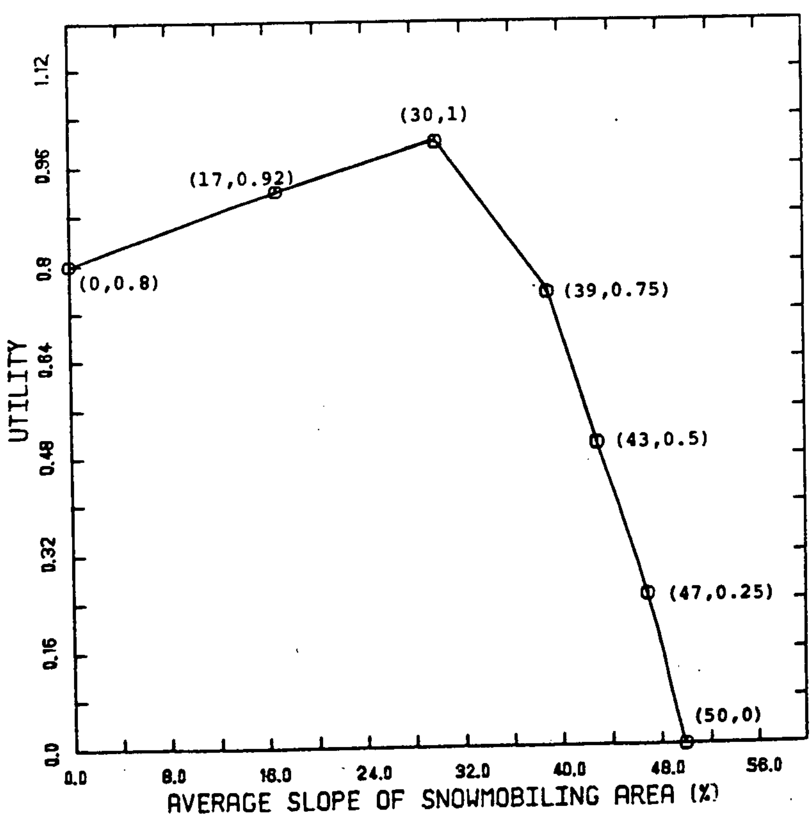
A. .3 Snowmobiling





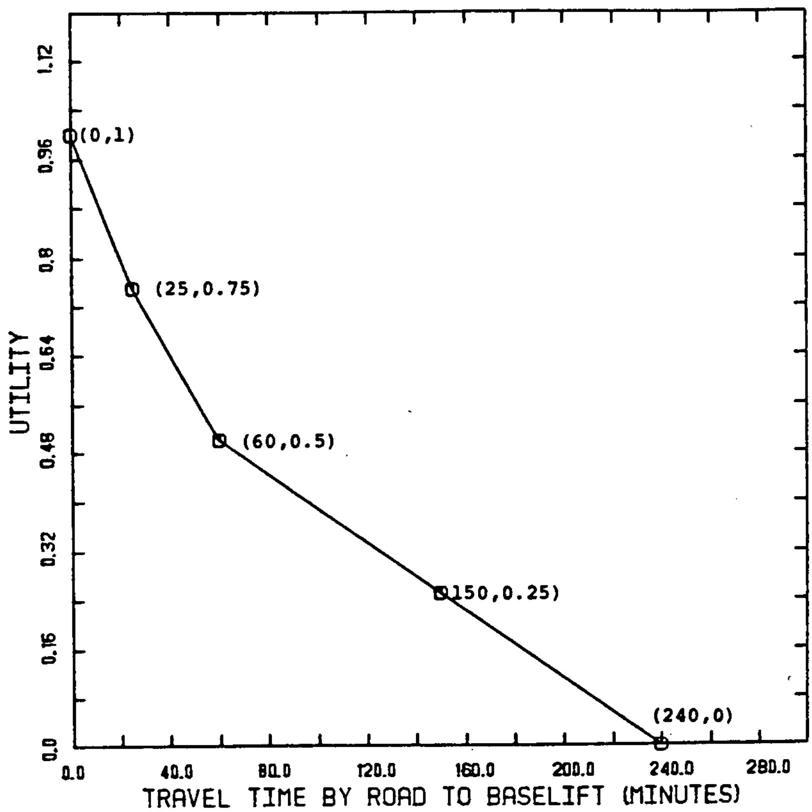


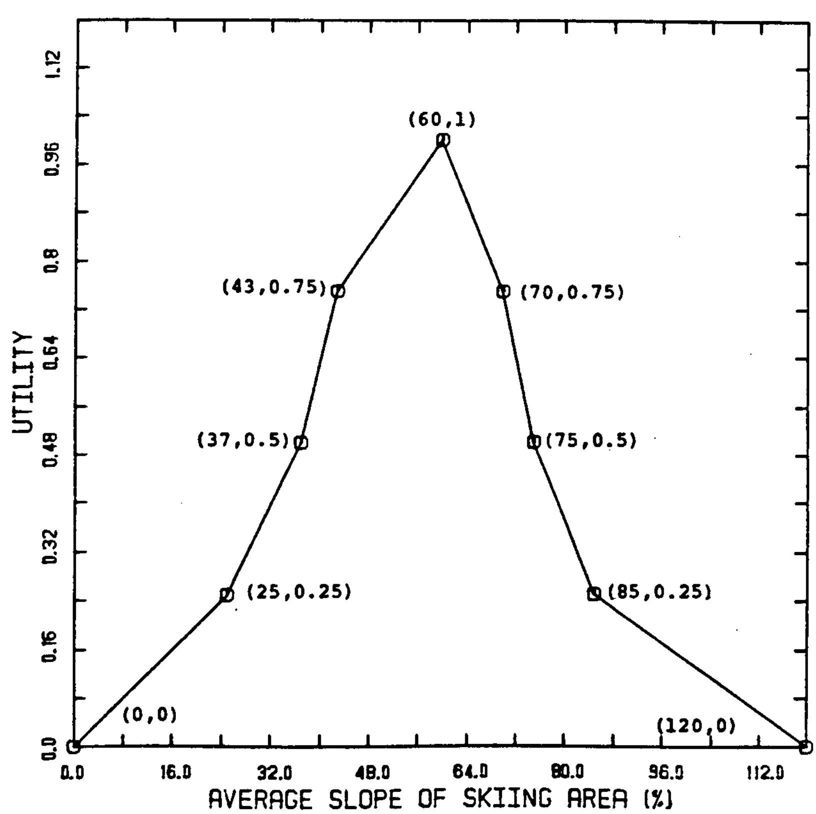
(91,1)
(64,0.75)
(155,0.75)
(52,0.5)
(190,0.5)
(44,0.25)
(206,0.25)
UTILITY
0.0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
AVERAGE WINTER SNOW DEPTH OF SNOWMOBILING AREA (CM)

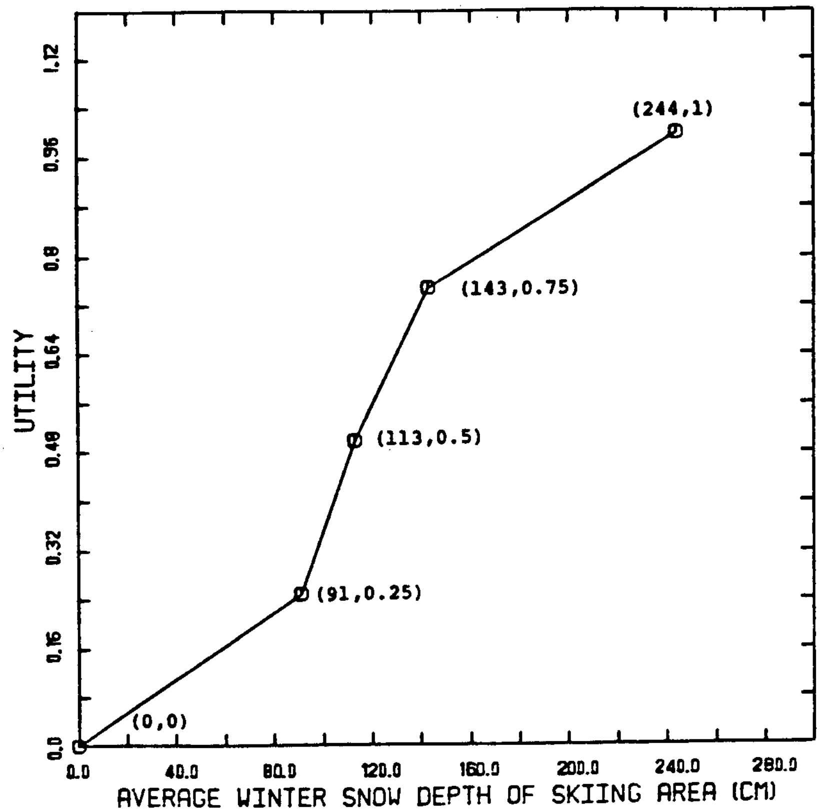


(30,1)
(17,0.92)
(0,0.8)
(39,0.75)
(43,0.5)
(47,0.25)
(50,0)
UTILITY
0.0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
AVERAGE SLOPE OF SNOWMOBILING AREA (%)

A. .4 Downhill Skiing

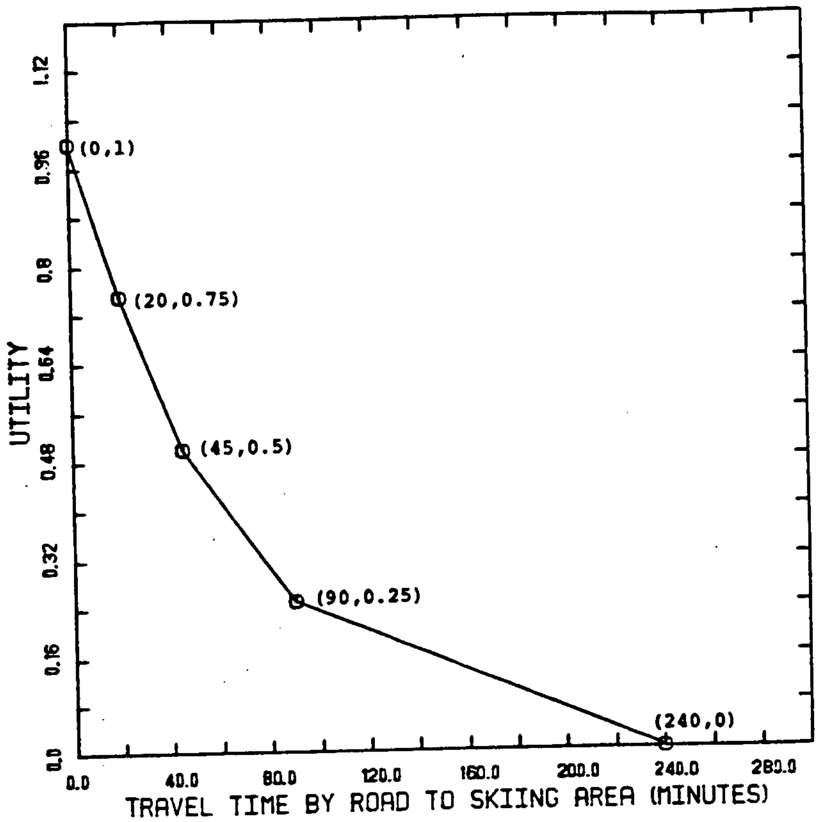


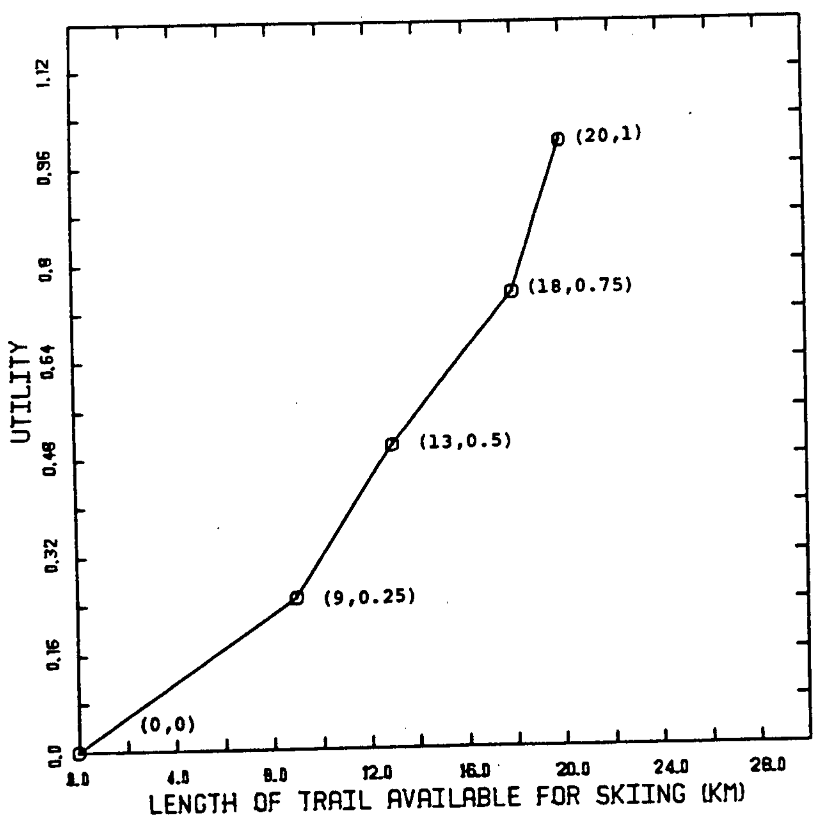


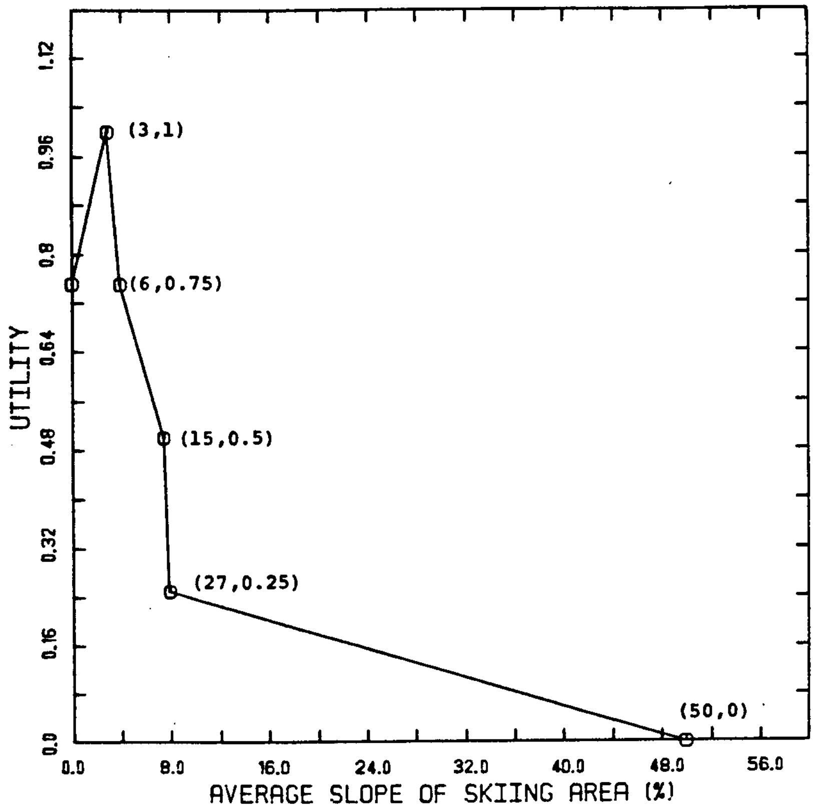


(244,1)
(143,0.75)
(113,0.5)
(91,0.25)
(0,0)
UTILITY
0.0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
AVERAGE WINTER SNOW DEPTH OF SKIING AREA (CM)

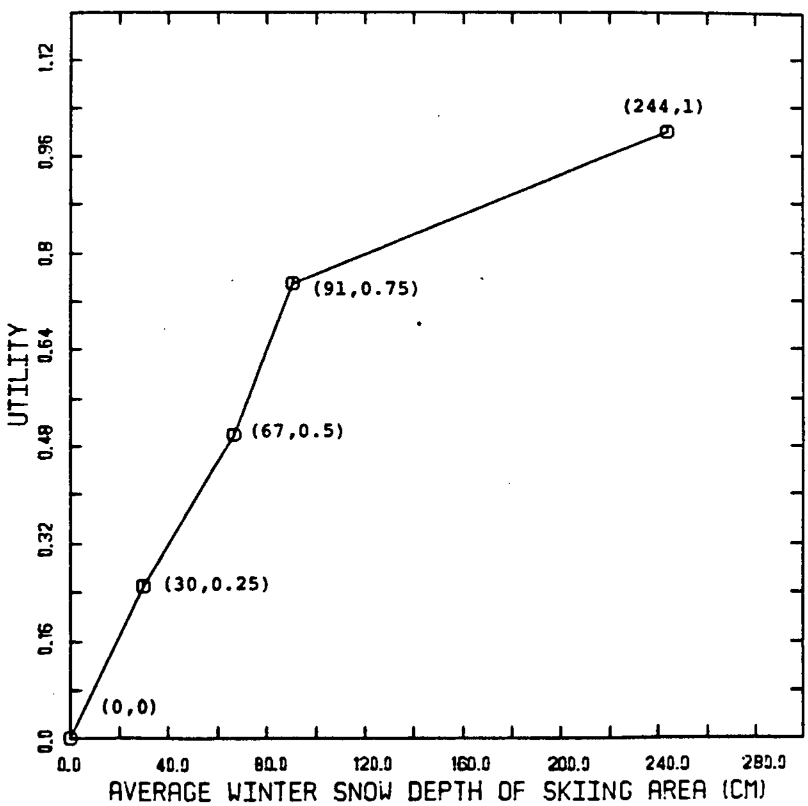
A. .5 Cross-Country Skiing





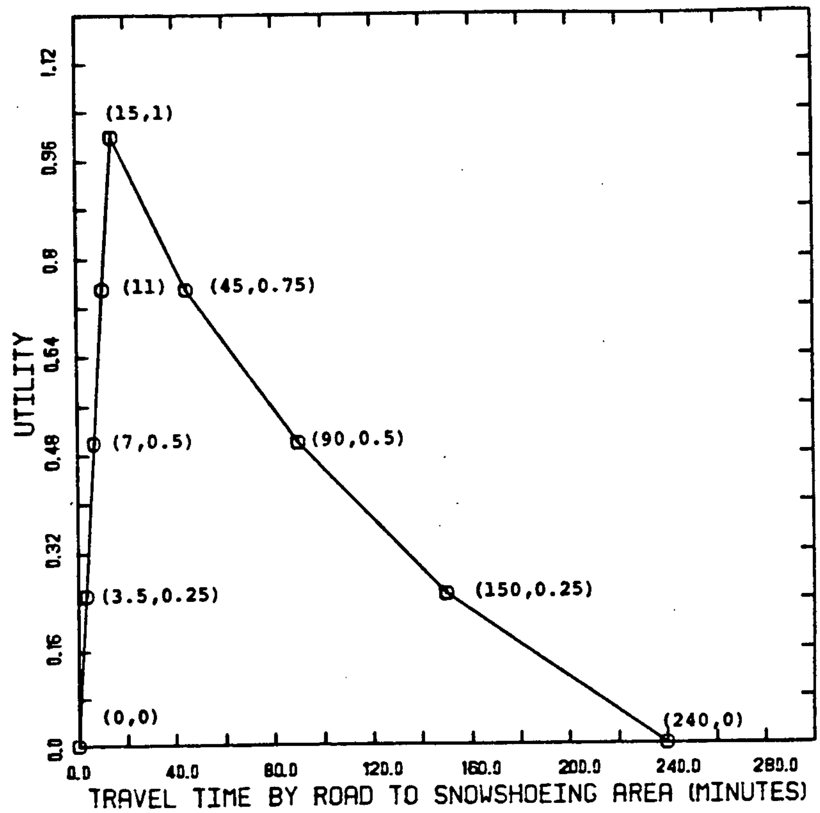


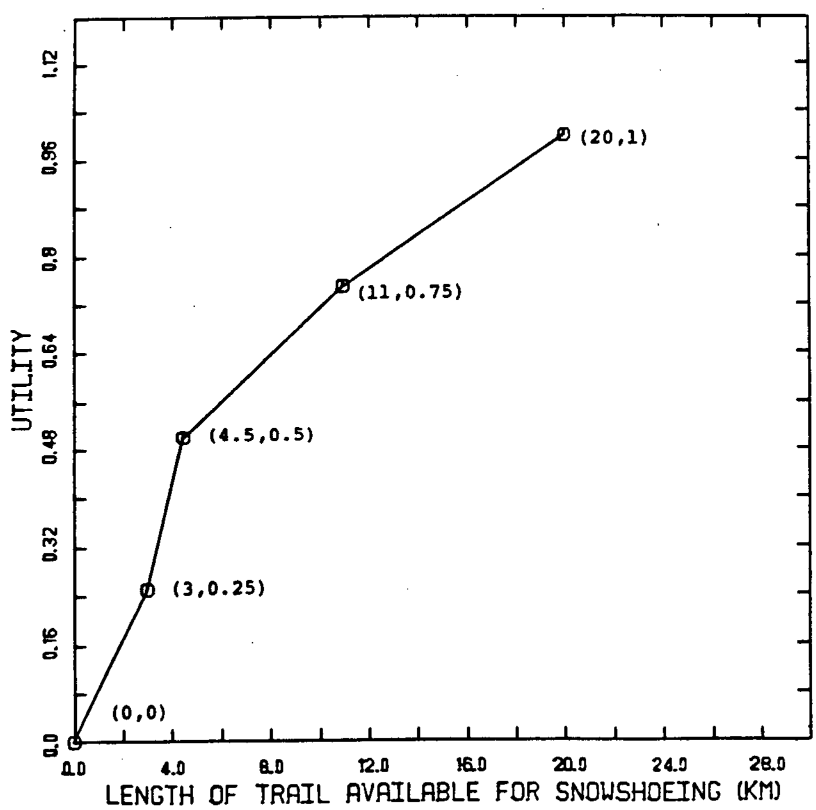
(3,1)
(6,0.75)
(15,0.5)
(27,0.25)
(50,0)
UTILITY
0.0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
AVERAGE SLOPE OF SKIING AREA (%)

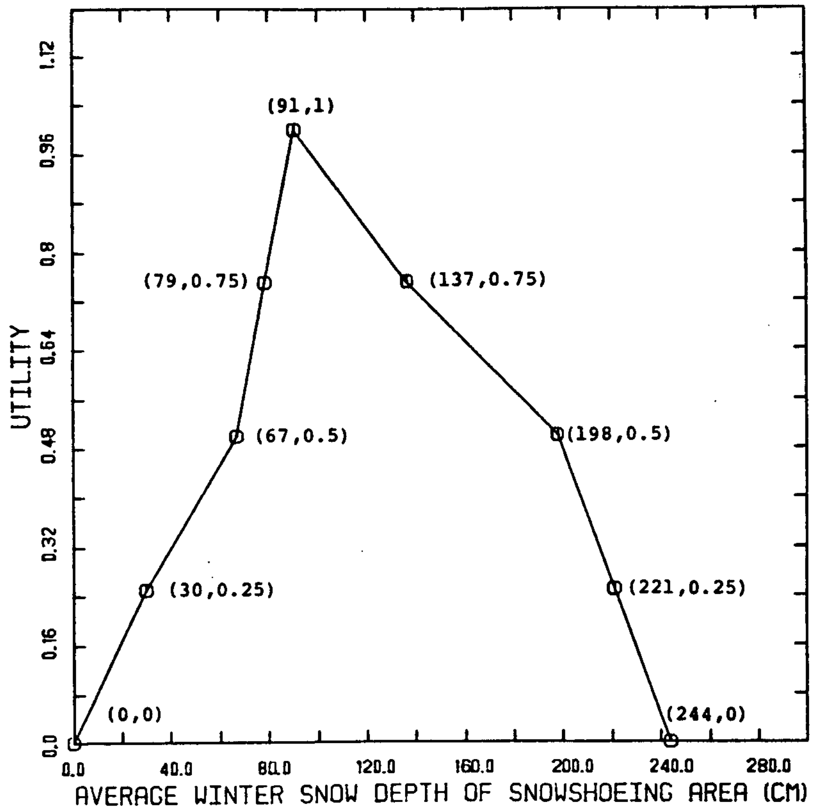


(244,1)
(91,0.75)
(67,0.5)
(30,0.25)
(0,0)
UTILITY
0.0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
AVERAGE WINTER SNOW DEPTH OF SKIING AREA (CM)

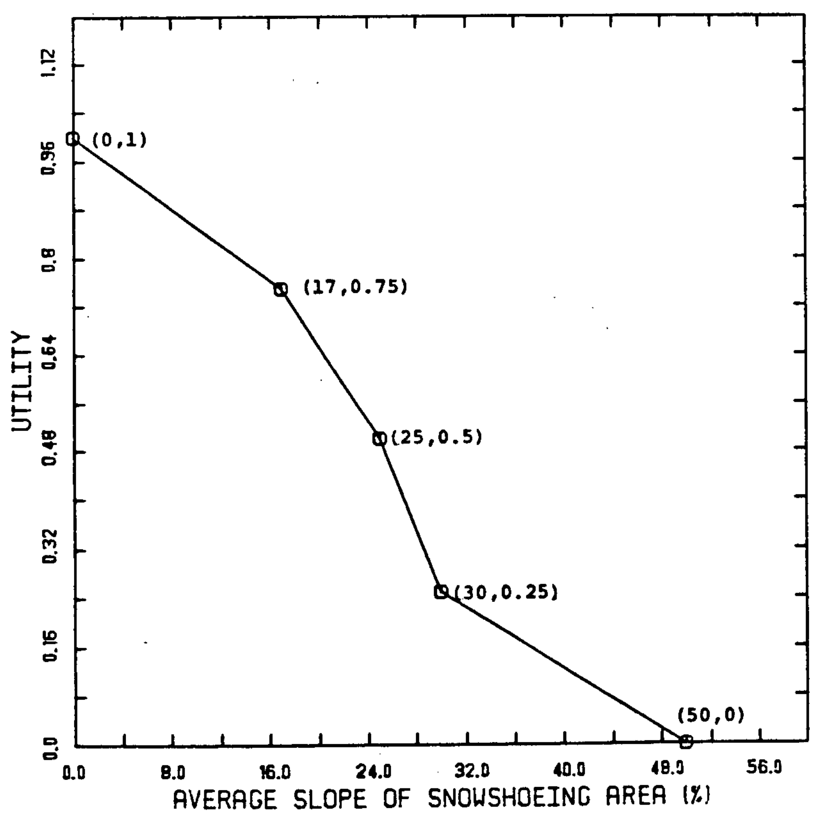
A. .6 Snowshoeing





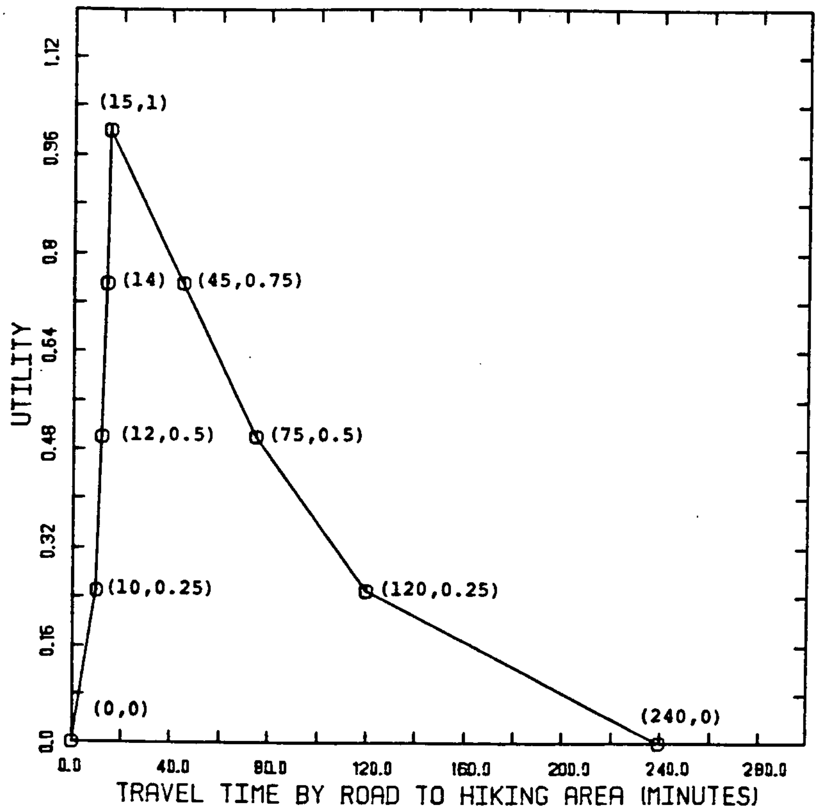


UTILITY
1.12
0.96
0.8
0.64
0.48
0.32
0.16
0.0
(91,1)
(79,0.75)
(137,0.75)
(67,0.5)
(198,0.5)
(30,0.25)
(221,0.25)
(0,0)
(244,0)
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
AVERAGE WINTER SNOW DEPTH OF SNOWSHOEING AREA (CM)

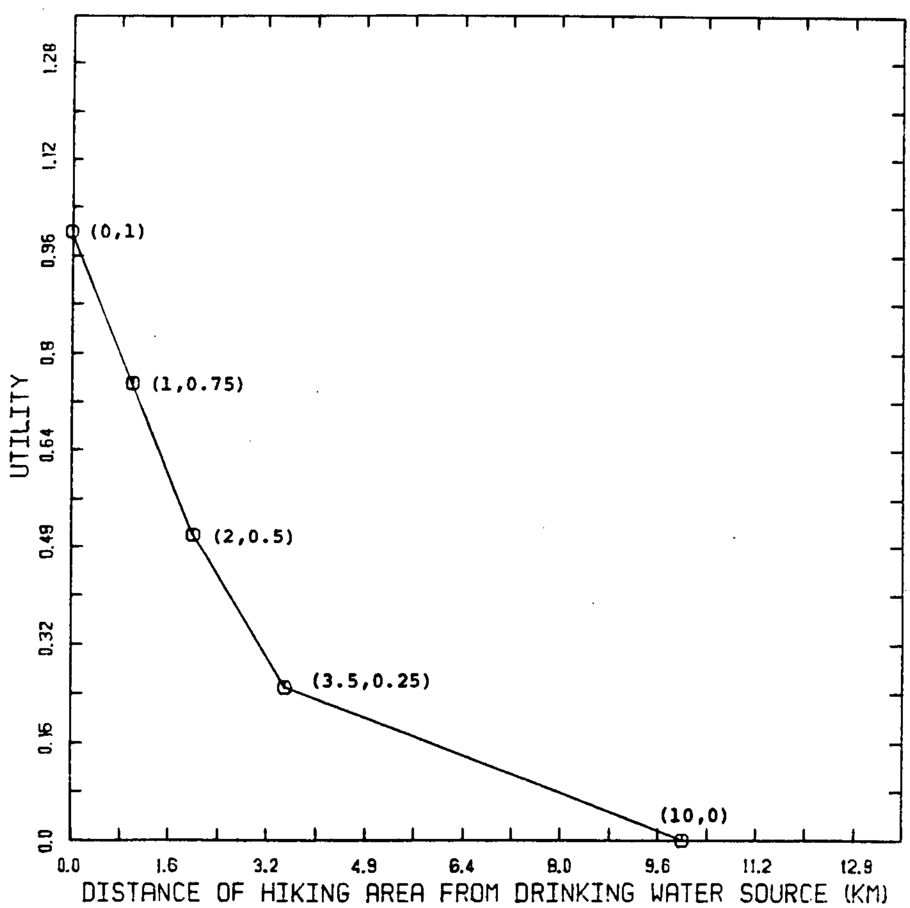


UTILITY
1.12
0.96
0.8
0.64
0.48
0.32
0.16
0.0
(0,1)
(17,0.75)
(25,0.5)
(30,0.25)
(50,0)
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
AVERAGE SLOPE OF SNOWSHOEING AREA (%)

A. .7 Hiking

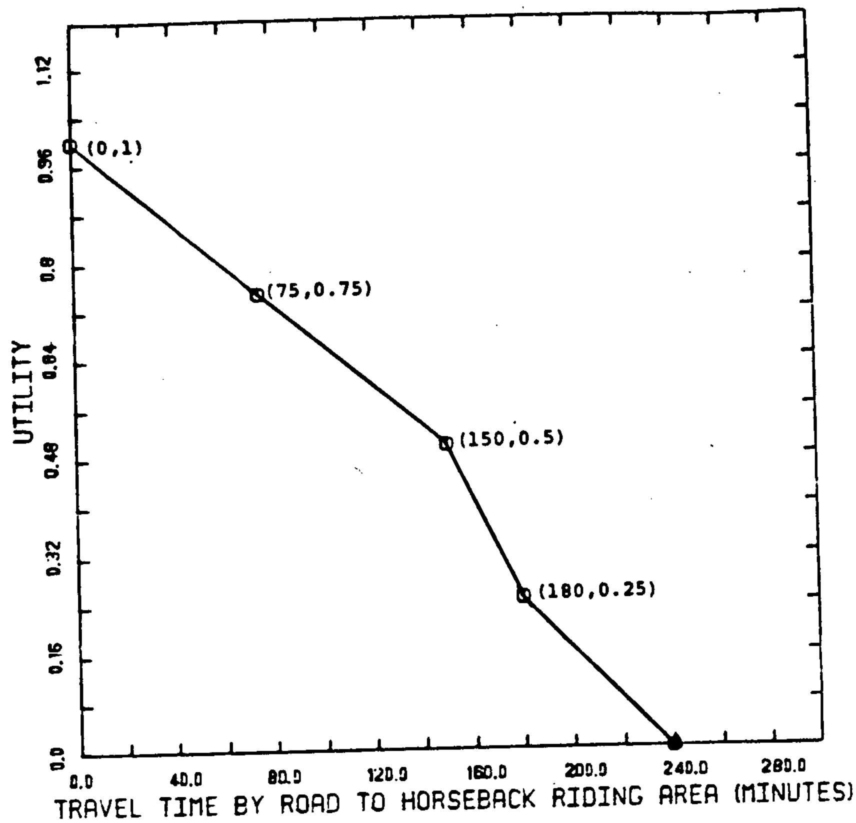


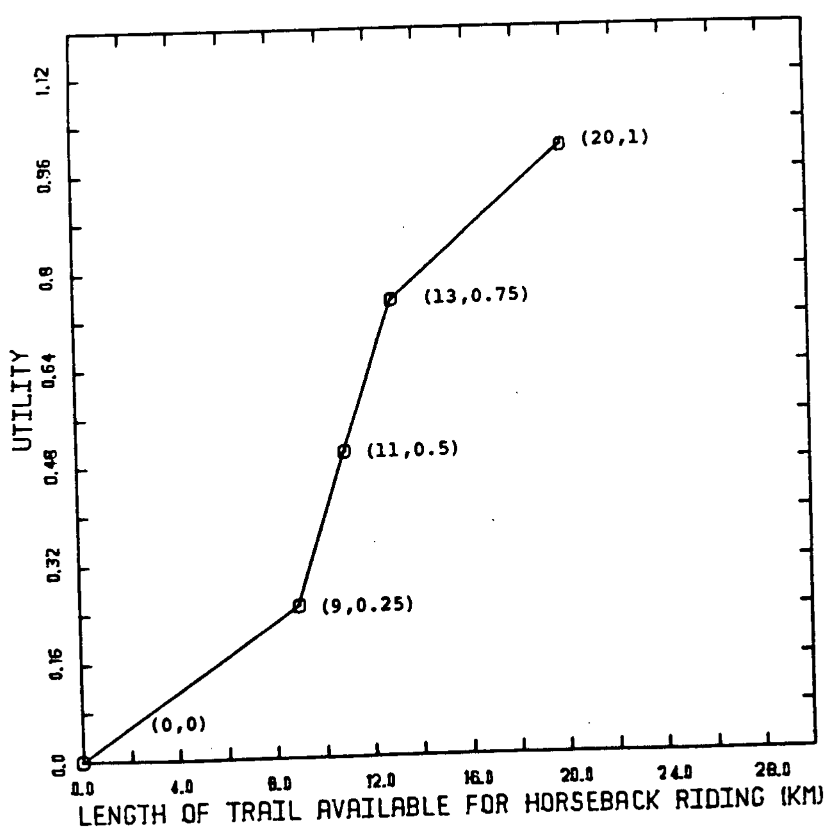
UTILITY
1.12
0.96
0.8
0.64
0.48
0.32
0.16
0.0
(15,1)
(14)
(45,0.75)
(12,0.5)
(75,0.5)
(10,0.25)
(120,0.25)
(0,0)
(240,0)
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
TRAVEL TIME BY ROAD TO HIKING AREA (MINUTES)

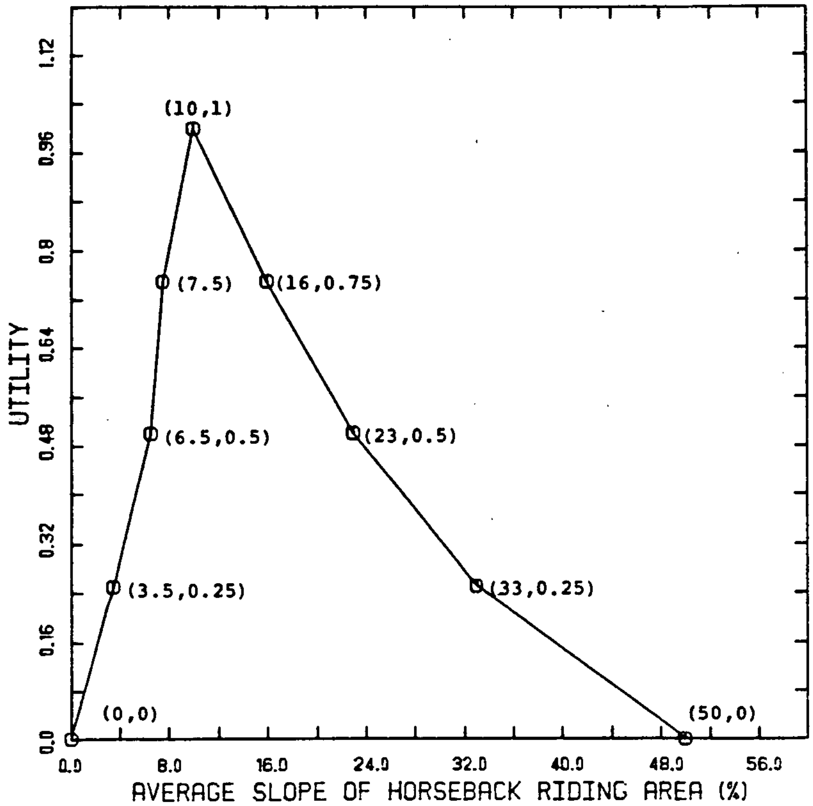


UTILITY
1.28
1.12
0.96
0.8
0.64
0.48
0.32
0.16
0.0
(0,1)
(1,0.75)
(2,0.5)
(3.5,0.25)
(10,0)
0.0
1.6
3.2
4.8
6.4
8.0
9.6
11.2
12.8
DISTANCE OF HIKING AREA FROM DRINKING WATER SOURCE (KM)

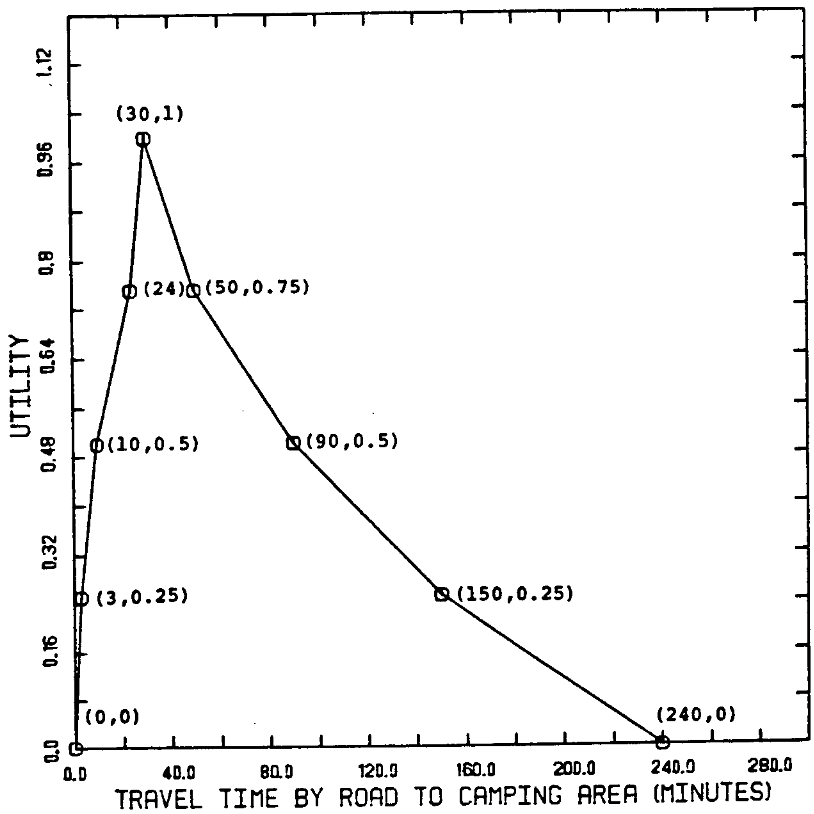
A. .8 Horseback Riding

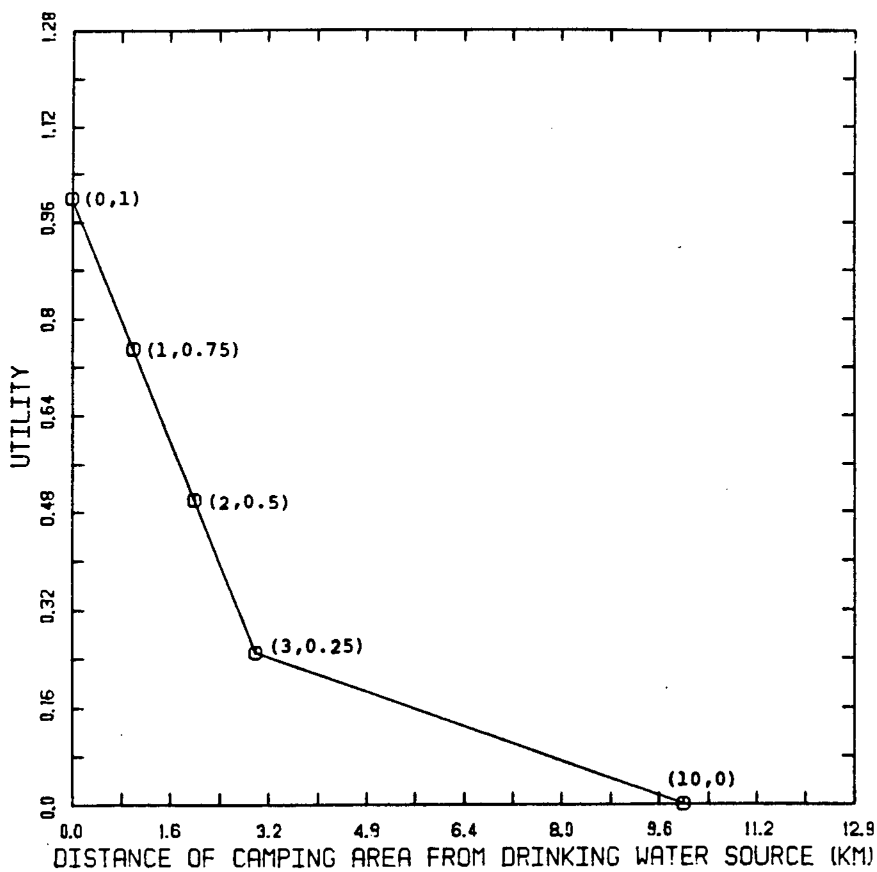


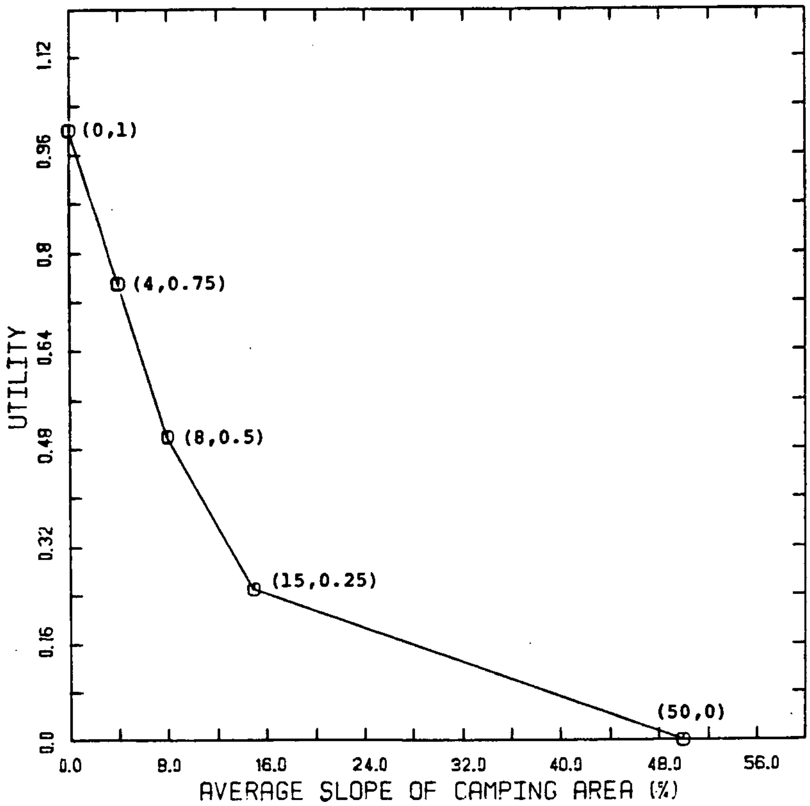



UTILITY
0.0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
(10,1)
(7.5)
(16,0.75)
(6.5,0.5)
(23,0.5)
(3.5,0.25)
(33,0.25)
(0,0)
(50,0)
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
AVERAGE SLOPE OF HORSEBACK RIDING AREA (%)

A. .9 Summer Motorized Camping





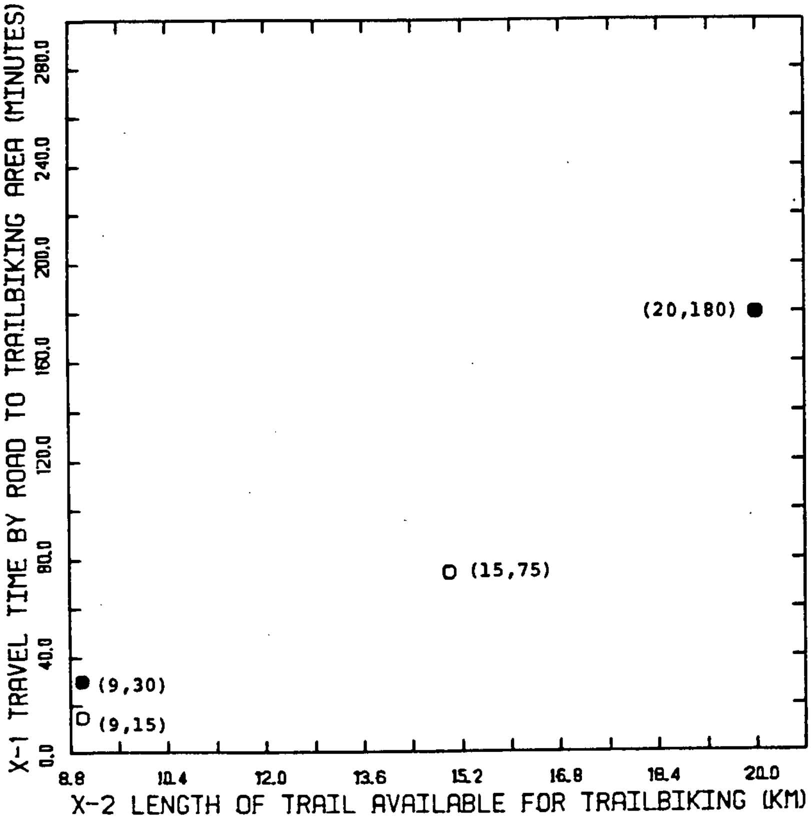

UTILITY
1.12
0.96
0.8
0.64
0.48
0.32
0.16
0.0
(0,1)
(4,0.75)
(8,0.5)
(15,0.25)
(50,0)
0.0
8.0
16.0
24.0
32.0
40.0
48.0
56.0
AVERAGE SLOPE OF CAMPING AREA (%)

APPENDIX

Attribute Tradeoffs for Assessing Scaling Constants

ATTRIBUTE TRADEOFFS FOR ASSESSING SCALING CONSTANTS

A. .1 Trailbiking



U(9) = 0.580
U(15) = 0.925
U(15) = 0.770
U(75) = 0.580

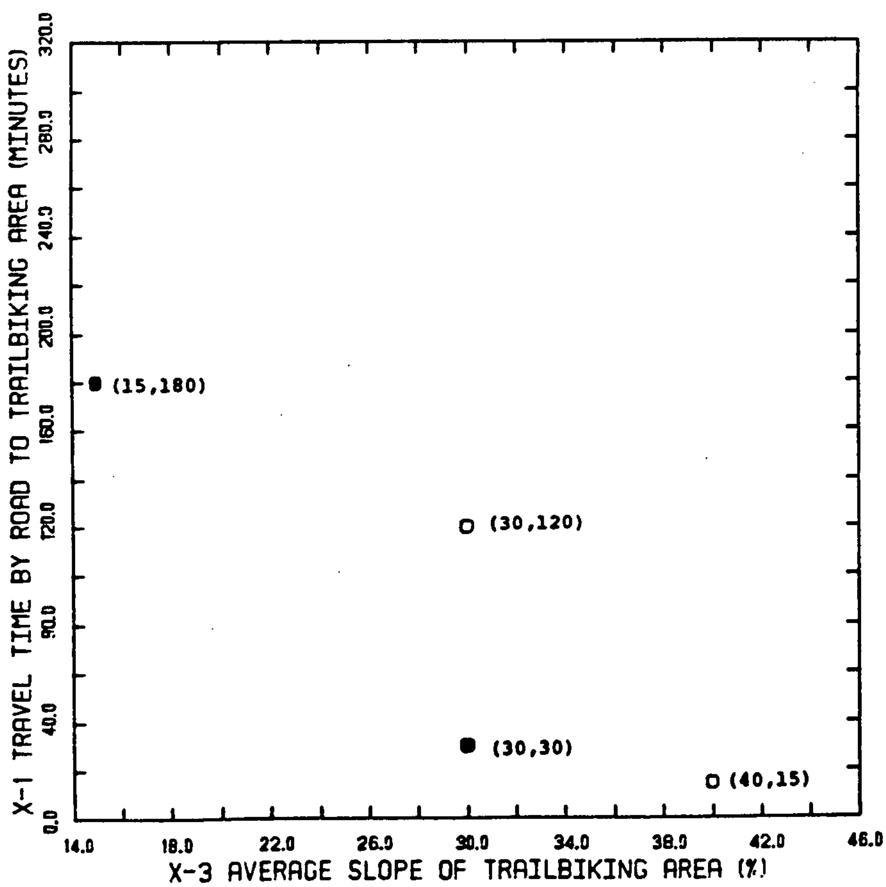
o $k_1 = 0.551k_2$

U(9) = 0.580
U(30) = 0.820
U(20) = 1.00
U(180) = 0.140

• $k_1 = 0.618k_2$

Average

$k_1 = 0.585k_2$



U(30) = 0.650
U(120) = 0.335
U(40) = 0.340
U(15) = 0.925

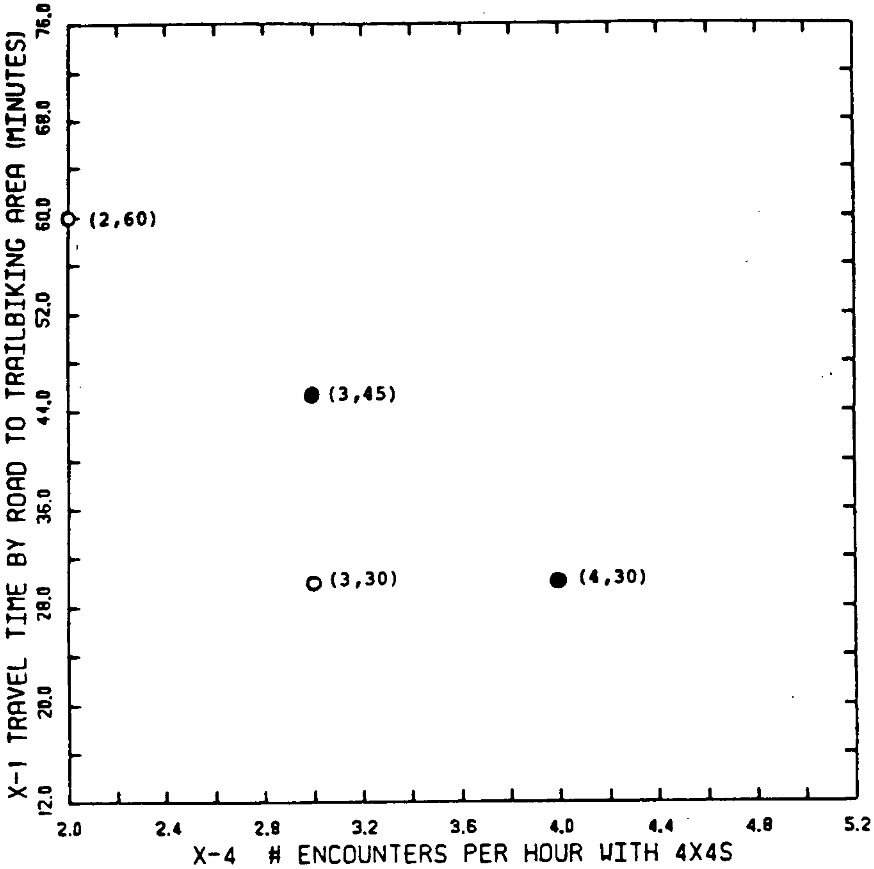
o $k_1 = 0.525k_3$

U(30) = 0.650
U(30) = 0.810
U(15) = 1.00
U(180) = 0.140

• $k_1 = 0.522k_3$

Average

$k_1 = 0.524k_3$



U(2) = 0.200
U(60) = 0.650
U(3) = 0.100
U(30) = 0.810

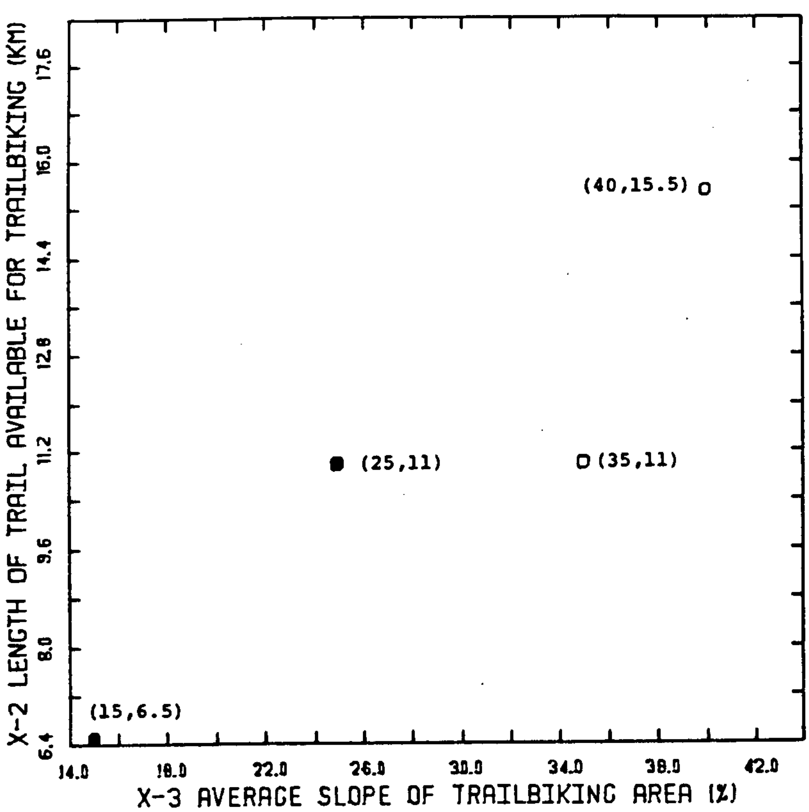
o $k_1 = 0.625k_4$

U(3) = 0.100
U(45) = 0.725
U(4) = 0.000
U(30) = 0.810

● $k_1 = 1.18k_4$

Average

$k_1 = 0.903k_4$



U(35) = 0.500
U(11) = 0.670
U(40) = 0.340
U(15.5) = 0.840

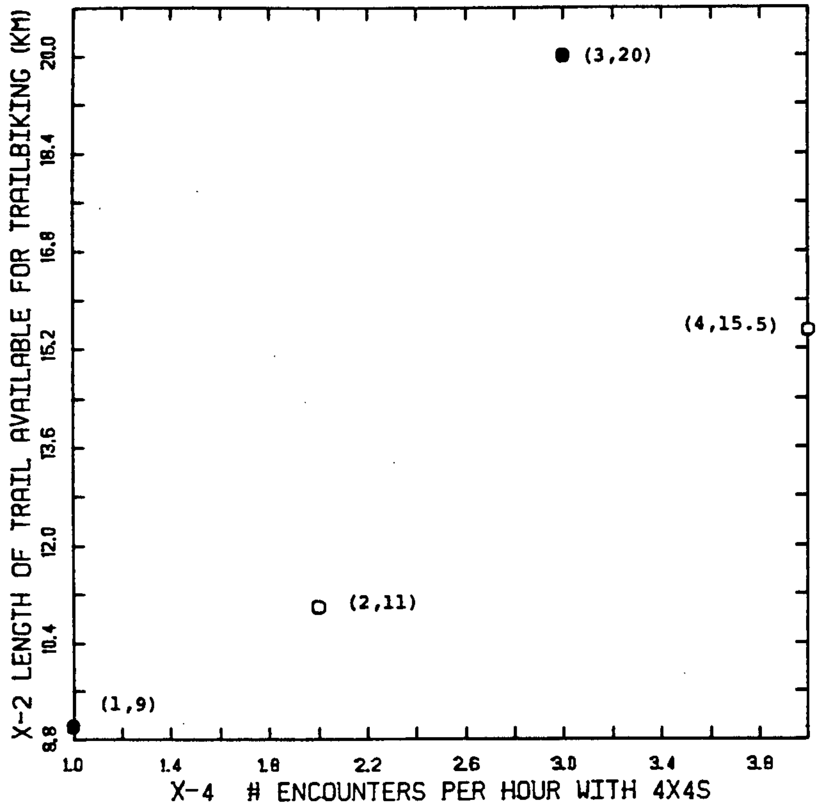
o $k_2 = 0.941k_3$

U(15) = 1.00
U(6.5) = 0.410
U(25) = 0.795
U(11) = 0.670

● $k_2 = 0.788k_3$

Average

$k_2 = 0.865k_3$



U(2) = 0.200
U(11) = 0.670
U(4) = 0.000
U(15.5) = 0.840

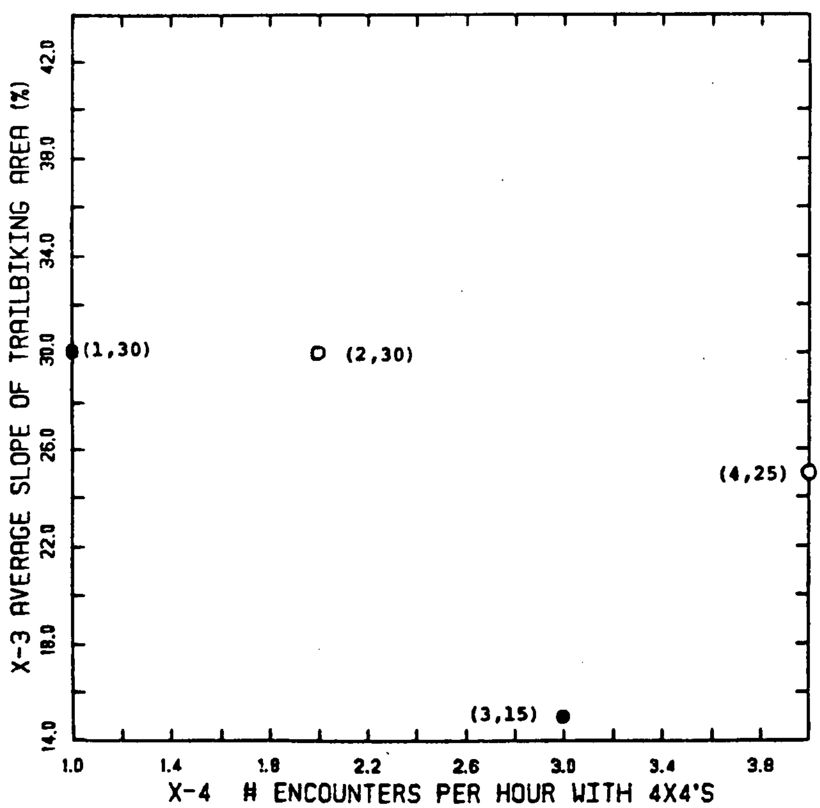
o $k_2 = 1.18k_4$

U(1) = 0.500
U(9) = 0.580
U(3) = 0.100
U(20) = 1.00

● $k_2 = 0.952k_4$

<u>Average</u>

$k_2 = 1.07k_4$



U(2) = 0.200
U(30) = 0.650
U(4) = 0.00
U(25) = 0.795

o $k_3 = 1.38k_4$

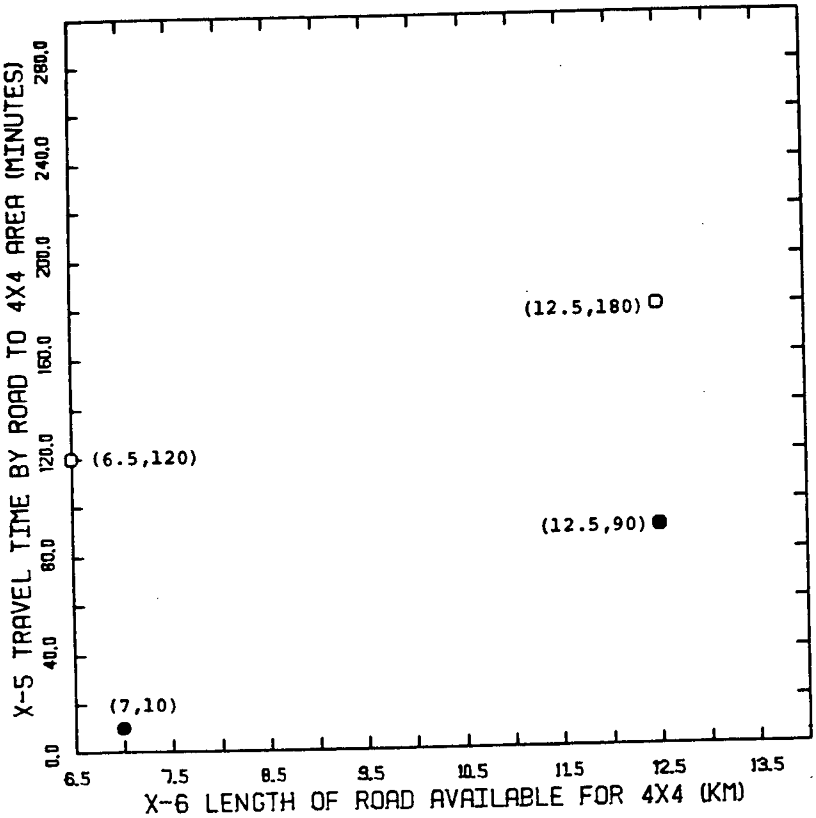
U(1) = 0.500
U(30) = 0.650
U(3) = 0.100
U(15) = 1.00

● $k_3 = 1.14k_4$

<u>Average</u>

$k_3 = 1.26k_4$

A. .2 Four-Wheel Driving



U(6.5) = 0.470
U(120) = 0.500
U(12.5) = 0.695
U(180) = 0.190

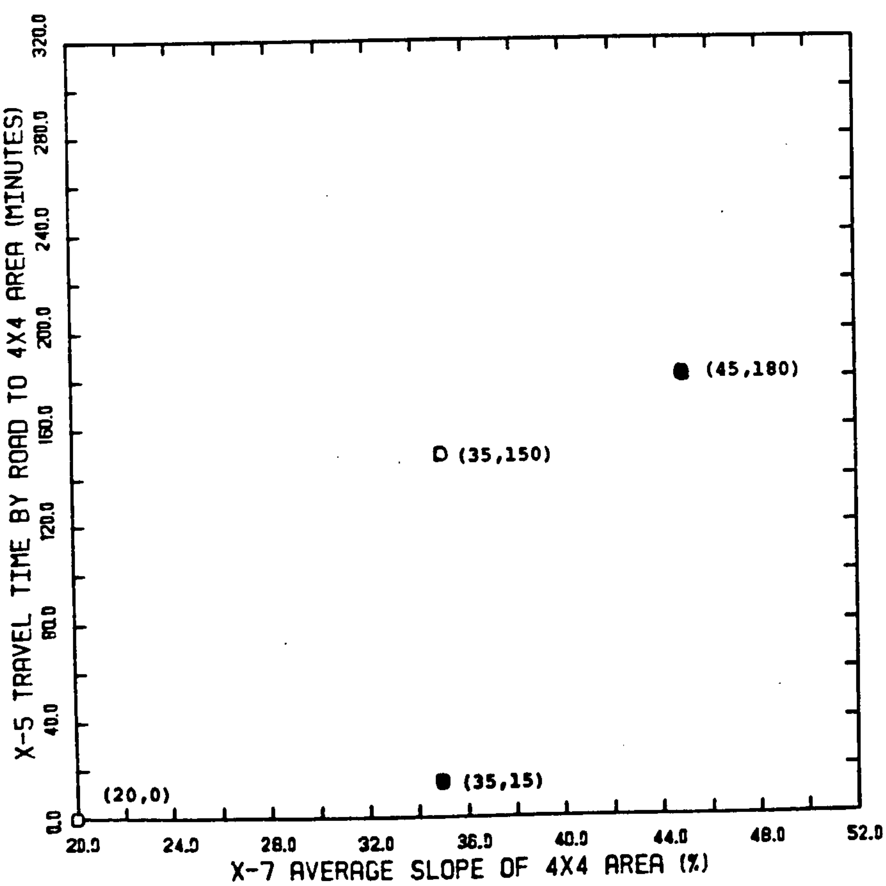
o $k_5 = 0.726k_6$

U(7) = 0.500
U(10) = 0.880
U(12.5) = 0.695
U(90) = 0.575

● $k_5 = 0.639k_6$

Average

$k_5 = 0.683k_6$



U(20) = 0.180
U(0) = 1.00
U(35) = 0.500
U(150) = 0.315

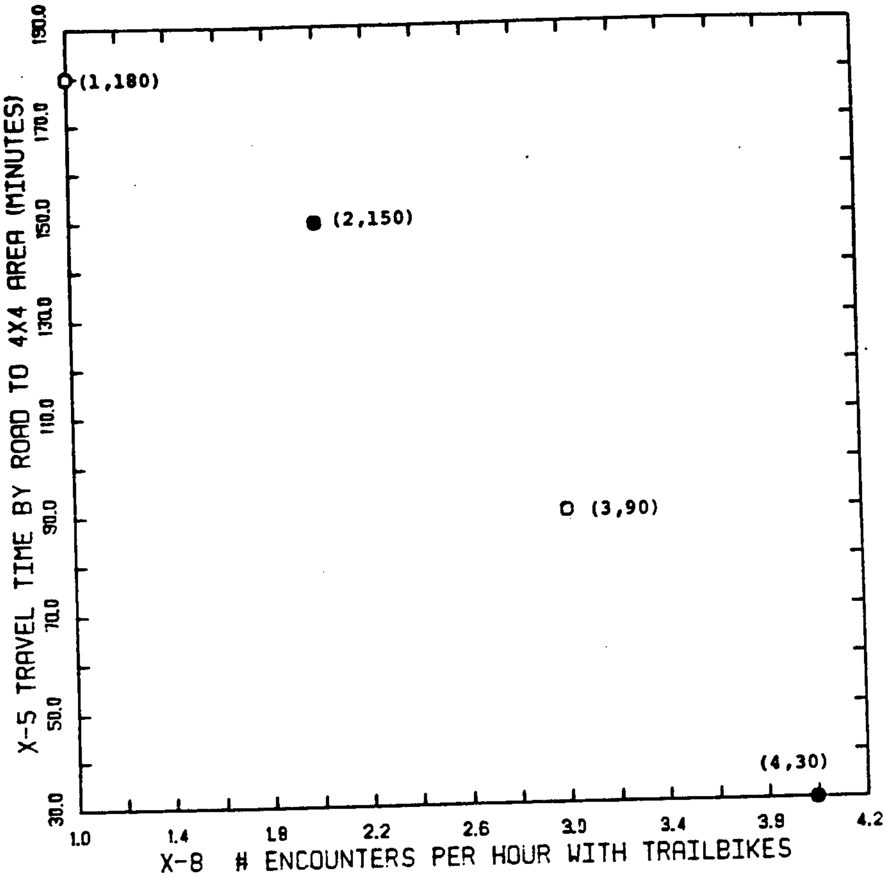
o $k_5 = 0.467k_7$

U(35) = 0.500
U(15) = 0.815
U(45) = 0.895
U(180) = 0.190

● $k_5 = 0.632k_7$

Average

$k_5 = 0.550k_7$



U(1) = 0.830
U(180) = 0.190
U(3) = 0.250
U(90) = 0.575

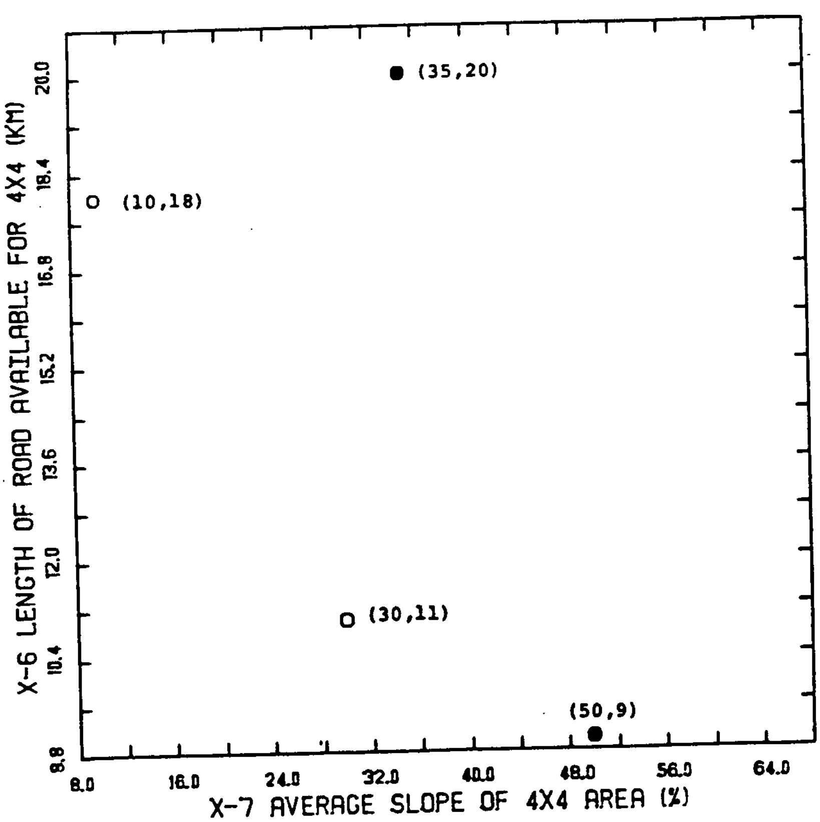
o $k_5 = 1.51k_8$

U(2) = 0.500
U(150) = 0.315
U(4) = 0.00
U(30) = 0.720

● $k_5 = 1.23k_8$

Average

$k_5 = 1.37k_8$



U(10) = 0.090
U(18) = 0.940
U(30) = 0.320
U(11) = 0.640

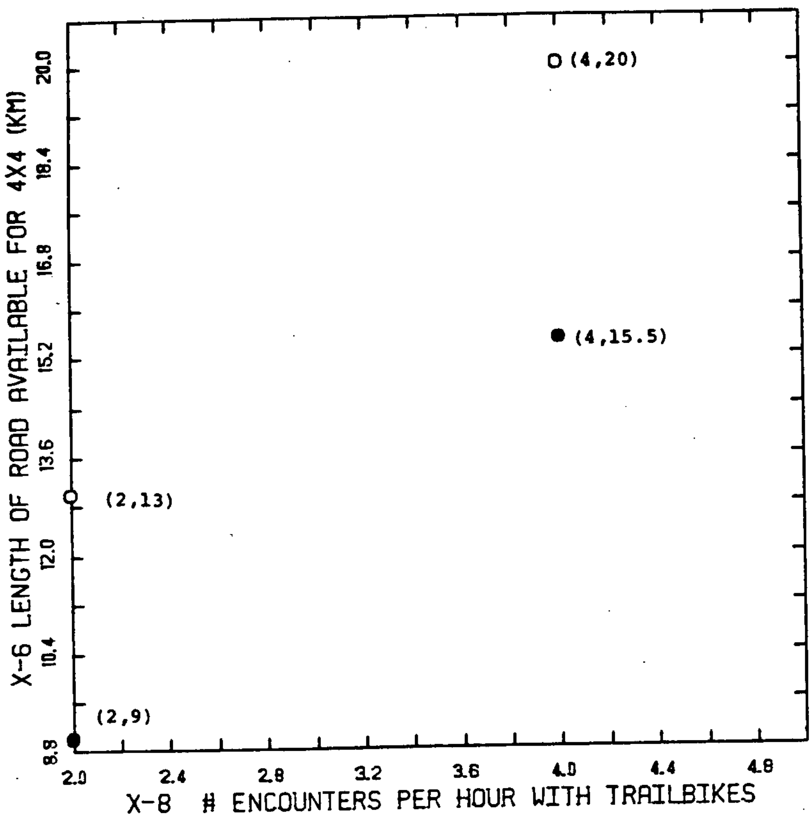
o $k_6 = 0.767k_7$

U(35) = 0.500
U(20) = 1.00
U(50) = 1.00
U(9) = 0.565

● $k_6 = 1.15k_7$

Average

$k_6 = 0.959k_7$



U(2) = 0.500
U(13) = 0.695
U(4) = 0.000
U(20) = 1.00

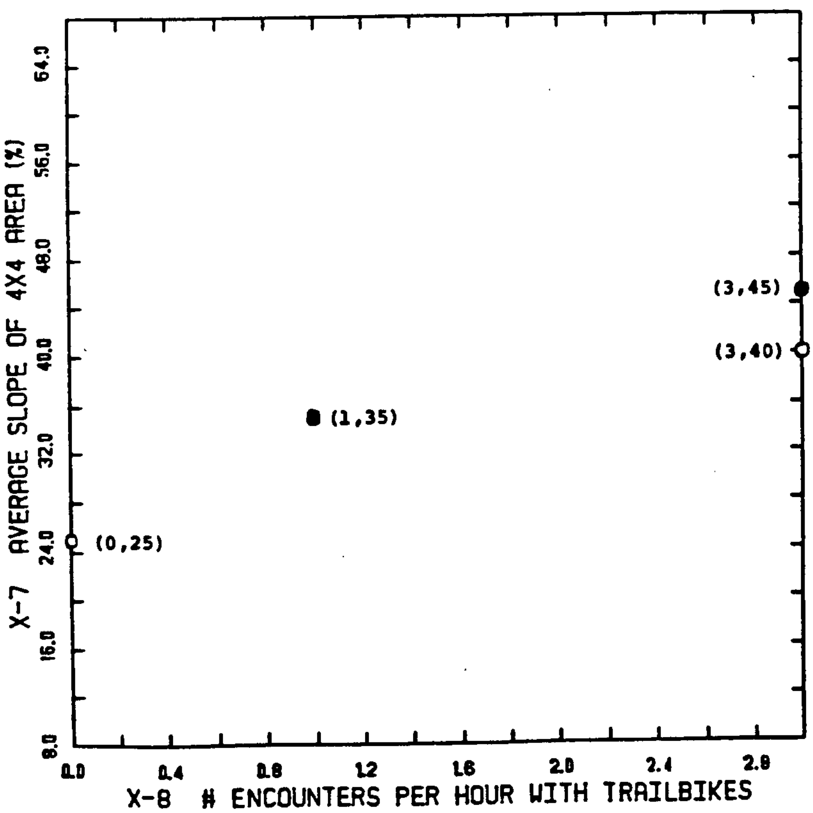
o $k_6 = 1.64k_8$

U(2) = 0.500
U(9) = 0.565
U(4) = 0.000
U(15.5) = 0.805

● $k_6 = 2.08k_8$

<u>Average</u>

$k_6 = 1.86k_8$



U(0) = 1.00
U(25) = 0.220
U(3) = 0.250
U(40) = 0.790

o $k_7 = 1.32k_8$

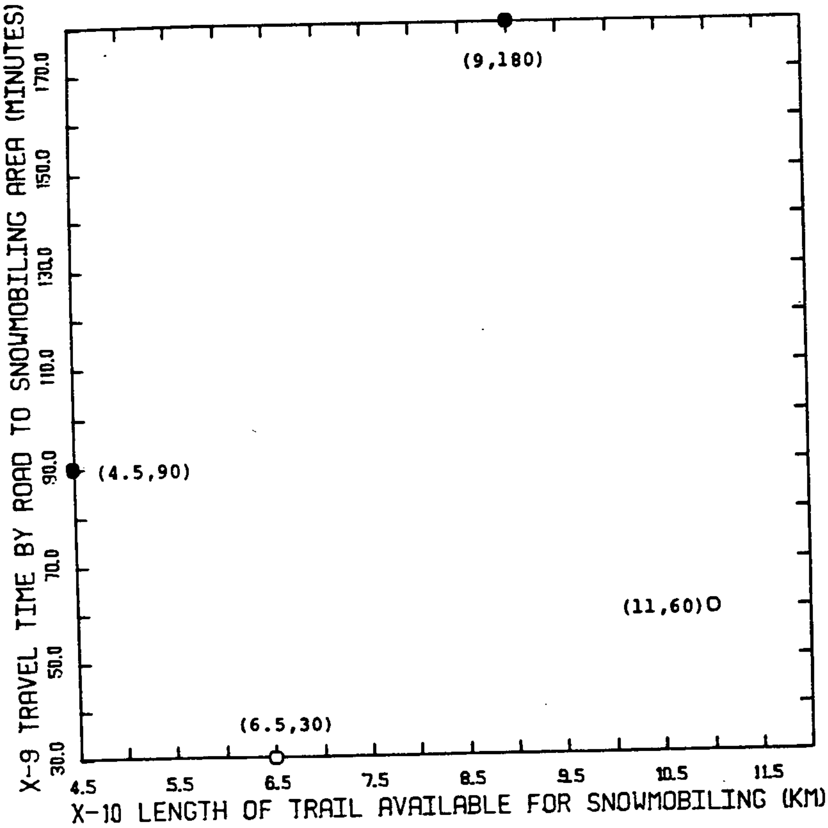
U(1) = 0.830
U(35) = 0.500
U(3) = 0.250
U(45) = 0.895

● $k_7 = 1.47k_8$

<u>Average</u>

$k_7 = 1.40k_8$

A. .3 Snowmobiling



U(6.5) = 0.410
U(30) = 1.00
U(11) = 0.775
U(60) = 0.695

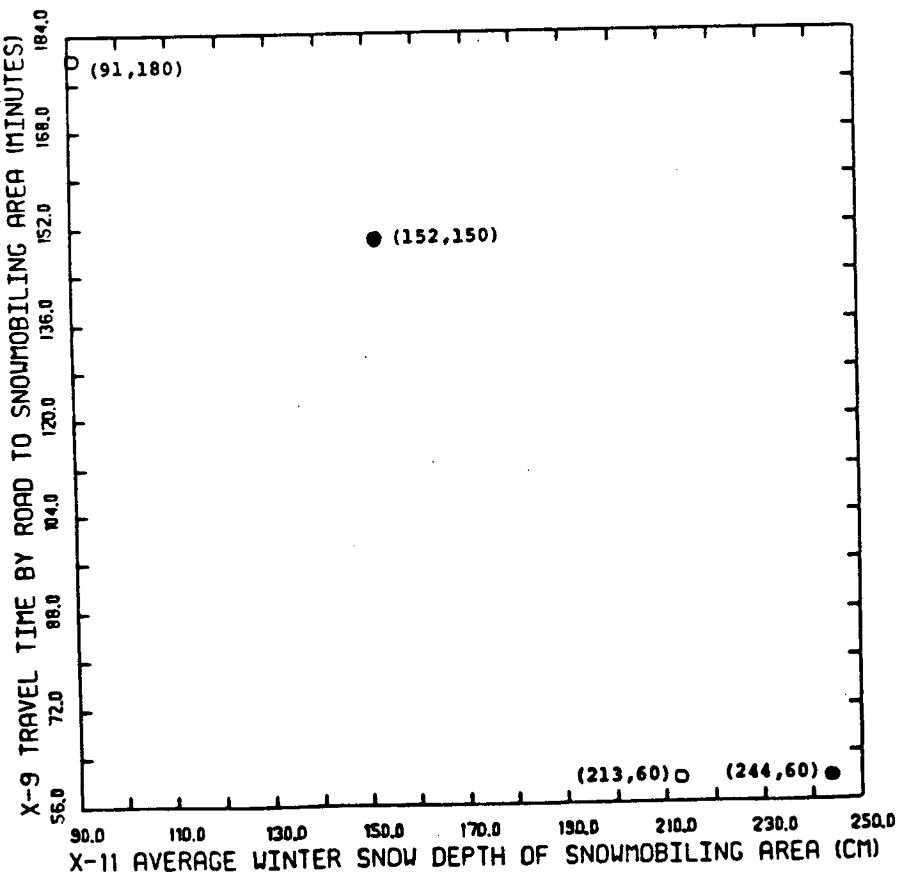
○ $k_9 = 1.20k_{10}$

U(4.5) = 0.280
U(90) = 0.530
U(9) = 0.625
U(180) = 0.160

● $k_9 = 0.932k_{10}$

Average

$k_9 = 1.07k_{10}$



U(91) = 1.00
U(180) = 0.160
U(213) = 0.200
U(60) = 0.695

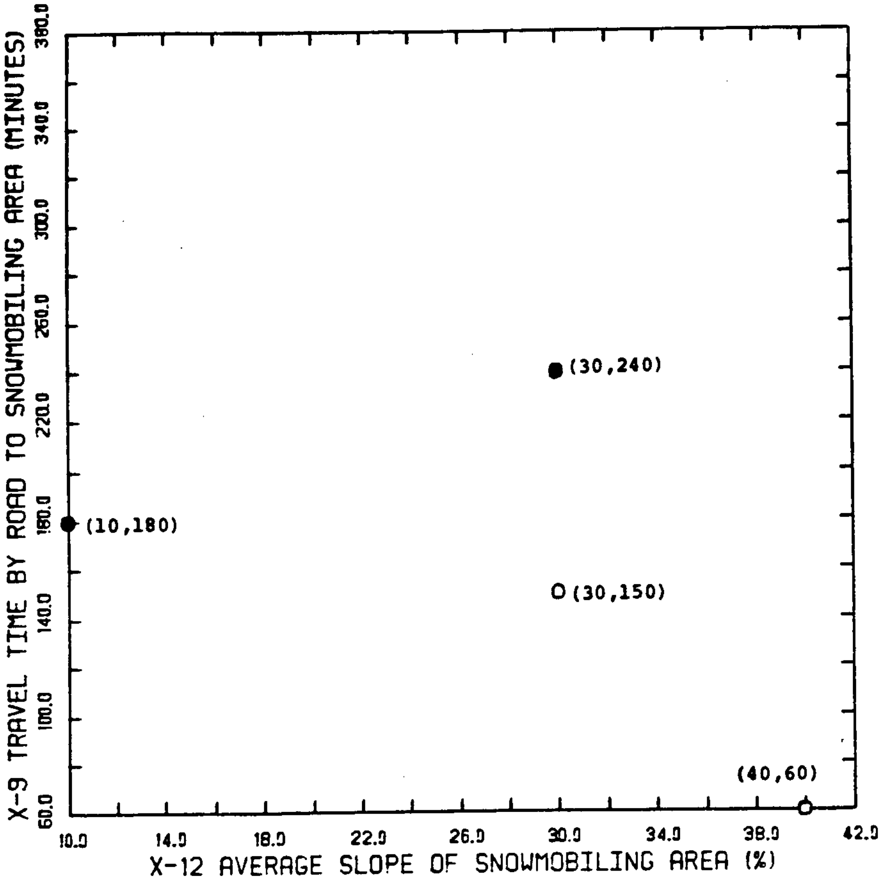
○ $k_9 = 1.50k_{11}$

U(152) = 0.760
U(150) = 0.250
U(244) = 0.00
U(60) = 0.695

● $k_9 = 1.71k_{11}$

Average

$k_9 = 1.61k_{11}$



U(30) = 1.00
U(150) = 0.250
U(40) = 0.680
U(60) = 0.695

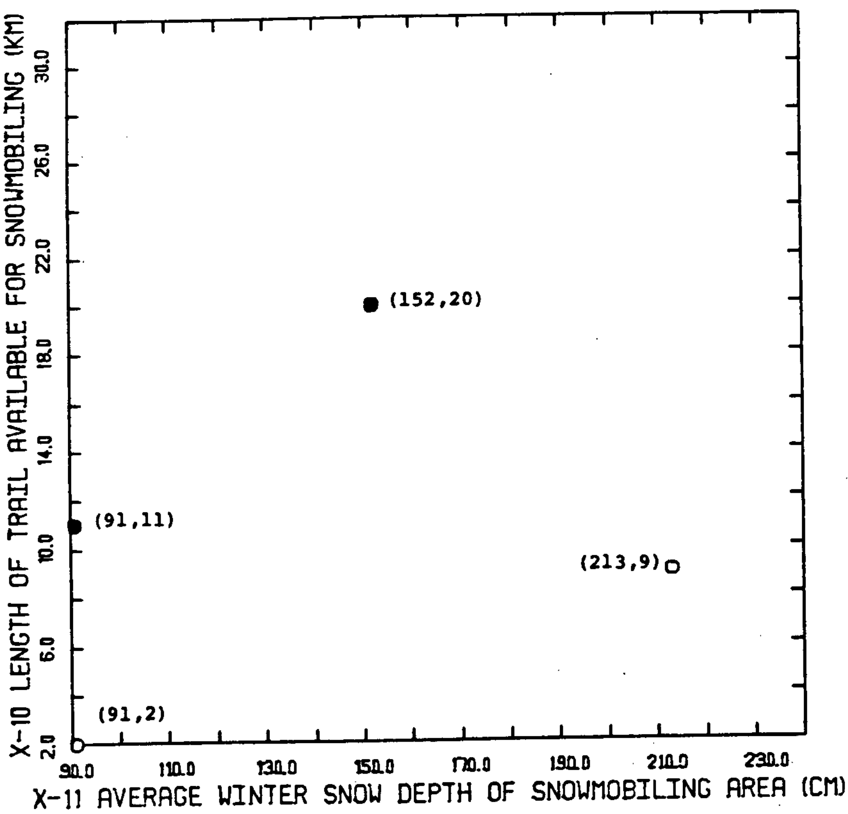
o $k_9 = 0.719k_{12}$

U(10) = 0.840
U(180) = 0.160
U(30) = 1.00
U(240) = 0.000

● $k_9 = 1.00k_{12}$

<u>Average</u>

$k_9 = 0.860k_{12}$



U(91) = 1.00
U(2) = 0.120
U(213) = 0.200
U(9) = 0.625

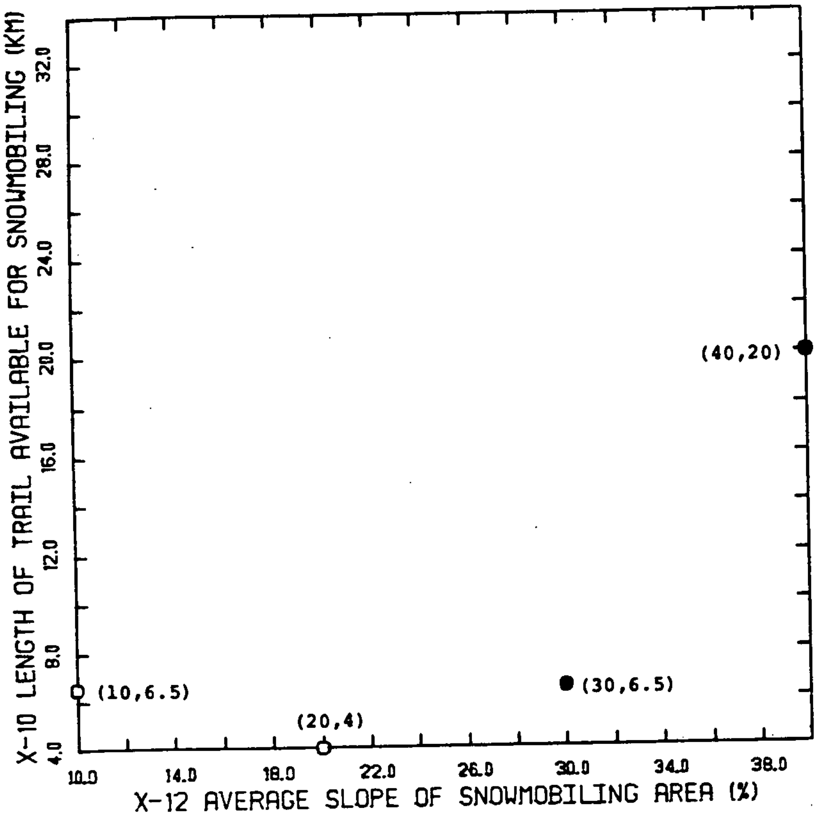
o $k_{10} = 1.58k_{11}$

U(91) = 1.00
U(11) = 0.775
U(152) = 0.760
U(20) = 1.00

● $k_{10} = 1.07k_{11}$

<u>Average</u>

$k_{10} = 1.33k_{11}$



U(10) = 0.840
U(6.5) = 0.410
U(20) = 0.933
U(4) = 0.250

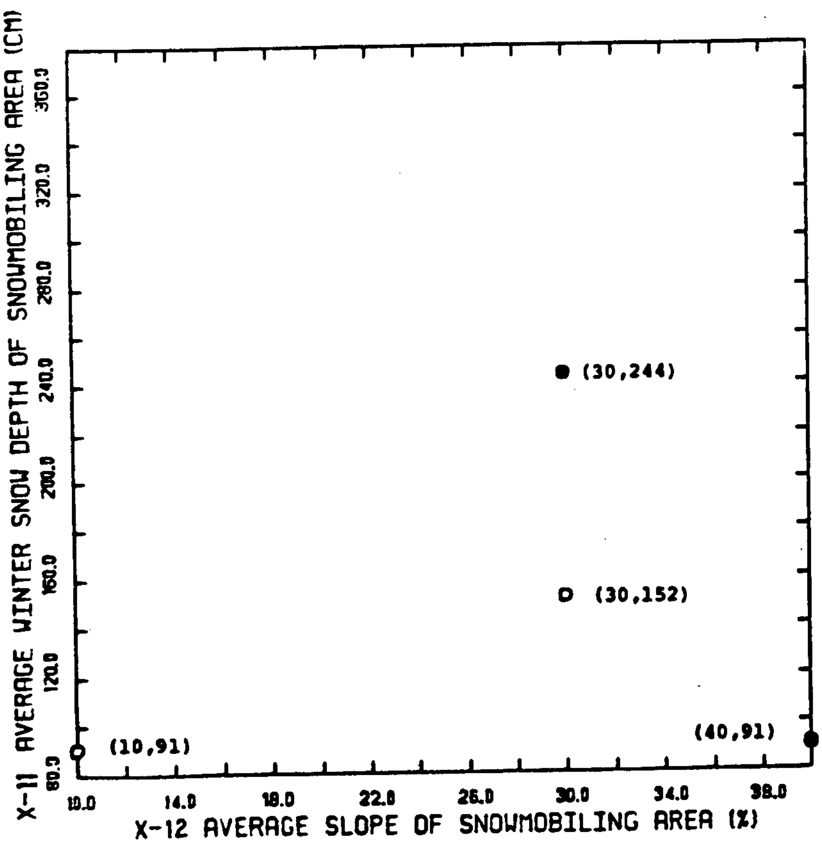
o $k_{10} = 0.581k_{12}$

U(30) = 1.00
U(6.5) = 0.410
U(40) = 0.680
U(20) = 1.00

● $k_{10} = 0.542k_{12}$

Average

$k_{10} = 0.562k_{12}$



U(10) = 0.840
U(91) = 1.00
U(30) = 1.00
U(152) = 0.760

o $k_{11} = 0.667k_{12}$

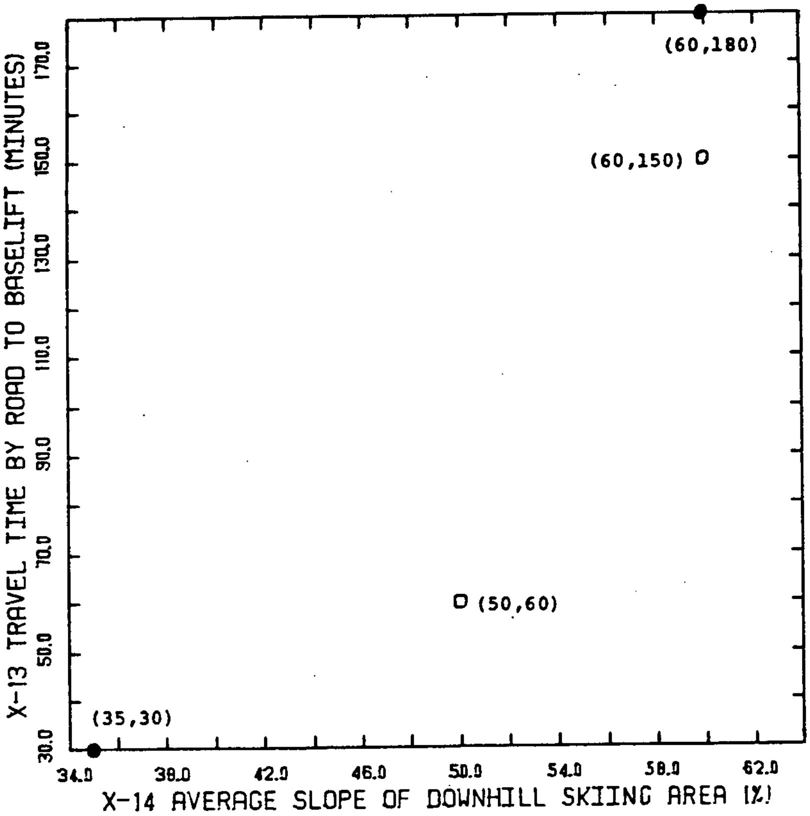
U(30) = 1.00
U(244) = 0.000
U(40) = 0.680
U(91) = 1.00

● $k_{11} = 0.320k_{12}$

Average

$k_{11} = 0.494k_{12}$

A. .4 Downhill Skiing



U(50) = 0.885
U(60) = 0.415
U(60) = 1.00
U(150) = 0.250

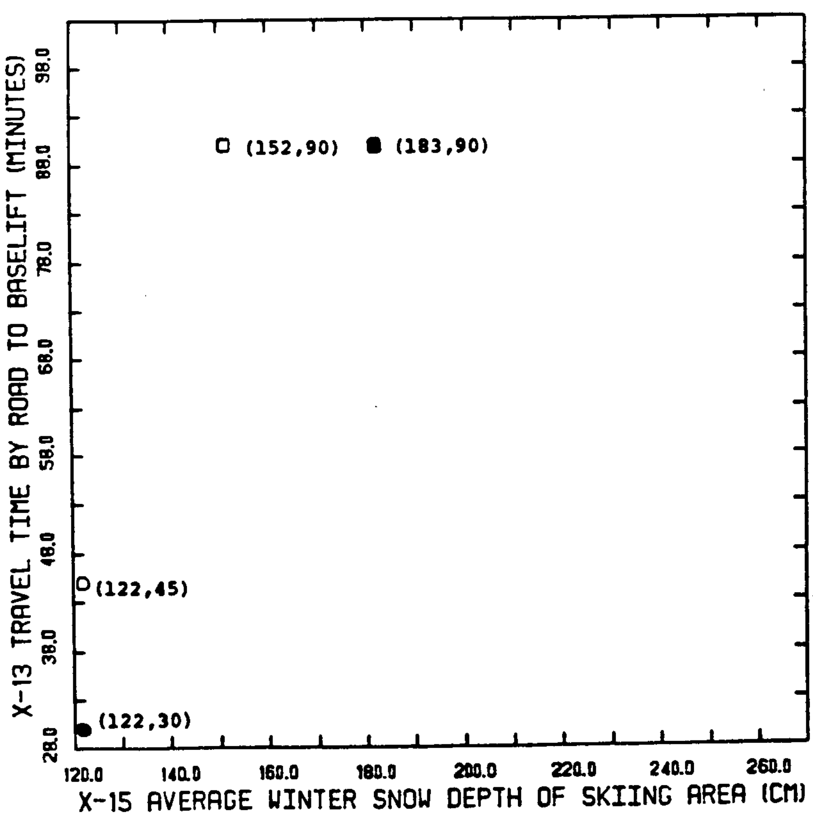
o $k_{13} = 0.697k_{14}$

U(35) = 0.620
U(30) = 0.720
U(60) = 1.00
U(180) = 0.165

● $k_{13} = 0.685k_{14}$

Average

$k_{13} = 0.691k_{14}$



U(122) = 0.570
U(45) = 0.615
U(152) = 0.785
U(90) = 0.415

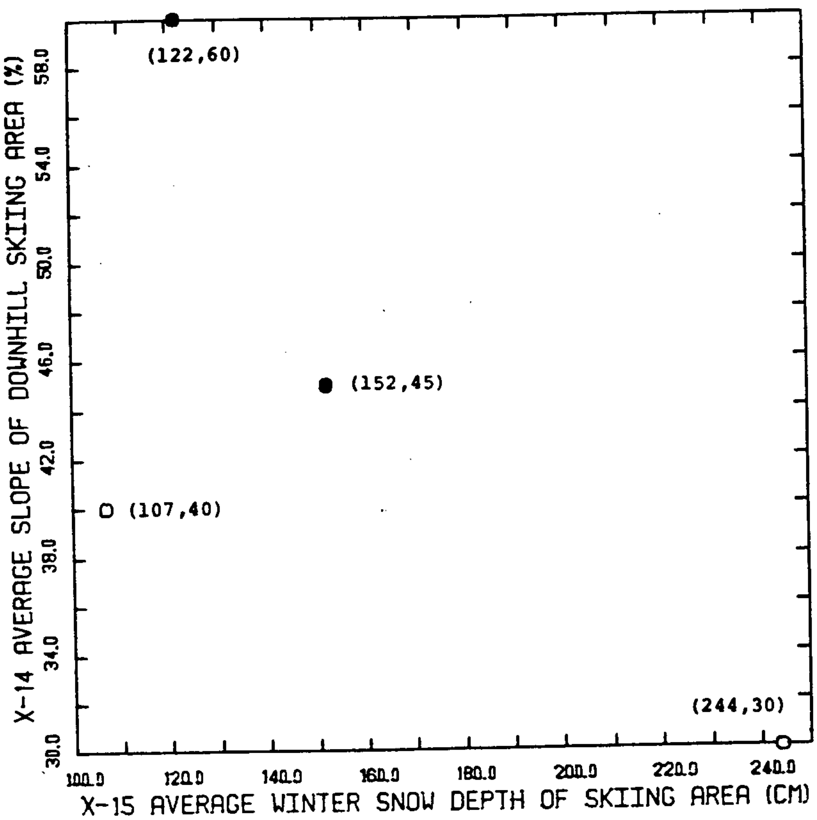
o $k_{13} = 1.08k_{15}$

U(122) = 0.570
U(30) = 0.720
U(183) = 0.940
U(90) = 0.415

● $k_{13} = 1.21k_{15}$

Average

$k_{13} = 1.15k_{15}$



U(107) = 0.435
U(40) = 0.770
U(244) = 1.00
U(30) = 0.430

o $k_{14} = 1.66k_{15}$

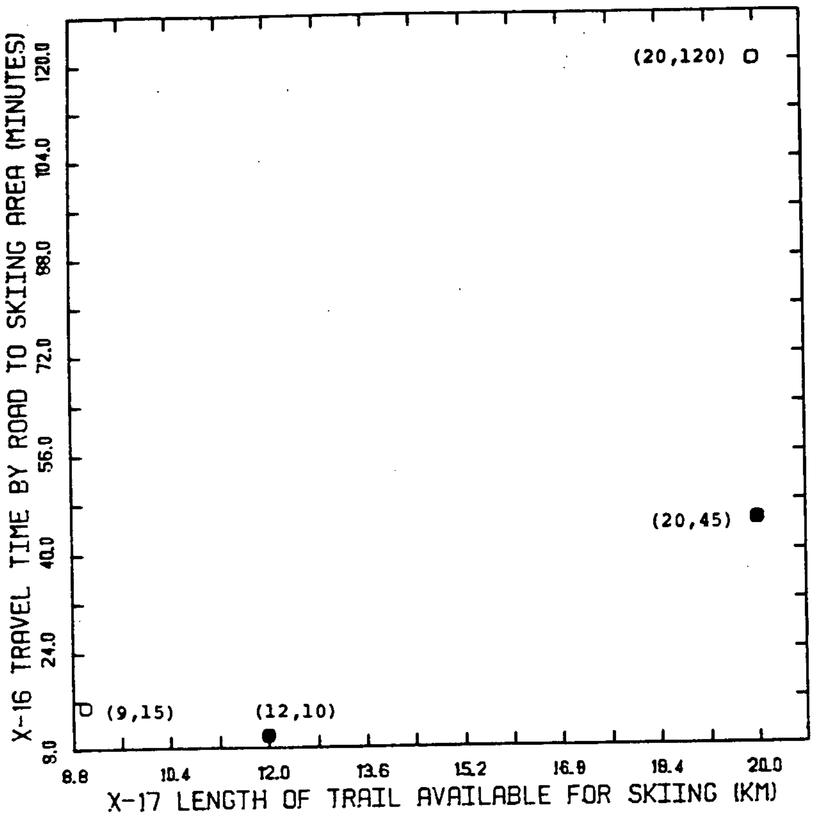
U(122) = 0.570
U(60) = 1.00
U(152) = 0.795
U(45) = 0.830

● $k_{14} = 1.32k_{15}$

<u>Average</u>

$k_{14} = 1.49k_{15}$

A. .5 Cross-Country Skiing



U(9) = 0.250
U(15) = 0.810
U(20) = 1.00
U(120) = 0.200

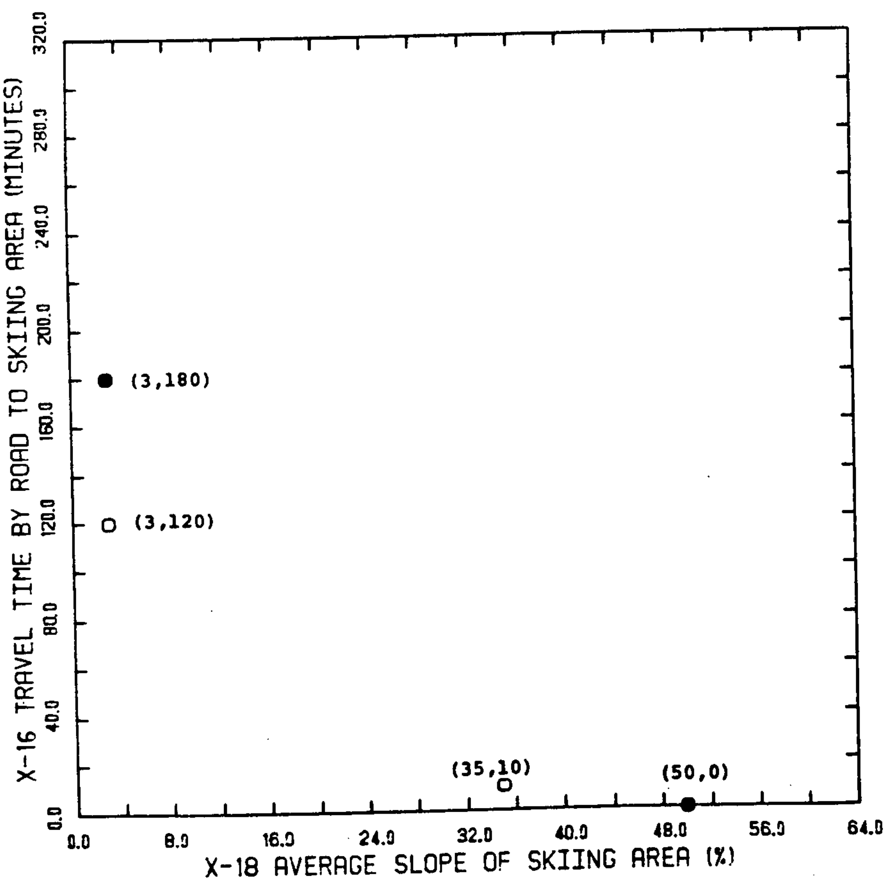
o $k_{16} = 1.23k_{17}$

U(12) = 0.440
U(10) = 0.870
U(20) = 1.00
U(45) = 0.500

● $k_{16} = 1.51k_{17}$

Average

$k_{16} = 1.37k_{17}$



U(3) = 0.800
U(120) = 0.200
U(35) = 0.160
U(10) = 0.870

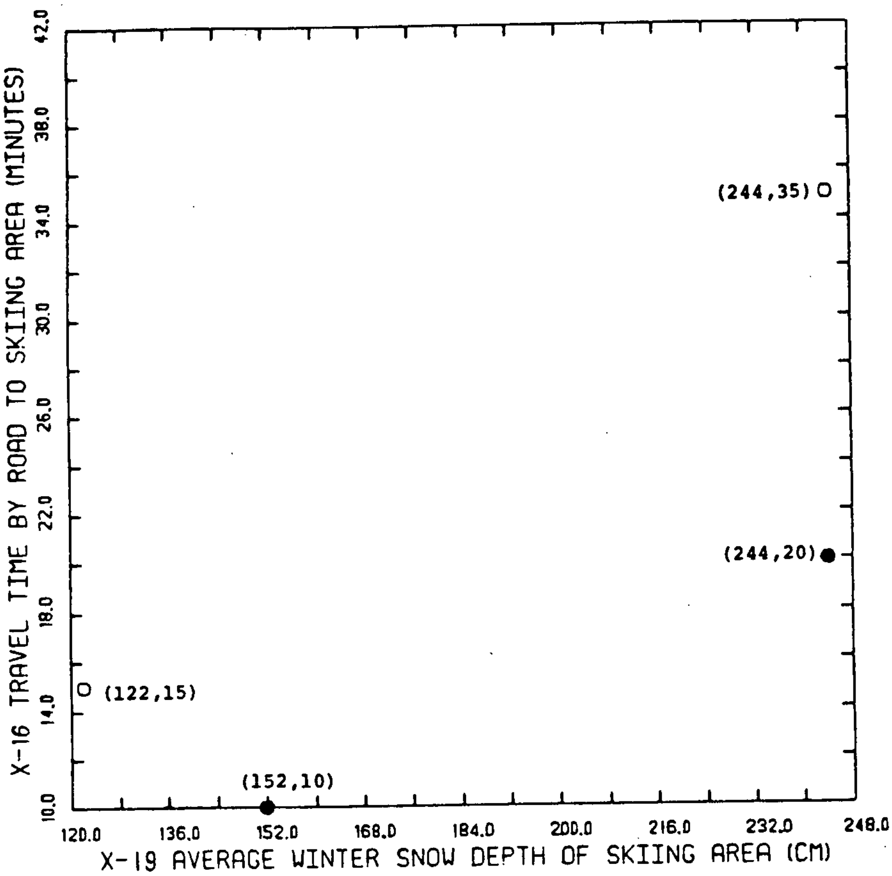
o $k_{16} = 0.955k_{18}$

U(3) = 0.800
U(180) = 0.100
U(50) = 0.00
U(0) = 1.00

● $k_{16} = 0.889k_{18}$

Average

$k_{16} = 0.922k_{18}$



U(122) = 0.790
U(15) = 0.810
U(244) = 1.00
U(35) = 0.600

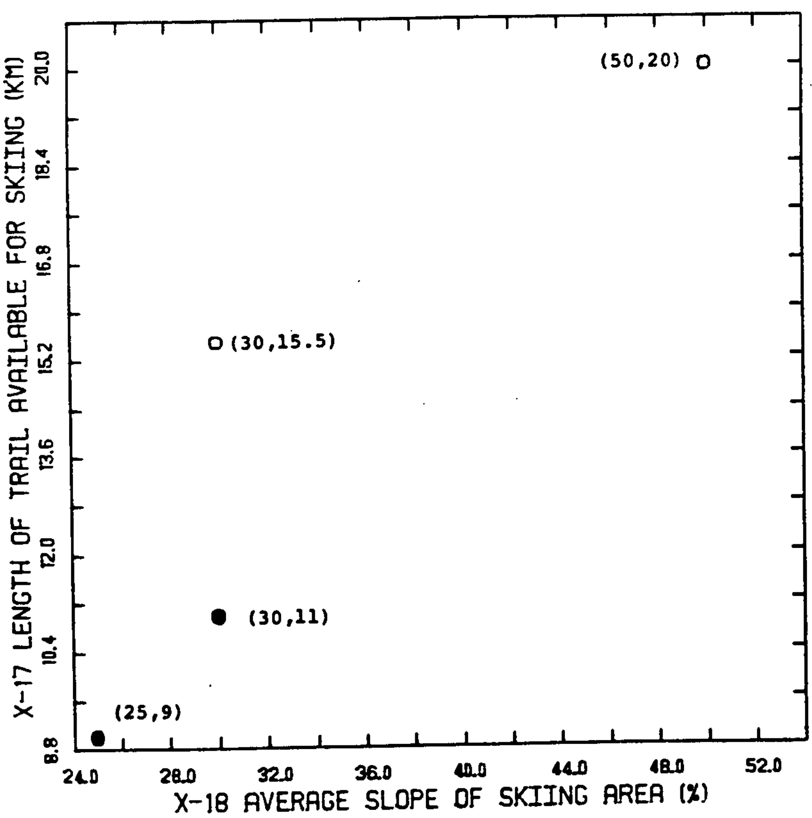
o $k_{16} = 1.00k_{19}$

U(152) = 0.840
U(10) = 0.870
U(244) = 1.00
U(20) = 0.745

● $k_{16} = 1.28k_{19}$

Average

$k_{16} = 1.14k_{19}$



U(30) = 0.215
U(15.5) = 0.625
U(50) = 0.00
U(20) = 1.00

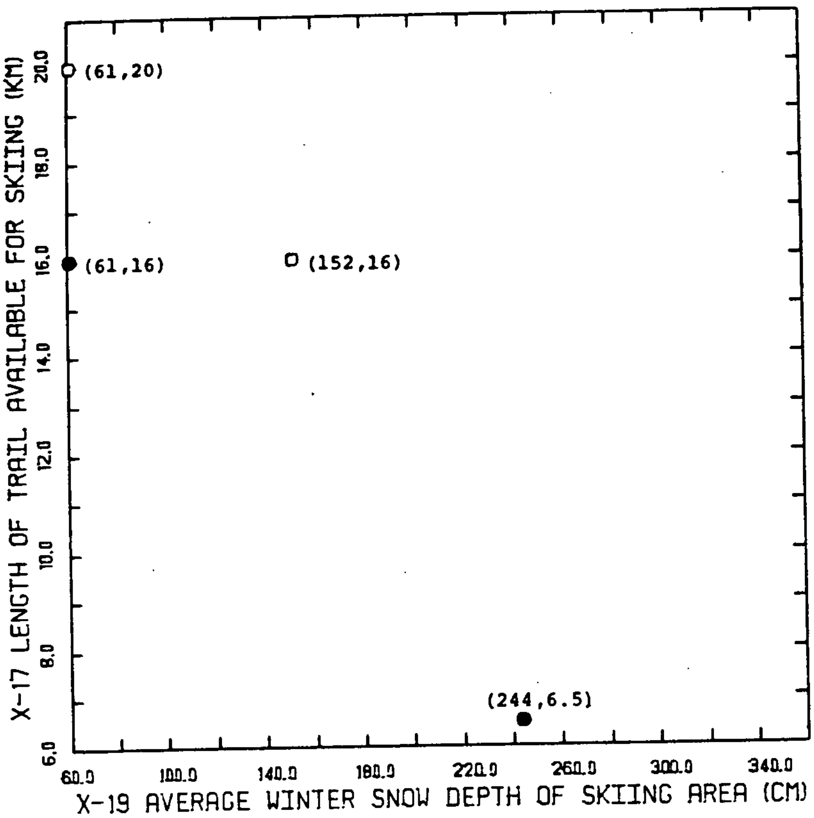
o $k_{17} = 0.573k_{18}$

U(25) = 0.290
U(9) = 0.250
U(30) = 0.215
U(11) = 0.370

● $k_{17} = 0.625k_{18}$

Average

$k_{17} = 0.599k_{18}$



U(61) = 0.450
U(20) = 1.00
U(152) = 0.840
U(16) = 0.650

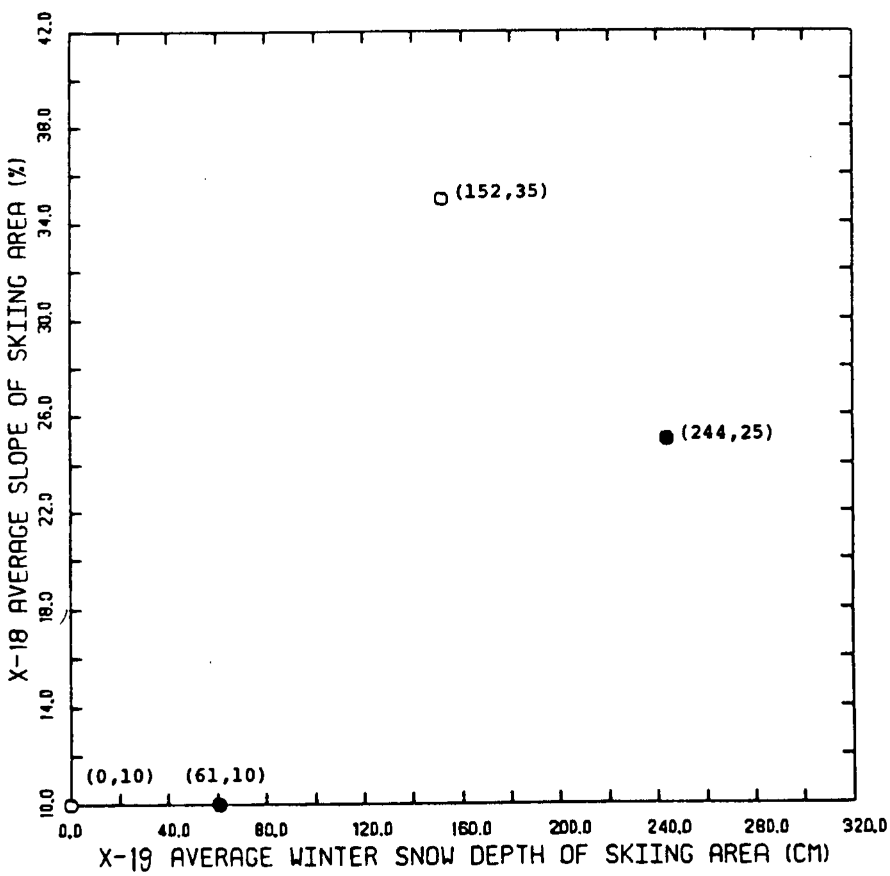
o $k_{17} = 1.11k_{19}$

U(61) = 0.450
U(16) = 0.650
U(244) = 1.00
U(6.5) = 0.180

● $k_{17} = 1.17k_{19}$

<u>Average</u>

$k_{17} = 1.14k_{19}$



U(0) = 0.00
U(10) = 0.640
U(152) = 0.840
U(35) = 0.160

o $k_{18} = 1.75k_{19}$

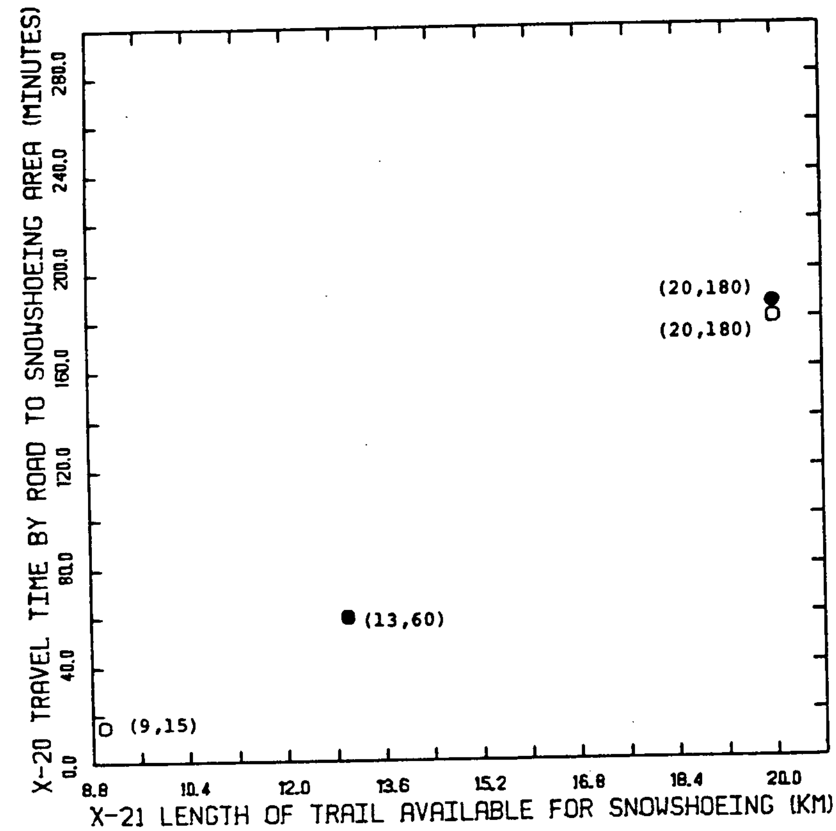
U(61) = 0.450
U(10) = 0.640
U(244) = 1.00
U(25) = 0.290

● $k_{18} = 1.57k_{19}$

<u>Average</u>

$k_{18} = 1.66k_{19}$

A. .6 Snowshoeing



U(9) = 0.670
U(15) = 1.00
U(20) = 1.00
U(180) = 0.170

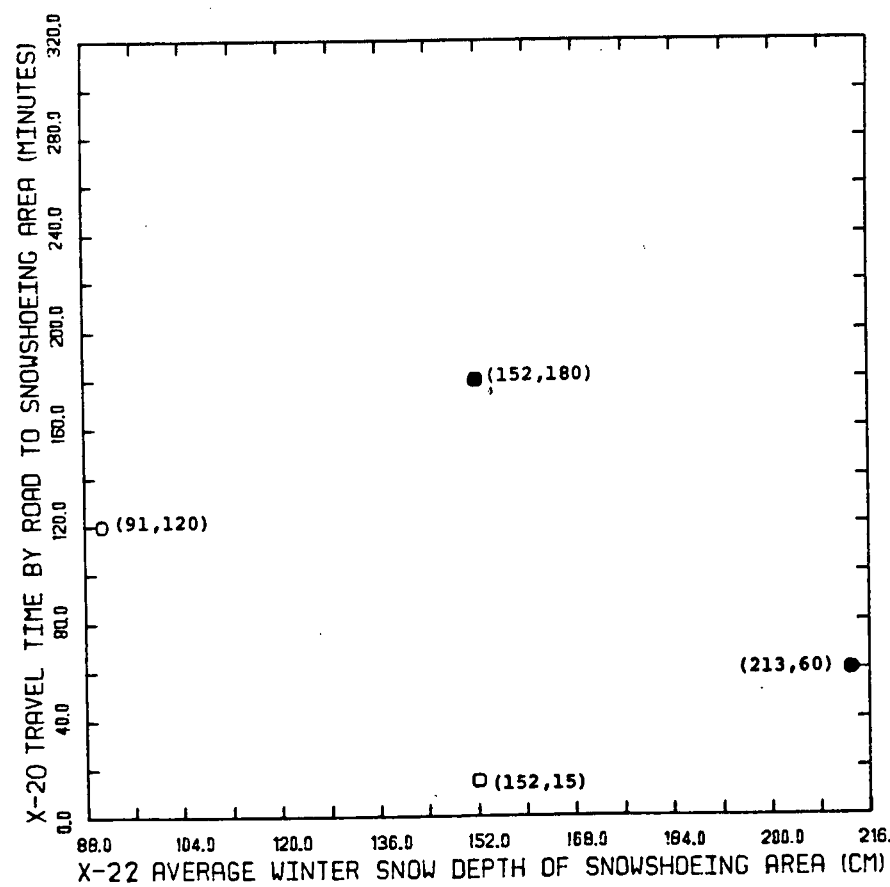
o k_{20} = 0.398k_{21}

U(13) = 0.800
U(60) = 0.670
U(20) = 1.00
U(180) = 0.170

o k_{20} = 0.400k_{21}

Average

k_{20} = 0.399k_{21}



U(91) = 1.00
U(120) = 0.370
U(152) = 0.680
U(15) = 1.00

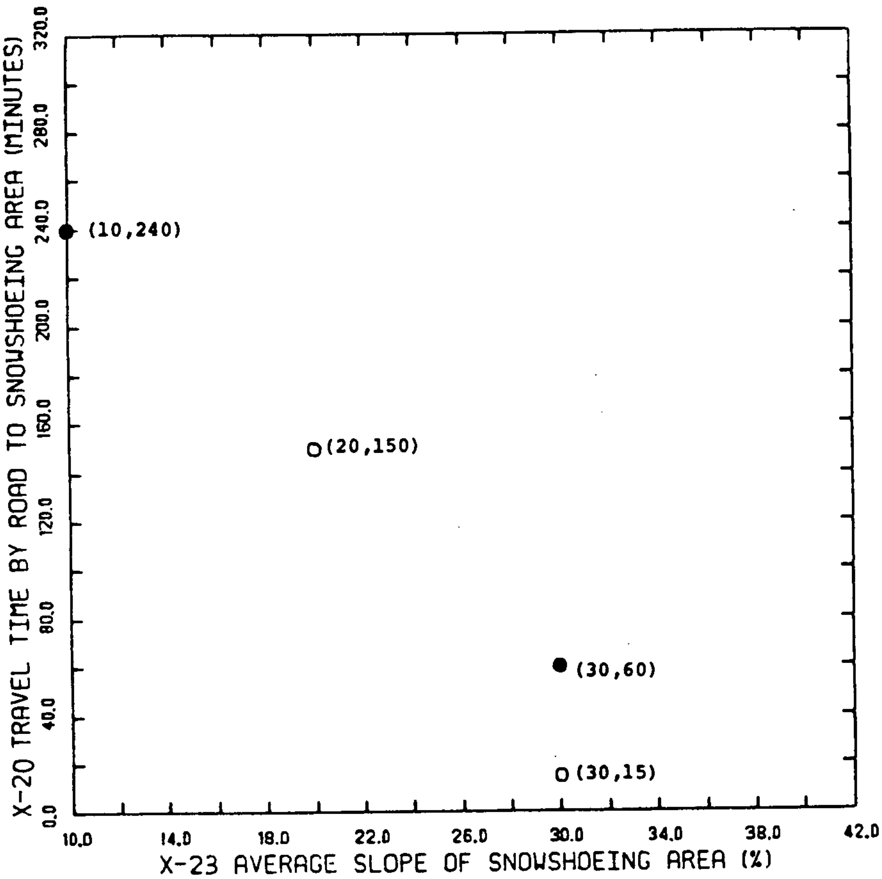
o k_{20} = 0.508k_{22}

U(152) = 0.680
U(180) = 0.170
U(213) = 0.340
U(60) = 0.670

• k_{20} = 0.680k_{22}

Average

k_{20} = 0.594k_{22}



U(20) = 0.660
U(150) = 0.250
U(30) = 0.250
U(15) = 1.00

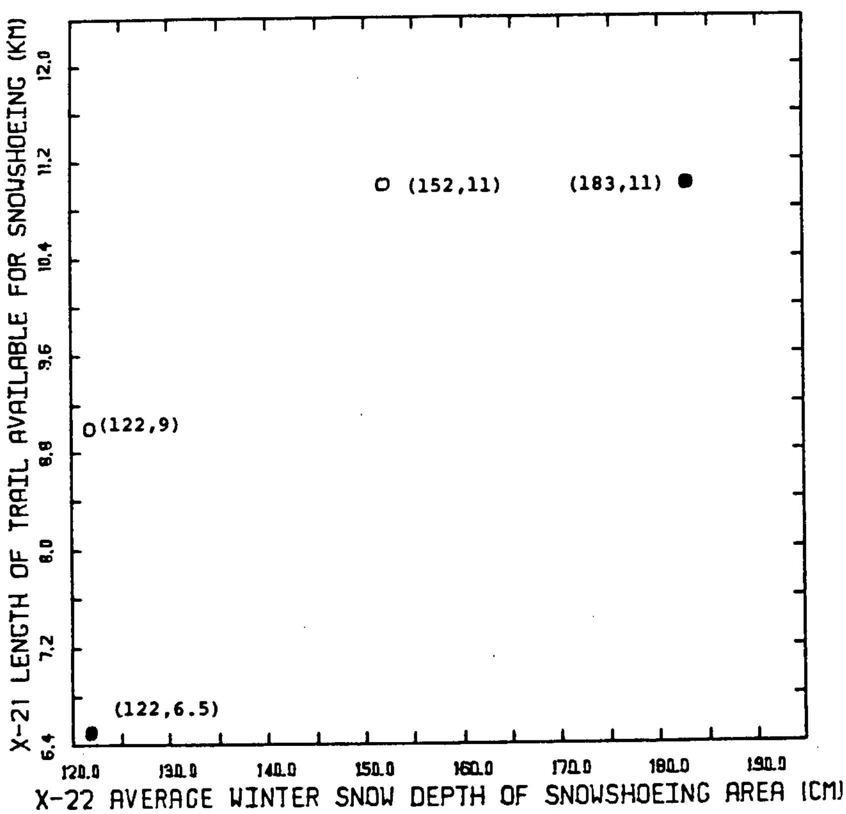
o $k_{20} = 0.547k_{23}$

U(10) = 0.850
U(240) = 0.00
U(30) = 0.250
U(60) = 0.670

● $k_{20} = 0.896k_{23}$

Average

$k_{20} = 0.722k_{23}$



U(122) = 0.820
U(9) = 0.670
U(152) = 0.680
U(11) = 0.750

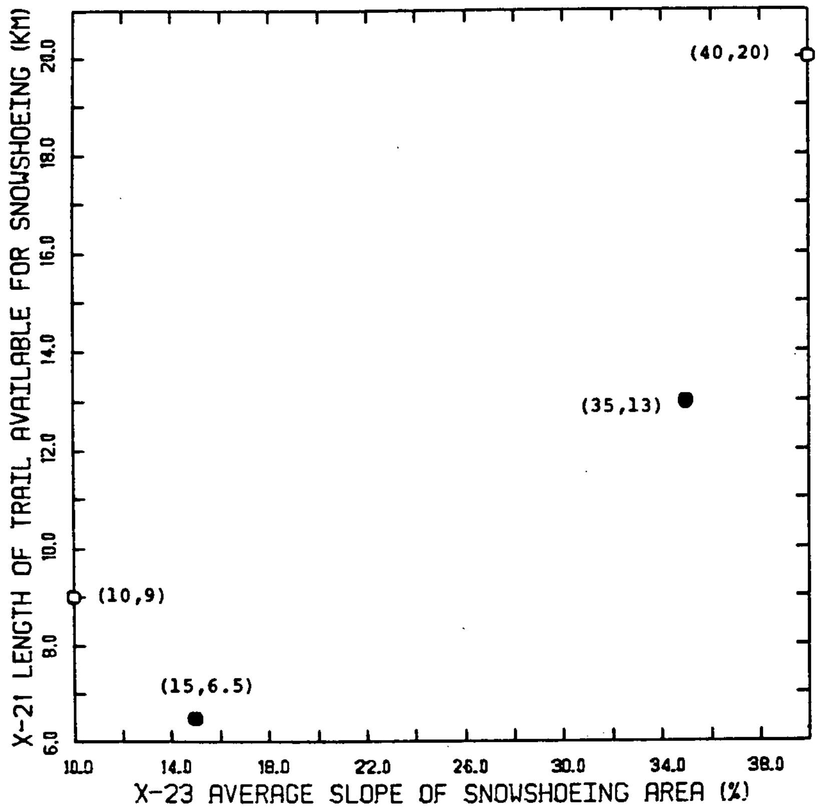
o $k_{21} = 1.75k_{22}$

U(122) = 0.820
U(6.5) = 0.575
U(183) = 0.560
U(11) = 0.750

● $k_{21} = 1.49k_{22}$

Average

$k_{21} = 1.62k_{22}$



U(10) = 0.850
U(9) = 0.670
U(40) = 0.125
U(20) = 1.00

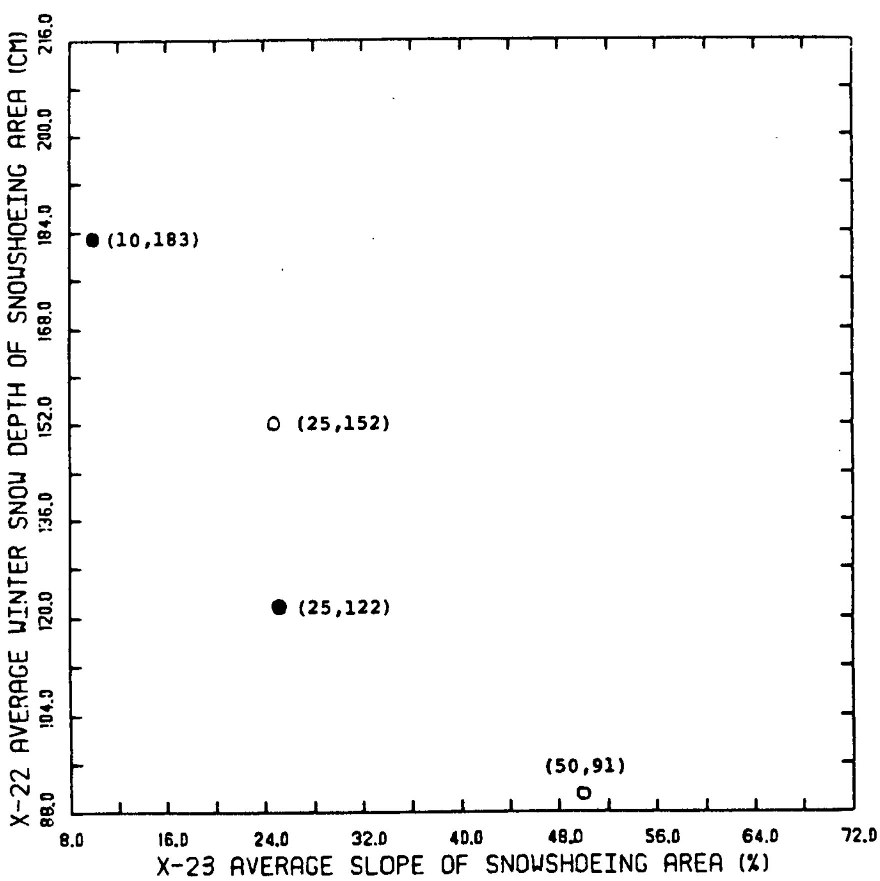
o $k_{21} = 2.20k_{23}$

U(15) = 0.780
U(6.5) = 0.575
U(35) = 0.190
U(13) = 0.800

● $k_{21} = 2.62k_{23}$

Average

$k_{21} = 2.41k_{23}$



U(25) = 0.500
U(152) = 0.680
U(50) = 0.00
U(91) = 1.00

o $k_{22} = 1.56k_{23}$

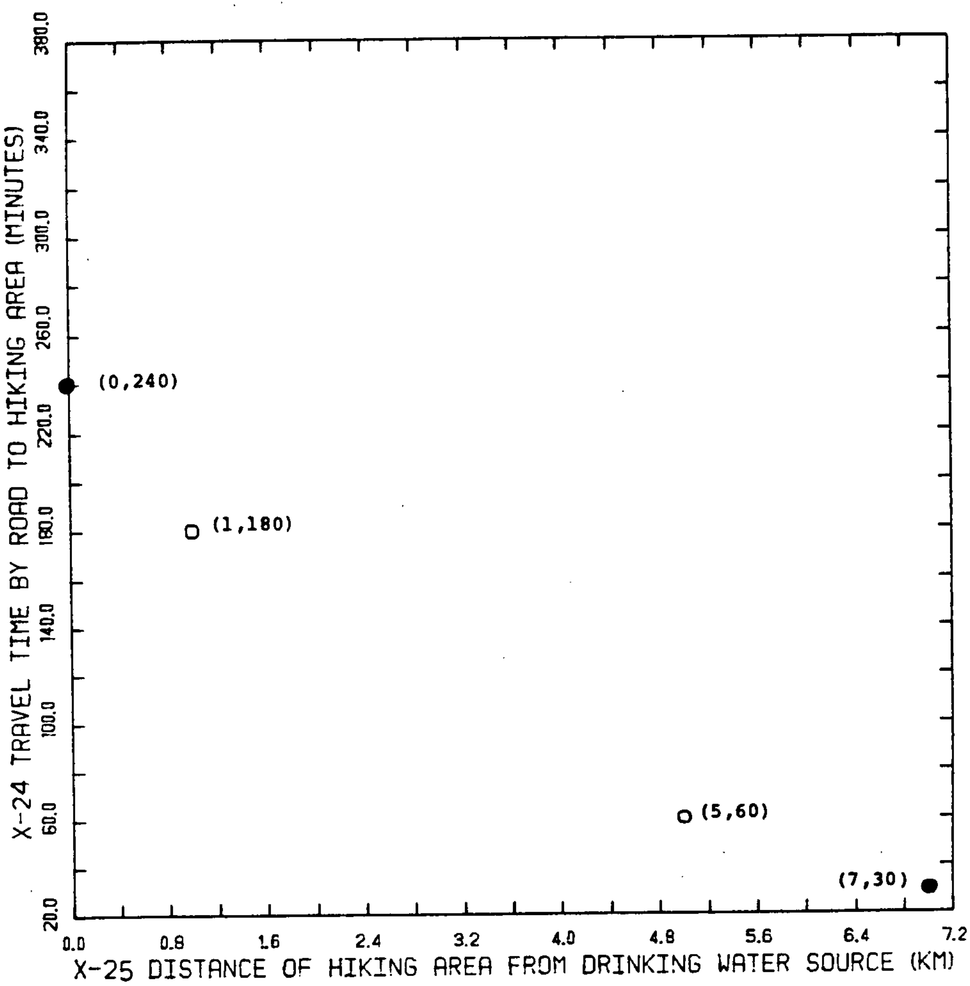
U(10) = 0.850
U(183) = 0.560
U(25) = 0.500
U(122) = 0.820

● $k_{22} = 1.35k_{23}$

Average

$k_{22} = 1.46k_{23}$

A. .7 Hiking



U(1) = 0.75
U(180) = 0.125
U(5) = 0.195
U(60) = 0.635

o $k_{24} = 1.09k_{25}$

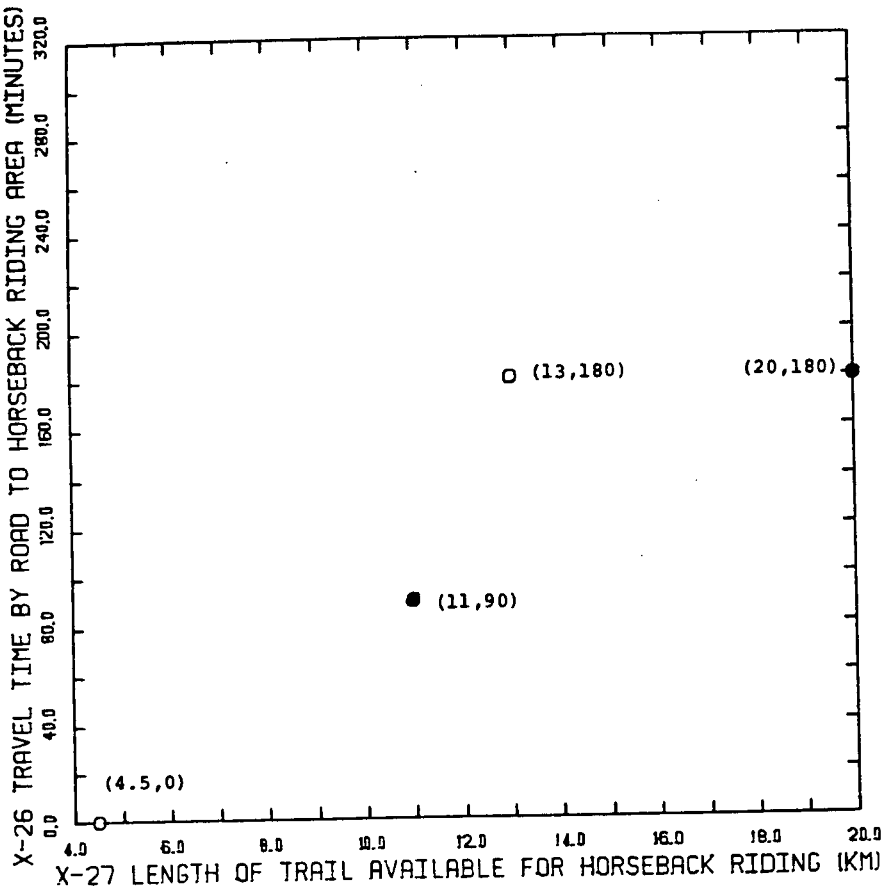
U(0) = 1.00
U(240) = 0.00
U(7) = 0.120
U(30) = 0.875

● $k_{24} = 1.01k_{25}$

Average

$k_{24} = 1.05k_{25}$

A. .8 Horseback Riding



U(4.5) = 0.130
U(0) = 1.00
U(13) = 0.750
U(180) = 0.250

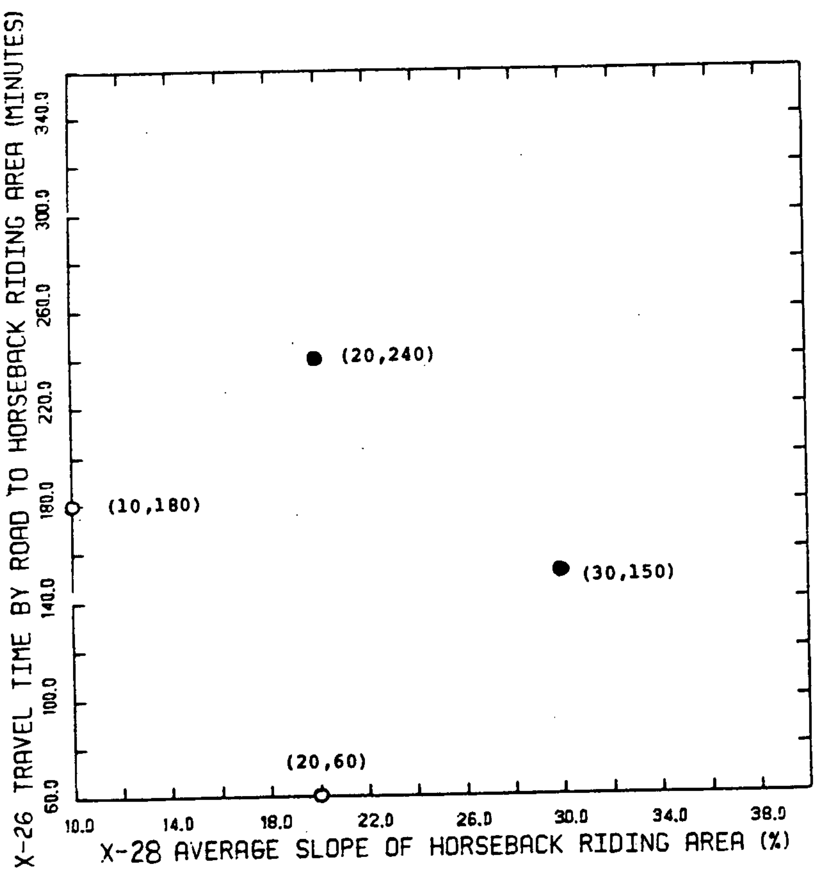
o $k_{26} = 0.827k_{27}$

U(11) = 0.500
U(90) = 0.700
U(20) = 1.00
U(180) = 0.250

● $k_{26} = 1.11k_{27}$

Average

$k_{26} = 0.969k_{27}$



U(10) = 1.00
U(180) = 0.250
U(20) = 0.605
U(60) = 0.800

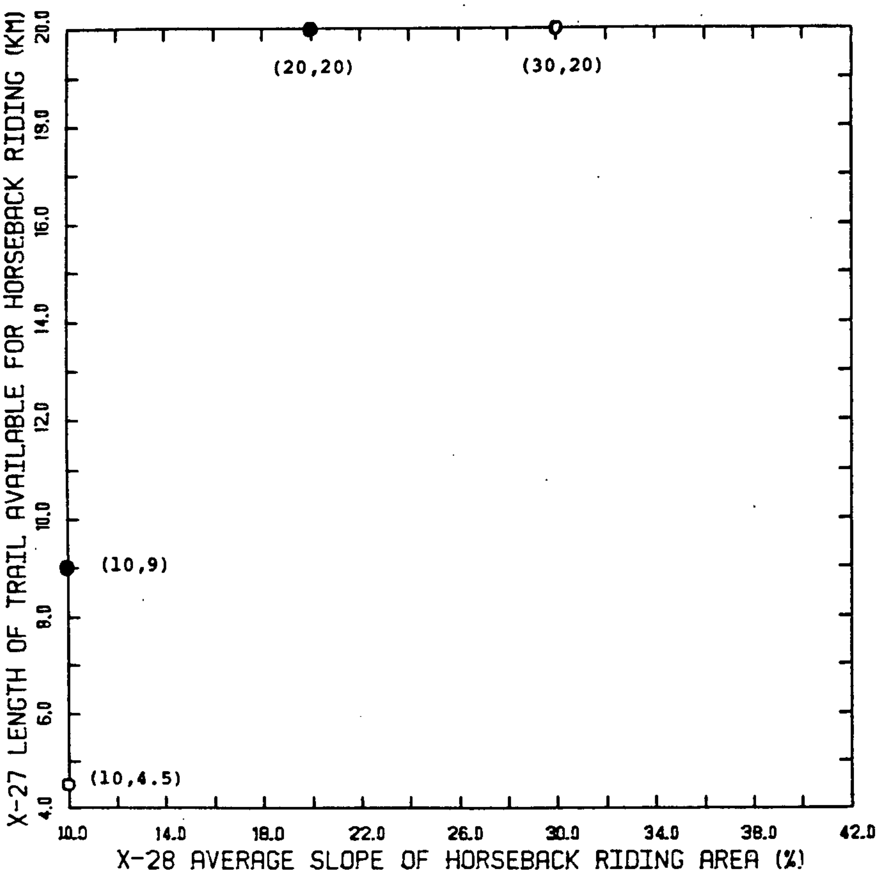
o $k_{26} = 0.718k_{28}$

U(20) = 0.605
U(240) = 0.00
U(30) = 0.320
U(150) = 0.500

● $k_{26} = 0.570k_{28}$

Average

$k_{26} = 0.644k_{28}$



U(10) = 1.00
U(4.5) = 0.130
U(30) = 0.320
U(20) = 1.00

o $k_{27} = 0.782k_{28}$

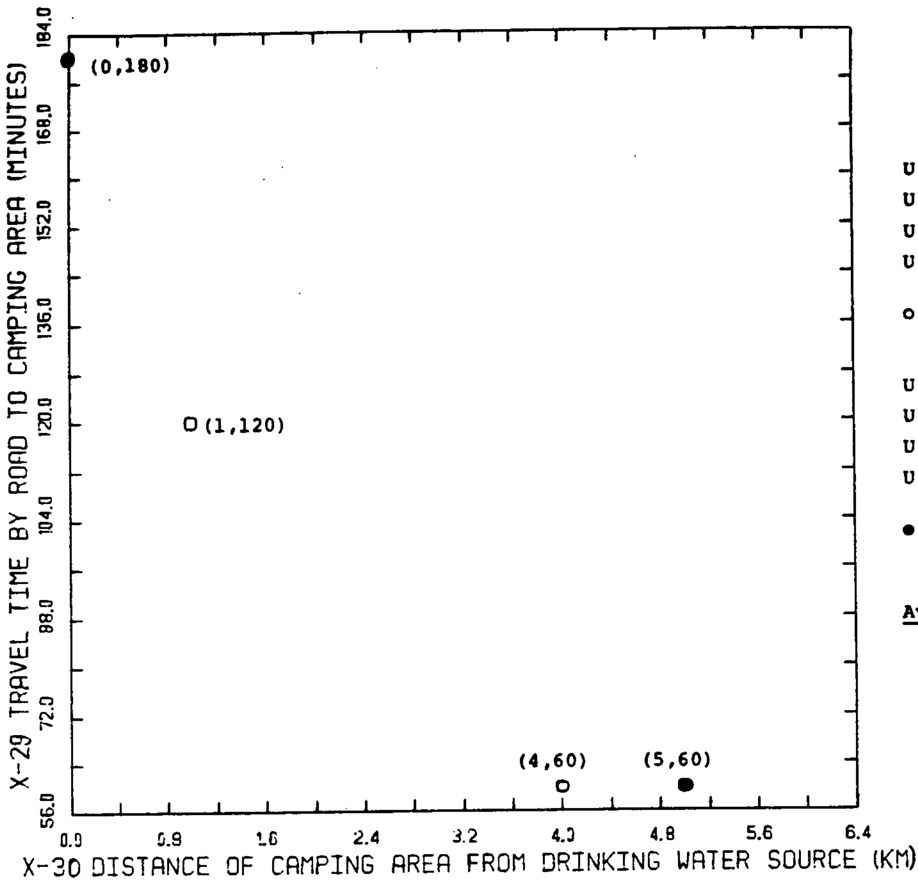
U(10) = 1.00
U(9) = 0.250
U(20) = 0.605
U(20) = 1.00

● $k_{27} = 0.527k_{29}$

<u>Average</u>

$k_{27} = 0.655k_{29}$

A. .9 Summer Motorized Camping



U(4) = 0.220
U(60) = 0.690
U(1) = 0.750
U(120) = 0.375

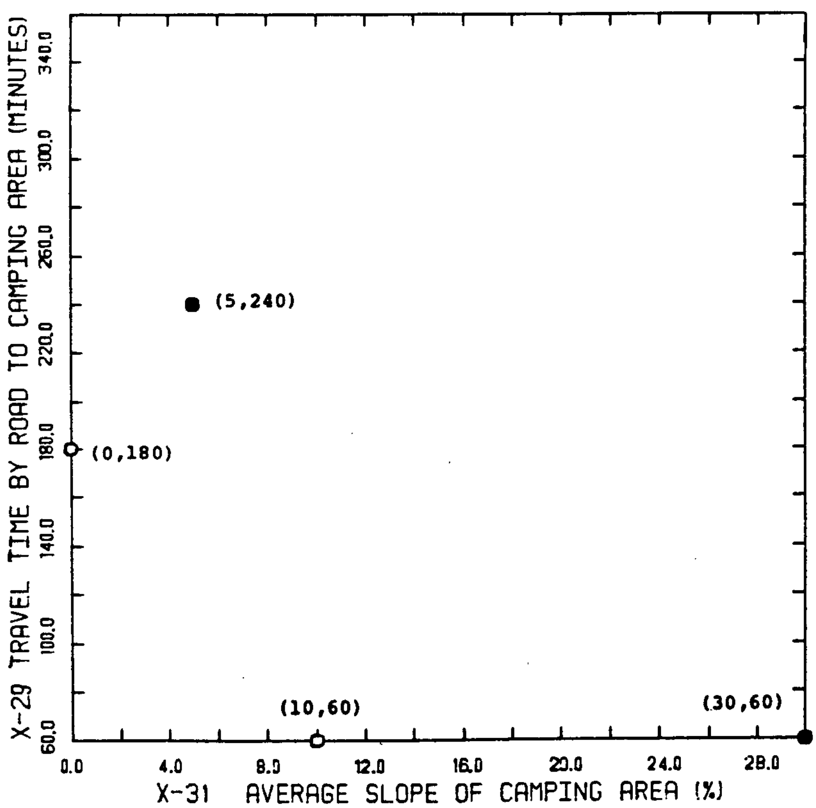
o $k_{29} = 1.68k_{30}$

U(5) = 0.180
U(60) = 0.690
U(0) = 1.00
U(180) = 0.160

● $k_{29} = 1.55k_{30}$

__Average__

$k_{29} = 1.62k_{30}$



U(0) = 1.00
U(180) = 0.160
U(10) = 0.425
U(60) = 0.690

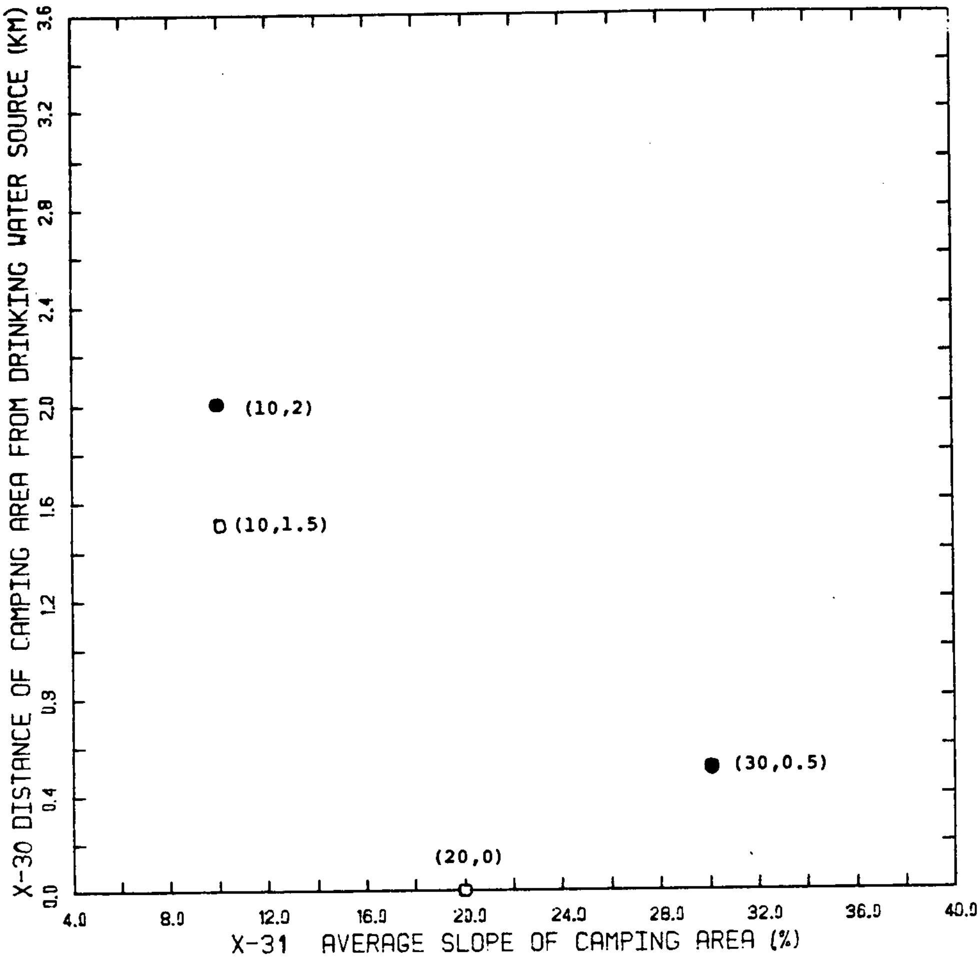
o $k_{29} = 1.08k_{31}$

U(30) = 0.145
U(60) = 0.690
U(5) = 0.680
U(240) = 0.00

● $k_{29} = 0.775k_{31}$

__Average__

$k_{29} = 0.928k_{31}$



U(10) = 0.425
U(1.5) = 0.620
U(20) = 0.220
U(0) = 1.00

o $k_{30} = 0.539k_{31}$

U(10) = 0.425
U(2) = 0.500
U(30) = 0.145
U(0.5) = 0.880

● $k_{30} = 0.737k_{31}$

<u>Average</u>

$k_{30} = 0.638k_{31}$

APPENDIX

Additive Utility Functions

ADDITIVE UTILITY FUNCTIONS

Symbolism

$U_i(X_i)$ = Utility of attribute i at attribute level X.

Trailbiking (TB)

$$U_{TB} = 0.175\ U_1(X_1) + 0.298\ U_2(X_2) + 0.333\ U_3(X_3) + 0.194\ U_4(X_4)$$

Four-Wheel Driving (4x4)

$$U_{4x4} = 0.200\ U_5(X_5) + 0.291\ U_6(X_6) + 0.363\ U_7(X_7) + 0.146\ U_8(X_8)$$

Snowmobiling (SNOW)

$$U_{SNOW} = 0.269\ U_9(X_9) + 0.252\ U_{10}(X_{10}) + 0.167\ U_{11}(X_{11}) + 0.312\ U_{12}(X_{12})$$

Downhill Skiing (DOWN)

$$U_{DOWN} = 0.301\ U_{13}(X_{13}) + 0.437\ U_{14}(X_{14}) + 0.262\ U_{15}(X_{15})$$

Cross-Country Skiing (X-C)

$$U_{X\text{-}C} = 0.271\ U_{16}(X_{16}) + 0.198\ U_{17}(X_{17}) + 0.293\ U_{18}(X_{18}) + 0.238\ U_{19}(X_{19})$$

Snowshoeing (SHOE)

$$U_{SHOE} = 0.152\ U_{20}(X_{20}) + 0.382\ U_{21}(X_{21}) + 0.255\ U_{22}(X_{22}) + 0.211\ U_{23}(X_{23})$$

Hiking (HIKE)

$$U_{HIKE} = 0.512\ U_{24}(X_{24}) + 0.488\ U_{25}(X_{25})$$

Horseback Riding (HORSE)

$$U_{HORSE} = 0.279\ U_{26}(X_{26}) + 0.288\ U_{27}(X_{27}) + 0.433\ U_{28}(X_{28})$$

Summer Motorized Camping (CAMP)

$$U_{CAMP} = 0.371\ U_{29}(X_{29}) + 0.229\ U_{30}(X_{30}) + 0.400\ U_{31}(X_{31})$$

APPENDIX

Relative Importance of the Attributes to each Decision Maker

RELATIVE IMPORTANCE OF THE ATTRIBUTES TO EACH DECISION MAKER

Symbolism

$\succeq$ represents "more important to the decision maker than"

Trailbiking

Slope $\succeq$ Length of Trail $\succeq$ Conflicts with 4x4s $\succeq$ Travel Time

Four-Wheel Driving

Slope $\succeq$ Length of Trail $\succeq$ Travel Time $\succeq$ Conflicts with Trailbikes

Snowmobiling

Slope $\succeq$ Travel Time $\succeq$ Length of Trail $\succeq$ Snow Depth

Downhill Skiing

Slope $\succeq$ Travel Time $\succeq$ Snow Depth

Cross-Country Skiing

Slope $\succeq$ Travel Time $\succeq$ Snow Depth $\succeq$ Length of Trail

Snowshoeing

Length of Trail $\succeq$ Snow Depth $\succeq$ Slope $\succeq$ Travel Time

Hiking

Travel Time $\succeq$ Distance from Drinking Water Source

Horseback Riding

Slope $\succeq$ Length of Trail $\succeq$ Travel Time

Summer Motorized Camping

Slope $\succeq$ Travel Time $\succeq$ Distance from Drinking Water Source

APPENDIX

The NLP.S Algorithm

THE NLP.S ALGORITHM

(Computer Language = FORTRAN)

```
      FUNCTION XDFUNC(XX,NUM)
C
C        Function 'XDFUNC' evaluates the objective function
C        for a land use plan.  Although we actually want
C        to maximize the utility function, the available
C        software only allows functions to be minimized.
C        To get around this, the last command in this
C        algorithm sets XDFUNC = -XDFUNC.
C
C        Variables used :
C           XX       - The mine waste plan to be evaluated.
C                      Each array element represents one grid square
C                      and contains a number between 1 & 16, depending
C                      on the land use class assigned to that square.
C           X        - Rounded-off version of array XX. We require
C                      integers to evaluate the utility function.
C           NUM      - Dummy variable; dimension of XX.
C           SCALE    - Utility scale factors for each of the
C                      9 activities.
C           U        - Cumulative utility for each activity.
C           N        - Number of squares assigned to each activity.
C           TRAILS   - Keeps track of the maximum trail available
C                      for each activity for the current plan.
C           INFLAG   - 0/1 flag to determine whether the function
C                      has been previously called.  If not called,
C                      input data must be read in first before
C                      proceeding.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION XX(100)
      DIMENSION SCALE(9), U(9), N(9), TRAILS(9)
      INTEGER X(100)
      DATA SCALE/0.046,0.111,0.084,0.133,0.087,0.064,0.146,
     +           0.078,0.254/
      DATA INFLAG/1/
      COMMON /MAXTRL/ TRAILS
C
C        Get input data from files first time through.
C
      IF (INFLAG.EQ.1) CALL GETDAT
      INFLAG = 0
C
C        Round off all 100 variables.
C
      DO 10 I=1,100
        X(I) = XX(I)+0.5
   10 CONTINUE
C
C        Evaluate the utilities twice.
C        The first time just determines the maximum trail
C        distance for each activity for the given plan.
C        The second time evaluates the actual utilities
C        using these maximum trail distances.
C
      DO 15 I=1,9
        TRAILS(I) = 0.0
   15 CONTINUE
      DO 501 LOOP = 1,2
C
C        Initialize all arrays.
C
      DO 20 I=1,9
        U(I) = 0.0
        N(I) = 0
   20 CONTINUE
```

```
          DO 500 K=1,100
C            Land use classes should be between 1 & 16.
          IF ((X(K).GT.16.5).OR.(X(K).LT.0.5)) GOTO 499
C
C            Convert K to row (I) and column (J).
C            K = 1   --> Top left square.
C            K = 100 --> Bottom right square.
C
            I = (K-1)/10 + 1
            J = K - (I-1)*10
C
C            MOD1 = 0 --> Land use plans 1,2,3 in square K.
C                   1 -->                4,5,6
C                   2 -->                7,8,9
C                   3 -->               10,11,12
C                   4 -->               13,14,15
C
            MOD1 = (X(K)-1)/3
C
C            MOD2 = 1 --> Land use plans 1,4,7,10,13 in square K.
C                   2 -->                2,5,8,11,14
C                   3 -->                3,6,9,12,15
C
            MOD2 = X(K) - 3*MOD1
C
            IF (MOD1.EQ.0) GOTO 30
            IF (MOD1.EQ.1) GOTO 40
            IF (MOD1.EQ.2) GOTO 50
            IF (MOD1.EQ.3) GOTO 60
            IF (MOD1.GE.4) GOTO 70
   30       CONTINUE
C
C            TB - Increment activity 1.
C
            U(1) = U(1) + U1(X,I,J,NUM)
            N(1) = N(1) + 1
            GOTO 100
   40       CONTINUE
C
C            4x4 - Increment activity 2.
C
            U(2) = U(2) + U2(X,I,J,NUM)
            N(2) = N(2) + 1
            GOTO 100
   50       CONTINUE
C
C            TB/4x4 - Increment activities 1 & 2.
C
            U(1) = U(1) + U1(X,I,J,NUM)
            U(2) = U(2) + U2(X,I,J,NUM)
            N(1) = N(1) + 1
            N(2) = N(2) + 1
            GOTO 100
   60       CONTINUE
C
C            Hiking/Camping/Horse - Increment activities 7,8 & 9.
C
            U(7) = U(7) + U7(X,I,J,NUM)
            U(8) = U(8) + U8(X,I,J,NUM)
            U(9) = U(9) + U9(X,I,J,NUM)
            N(7) = N(7) + 1
            N(8) = N(8) + 1
            N(9) = N(9) + 1
            GOTO 100
   70       CONTINUE
C
C            No Activity.
C
            GOTO 100
  100       CONTINUE
C
            IF (X(K).EQ.16) GOTO 110
            IF (MOD2.EQ.1) GOTO 120
            IF (MOD2.EQ.2) GOTO 130
            IF (MOD2.EQ.3) GOTO 140
  110       CONTINUE
```

```
C
C          Downhill Skiing - Increment activity 4.
C
        U(4) = U(4) + U4(X,I,J,NUM)
        N(4) = N(4) + 1
        GOTO 499
  120   CONTINUE
C
C          Snowmobiling - Increment activity 3.
C
        U(3) = U(3) + U3(X,I,J,NUM)
        N(3) = N(3) + 1
        GOTO 499
  130   CONTINUE
C
C          X/C Skiing, Snowshoeing - Increment activities 5 & 6.
C
        U(5) = U(5) + U5(X,I,J,NUM)
        U(6) = U(6) + U6(X,I,J,NUM)
        N(5) = N(5) + 1
        N(6) = N(6) + 1
        GOTO 499
  140   CONTINUE
C
C          No Activity.
C
        GOTO 499
  499   CONTINUE
  500   CONTINUE
  501   CONTINUE
C
C          Now, sum up the total utility.
C
        XDFUNC = 0.0
        DO 200 I=1,9
C
C          U(I)/N(I) is the average utility of activity I
C          over all squares allocated to the activity.
C
        IF (N(I).NE.0) XDFUNC = XDFUNC + SCALE(I)*U(I)/N(I)
  200   CONTINUE
C
C          Convert maximizing to minimizing function.
C
        XDFUNC = -XDFUNC
        RETURN
      END
C
      FUNCTION XDG(X,N,I)
C
C          This function supplies the optimizing routine
C          with lower constraints for each of the 100 variables.
C          In this program, the constraint is  1 < Xi  for all
C          100 variables.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X(N)
      XDG = 0.5
      RETURN
      END
C
C
C
      FUNCTION XDH(X,N,I)
C
C          This function supplies the optimizing routine
C          with upper constraints for each of the 100 variables.
C          In this program, the constraint is  Xi < 16  for all
C          100 variables.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X(N)
      XDH = 16.5
      RETURN
      END
```

```
C
C
C
      FUNCTION XDX(X,N,I)
C
C         This function supplies the optimizing routine with
C         any implicit variables required.  For this program,
C         there are no implicit variables; this is a dummy
C         function to satisfy the routine's requirements and
C         is never called.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X(N)
      XDX = 0.0
      RETURN
      END
C
C
C
      FUNCTION U1(X,I,J,N)
C
C         Functions U1,U2,...,U9 evaluate the utility of
C         the corresponding activity in the square (I,J).
C         The array X is used to determine surrounding
C         activities for evaluating conflicts.
C         The input arrays SNOW, SLOPE, & TRAILS are used
C         to evaluate the physical qualities of square (I,J).
C
C
C                ACTIVITY #1   TRAILBIKING
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
C
C         Array K stores the multiplicative factors for U-TB.
C
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.175,0.298,0.333,0.194/
C
C         N1 counts the number of adjoining TB squares.
C         N2 counts the number of adjoining 4x4 squares.
C
      N1 = 1
      IJSQ = 10*(I-1)+J
      N2 = 0
      IF ((X(IJSQ).GE.7).AND.(X(IJSQ).LE.9)) N2 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
C
C         Ensure that we are looking at a square inside
C         the 10x10 planning area.
C
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
C
C         Don't process square (I,J)
C
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      IF ((MOD1.EQ.0).OR.(MOD1.EQ.2)) N1 = N1 + 1
      IF ((MOD1.EQ.1).OR.(MOD1.EQ.2)) N2 = N2 + 1
   10 CONTINUE
C
C         Calculate travel time at 70 KM/H on highway and
C            40 KM/H on trails.ed to run along columns.
C         Highways are assumed to run along columns J.
C         Trails are assumed to run along rows I.
```

```
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X1 = DHWY*70./60. + DTRL*40./60.
C
C         Calculate trail distance.
C
      X2 = 1.7*N1+3.1
C
C         Trail distance utility is assigned the maximum
C         trail distance for the plan.
C
      IF (X2.LT.TRAILS(1)) X2=TRAILS(1)
      IF (X2.GT.TRAILS(1)) TRAILS(1)=X2
C
C        Average slope value for square K.
C
      X3 = SLOPE(I,J)
C
C         If land use plans 7,8,9, # conflicts are 4/(N1*N2)
C         Otherwise, there are no conflicts.
C
      IF ((X(IJSQ).GE.7).AND.(X(IJSQ).LE.9)) X4 = 4.0/(N1*N2)
      IF ((X(IJSQ).LT.7).OR.(X(IJSQ).GT.9))  X4 = 0.0
      U1 = K(1)*UF(1,X1) + K(2)*UF(2,X2) + K(3)*UF(3,X3) +
     +     K(4)*UF(4,X4)
      RETURN
      END
C
C
C                ACTIVITY #2   FOUR-WHEEL DRIVING
C
C
C
      FUNCTION U2(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.200,0.291,0.363,0.146/
      N1 = 1
      N2 = 0
      IJSQ = 10*(I-1) + J
      IF ((X(IJSQ).GE.7).AND.(X(IJSQ).LE.9)) N2 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      IF ((MOD1.EQ.0).OR.(MOD1.EQ.2)) N2 = N2 + 1
      IF ((MOD1.EQ.1).OR.(MOD1.EQ.2)) N1 = N1 + 1
   10 CONTINUE
C
C         Travel at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X5 = DHWY*70./60. + DTRL*40./60.
      X6 = 1.7*N1+3.1
      IF (X6.LT.TRAILS(2)) X6=TRAILS(2)
      IF (X6.GT.TRAILS(2)) TRAILS(2)=X6
      X7 = SLOPE(I,J)
      IF ((X(IJSQ).GE.7).AND.(X(IJSQ).LE.9)) X8 = 4.0/(N1*N2)
      IF ((X(IJSQ).LT.7).OR.(X(IJSQ).GT.9))  X8 = 0.0
      U2 = K(1)*UF(5,X5) + K(2)*UF(6,X6) + K(3)*UF(7,X7) +
     +     K(4)*UF(8,X8)
      RETURN
      END
```

```
C
C
C             ACTIVITY #3   SNOWMOBILING
C
C
C
      FUNCTION U3(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.269,0.252,0.167,0.312/
      N1 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      MOD2 = X(ISQ) - MOD1*3
      IF (X(ISQ).EQ.16) GOTO 10
      IF (MOD2.EQ.1) N1 = N1 + 1
   10 CONTINUE
C
C        Travel at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X9 = DHWY*70./60. + DTRL*40./60.
      X10 = 1.7*N1 + 3.1
      IF (X10.LT.TRAILS(3)) X10=TRAILS(3)
      IF (X10.GT.TRAILS(3)) TRAILS(3)=X10
C
C        Average snow depth value for square K.
C
      X11 = SNOW(I,J)
C
      X12 = SLOPE(I,J)
      U3 = K(1)*UF(9,X9) + K(2)*UF(10,X10) + K(3)*UF(11,X11) +
     +     K(4)*UF(12,X12)
      RETURN
      END
C
C
C             ACTIVITY #4   DOWNHILL SKIING
C
C
C
      FUNCTION U4(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.301,0.437,0.262,0.0/
      N1 = 0
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      IF (X(ISQ).EQ.16) N1 = N1 + 1
   10 CONTINUE
```

```
C
C          Travel at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X13 = DHWY*70./60. + DTRL*40./60.
      X14 = SLOPE(I,J)
      X15 = SNOW(I,J)
      U4 = K(1)*UF(13,X13) + K(2)*UF(14,X14) + K(3)*UF(15,X15)
      RETURN
      END
C
C
C               ACTIVITY #5   CROSS-COUNTRY SKIING
C
C
C
      FUNCTION U5(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.271,0.198,0.293,0.238/
      N1 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      MOD2 = X(ISQ)-3*MOD1
      IF (MOD2.EQ.2) N1 = N1 + 1
   10 CONTINUE
C
C          Travel at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X16 = DHWY*70./60. + DTRL*40./60.
      X17 = 1.7*N1 + 3.1
      IF (X17.LT.TRAILS(5)) X17=TRAILS(5)
      IF (X17.GT.TRAILS(5)) TRAILS(5)=X17
      X18 = SLOPE(I,J)
      X19 = SNOW(I,J)
      U5 = K(1)*UF(16,X16) + K(2)*UF(17,X17) + K(3)*UF(18,X18) +
     +     K(4)*UF(19,X19)
      RETURN
      END
C
C
C               ACTIVITY #6   SNOWSHOEING
C
C
C
      FUNCTION U6(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.152,0.382,0.255,0.211/
      N1 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
```

```
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      MOD2 = X(ISQ)-3*MOD1
      IF (MOD2.EQ.2) N1 = N1 + 1
   10 CONTINUE
C
C        Travel at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X20 = DHWY*70./60. + DTRL*40./60.
      X21 = 1.7*N1 + 3.1
      IF (X21.LT.TRAILS(6)) X21=TRAILS(6)
      IF (X21.GT.TRAILS(6)) TRAILS(6)=X21
      X22 = SNOW(I,J)
      X23 = SLOPE(I,J)
      U6 = K(1)*UF(20,X20) + K(2)*UF(21,X21) + K(3)*UF(22,X22) +
     +     K(4)*UF(23,X23)
      RETURN
      END
C
C
C              ACTIVITY #7   HIKING
C
C
C
      FUNCTION U7(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      DATA K/0.512,0.488,0.0,0.0/
C
C        Travel at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X24 = DHWY*70./60. + DTRL*40./60.
      X25 = 1000000.0
C
C        Calculate the distance to nearest drinking water source.
C
      IF (NLAKES.EQ.0) GOTO 11
      DO 10 II=1,NLAKES
        IL = (LAKES(II) - 1)/10 + 1
        JL = LAKES(II) - (IL-1)*10
        DX = DSQRT(1.DO*(I-IL)*(I-IL) + (J-JL)*(J-JL))
        IF (XD.LT.X25) X25 = XD
   10 CONTINUE
   11 CONTINUE
      U7 = K(1)*UF(24,X24) + K(2)*UF(25,X25)
      RETURN
      END
C
C
C              ACTIVITY #8   HORSEBACK RIDING
C
C
C
      FUNCTION U8(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.279,0.288,0.433,0.0/
      N1 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
```

```
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      IF (MOD1.EQ.3) N1 = N1 + 1
   10 CONTINUE
C
C         Travel at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X26 = DHWY*70./60. + DTRL*40./60.
      X27 = 1.7*N1 + 3.1
      IF (X27.LT.TRAILS(8)) X27=TRAILS(8)
      IF (X27.GT.TRAILS(8)) TRAILS(8)=X27
      X28 = SLOPE(I,J)
      U8 = K(1)*UF(26,X26) + K(2)*UF(27,X27) + K(3)*UF(28,X28)
      RETURN
      END
C
C
C               ACTIVITY #9   SUMMER MOTORIZED CAMPING
C
C
C
      FUNCTION U9(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      DATA K/0.371,0.229,0.400,0.0/
C
C         Travel at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X29 = DHWY*70./60. + DTRL*40./60.
      X30 = 1000000.0
C
C         Calculate the distance to nearest drinking water source.
C
      IF (NLAKES.EQ.0) GOTO 11
      DO 10 II=1,NLAKES
        IL = (LAKES(II) - 1)/10 + 1
        JL = LAKES(II) - (IL-1)*10
        DX = DSQRT(1.D0*(I-IL)*(I-IL) + (J-JL)*(J-JL))
        IF (XD.LT.X30) X30 = XD
   10 CONTINUE
   11 CONTINUE
      X31 = SLOPE (I,J)
      U9 = K(1)*UF(29,X29) + K(2)*UF(30,X30) + K(3)*UF(31,X31)
      RETURN
      END
C
C
C
      FUNCTION UF(I,X)
C
C         This function evaluates the utility for one of the
C         the 31 attributes.
C         I is the attribute number.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION UTIL(31,9),XR(31,9)
      COMMON /UTILTY/ UTIL,XR
C
C         Find a range of input X-values which surround
C         the attribute value.
C
      DO 10 J=1,9
      IF (X.LE.XR(I,J)) GOTO 20
   10 CONTINUE
C
```

```
C         If no range is found, assign the last utility.
C
      UF = UTIL(I,9)
      RETURN
 20   CONTINUE
      IF (J.EQ.1) GOTO 30
      JM1 = J-1
C
C         Utility is assigned by a straight line approximation
C         between the surrounding data points.
C
      UF = UTIL(I,JM1) + (X-XR(I,JM1))/(XR(I,J)-XR(I,JM1))*
     +                   (UTIL(I,J)-UTIL(I,JM1))
      RETURN
 30   CONTINUE
C
C         If the attribute value is less than the first input
C         X-value, assign the first utility.
C
      UF = UTIL(I,1)
      RETURN
      END
C
C
C
      SUBROUTINE GETDAT
C
C         This subroutine reads the input data from files.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10), SLOPE(10,10), LAKES(100)
      DIMENSION UTIL(31,9), XR(31,9)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /UTILTY/ UTIL,XR
C
C         Initialize all arrays first.
C
      DO 5 I=1,10
      DO 5 J=1,10
      SNOW(I,J) = 0.0
 5    SLOPE(I,J) = 0.0
      DO 6 I=1,100
 6    LAKES(I) = 0
      NLAKES = 0
C
C         Read snow depths from unit 1 and slopes from unit 2.
C
      DO 10 I=1,10
        READ (1,100,END=8) (SNOW(I,J),J=1,10)
 8      CONTINUE
        READ (2,100,END=9) (SLOPE(I,J),J=1,10)
 9      CONTINUE
 100  FORMAT (10F8.2)
 10   CONTINUE
C
C         Read squares containing water from unit 3.
C            Note : Top row is #001 - #010.
C                   Bottom row is #091 - #100.
C
      DO 20 I=1,100
        READ (3,200,END=25) LAKES(I)
 20   CONTINUE
 200  FORMAT (I3)
      I = 101
 25   CONTINUE
      NLAKES = I-1
C
C         Read utility graph points from unit 4.
C
      DO 30 I=1,31
      READ (4,300,END=30) (XR(I,J),UTIL(I,J),J=1,9)
 30   CONTINUE
```

```
  300 FORMAT (18F8.2)
C
C        Read position of town from terminal (interactively).
C        Note : Input should be in real numbers (e.g. 1.0,3.0).
C
      WRITE (6,400)
      READ (5,401) TOWNI,TOWNJ
  400 FORMAT (' ENTER COORDINATES OF TOWN (1,1 IS TOP LEFT CORNER',
     +        ' OF GRID BOX)')
  401 FORMAT (2F10.3)
      RETURN
      END
End of file
```

APPENDIX

Explanation of the NLP.S Algorithm

EXPLANATION OF THE NLP.S ALGORITHM

This appendix explains the NLP.S algorithm which evaluates the objective function developed in Part 1 for a recreation land use plan within the 10 km x 10 km section of mine waste. The following discussion elaborates on certain sections of the algorithm, referred to by their line number in Appendix .

Lines 33-34

These lines contain the activity scaling factors determined for the objective function in Section 2.10.

Lines 40-41

For a recreation land use plan, the subroutine GETDAT (line 692) gets the data on snow depths, slope values, drinking water source locations and attribute utility functions from their respective files the first time through the algorithm.

Lines 45-47

For a recreation land use plan, the variables (land uses) are rounded off. These lines make the program an INTEGER program; therefore a non-linear optimization routine using REAL numbers cannot be used.

Lines 55-58

The algorithm calculates the maximum trail distance for each activity the first time through the algorithm and uses these trail distances to calculate the activity utilities the second time through the algorithm. The maximum trail distance found for each activity is used to calculate the utility for the trail distance attribute. The following example illustrates why the maximum trail distance is used:

Example

For example, let one allocation of trailbiking have a trail distance of 3 km. Let another have a trail distance of 10 km. The utility for trailbiking for the plan will include the average utility of the attribute trail distance. For this example, it will be the average of the utility of 3 km and the utility of 10 km; hence, having an allocation with a small trail distance will decrease the utility of an allocation with a large trail distance. To get around this problem, the algorithm uses the maximum trail distance found for an activity allocation and uses it for the trail distance utility calculations.

Lines 74-75

K is the grid square under examination by NLP.S.

Lines 83 and 89

X(K) is the land use for the K^{th} square. These lines count the land uses assigned to each grid square.

Lines 100-171

These lines calculate how many squares have each activity until all 100 grid squares have been examined.

Lines 175-176

These lines add the total utility for each of the 9 activities.

Lines 181-182

These lines evaluate the objective function developed in Section 2.10.

Lines 186-187

These lines change the sign of the objective function from positive to negative. Most available software for optimizing routines minimize the objective function. The algorithm is set up to give the minimum function value for future use when software becomes available for non-linear INTEGER optimization.

Lines 190-216

If an optimization routine is used, these lines constrain each of the 100 variables or grid squares to be between land uses 1 and 16.

Line 258

This line supplies the scaling constants for the additive utility function for trailbiking.

Lines 263-272

These lines count the number of adjoining trailbiking and four-wheel driving squares for the conflict calculation (land uses 7, 8 and 9) in lines 314-315.

Lines 293-295

These lines calculate the travel times to each grid square using the equations developed in Section 4.41.

Line 299

These lines calculate the trail distance of trailbiking allocations using the equation developed in Section 4.42.

Line 309

This line assigns a slope value to square K from the file with slope values.

Lines 314-315

These lines calculate the number of conflicts between trailbiking and four-wheel driving using the equation developed in Section 4.44.

Line 316

This line calculates the utility of trailbiking for the square under examination, K, using the attribute levels determined by lines 293-315.

Lines 322-649

These lines calculate the utility values for the remaining activities in the same way as for trailbiking.

Lines 562-567

These lines calculate the distance of the grid square under examination, K, to the nearest drinking water source for the activity hiking. These lines use the equations developed in Section 4.45.

Lines 696-738

Subroutine GETDAT reads the data from files containing snow depth values and slope values (lines 714-720), drinking water source locations (lines 726-732), and utility function data points (lines 736-738).

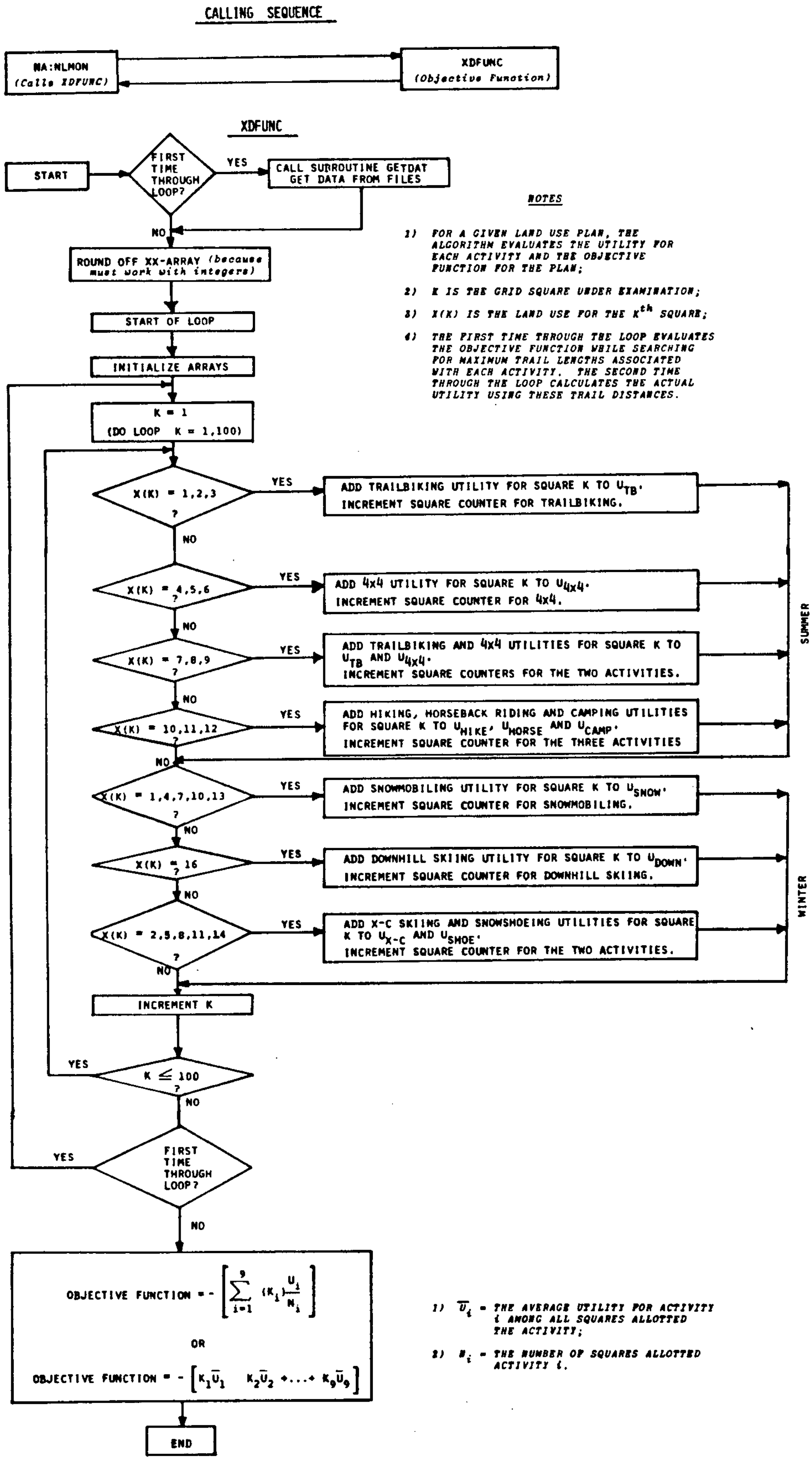
<u>Lines 739-750</u>

The location of the town is input to the algorithm. The user is prompted using the non-linear monitor to enter the I,J coordinates of the town in REAL numbers. The town may be anywhere inside or outside the grid square.

APPENDIX

The NLP.S Algorithm Flowchart

FIG.28. THE NLP.S ALGORITHM FLOWCHART



APPENDIX

Procedure for Using the NLP.S Algorithm

PROCEDURE FOR USING THE NLP.S ALGORITHM

The monitor for non-linear function optimization at the University of British Columbia can be used to obtain objective function values for land use plans. The following steps illustrate how to use the monitor with the NLP.S algorithm:

Step 1

The algorithm NLP.S must be compiled into an object file. The first step is to create an object file, for example NLP.O. NLP.S is compiled into the object file by the following command:

```
$RUN *FTN SCARDS=NLP.S SPUNCH=NLP.O
```

Step 2

Step 2 is to create a file to store the land use plan, for example, the file SOLN1.

Step 3

Step 3 is to call the monitor using NLP.O by the following command:

```
$RUN NLP.O+NA:NLMON 1=SNOW 2=SLOPES 3=LAKES 4=UTILITY
```

where: NA:NLMON calls the monitor;

SNOW = the file with snow depth values for the plan under examination. The file with snow depths corresponds to unit 1;

SLOPES = the file with slope values for the plan under examination. The file with slope values corresponds to unit 2;

LAKES = the file with drinking water source locations. The file with drinking water source locations corresponds to unit 3;

UTILITY = the file with attribute utility function data points. The file with attribute utility function data points corresponds to unit 4 and are presented in Appendix 13.

The following steps illustrate what is displayed on the terminal and what is required as input:

DISPLAY: /READY

Step 4

The next step is to input the values of the 100 variables or grid squares to evaluate the objective function for the plan. Land uses (INTEGERS 1 to 16) are entered from square 001 to square 100 until 100 land uses have been entered. A land use may be repeated by the multiplication sign *. For example, to initialize 100 grid squares, the input may be 100*3 for 100 grid squares allocated land use 3, or 9,11,3,4,96*3 for squares 001 to 004 allocated land uses 9,11,3 and 4 respectively and squares 005 to 100 allocated land use 3. The following commands initialize the land uses:

DISPLAY: /READY

INPUT: INIT P

DISPLAY: ?

INPUT: 9,11,3

DISPLAY: ?

4,96*3

DISPLAY: /READY

Step 5

The next step is to print the function value for the plan by the following command:

DISPLAY: /READY

INPUT: PRINT F

DISPLAY: ENTER COORDINATES OF TOWN (1,1 is in top left corner of grid box):

INPUT: -20.0,7.0 (an example town location)

DISPLAY: Function value F = -0.786995847789 (an example value)

Step 6

To store the plan in the created file SOLN1, the following commands are entered:

DISPLAY: /READY

INPUT: ASSIGN 20=SOLN1

DISPLAY: /READY

INPUT: SAVE PAR ON 20

DISPLAY: /READY

Step 7

To change land uses of grid squares, the following commands are entered:

DISPLAY: /READY

INPUT: MODIFY

DISPLAY: /ENTER PARAMETER INDEX AND NEW VALUE, OR NULL LINE:

INPUT: 47 8 (change square 47 to land use 8)

DISPLAY: /ENTER PARAMETER INDEX AND NEW VALUE, OR NULL LINE

Press "BREAK" on the keyboard to stop entering new values.

DISPLAY: /READY

INPUT: PRINT F

DISPLAY: Function value F = -0.888787954687 (new function value)

DISPLAY: /READY

Step 8

To stop the monitor, enter MTS or STOP. This will transfer the user to the MTS mode.

Step 9

To view the land use plan on the terminal screen, the following commands are entered:

DISPLAY: #

INPUT: $RUN OUTPUT.O 1=SOLN1

Step 10

To print the land use plan on the XEROX 9700 printer, the following commands are entered:

DISPLAY: #

INPUT: $RUN OUTPUT.O 1=SOLN1 6=*PRINT*

For steps 9 and 10, the file OUTPUT.O is an object file containing the compiled file OUTPUT.S presented in Appendix 14. OUTPUT.S is an algorithm which takes the land use plan in machine language from SOLN1 and presents it for viewing on the terminal screen.

To compile OUTPUT.S into file OUTPUT.O, the following command is entered:

DISPLAY: #

INPUT: $RUN *FTN SCARDS=OUTPUT.S SPUNCH=OUTPUT.O

APPENDIX

File Containing the Data Points of the 31 Attribute Utility Functions

TABLE 4.
FILE CONTAINING THE DATA POINTS OF THE 31 ATTRIBUTE UTILITY FUNCTIONS

ATTRIBUTE UTILITY FUNCTION DATA POINTS

FILE = UTILITYFCNS

```
1   0,1,40,0.75,90,0.5,135,0.25,240,0,100000,0.0
2   0,0,5.5,0.25,7,0.5,13,0.75,20,1,100000,1.0
3   0,0.8,15,1,27,0.75,35,0.5,43,0.25,50,0,100000,0.0
4   0,1,1,0.5,1.5,0.25,4,0,100000,0.0
5   0,1,20,0.75,120,0.5,160,0.25,240,0,100000,0.0
6   0,0,3,0.25,7,0.5,14,0.75,20,1,100000,1.0
7   0,0,28,0.25,35,0.5,38,0.75,50,1,53,0.75,55,0.5,57,0.25,60,0,100000,0
8   0,1,1.5,0.75,2,0.5,3,0.25,4,0,100000,0.0
9   0,0,13,0.25,17,0.5,20,0.75,30,1,50,0.75,95,0.5,150,0.25,240,0,100000,0
10  0,0,4,0.25,8,0.5,10,0.75,20,1,100000,1.0
11  0,0,44,0.25,52,0.5,64,0.75,91,1,155,0.75,190,.5,206,.25,244,0,100000,0
12  0,0.8,17,0.92,30,1,39,0.75,43,0.5,47,0.25,50,0,100000,0.00
13  0,1,25,0.75,60,0.5,150,0.25,240,0,100000,0.0
14  0,0,25,0.25,37,0.5,43,0.75,60,1,70,0.75,75,0.5,85,0.25,120,0,100000,0
15  0,0,91,0.25,113,0.5,143,0.75,244,1,100000,1.0
16  0,1,20,0.75,45,0.5,90,0.25,240,0,100000,0.0
17  0,0,9,0.25,13,0.5,18,0.75,20,1,100000,1.0
18  0,0.75,3,1,6,0.75,15,0.5,27,0.25,50,0,100000,0.0
19  0,0,30,0.25,67,0.5,91,0.75,244,1,100000,1.0
20  0,0,3.5,0.25,7,.5,11,.75,15,1,45,0.75,90,0.5,150,0.25,240,0,100000,0.0
21  0,0,3,0.25,4.5,0.5,11,0.75,20,1,100000,1.0
22  0,0,30,0.25,67,0.5,79,0.75,91,1,137,0.75,198,0.5,221,0.25,244,0,100000,0.0
23  0,1,17,0.75,25,0.5,30,0.25,50,0,100000,0.0
24  0,0,10,0.25,12,0.5,14,0.75,15,1,45,0.75,75,0.5,120,0.25,240,0,100000,0
25  0,1,1,0.75,2.0,0.5,3.5,0.25,10,0,100000,0.0
26  0,1,75,0.75,150,0.5,180,0.25,240,0,100000,0.0
27  0,0,9,0.25,11,0.5,13,0.75,20,1,100000,1
28  0,0,3.5,0.25,6.5,0.5,7.5,0.75,10,1,16,0.75,23,0.5,33,0.25,50,0,100000,0.0
29  0,0,3,0.25,10,0.5,24,0.75,30,1,50,0.75,90,0.5,150,0.25,240,0,100000,0
30  0,1,1,0.75,2,0.5,3,0.25,10,0,100000,0
31  0,1,4,0.75,8,0.5,15,0.25,50,0,100000,0.0
```

APPENDIX

The OUTPUT.S Algorithm

THE OUTPUT.S ALGORITHM

(Computer Language = FORTRAN)

```
      REAL*8 X(100)
      INTEGER M(100)
C
C         Read land uses from file.
C
      READ (1) N,(X(I),I=1,N)
C
C         Round off reals to integers.
C
      DO 10 I=1,100
   10 M(I) = X(I) + 0.5
C
C         Write the integer array to unit 6.
C
      WRITE (6,1000) M
 1000 FORMAT (/,/,10(/,10I4))
      STOP
      END
End of file
```

APPENDIX

Data on Snow Depth, Slope and Drinking Water Sources for the Land Use Plan

TABLE 5.
DATA ON SNOW DEPTH, SLOPE AND DRINKING WATER SOURCES FOR THE LAND USE PLAN

AVERAGE SNOW DEPTH VALUES FOR THE LAND USE PLAN (cm)

FILE = SNOW

1	244,244,091,152,137,122,000,091,091,152,
2	244,213,122,152,137,122,122,000,091,152,
3	213,198,168,137,122,122,000,107,122,122,
4	168,183,152,137,122,122,000,107,122,122,
5	198,183,152,122,122,000,122,107,122,152,
6	107,091,091,000,000,107,107,152,168,152,
7	107,091,091,000,107,122,152,168,183,213,
8	107,091,091,000,107,122,152,168,183,213,
9	122,107,091,000,091,122,152,168,198,213,
10	107,091,076,000,000,076,137,168,198,213,

AVERAGE SLOPE VALUES FOR THE LAND USE PLAN (%)

FILE = SLOPES

1	000,000,100,015,010,000,000,000,050,050,
2	000,095,025,015,000,000,000,000,050,025,
3	090,020,010,000,000,000,000,010,050,050,
4	050,050,050,000,000,000,000,025,050,050,
5	050,050,040,010,000,000,015,050,050,050,
6	090,090,015,000,000,000,010,050,050,050,
7	090,070,020,000,000,015,050,050,050,035,
8	090,070,020,000,000,040,050,050,055,020,
9	080,060,025,000,000,040,050,050,060,040,
10	070,050,000,000,000,040,050,055,030,010,

GRID SQUARES CONTAINING A DRINKING WATER SOURCE - PLAN

(Grid squares for this file are numbered from 1 to 100. Square (1,1) is number 001; square (10,10) is number 100)

FILE = LAKES

1	007
2	018
3	027
4	037
5	046
6	055
7	064
8	074
9	084
10	095

APPENDIX

The UTILVAL.S Algorithm

THE UTILVAL.S ALGORITHM

(Computer Language = FORTRAN)

```
C         Function 'XDFUNC' evaluates the objective function
C         that is to be minimized. Although we actually want
C         to maximize the utility function, the available
C         optimizing softaware only allows functions to be
C         minimized.  To get around this, the last command
C         in this function sets XDFUNC = -XDFUNC.
C
C         Variables used :
C            XX       - The mine waste plan to be evaluated.
C                       Each array element represents one grid square
C                       and contains a number between 1 & 16, depending
C                       on the land use class assigned to that square.
C            X        - Rounded-off version of array XX. We require
C                       integers to evaluate the utility function.
C            NUM      - Dummy variable; dimension of XX.
C            SCALE    - Utility scale factors for each of the
C                       9 activities.
C            U        - Cumulative utility for each activity.
C            N        - Number of squares assigned to each activity.
C            TRAILS   - Keeps track of the maximum trail available
C                       for each activity for the current plan.
C            INFLAG   - 0/1 flag to determine whether the function
C                       has been previously called.  If not called,
C                       input data must be read in first before
C                       proceeding.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION XX(100)
      DIMENSION TRAILS(9)
      DIMENSION UT(10,10)
      INTEGER X(100)
      DATA INFLAG/1/
      COMMON /MAXTRL/ TRAILS
C
C         Get input data from files first time through.
C
      IF (INFLAG.EQ.1) CALL GETDAT
      INFLAG = 0
C
C         Round off all 100 variables.
C
      DO 10 I=1,100
        X(I) = XX(I)+0.5
   10 CONTINUE
   15 CONTINUE
      WRITE (5,3000)
      READ (6,3010) IACT
 3000 FORMAT ('Which activity do you wish to analyze?')
 3010 FORMAT (I1)
      IF (IACT.EQ.0) STOP
      IF ((IACT.LT.0).OR.(IACT.GT.9)) GOTO 15
      DO 500 K=1,100
C
C         Convert K to row (I) and column (J).
C         K = 1   --> Top left square.
C         K = 100 --> Bottom right square.
C
        I = (K-1)/10 + 1
        J = K - (I-1)*10
        GOTO (21,22,23,24,25,26,27,28,29),IACT
   21   CONTINUE
        UT(I,J) = U1(X,I,J,N)
        GOTO 500
   22   CONTINUE
        UT(I,J) = U2(X,I,J,N)
        GOTO 500
   23   CONTINUE
        UT(I,J) = U3(X,I,J,N)
        GOTO 500
   24   CONTINUE
```

```
             UT(I,J) = U4(X,I,J,N)
             GOTO 500
  25         CONTINUE
             UT(I,J) = U5(X,I,J,N)
             GOTO 500
  26         CONTINUE
             UT(I,J) = U6(X,I,J,N)
             GOTO 500
  27         CONTINUE
             UT(I,J) = U7(X,I,J,N)
             GOTO 500
  28         CONTINUE
             UT(I,J) = U8(X,I,J,N)
             GOTO 500
  29         CONTINUE
             UT(I,J) = U9(X,I,J,N)
             GOTO 500
  500        CONTINUE
             WRITE (8,4000) IACT
  4000       FORMAT ('1','  Summary of Utility Functions for',
     +                 ' Activity ',I1,/)
  4010       FORMAT (10(/,' ',10F8.5))
             GOTO 15
           END
C
           FUNCTION XDG(X,N,I)
C
C              This function supplies the optimizing routine
C              with lower constraints for each of the 100 variables.
C              In this program, the constraint is  1 < Xi  for all
C              100 variables.
C
           IMPLICIT REAL*8 (A-H,O-Z)
           DIMENSION X(N)
           XDG = 1.0
           RETURN
           END
C
C
C
           FUNCTION XDH(X,N,I)
C
C              This function supplies the optimizing routine
C              with upper constraints for each of the 100 variables.
C              In this program, the constraint is  Xi < 16  for all
C              100 variables.
C
           IMPLICIT REAL*8 (A-H,O-Z)
           DIMENSION X(N)
           XDH = 16.0
           RETURN
           END
C
C
C
           FUNCTION XDX(X,N,I)
C
C              This function supplies the optimizing routine with
C              any implicit variables required.  For this program,
C              there are no implicit variables; this is a dummy
C              function to satisfy the routine's requirements and
C              is never called.
C
           IMPLICIT REAL*8 (A-H,O-Z)
           DIMENSION X(N)
           XDX = 0.0
           RETURN
           END
C
C
C
           FUNCTION U1(X,I,J,N)
C
C              Functions U1,U2,....,U9 evaluate the utility of
C              the corresponding activity in the square (I,J).
```

```
C         The array X is used to determine surrounding
C         activities for evaluating conflicts.
C         The input arrays SNOW, SLOPE, & TRAILS are used
C         to evaluate the physical qualities of square (I,J).
C
C
C               ACTIVITY #1   TRAILBIKING
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
C
C         Array K stores the multiplicative factors for U-TB.
C
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.175,0.298,0.333,0.194/
C
C         N1 counts the number of adjoining TB squares.
C         N2 counts the number of adjoining Hike/Horse/Camp squares.
C
      N1 = 1
      IJSQ = 10*(I-1)+J
      N2 = 0
      IF ((X(IJSQ).GE.7).AND.(X(IJSQ).LE.9)) N2 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
C
C         Ensure that we are looking at a square inside
C         the 10x10 planning area.
C
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
C
C         Don't process square (I,J)
C
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      IF ((MOD1.EQ.0).OR.(MOD1.EQ.2)) N1 = N1 + 1
      IF ((MOD1.EQ.1).OR.(MOD1.EQ.2)) N2 = N2 + 1
 10   CONTINUE
C
C         Calculate travel time at 70 KM/H on highway and
C         40 KM/H on trail.
C         Highways are assumed to run along columns J.
C         Trails are assumed to run along rows I.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X1 = DHWY*70./60. + DTRL*40./60.
C
C         Calculate trail distance.
C
      X2 = 1.7*N1+3.1
C
C         Trail distance utility is assigned the maximum
C         trail distance for the plan.
C
      IF (X2.LT.TRAILS(1)) X2=TRAILS(1)
      IF (X2.GT.TRAILS(1)) TRAILS(1)=X2
C
C         Average slope value for square K.
C
      X3 = SLOPE(I,J)
C
C         If land use plans 7,8,9, # conflicts are 4/(N1*N2)
C         Otherwise, there are no conflicts.
C
      IF ((X(IJSQ).GE.7).AND.(X(IJSQ).LE.9)) X4 = 4.0/(N1*N2)
      IF ((X(IJSQ).LT.7).OR.(X(IJSQ).GT.9))  X4 = 0.0
      U1 = K(1)*UF(1,X1) + K(3)*UF(3,X3) + K(4)*UF(4,X4)
```

```
      RETURN
      END
C
C
C           ACTIVITY #2   FOUR-WHEEL DRIVING
C
C
C
      FUNCTION U2(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.200,0.291,0.363,0.146/
      N1 = 1
      N2 = 0
      IJSQ = 10*(I-1) + J
      IF ((X(IJSQ).GE.7).AND.(X(IJSQ).LE.9)) N2 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      IF ((MOD1.EQ.0).OR.(MOD1.EQ.2)) N2 = N2 + 1
      IF ((MOD1.EQ.1).OR.(MOD1.EQ.2)) N1 = N1 + 1
 10   CONTINUE
C
C        Travel time at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X5 = DHWY*70./60. + DTRL*40./60.
      X6 = 1.7*N1+3.1
      IF (X6.LT.TRAILS(2)) X6=TRAILS(2)
      IF (X6.GT.TRAILS(2)) TRAILS(2)=X6
      X7 = SLOPE(I,J)
      IF ((X(IJSQ).GE.7).AND.(X(IJSQ).LE.9)) X8 = 4.0/(N1*N2)
      IF ((X(IJSQ).LT.7).OR.(X(IJSQ).GT.9))  X8 = 0.0
      U2 = K(1)*UF(5,X5) + K(3)*UF(7,X7) + K(4)*UF(8,X8)
      RETURN
      END
C
C
C           ACTIVITY #3   SNOWMOBILING
C
C
C
      FUNCTION U3(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.269,0.252,0.167,0.312/
      N1 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      MOD2 = X(ISQ) - MOD1*3
      IF (X(ISQ).EQ.16) GOTO 10
      IF (MOD2.EQ.1) N1 = N1 + 1
 10   CONTINUE
```

```
C
C         Travel time at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X9 = DHWY*70./60. + DTRL*40./60.
      X10 = 1.7*N1 + 3.1
      IF (X10.LT.TRAILS(3)) X10=TRAILS(3)
      IF (X10.GT.TRAILS(3)) TRAILS(3)=X10
C
C         Average snow depth value for square K.
C
      X11 = SNOW(I,J)
C
      X12 = SLOPE(I,J)
      U3 = K(1)*UF(9,X9) + K(3)*UF(11,X11) + K(4)*UF(12,X12)
      RETURN
      END
C
C
C               ACTIVITY #4   DOWNHILL SKIING
C
C
C
      FUNCTION U4(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.301,0.437,0.262,0.0/
      N1 = 0
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      IF (X(ISQ).EQ.16) N1 = N1 + 1
   10 CONTINUE
C
C         Travel time at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X13 = DHWY*70./60. + DTRL*40./60.
      X14 = SLOPE(I,J)
      X15 = SNOW(I,J)
      U4 = K(1)*UF(13,X13) + K(2)*UF(14,X14) + K(3)*UF(15,X15)
      RETURN
      END
C
C
C               ACTIVITY #5   CROSS-COUNTRY SKIING
C
C
C
      FUNCTION U5(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.271,0.198,0.293,0.238/
      N1 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
```

```
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      MOD2 = X(ISQ)-3*MOD1
      IF (MOD2.EQ.2) N1 = N1 + 1
   10 CONTINUE
C
C        Travel time at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X16 = DHWY*70./60. + DTRL*40./60.
      X17 = 1.7*N1 + 3.1
      IF (X17.LT.TRAILS(5)) X17=TRAILS(5)
      IF (X17.GT.TRAILS(5)) TRAILS(5)=X17
      X18 = SLOPE(I,J)
      X19 = SNOW(I,J)
      U5 = K(1)*UF(16,X16) + K(3)*UF(18,X18) + K(4)*UF(19,X19)
      RETURN
      END
C
C
C              ACTIVITY #6   SNOWSHOEING
C
C
C
      FUNCTION U6(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.152,0.382,0.255,0.211/
      N1 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      MOD2 = X(ISQ)-3*MOD1
      IF (MOD2.EQ.2) N1 = N1 + 1
   10 CONTINUE
C
C        Travel time at 70 KM/H on highway and 40 KM/h on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X20 = DHWY*70./60. + DTRL*40./60.
      X21 = 1.7*N1 + 3.1
      IF (X21.LT.TRAILS(6)) X21=TRAILS(6)
      IF (X21.GT.TRAILS(6)) TRAILS(6)=X21
      X22 = SNOW(I,J)
      X23 = SLOPE(I,J)
      U6 = K(1)*UF(20,X20) + K(3)*UF(22,X22) + K(4)*UF(23,X23)
      RETURN
      END
C
C
C              ACTIVITY #7   HIKING
C
C
C
      FUNCTION U7(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      DATA K/0.512,0.488,0.0,0.0/
```

```
C
C          Travel time at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X24 = DHWY*70./60. + DTRL*40./60.
      X25 = 1000000.0
      IF (NLAKES.EQ.0) GOTO 11
      DO 10 II=1,NLAKES
        IL = (LAKES(II) - 1)/10 + 1
        JL = LAKES(II) - (IL-1)*10
        DX = DSQRT(1.DO*(I-IL)*(I-IL) + (J-JL)*(J-JL))
        IF (XD.LT.X25) X25 = XD
   10 CONTINUE
   11 CONTINUE
      U7 = K(1)*UF(24,X24) + K(2)*UF(25,X25)
      RETURN
      END
C
C
C                 ACTIVITY #8   HORSEBACK RIDING
C
C
C
      FUNCTION U8(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100), TRAILS(9)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /MAXTRL/ TRAILS
      DATA K/0.279,0.288,0.433,0.0/
      N1 = 1
      IM1 = I - 1
      IP1 = I + 1
      JM1 = J - 1
      JP1 = J + 1
      DO 10 II=IM1,IP1
      DO 10 JJ=JM1,JP1
      IF ((II.LT.1).OR.(II.GT.10).OR.(JJ.LT.1).OR.(JJ.GT.10)) GOTO 10
      IF ((II.EQ.I).AND.(JJ.EQ.J)) GO TO 10
      ISQ = 10*(II-1) + JJ
      MOD1 = (X(ISQ)-1)/3
      IF (MOD1.EQ.3) N1 = N1 + 1
   10 CONTINUE
C
C          Travel time at 70 KM/H on highway and 40 KM/H on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
      X26 = DHWY*70./60. + DTRL*40./60.
      X27 = 1.7*N1 + 3.1
      IF (X27.LT.TRAILS(8)) X27=TRAILS(8)
      IF (X27.GT.TRAILS(8)) TRAILS(8)=X27
      X28 = SLOPE(I,J)
      U8 = K(1)*UF(26,X26)
      RETURN
      END
C
C
C                 ACTIVITY #9   SUMMER MOTORIZED CAMPING
C
C
C
      FUNCTION U9(X,I,J,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10),SLOPE(10,10),LAKES(100)
      INTEGER X(100)
      REAL K(5)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      DATA K/0.371,0.229,0.400,0.0/
C
C          Travel time at 70 KM/H on highway and 40 KM/h on trail.
C
      DHWY = DABS(TOWNI-I)
      DTRL = DABS(TOWNJ-J)
```

```
      X29 = DHWY*70./60. + DTRL*40./60.
      X30 = 1000000.0
      IF (NLAKES.EQ.0) GOTO 11
      DO 10 II=1,NLAKES
        IL = (LAKES(II) - 1)/10 + 1
        JL = LAKES(II) - (IL-1)*10
        DX = DSQRT(1.DO*(I-IL)*(I-IL) + (J-JL)*(J-JL))
        IF (XD.LT.X30) X30 = XD
 10   CONTINUE
 11   CONTINUE
      X31 = SLOPE (I,J)
      U9 = K(1)*UF(29,X29) + K(3)*UF(31,X31)
      RETURN
      END
C
C
C
      FUNCTION UF(I,X)
C
C         This function evaluates the utility for one of the
C         the 31 attributes.
C         I is the attribute number.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION UTIL(31,9),XR(31,9)
      COMMON /UTILTY/ UTIL,XR
C
C         Find a range of input X-values which surround
C         the attribute value.
C
      DO 10 J=1,9
      IF (X.LE.XR(I,J)) GOTO 20
 10   CONTINUE
C
C         If no range is found, assign the last utility.
C
      UF = UTIL(I,9)
      RETURN
 20   CONTINUE
      IF (J.EQ.1) GOTO 30
      JM1 = J-1
C
C         Utility is assigned by a straight line approximation
C         between the surrounding data points.
C
      UF = UTIL(I,JM1) + (X-XR(I,JM1))/(XR(I,J)-XR(I,JM1))*
     +                   (UTIL(I,J)-UTIL(I,JM1))
      RETURN
 30   CONTINUE
C
C         If the attribute value is less than the first input
C         X-value, assign the first utility.
C
      UF = UTIL(I,1)
      RETURN
      END
C
C
C
      SUBROUTINE GETDAT
C
C         This subroutine reads the intut data from files.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SNOW(10,10), SLOPE(10,10), LAKES(100)
      DIMENSION UTIL(31,9), XR(31,9)
      COMMON /DATA/ SNOW,SLOPE,TOWNI,TOWNJ,LAKES,NLAKES
      COMMON /UTILTY/ UTIL,XR
C
C         Initialize all arrays first.
C
      DO 5 I=1,10
      DO 5 J=1,10
```

```
         SNOW(I,J) = 0.0
    5    SLOPE(I,J) = 0.0
         DO 6 I=1,100
    6    LAKES(I) = 0
         NLAKES = 0
C
C            Read snow depths from unit 1 and slopes from unit 2.
C
         DO 10 I=1,10
           READ (1,100,END=8) (SNOW(I,J),J=1,10)
    8      CONTINUE
           READ (2,100,END=9) (SLOPE(I,J),J=1,10)
    9      CONTINUE
  100    FORMAT (10F8.2)
   10    CONTINUE
C
C            Read squares containing water from unit 3.
C              Note : Top row is #001 - #010.
C                     Bottom row is #091 - #100.
C
         DO 20 I=1,100
           READ (3,200,END=25) LAKES(I)
   20    CONTINUE
  200    FORMAT (I3)
         I = 101
   25    CONTINUE
         NLAKES = I-1
C
C            Read utility graph points from unit 4.
C
         DO 30 I=1,31
         READ (4,300,END=30) (XR(I,J),UTIL(I,J),J=1,9)
   30    CONTINUE
  300    FORMAT (18F8.2)
C
C            Read position of town from terminal (interactively).
C            Note : Input should be in real numbers (e.g. 1.0,3.0).
C
         WRITE (6,400)
         READ (5,401) TOWNI,TOWNJ
  400    FORMAT ('  ENTER COORDINATES OF TOWN (1,1 IS IN TOP LEFT CORNER'
     +          ,' OF GRID SQUARE)')
  401    FORMAT (2F10.3)
         RETURN
         END
End of file
```

APPENDIX

Procedure for Using the UTILVAL.S Algorithm

PROCEDURE FOR USING THE UTILVAL.S ALGORITHM

Using UTILVAL.S, the user is able to examine the utility values for each activity for every grid square of a recreation plan. The algorithm does not include trail lengths in the utility calculations and conflict attributes have a utility value of 1.0 (no conflicts because all grid squares are allocated the same activity). The following steps illustrate how to use UTILVAL.S:

Step 1

An object file is created, for example UTILVAL.O. The algorithm UTILVAL.S is compiled into UTILVAL.O by the following command:

```
$RUN *FTN SCARDS=UTILVAL.S SPUNCH=UTILVAL.O
```

Step 2

A file is created, for example file OUT, for storing the resulting utility values.

Step 3

The following command begins the UTILVAL.S program:

```
$RUN UTILVAL.O 1=SNOW1 2=SLOPES1 3=LAKES 4=UTILITY 8=OUT
```

where units 1, 2, 3, and 4 correspond to files containing snow depths, slope values, drinking water source locations and attribute utility function data points respectively. Unit 8 contains the file which stores the resulting utility values.

The following steps illustrate what is displayed on the terminal and what is required as input using UTILVAL.S:

Step 4

DISPLAY: ENTER COORDINATES OF TOWN (1,1 is in top left corner of grid box):

INPUT: -20.0,7.0 (an example town location)

DISPLAY: WHICH ACTIVITY DO YOU WISH TO ANALYZE?

Step 5

The following numbers correspond to the respective activities:

1 = Trailbiking	6 = Snowshoeing
2 = Four-Wheel Driving	7 = Hiking
3 = Snowmobiling	8 = Horseback Riding
4 = Downhill Skiing	9 = Summer Motorized Camping
5 = Cross-Country Skiing	0 = To get out of program (MTS)

DISPLAY: WHICH ACTIVITY DO YOU WISH TO ANALYZE?

INPUT: 1 (an example activity)

DISPLAY: WHICH ACTIVITY DO YOU WISH TO ANALYSE?

(The utility values are being stored in file OUT)

INPUT: 0

DISPLAY: # (MTS mode)

Step 6

The following command lists the utility values on the screen:

$LIST OUT

The following command prints the values with the XEROX 9700:

$LIST OUT *PRINT*

APPENDIX

Utility Values Generated by the UTILVAL.S Algorithm for Each Activity for Each Grid Square

TABLE 6.
UTILITY VALUES GENERATED BY THE UTILVAL.S ALGORITHM FOR EACH ACTIVITY FOR EACH GRID SQUARE

Summary of Utility Functions for Activity 1
(TRAILBIKING)

0.60423	0.60496	0.33929	0.67302	0.65154	0.60787	0.60860	0.60787	0.34074	0.34002
0.60295	0.33728	0.60164	0.67174	0.60587	0.60660	0.60733	0.60660	0.33947	0.60236
0.33528	0.63432	0.64753	0.60386	0.60459	0.60532	0.60605	0.64972	0.33819	0.33746
0.33400	0.33473	0.33546	0.60259	0.60332	0.60405	0.60477	0.60127	0.33692	0.33619
0.33272	0.33345	0.44865	0.64571	0.60204	0.60277	0.67010	0.33637	0.33564	0.33491
0.33145	0.33218	0.66591	0.60004	0.60076	0.60149	0.64662	0.33509	0.33436	0.33364
0.33017	0.33090	0.62994	0.59876	0.59949	0.66682	0.33455	0.33382	0.33309	0.49886
0.32890	0.32962	0.62867	0.59748	0.59821	0.44701	0.33327	0.33254	0.33181	0.62940
0.32762	0.32835	0.59270	0.59621	0.59694	0.44573	0.33199	0.33127	0.33054	0.44428
0.32634	0.32707	0.59420	0.59493	0.59566	0.44446	0.33072	0.32999	0.54779	0.63933

Summary of Utility Functions for Activity 2
(FOUR-WHEEL DRIVING)

0.29175	0.29208	0.29242	0.34137	0.32549	0.29342	0.29375	0.29342	0.65608	0.65575
0.29117	0.29150	0.37286	0.34078	0.29250	0.29283	0.29317	0.29283	0.65550	0.37319
0.29058	0.35574	0.32366	0.29158	0.29192	0.29225	0.29258	0.32466	0.65492	0.65458
0.65300	0.65333	0.65367	0.29100	0.29133	0.29167	0.29200	0.37269	0.65433	0.65400
0.65242	0.65275	0.57746	0.32283	0.29075	0.29108	0.34003	0.65408	0.65375	0.65342
0.28883	0.28917	0.33812	0.28983	0.29017	0.29050	0.32324	0.65350	0.65317	0.65283
0.28825	0.28858	0.35374	0.28925	0.28958	0.33853	0.65325	0.65292	0.65258	0.47075
0.28767	0.28800	0.35315	0.28867	0.28900	0.57671	0.65267	0.65233	0.47050	0.35349
0.28708	0.28742	0.36878	0.28808	0.28842	0.57612	0.65208	0.65175	0.28842	0.57546
0.28650	0.64983	0.28717	0.28750	0.28783	0.57554	0.65150	0.46967	0.40451	0.31991

Summary of Utility Functions for Activity 3
(SNOWMOBILING)

0.50851	0.50403	0.41695	0.65530	0.64959	0.63287	0.48161	0.65310	0.40798	0.37267
0.51636	0.29633	0.70697	0.66315	0.63542	0.64072	0.63624	0.49394	0.41582	0.68292
0.30026	0.62386	0.64700	0.64775	0.65305	0.64856	0.49730	0.68037	0.40345	0.40793
0.37202	0.35637	0.39397	0.65559	0.66089	0.65641	0.50515	0.71900	0.41129	0.41578
0.32098	0.35244	0.60454	0.68348	0.66370	0.51748	0.69281	0.42444	0.41410	0.39228
0.41099	0.42367	0.70855	0.51075	0.51300	0.67180	0.69607	0.39284	0.37314	0.38836
0.40707	0.41975	0.71479	0.50683	0.66564	0.69113	0.39116	0.37146	0.35132	0.55996
0.40315	0.41582	0.71087	0.50291	0.66171	0.61907	0.38724	0.36753	0.34740	0.58017
0.38944	0.40146	0.71654	0.49899	0.66823	0.61515	0.38332	0.36361	0.31425	0.49794
0.39530	0.40798	0.63663	0.49506	0.49730	0.60825	0.38918	0.35969	0.62233	0.55115

Summary of Utility Functions for Activity 4
(DOWNHILL SKIING)

0.48022	0.48166	0.34902	0.49041	0.45106	0.37604	0.22725	0.29089	0.66219	0.79760
0.47772	0.53708	0.47848	0.48790	0.40485	0.37353	0.37497	0.22288	0.65969	0.53160
0.54875	0.53421	0.47249	0.40091	0.36959	0.37102	0.22181	0.37721	0.74233	0.74089
0.79615	0.80731	0.78864	0.39840	0.36708	0.36852	0.21930	0.44025	0.73982	0.73839
0.81310	0.80480	0.68652	0.40684	0.36457	0.21536	0.43299	0.70123	0.73731	0.78756
0.41246	0.36626	0.33960	0.20998	0.21142	0.32599	0.37112	0.78792	0.79686	0.78506
0.40995	0.59786	0.35894	0.20747	0.32204	0.42654	0.78685	0.79579	0.80408	0.64966
0.40745	0.59535	0.35643	0.20497	0.31954	0.63161	0.78434	0.79328	0.83371	0.53426
0.51268	0.74973	0.37577	0.20246	0.26939	0.62910	0.78183	0.79077	0.87306	0.71748
0.63654	0.63532	0.25322	0.19995	0.20138	0.53064	0.76039	0.82040	0.58832	0.48555

Summary of Utility Functions for Activity 5
(CROSS-COUNTRY SKIING)

0.63796	0.63977	0.36233	0.53436	0.57102	0.59955	0.41080	0.58750	0.36594	0.38786
0.63480	0.40480	0.45668	0.53120	0.60042	0.59639	0.59820	0.40584	0.36278	0.47015
0.39984	0.51179	0.57314	0.59545	0.59142	0.59323	0.40448	0.55484	0.37167	0.36987
0.37917	0.38681	0.37657	0.59229	0.58826	0.59007	0.40132	0.44994	0.36851	0.36671
0.38768	0.38365	0.40525	0.55074	0.58510	0.39635	0.51546	0.36132	0.36535	0.37521
0.34913	0.34471	0.49302	0.38958	0.39138	0.57791	0.54716	0.37566	0.38008	0.37205
0.34597	0.34155	0.45934	0.38641	0.57294	0.50733	0.37431	0.37872	0.38275	0.44038
0.34281	0.33839	0.45618	0.38325	0.56978	0.38952	0.37115	0.37556	0.37959	0.50543
0.34548	0.34145	0.42249	0.38009	0.56040	0.38636	0.36798	0.37240	0.38226	0.41813
0.33648	0.33207	0.51644	0.37693	0.37874	0.33395	0.35899	0.36924	0.44279	0.57032

Summary of Utility Functions for Activity 6
(SNOWSHOEING)

0.34590	0.34674	0.39159	0.47746	0.50950	0.56216	0.35097	0.60512	0.39328	0.31301
0.34442	0.22019	0.45265	0.47599	0.53905	0.56068	0.56153	0.34864	0.39180	0.41703
0.21787	0.39876	0.47246	0.53673	0.55836	0.55920	0.34801	0.54896	0.34736	0.34652
0.28932	0.27449	0.30773	0.53525	0.55688	0.55773	0.34653	0.47301	0.34588	0.34504
0.25649	0.27301	0.33263	0.52353	0.55540	0.34421	0.51055	0.36604	0.34440	0.30710
0.36034	0.38336	0.54866	0.34104	0.34189	0.57556	0.54537	0.30731	0.28974	0.30562
0.35886	0.38188	0.52119	0.33957	0.57324	0.50675	0.30667	0.28911	0.27259	0.25405
0.35738	0.38040	0.51971	0.33809	0.57176	0.36719	0.30520	0.28763	0.27111	0.35148
0.33512	0.35675	0.48527	0.33661	0.59246	0.36571	0.30372	0.28615	0.25396	0.23791
0.35443	0.37744	0.50960	0.33513	0.33598	0.32751	0.31792	0.28467	0.30523	0.39003

Summary of Utility Functions for Activity 7
(HIKING)

0.94240	0.94524	0.94809	0.95093	0.95378	0.95662	0.95947	0.95662	0.95378	0.95093
0.93742	0.94027	0.94311	0.94596	0.94880	0.95164	0.95449	0.95164	0.94880	0.94596
0.93244	0.93529	0.93813	0.94098	0.94382	0.94667	0.94951	0.94667	0.94382	0.94098
0.92747	0.93031	0.93316	0.93600	0.93884	0.94169	0.94453	0.94169	0.93884	0.93600
0.92249	0.92533	0.92818	0.93102	0.93387	0.93671	0.93956	0.93671	0.93387	0.93102
0.91751	0.92036	0.92320	0.92604	0.92889	0.93173	0.93458	0.93173	0.92889	0.92604
0.91253	0.91538	0.91822	0.92107	0.92391	0.92676	0.92960	0.92676	0.92391	0.92107
0.90756	0.91040	0.91324	0.91609	0.91893	0.92178	0.92462	0.92178	0.91893	0.91609
0.90258	0.90542	0.90827	0.91111	0.91396	0.91680	0.91964	0.91680	0.91396	0.91111
0.89760	0.90044	0.90329	0.90613	0.90898	0.91182	0.91467	0.91182	0.90898	0.90613

Summary of Utility Functions for Activity 8
(HORSEBACK RIDING)

0.25249	0.25311	0.25373	0.59715	0.68797	0.25559	0.25621	0.25559	0.25497	0.25435
0.25141	0.25203	0.44750	0.59606	0.25389	0.25451	0.25513	0.25451	0.25389	0.44812
0.25032	0.51384	0.68456	0.25218	0.25280	0.25342	0.25404	0.68642	0.25280	0.25218
0.24924	0.24986	0.25048	0.25110	0.25172	0.25234	0.25296	0.44719	0.25172	0.25110
0.24815	0.24877	0.31307	0.68301	0.25063	0.25125	0.59467	0.25125	0.25063	0.25001
0.24707	0.24769	0.59110	0.24893	0.24955	0.25017	0.68379	0.25017	0.24955	0.24893
0.24598	0.24660	0.51012	0.24784	0.24846	0.59188	0.24970	0.24908	0.24846	0.34336
0.24490	0.24552	0.50903	0.24676	0.24738	0.31168	0.24862	0.24800	0.24738	0.50965
0.24381	0.24443	0.43990	0.24567	0.24629	0.31059	0.24753	0.24691	0.24629	0.30935
0.24273	0.24335	0.24397	0.24459	0.24521	0.30951	0.24645	0.24583	0.38593	0.67759

Summary of Utility Functions for Activity 9
(SUMMER MOTORIZED CAMPING)

0.97681	0.96651	0.55620	0.64590	0.70702	0.92528	0.91498	0.92528	0.53559	0.54590
0.99485	0.58454	0.64566	0.66393	0.95362	0.94332	0.93301	0.94332	0.55362	0.63536
0.59614	0.68494	0.76370	0.98197	0.97166	0.96135	0.95105	0.73278	0.57166	0.58197
0.59072	0.59382	0.59691	1.00000	0.98969	0.97939	0.96908	0.65082	0.58969	0.60000
0.58531	0.58841	0.62007	0.76602	0.99768	0.99742	0.68712	0.59742	0.59768	0.59459
0.57990	0.58300	0.68609	0.98918	0.99227	0.99536	0.76988	0.59536	0.59227	0.58918
0.57449	0.57759	0.66639	0.98377	0.98686	0.68995	0.59304	0.58995	0.58686	0.62663
0.56908	0.57217	0.66098	0.97836	0.98145	0.61311	0.58763	0.58454	0.58145	0.66407
0.56367	0.56676	0.64128	0.97295	0.97604	0.60770	0.58222	0.57913	0.57604	0.60152
0.55826	0.56135	0.96445	0.96754	0.97063	0.60229	0.57681	0.57372	0.62777	0.73897

APPENDIX

The OUTSPLIT.S Algorithm

THE OUTSPLIT.S ALGORITHM

(Computer Language = FORTRAN)

```
C            This program splits the output matrix from a land use
C            plan into the individual activities.  The output shows
C            the 10x10 planning area for each activity with each
C            square marked by a zero (0) if the activity is not
C            allocated to that square and one (1) if the activity is
C            allocated to that square.
C
C            Variables used:
C                 X     - Double precision real matrix to contain
C                         the land use values.
C                 M     - Integer array to contain the rounded values
C                         of X.
C                 OUT1, OUT2, OUT3, OUT4, OUT5, OUT6 -
C                         Six 100 element arrays which will be set
C                         to 0/1 for each of the six classes of
C                         activities.
C
      REAL*8 X(100)
      INTEGER M(100)
      INTEGER OUT1(100),OUT2(100),OUT3(100),OUT4(100),OUT5(100)
      INTEGER OUT6(100)
C
C          Read values from land use plan file.
C
      READ(1) N, (X(I),I=1,N)
C
C          Round variables to integer.
C
      DO 10 I=1,100
      M(I) = X(I)+0.5
   10 CONTINUE
C
C          Analyze each of the 100 variables in the land use plan.
C
      DO 20 K=1,100
      OUT1(K) = 0
      OUT2(K) = 0
      OUT3(K) = 0
      OUT4(K) = 0
      OUT5(K) = 0
      OUT6(K) = 0
      MOD1 = (M(K)-1)/3
      MOD2 = M(K) - 3*MOD1
C
C            Is TB allocated?
C
      IF ((MOD1.EQ.0).OR.(MOD1.EQ.2)) OUT1(K) = 1
C
C            Is 4x4 allocated?
C
      IF ((MOD1.EQ.1).OR.(MOD1.EQ.2)) OUT2(K) = 1
C
C            Is Hiking/Horseback Riding/Camping allocated?
C
      IF  (MOD1.EQ.3)                 OUT3(K) = 1
C
C            Is Snowmobiling allocated?
C
      IF ((MOD2.EQ.1).AND.(M(K).NE.16))
     +                                OUT4(K) = 1
```

```
      C
      C             Is Snowshoeing/X-C Skiing allocated?
      C
            IF  (MOD2.EQ.2)                    OUT5(K) = 1
      C
      C             Is Downhill Skiing allocated?
      C
            IF  (M(K).EQ.16)                   OUT6(K) = 1
       20   CONTINUE
      C
      C           Begin output.
      C
            WRITE (6,1000)
       1000 FORMAT ('1',T44,'LAND USE PLAN ALLOCATION BY ACTIVITY',
           +          /,/,/,
           +            /,T24,'SUMMER ACTIVITIES',T84,'WINTER ACTIVITIES',
           +            /,T24,'-----------------',T84,'-----------------',
           +          /,/,T24,'    Trailbiking    ',T86,'Snowmobiling')
            DO 30 I=1,10
            I1 = 10*(I-1) + 1
            I2 = I1+9
            WRITE (6,1010) (OUT1(J),J=I1,I2),(OUT4(J),J=I1,I2)
       1010 FORMAT (/,10X,10I4,20X,10I4)
       30   CONTINUE
            WRITE (6,1020)
       1020 FORMAT(///,T24,'        4x4s          ',T82,'Snowshoeing/X-C Skiing')
            DO 40 I=1,10
            I1 = 10*(I-1) + 1
            I2 = I1+9
            WRITE (6,1010) (OUT2(J),J=I1,I2),(OUT5(J),J=I1,I2)
       40   CONTINUE
            WRITE (6,1030)
       1030 FORMAT ('1',/,
           +          '1',T24,'SUMMER ACTIVITIES',T84,'WINTER ACTIVITIES',
           +            /,T24,'-----------------',T84,'-----------------',
           +          /,/,T17,'Hiking/Horseback Riding/Camping',T84,'Downhill
           +Skiing')
            DO 50 I=1,10
            I1 = 10*(I-1) + 1
            I2 = I1+9
            WRITE (6,1010) (OUT3(J),J=I1,I2),(OUT6(J),J=I1,I2)
       50   CONTINUE
            STOP
            END
End of file
```

APPENDIX

Procedure for Using the OUTSPLIT.S Algorithm

PROCEDURE FOR USING THE OUTSPLIT.S ALGORITHM

The algorithm OUTSPLIT.S allows the user to see which activities are allocated to each grid square for a given recreation land use plan. The following steps illustrate to procedure for using OUTSPLIT.S:

Step 1

An object file is create, for example, OUTSPLIT.O. The algorithm OUTSPLIT.S is compiled into OUTSPLIT.O by the following command:

```
$RUN *FTN SCARDS=OUTSPLIT.S SPUNCH=OUTSPLIT.O
```

Step 2

To run OUTSPLIT.S and to print the results on paper with the XEROX 9700, the following command is entered:

```
$RUN OUTSPLIT.O 1=SOLN1 6=*PRINT*
```

where SOLN1 is a file with the land use plan which is to be split into activity allocations.