Development of a Fuzzy Multi-Criteria Decision Support System for Municipal Solid Waste Management

A Thesis

Submitted to the Faculty of Graduate Studies and Research

in Partial Fulfillment of the Requirements

for the Degree of

Master of Applied Science

in Advanced Manufacturing and Process Systems

University of Regina

by

Steven KwokYam Cheng

Regina, Saskatchewan

December 2000

0-612-60219-2

ABSTRACT

In this study, a multi-criteria decision-support system for municipal solid waste management is constructed to provide decision makers with an automated tool to perform impact evaluation according to several criteria. This system is initially designed for a landfill selection problem in the city of Regina, but can also be used to deal with other decision problems. Five commonly used multi-attribute decision making (MADM) methods are implemented in this system for impact evaluation, including:

- Simple Weighted Addition method
- Weighted Product method
- Cooperative Game Theory
- TOPSIS
- ELECTRE with complementary analysis

Given a set of possible alternatives and criteria, these MADM methods will help to rank the alternatives based on decision makers' preferences. Since different MADM methods might result in different ranking orders, a set of aggregation methods needs to be used for further analysis.

To perform an impact evaluation for landfill selection in the City of Regina, two problems are commonly encountered as follows:

- The acquired information contains uncertainties where data obtained for the site evaluation are mostly descriptive, and not in a numerical format.

- Public and political concerns are subjective factors and usually not considered in environmental impact evaluation; however, they have great influence on the siting of a new landfill.

These two problems make the evaluation process difficult. In order to compare the alternatives under different impacts and to find the most preferable site, multi-criteria decision support system is used in this study to help decision makers or interest groups gain more insight into the problem. The result is found to be satisfactory and consistent with the interested parties' preferences.

ACKNOWLEDGEMENT

I wish to express my sincere thanks to Dr. C.W. Chan and Dr. G.H. Huang for their supervision, support and guidance of this work. I would also like to thank a number of my friends who have always encouraged me and given me wise suggestions. They include Linli Chen, Liqiang Geng, Xin Wang, Yao Peng, and Varanon Uraikul.

Special thanks are due to Jan Yip and Eric Huang for their help. I am also grateful for the financial support from my supervisors through their grants from Natural Sciences and Engineering Research Council of Canada.

Finally, I would like to thank my family for their encouragement, love, and emotional support.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Abbreviations

AHP	Analytic Hierarchical Process – a MADM methods
CGT	Cooperative Game Theory – a MADM methods
DSS	Decision Support System
ELECTRE	Elimination Et Choice Translating Reality – a MADM methods
GIS	Graphical Information System
MADM	Multi-Attribute Decision Making
MCDA	Multi-Criteria Decision Analysis
MCDSS	Multi-Criteria Decision Support System
MODM	Multi-Objective Decision Making
MOLP	Multi-Objective Linear Programming
MPA	Multi-Purpose Advisor
SWA	Simple Weighted Addition – a MADM methods
SWM	Solid-Waste Management
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution. One of the MADM methods
WP	Weighted Product method – a MADM methods

1. INTRODUCTION

A multi-criteria decision support system (MCDSS) is a system that helps decision making under multiple, and conflicting criteria. It can also be described as an integrated system with an analyzing technique called multi-criteria decision analysis (MCDA). MCDA provides a systematic procedure to help decision makers choose the most desirable and satisfactory alternative under uncertain situations. For example, in order to select a new car, many criteria need to be considered, including cost, speed, interior capacity, comfort level, and reliability. There is no optimal solution for this car selection problem. One might want to choose a fast but inexpensive car, while others might want a comfortable and reliable one. Using MCDA, a decision can be made according to the decision maker's preference. If the problem becomes more complicated, computer aided models may become necessary, leading to MCDSS. In the last two decades, MCDSS has become a powerful tool for decision analysis and has been rapidly growing in fields of management, engineering, and many other areas (see Buede 1996 and Eom 1999). In solid waste management (SWM), for example, allocating a new landfill requires an impact evaluation. Some criteria may be more or less important than others, and it is the responsibility of decision makers to make a proper judgment. MCDSS can be used to help them go through the judging process and find a suitable landfill site.

Relying on factual knowledge alone is not always sufficient in making a decision. Value judgments, depending on the role and the goals of each decision maker, are among the critical issues requiring attention. Decision makers need an appropriate means to express their preferences, which are often expressed in qualitative terms. Most of the MCDA methods neglect these qualitative inputs and only numeric values are explored, which may limit the capability of the systems. To allow maximum usability of MCDSS, fuzzy set theory is introduced to deal with this problem. Whilst there has been much theoretical work on the use of concepts from fuzzy set theory in MCDA during the last two decades, little attention has been paid to the potential for integrating these ideas and developing a fuzzy MCDSS. Hence, this thesis focuses on the development of such a system and in particular it will look at solving the SWM problem in the City of Regina.

The objective of this study is to develop a MCDSS and then to further apply it to solve the SWM problem in Regina. A fuzzy MCDSS called Multi-Purpose Advisor (MPA) is developed which implements a set of methods used in MCDA in order to facilitate the exploration of the SWM problem. The aims of MPA are to improve comprehension of the system conditions and to arrive at a better informed decision. Specifically, there are three major tasks to be achieved:

- Creating a generic fuzzy decision support system (DSS) tool for solving multiple criteria problems;
- Allocating a preferred landfill site in the city of Regina; and
- Proposing a systematic approach for the landfill selection.

Since the current sanitary landfill in Regina will be filled in 10 years, a new landfill should be developed soon. A number of potential landfill locations were proposed, but as well many problematic questions also arose. Some of the main problems include, which of these potential sites would cause the least adverse impact under social, economic, and environmental considerations? How can the impact evaluation be performed if most of the selection criteria are uncertain? How can the decision maker's opinions affect the decision? Also, who should act as the decision maker? These questions will be answered in the investigation conducted in this thesis project.

Before investigating the structure of MPA, it is necessary to understand who the users of this system are. In general, two types of users can be defined to use MCDSS (Belton et al. 1999): analysts and decision makers. The analysts are responsible for initializing the issue, building the structure of the multicriteria model, inputting judgments elicited from the decision makers, and helping the decision makers to explore possible solutions. The decision makers, on the other hand, may be actively engaged in using MCDSS to help explore their preferences. They may be required to continuously and interactively express their preferences in order to obtain the desired result. In this study, the analysts are the intended users who would take control of the MCDSS because they are more familiar with the system and the related methods.

This thesis is organized into six chapters. Chapter Two presents brief introduction of the theory and techniques including MCDA, DSS, and the fuzzy set theory. They can be integrated together to form a powerful decision support tool. The previous studies in applying MCDA to waste management are also described in this chapter. Chapter Three introduces the MCDSS that can be used to handle fuzzy inputs and conceptualizes each part of MCDSS in detail. All formulae that are applied in MCDSS are presented here. Chapter Four describes how the fuzzy MCDSS is implemented. A system called Multi-

Purpose Advisor (MPA) is developed and its features are presented. Chapter Five shows how to apply MPA into a real case. The case study of the landfill site selection problem in the City of Regina is conducted. In this chapter, background information concerning the problem domain is first presented and is followed by the procedures of how data acquisition is performed in order to obtain information from several sources. The obtained data served as input parameters to MCDSS. After processing the data using the MCDSS, the result is then given and its findings are discussed. Lastly, a conclusion of this thesis is given in Chapter Six as well as recommendations for further research work.

2. LITERATURE REVIEW

2.1 Historical Studies on MCDA

Multi-criteria decision analysis is used to deal with problems that involve multiple conflicting goals. These problems are broadly classified into two types (Mollaghasemi et al. 1997):

1) multi-attribute decision problems – they refers to problems that have a relatively small number of alternatives, where the alternatives are represented in terms of attributes. Methods to solve this type of problems are called multi-attribute decision making (MADM) methods.
2) multi-objective decision problems – they refers to problems that have a very large number of feasible alternative, as described through the use of decision variables, where the objectives and the constraints are functionally related to the decision variables. Methods to solve this type of problems are called multi-objective decision making (MODM) methods.

In this chapter, the literature review of both MADM methods and MODM methods are briefly presented.

2.1.1 Multi-Attribute Decision Making (MADM) methods

MADM methods provide simple and intuitive tools for making decisions on problems that involve uncertain and subjective information. Since the early 1970s, these methods have been developed into many forms (Hwang et al. 1992). Among them, the simple weighted addition method (SWA), analytic hierarchical process (AHP), and outranking methods were commonly used in handling discrete problems of waste management. A few practical uses of MADM methods on waste facility selection or siting were reported. For example, Hokkanen et al. (1997) used outranking methods, such as ELECTRE (Elimination Et Choice Translating REality) and PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) as decision aids in the context of choosing a solid waste management system in the Oulu region, Finland. They proved to be useful when dealing with environmental problems and in cases where the outcomes of the various alternatives remain to some degree uncertain. Karagiannidis (1997) and Rogers et al. (1998) also used the ELECTRE III to deal with a problem of municipal solid-waste management. They both found that this MADM method is particularly suited to the environmental appraisal of complex engineering projects.

2.1.2 Fuzzy Multi-Criteria Decision Making (MCDM) methods

The fuzzy set theory is a powerful mathematical tool used for modeling and controlling uncertain systems in industry, humanity, and nature; fuzzy MCDM methods act as facilitators for approximate reasoning in decision making in the absence of complete and precise information (Isabel 1995). Chang (1996) introduced fuzzy AHP to cope with the fuzzy set computation in AHP method. Garavelli (1999) and Bisdorff (2000) applied fuzzy logic into a DSS to transform qualitative values into quantitative ones. The present study follows their examples in fuzzy-to-crisp transformation. In terms of application using fuzzy MCDM methods, not much literature can be found that is related to SWM or environmental resource management. In 1982, Hipel (1982) introduced a fuzzy multicriteria model to support the SWM problem. In the model, Hipel defined a number of alternatives that represent different solid waste disposal strategies, including two landfilling methods, incineration, composting, recycling, and combinations of them. Chang et al. (1997a) applied a fuzzy multi-objective programming model for the evaluation of sustainable management strategies of optimal land development in a reservoir watershed in Taiwan.

2.1.3 Multi-Objective Decision Making (MODM) methods

Since the early 1970's, many multi-objective linear programming (MOLP) models have been developed. For example, Yager (1978) introduced the application of fuzzy MOLP with emphasis on a means of including differing degrees of importance to different objectives. The nondifferentiable interactive multi-objecctive bundle-based optimization system (NIMBUS) developed by Haslinger et al. (1988) is one of the interactive methods that solve multi-objective optimization problems, such as the control problem of continuous casting of steel (Miettinen et al. 1998a) and water quality management problem (Miettinen 1998b). ReVelle (2000) suggested that Mixed Integer MOLP model can help in allocating a landfill site with a set of constraints, including cost, transportation, transfer stations, and landfill capacity. Also, Huang et al. (1998, 1999) has developed a number of MOLP models to deal with water environmental problems. Besides the MOLP models, different Goal Programming models are also widely used for solving MODM problems. Ioannis (1998) applied the Goal Programming model for allocating disposal or treatment facilities and scheduling hazardous waste routes along the links of a transportation network. Chang et al. (1997a) applies the fuzzy goal programming approach for optimal planning of solid waste management systems in a metropolitan region in Taiwan. Such approach demonstrates how fuzzy, or imprecise, objectives of the decision maker can be quantified through the use of specific membership functions in various types of SWM alternatives. Badri (1999) introduced a combination of AHP and Goal Programming model for solving site selection problems. In addition, Sarkis (2000) applied the Data Envelopment Analysis (DEA) and other MCDA approaches to Hokkanen's waste facility allocation problem in order to compare their advantages and disadvantages. These methods include ELECTRE, ELECTRE III, TOPSIS, SWA, and AHP. Although DEA was found to be more advantageous to users since it required less information from both the decision maker and the analyst, the performances and outputs from these testing methods are similar.

2.1.4 Multi-Criteria Decision Analysis with Decision Support System

The decision support system (DSS) was proposed in 1971 when Morton (1971) completed his doctoral dissertation about how computers and analytical models could help or support managers in making key decisions. Since then, there has been a growing amount of research performed in the area of decision support system. In the 1980s, realizing its limitations, the DSS was merged with MCDM methods in order to expand its capabilities. This integrated system was called the multi-criteria decision support system (MCDSS). A number of MCDSS have been constructed in different research domains (Eom et al. 1999). Bohanec (1990, 1991) built a general-purposed DSS called DEX which facilitated a modified AHP method and supported group decision making. Hong et al. (1991) designed a spreadsheet-based DSS integrated with SWA to perform loan approval judgments. French (1996) applied MADM methods to build a DSS for emergency responses on nuclear accidents. For resource planning, Al-Shemmeri et al. (1997) developed an effective monitoring system using an outranking method called PROMETHEE to deal with the use of water resources. Norbis et al. (1996) embedded multiobjective zero-one programming to the DSS in order to solve resource constrained scheduling problems. In Finland, PROMETHEE was used as a decision aid to solve the problems of a landfill allocation. Maniezzo et al. (1998) built a MCDSS and applied it to the problem of locating installations for industrial waste management in Italy. This system identified a heirarchy of objectives, where at the top level a 0/1 fixed cost transportation problem (FCTP) was solved. An organizational DSS called EM50-ODSS (Sen et al. 2000) was developed in 2000 to support hazardous waste clean up efforts. Its task was to help the Waste Management Division in the United States choose available technology for waste problems and waste resolution needed in the next 30 years. Haastrup et al. (1998) developed a DSS with a design of combinatorial optimization algorithms for solving facility location problems. This system, implemented in a database backbone, allowed generation and evaluation of suitable alternatives with respect to salient features of the problem, especially environmental consequences.

2.2 Previous Studies in Applying MCDA to Waste Management

Although most of the multi-attribute decision making (MADM) methods originated from Europe, they can be applied worldwide. However, even though MCDA has been used in other domains in the last three decades, it is not popular when it comes to the waste management problem. Several case studies can be found in the literature which show the usefulness of applying MCDA in waste management. Four studies from different countries are selected and summarized in this section. Two of them are directly related to municipal solid waste management, while the other two are related to industrial waste management.

2.2.1 Municipal Solid Waste Management in Finland

In Finland, Hokkanen (1994, 1997) applied several outranking methods to deal with the solid-waste management (SWM) problems in different locations. In an earlier project, she had used the ELECTRE I and II methods and discovered that neither of them could provide a satisfactory result. Later, the ELECTRE III method was adopted (Hokkanen et al. 1994). It was applied to the SWM problem in Central Finland, and was found to be more suitable than applying ELECTRE I and II. The problem involves selecting a SWM facility among all alternatives, which included the waste treatment methods such as sanitary landfilling, incineration and composting. After analyzing the alternatives, the result was reviewed by the municipal residents. It was found that they all supported the use of the ELECTRE III method.

In another study, Hokkanen et al. (1997) applied PROMETHEE I and II to the problem of locating a waste treatment facility in eastern Finland. PROMETHEE I and II are also a type of outranking methods similar to ELECTRE. The basic idea was to perform the environmental impact assessment (EIA) procedure as required in Finnish legislation and to complement it with a multicriteria analysis of the decision alternatives. EIA required many different factors to be dealt with. Therefore, the use of the PROMETHEE methods was suited since it preserved the information obtained in the decision-making process.

2.2.2 Sanitary Landfill Siting in Taiwan

To deal with landfill siting problem, DRASTIC index system (Aller et al. 1985) can be used which mainly focuses on minimizing the impact of groundwater pollution. DRASTIC is an impact evaluation system and the mechanism behind it is similar to the Simple Weighted Addition method. However, significant uncertainty for siting factors usually exists, especially on the information of underground area that is difficult and costly to collect. The DRASTIC system may not be able to eliminate all inappropriate sites. A modified system called fuzzy DRASTIC (Chen et al. 1997) was introduced to overcome the problem. The fuzzy DRASTIC system was applied to solve the landfill-siting problem in central Taiwan. Geographical information system (GIS) was used to collected various maps on the candidate sites. Results from fuzzy DRASTIC was obtained and compared with that from the original DRASTIC index system. Chen et al. believed that the proposed fuzzy DRASTIC was more appropriate for landfill siting analysis than the original one.

2.2.3 Hazardous Waste Management in Greece

In Greece, Briassoulis et al. (1996) presented an integrated multi-criteria methodology for siting hazardous waste management facilities. In the paper, Briassoulis introduced a multistage, multicriteria methodological framework to guide the site selection process. The process was divided into two stages: site generation and site selection / evaluation. The main purpose of the site generation stage was to identify the set of candidate sites in the study area by means of a screening procedure. Screening techniques were mostly heuristic and were based on establishing cutting values of the screening criteria and determining whether a region was above or below these values. In the site selection / evaluation stage, the candidate sites were ranked by using appropriate MADM or MODM methods. A MADM method called REGIME was applied to solve the siting problem for a toxic waste incinerator within the Greek territory. The REGIME method (Hinloopen et al. 1988) was chosen because of its simplicity and because it allowed simultaneous consideration of both quantitative and qualitative decision criteria. Briassoulis stated that the proposed multicriteria methodology could help reflect various siting concerns representative of different stages. It offered a framework for dealing with multi-actor decision settings and conflict resolution often encountered in siting industrial facilities.

2.2.4 Distribution of Industrial Waste in Italy

Paruccini et al. (1994) presented a multi-criteria decision support system for the rational management of the industrial waste using two decision modules, namely MAPPAC and PRAGMA methods. Both of these methods were based on the pairwise criterion comparison approach. This approach was opposite to that used by ELECTRE, where comparison was done for each pair of alternatives. It also incorporated a geographical information system (GIS) to enhance efficiency of data collection. The system was developed to evaluate the land-use policies and siting the industrial waste plant in the Lombardy region. In particular, MCDA was used to decide how to distribute the industrial waste in that region. Several scenarios were performed under different settings of weight. The result from the MCDSS suggested that waste distribution should be based on the preference of large customers, although the environmental impact criteria should be stressed. In the study, Paruccini (1994) suggested that MCDA could produce a deeper knowledge of the problem and supply a framework for integrating the knowledge of specialists from the various disciplines who were involved in the problem. More importantly, MCDA could formalize a decision study to supply technical documentation in support of decisions.

2.3 Literature Review Summary

Based on the case studies described in this chapter, it is concluded that multi-criteria decision analysis can be useful for real-world decision problems. However, only few methods have been applied to solid waste management (SWM). According to the studies mentioned in the previous section, there were also limitations to each of these MADM methods. For example, the approaches of Hokkanen et al. (1994, 1997) only allowed quantitative input parameters in the landfill selection problems. The fuzzy DRASTIC system proposed by Chen et al. (1997) concentrated on the various groundwater factors but disregarded other social and environmental factors. The pairwise criterion comparison approach by Paruccini et al. (1994) was not often seen in MCDA. It assumed that the weights of criteria were all the same. It would become problematic when the weights which were actually assigned by decision makers were different from each other. Regardless of their limitations, the MCDA methods for solid-waste management reported in these studies were immature and ineffective to support the decision making process. A better method is needed to overcome the mentioned limitations.

3. FUZZY MULTI-ATTRIBUTE DECISION MAKING

According to the previous studies, researchers would select various multi-attribute decision making methods to deal with the selection problems in solid waste management (SWM). Due to their limitations, however, these methods might not be effective enough. Hence, a new integrated approach is proposed. This approach can overcome the limitations of the existing MADM methods for the SWM problems as mentioned in the previous chapter. It supports both qualitative and quantitative inputs for analysis, which is often encountered in the impact assessment of solid-waste management. Also, the attributes analyzed are not restricted to the groundwater factor alone. Other social and environmental factors can be included as well. The use of the proposed approach is more flexible and can be applied to solve other decision problems. In this chapter, an overview of multi-criteria decision analysis is first provided to describe how it can help solve decision problems. Then, the new approach of fuzzy multi-attribute decision making (MADM) is introduced. This approach integrates fuzzy set theory, five MADM methods, and three aggregation methods to evaluate the impact of landfill site selection in the City of Regina.

3.1 Multiple Criteria Decision Analysis (MCDA)

Almost all decision problems involve simultaneous consideration of several goals that are often in conflict. Over the years, people struggle in finding efficient techniques to solve such problems. There is actually nothing new about making decisions when multiple criteria are present. Simple problems, such as those involving only a few criteria and a small number of alternatives, can usually be solved adequately without the use of sophisticated methods. When the number of criteria and alternatives becomes large, however, the need for more formal (analytical) techniques becomes much more acute. In addition, formal techniques are often required for business and governmental decisions where there is a need to document and justify the decision process to large groups of people. In the presence of a large number of conflicting criteria and numerous alternatives, techniques that aid decision makers in structuring their preferences and values is very useful. These techniques are needed for such complex decision problems because it becomes very difficult for decision makers to articulate trade-off information and maintain some measure of consistency in their responses.

The development of MCDA methods is actually relatively recent. According to Nijkamp et al. (1990), conventional decision techniques including single objective linear programming, cost-benefit analysis and fixed target approaches, dominated in solving decision problems until the end of the 1960s. These techniques are insufficient to solve decision problems because they only targeted on the economic criterion and ignored the negative external effects of economic growth. For example, increasing labors' work load in an industry might often bring up different types of environmental and health problems. More appropriate analytical techniques were urgently needed. Since the early 1970s, MCDA was introduced in order to cope with such problems. It aims at providing the decision makers with a systematic way to clarify the decision problem, helping to generate useful alternative solutions, and helping to evaluate the alternatives based on a decision maker's values and preferences. In general, the basic concept of making a decision include the following elements:

a) goals, objectives, or criteria to be achieved,

b) needs to be fulfilled,

c) constraints and requirements associated with and affected by the decision,

d) decision alternatives,

e) the environment in which the decision must be made, and

f) the experience and background of the decision maker(s).

A multiple-criteria problem begins when a decision maker has a situation that requires a decision. There are a number of criteria that the decision maker should be concerned with, and several different courses of action may be available to address most or all of the criteria in some way. The decision maker is faced with the problem of determining which course of action or alternative would best satisfy the criteria and fully satisfy the constraints.

For example, according to Chi (1997), the existing landfill in the city of Regina will be filled within ten years. Before the landfill expires, the government has to decide where a new landfill should be located. The decision has to be made based on certain criteria, such as the cost of the landfill, risk of groundwater contamination, public concerns, and so on. Many possible landfill sites were proposed. Among the possible sites, some of them probably cost less than others; some of them might be risk-free from groundwater contamination; and the others might locate where they are far away from the residential neighborhoods. These are only some of the criteria that need to be considered. The later chapters will cover the landfill selection problem with more details.

To solve a decision problem as mentioned above using MCDA, one has to follow the MCDA process as shown in Figure 3.1. The MCDA process refers to the procedure of problem solving. Its purpose is to provide systematic support to complex planning and decision problems and to improve the quality of the resulting decisions. To begin the MCDA process, first the decision maker has to define what problems are to be evaluated. The current situation is then diagnosed, and a number of alternatives are identified. Since MCDA consists of two classes of decision making methods, namely multi-attribute decision making (MADM) method and multi-objective decision making (MODM) method, it is important to define whether the number of alternatives is finite or continuous. In a situation where a finite set of feasible alternatives is considered, MADM methods are applied. Otherwise, if an infinite number of alternatives is considered, MODM methods are used. Since this study focuses on using MADM methods to solve problems, the following explanations refer to procedures for solving MADM problems explicitly. Dealing with MODM problems require a different set of procedures which will not be discussed here.

After identifying the possible alternatives, the next step is to define the criteria. Many resources have pointed out that defining criteria for a problem is the most difficult as well as the most time-consuming task (see Hwang et al. 1981, Hwang et al. 1992, and Yoon et al. 1995). It is especially true when dealing with MADM problems. To identify the

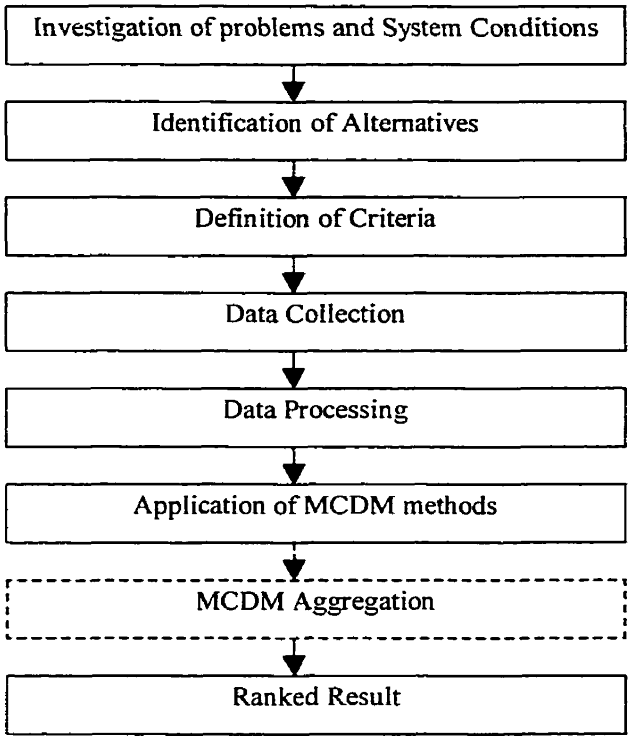

Figure 3.1. Overall procedure of MCDA application.

attributes in the problem area, Keeney et al. (1976) suggest the use of a literature survey and/or a panel of experts. Although this may help enrich the set of attributes, it is necessary that the attributes represent the desired factors. Hwang et al. (1992) suggests that the analyst should use either a deductive or inductive approach to build a hierarchy tree of attributes as shown in Figure 3.2. In this figure, a number of criteria for the decision-making problem are listed at the top level. For each of the criteria, it may be divided into several sub-criteria. If necessary, these sub-criteria may also be divided into more sub-criteria, and so on. Correctly representing attributes in a hierarchy tree can have the following advantages:

- This would clarify the intended meaning of the criteria at higher-levels.
- This would permit the decision maker to view listed attributes as independent entities among which appropriate trade-offs may later be made.
- This would help prevent undesirable "double-counting" of the same criterion in different branches of the hierarchy.

For example, Figure 3.3 shows a hierarchy tree of attributes for evaluating manufacturing sites. To locate a good site, the decision maker first need to focus on four major criteria: economic impact, functional impact, public acceptance, and quality of life. Under the criteria of economic impact, for instance, it can be divided into two sub-criteria: capital cost and operating cost.

Since defining criteria using attribute hierarchy is time-consuming, some researchers argued that the analyst should not pay too much attention to this stage. Nijkamp et al. (1990) explains that such technique "bears the danger of generating more or less artificial

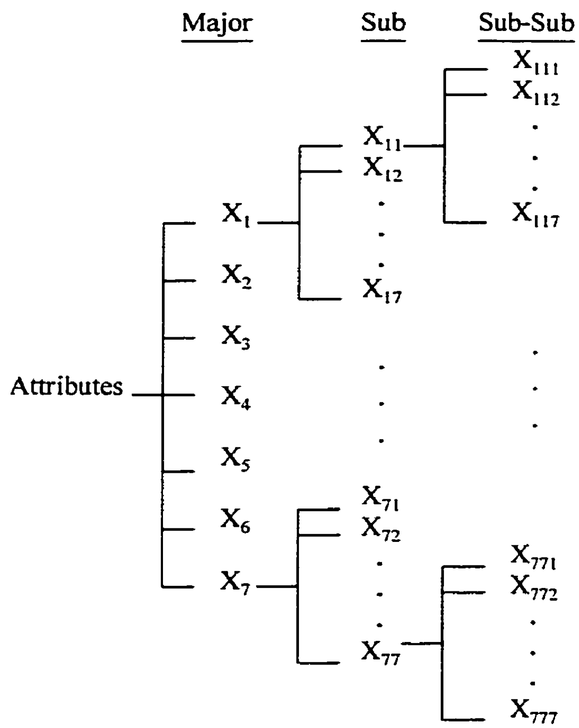

Figure 3.2 A hierarchy tree of attributes.

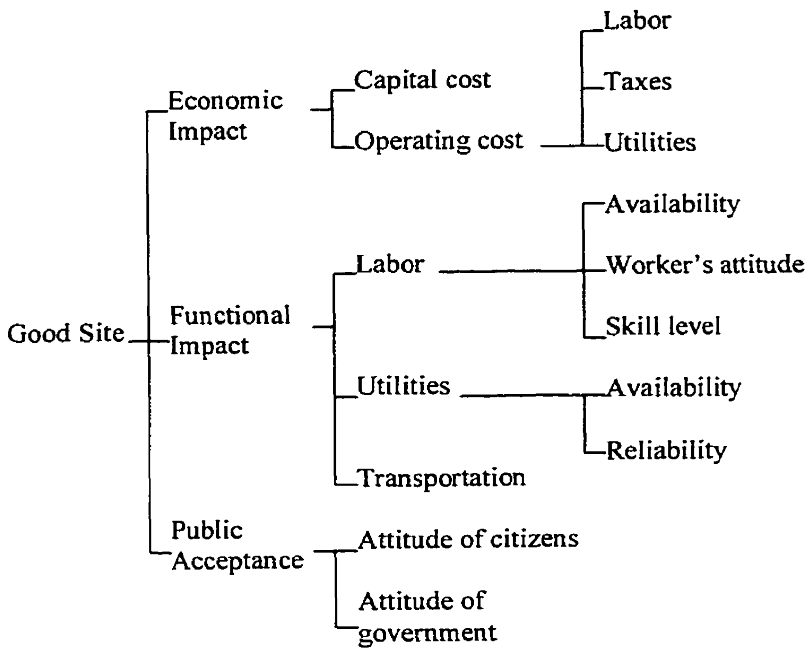

Figure 3.3 A hierarchy of attributes for evaluating plant sites.

hierarchical patterns, in which the form surpasses the content". However, it is undisputed that attribute hierarchy can clarify the concept and relationships among different types of criteria. According to recent literature, this technique is applied in most multi-criteria decision problems, including landfill selection. In the present study, the attribute hierarchy technique is adapted.

After defining the criteria for the problem, the next step is data acquisition. Unlike a conventional cost-benefit analysis that requires mandatory measurement of data, the characteristics of data used in MCDA are more flexible. Data can be either ordinal or cardinal. Ordinal data only indicates the position of the data in a series or order, whereas cardinal data allows the measure of relation between them. Different characteristics of input data can also influence the choices of MADM methods. For example, if only ordinal data is provided, the Lexicographic method or the Permutation method can be used. If cardinal data is provided instead, ELECTRE or TOPSIS can be applied. Also, there are a few techniques required to perform cardinalization, with which ordinal data can be artificially transformed into cardinal ones. The question is, of course, whether there is a sufficient basis for the application of a certain cardinalization scheme. In this study, only cardinal data will be dealt with.

Usually, input data might not be presented in a purely numeric form. In data acquisition, possibly heterogenous data types are given. In the landfill selection problem, for example, it is difficult to determine the risk of air pollution in a numeric form because such a risk is a foreseeable issue and will involve many unknown factors. However, an environmental expert might be able to evaluate the condition and describe it in an approximate range or verbal terms. These types of situations often appear with multi-criteria problems. To solve MADM problems with homogenous data type, two approaches can be used: (1) Data can be treated exclusively in order to form a set of uniform input parameters, and then classical MADM methods can be used to solve the problem; (2) MADM methods should be modified so that they are able to accept both qualitative and quantitative input parameters. Both approaches should lead to the same result, but the former one seems simpler and more efficient (Hwang et al. 1992).

Selecting a particular MADM method depends on the characteristics of a problem, and is also partly based on the decision maker's preference. In recent literature, common MADM methods include Simple Weighted Addition method (SWA), Analytic Hierarchical Process (AHP), Bayesian decision analysis, and different outranking methods such as ELECTRE and PROMETHEE. All these methods allow cardinal data as input parameters, which reflects that the decision maker would use MADM methods only when a certain degree of information is available. Among the methods, there is no research shown that any one of them will perform better than others, but there is much dissension about the "truthfulness" of the results. This is because, under different assumptions and constraints, inconsistent rankings between two MADM methods are possible. Since the result from one method might not be enough to provide confidence to the decision maker, it is suggested that more than one method be applied. If rankings from different MADM methods are similar, the highest ranked alternative is likely to be the most preferable one to a decision maker as it has the highest confidence level.

However, the situation is not always optimistic. The worst case scenario might occur when a variety of ranked orders exist. In this case, MADM aggregation can be used to analyze them. In this step, all rankings from MADM methods are aggregated for finding a consistent result. Three aggregation methods are introduced in order to increase the reliability of the outcome, which are the Average Ranking Procedure, the Borda method, and the Copeland method. Details of these methods are presented in later sections.

3.1.1 Multi-Objective Decision Making (MODM)

The difference between multi-objective decision making (MODM) and multi-attribute decision making (MADM) is briefly explained as follows. MODM methods deal with design and optimization problems, whereas MADM methods usually deal with selection problems. Mostly MODM methods evolved from the traditional linear programming. In general, MODM problems involve maximizing $p > 1$ objective functions defined over a set of feasible decisions. Mathematically, this problem is defined as:

$$\begin{array}{llll} \max & f_i(x) & i = 1, 2, \ldots, p & \\ s.t. & gj(x) \leq 0 & j = 1, 2, \ldots, m & \text{Eq. 3.1} \end{array}$$

where x is an n-dimensional vector of decision variables, $x \geq 0$; $f_i(x)$ are p distinct objective functions; and $g_j(x)$ are m distinct constraint functions.

This equation is also called the Multi-Objective Linear Programming (MOLP) model. Because of the conflicting nature of the given objectives, a single setting of the decision variables x will not maximize all of the objectives simultaneously. Instead, some solutions will be found that are good in dealing with some of the objectives but not in others, whereas other solutions would be better for a different subset of objectives.

3.1.2 Multi-Attribute Decision Making (MADM)

MADM refers to making decisions in the presence of multiple, usually conflicting, attributes. Problems for MADM are common occurrences that happen in every aspect of life. There are many MADM methods that have been developed in the past 20 years. According to Hwang et al. (1981, 1992), these methods can be classified into a group of 17 MADM applications based on the type and salient features of information received from the decision maker as shown in Figure 3.4. Later, the taxonomy is modified by Hwang et al. (1987). Three applications were added and six applications were removed as shown in Figure 3.5. For example, LINMAP, the interactive SAW, and the MDS with ideal point belong to the same branch of the original taxonomy. However, these applications were removed mainly because they require pairwise comparison between two alternatives, which is more difficult to assess than the information on attributes. In Figure 3.5, applications are first categorized by the type of information received from the decision maker. If no information is given, the Dominance method is applicable. If information on the environment is given as either pessimistic or optimistic, the Maximin or Maximax method is applicable. If information on attributes is given, a number of approaches can be applied based on the salient feature of the information received from the decision maker. In Figure 3.5, the salient feature of information are reduced from six different types in the classical MADM approach to only three:

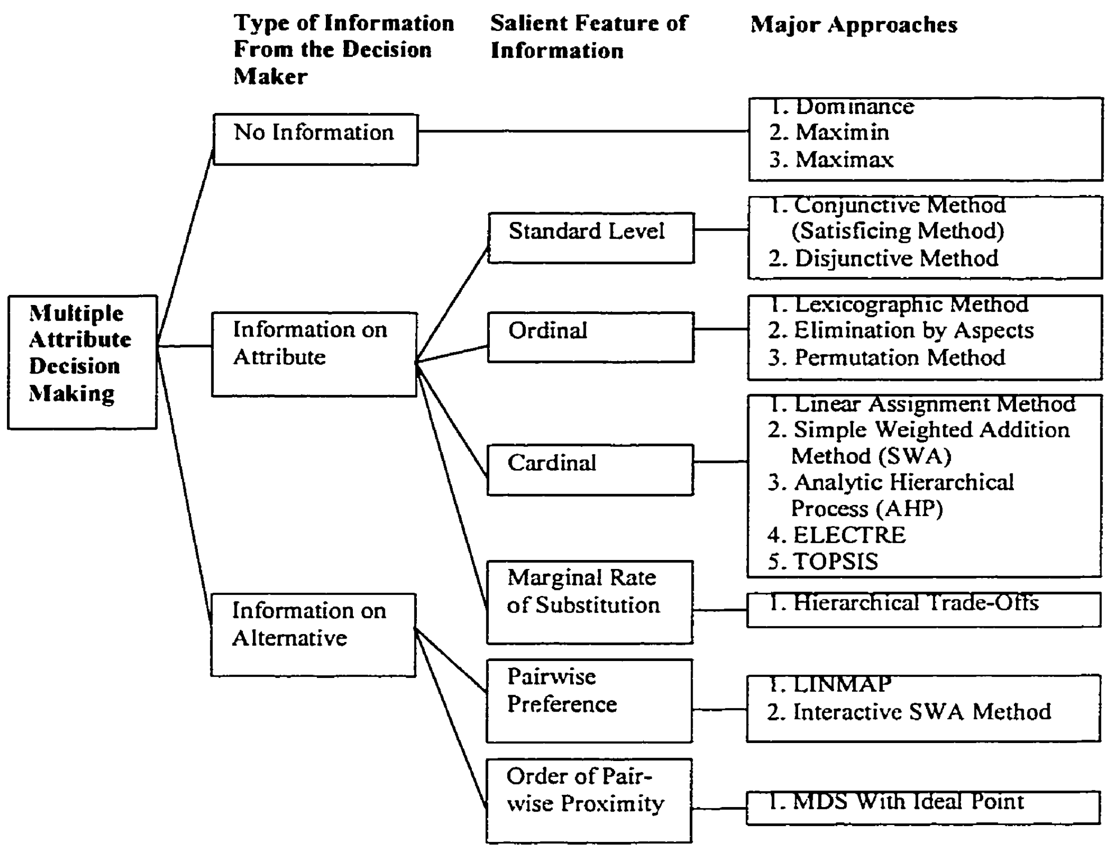

Figure 3.4 A taxonomy of approaches for classical MADM problems (Hwang et al. 1981)

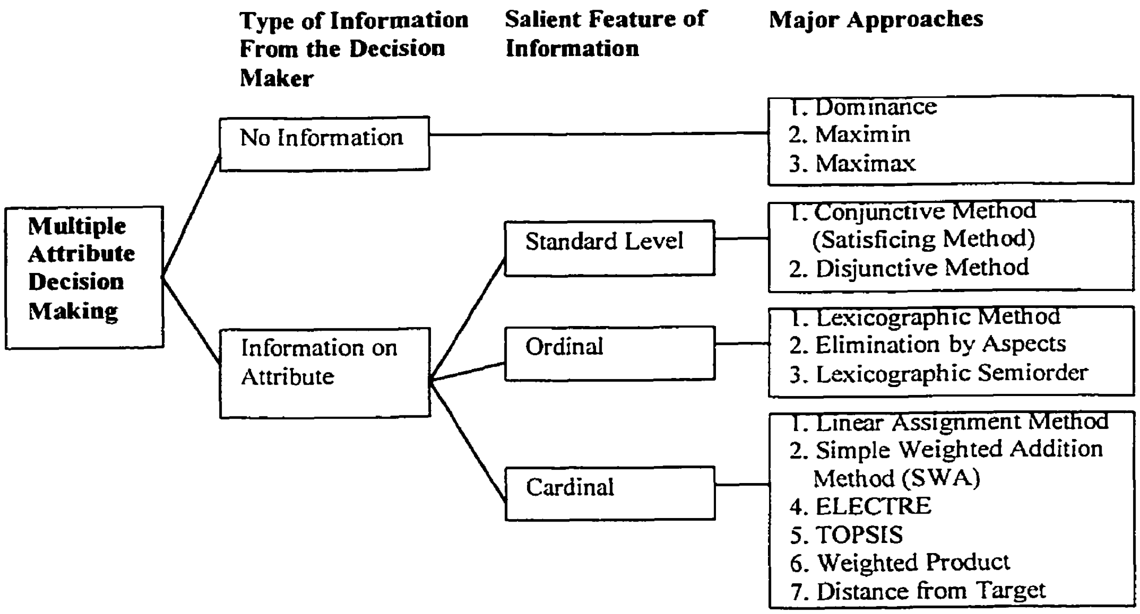

Figure 3.5 A new taxonomy of MADM approaches (Hwang et al. 1987)

- Standard level – which refers to the minimum acceptable value of data. In this category, decision maker only provides the minimum acceptable values for the attributes in the selection problem. If an alternative can satisfy the given requirements, it is then considered a feasible solution. Either Conjunctive Method or Disjunctive Method is used here.
- Ordinal data – which refers to the data that are given ranked orders. In this category, decision maker provides ordinal data on the attributes. Hence, the attributes or criteria are ranked in terms of the level of importance. The application will include Lexicographic Method, Elimination by Aspects, and Lexicographic Method.
- Cardinal data – which refers to the rated data. In this category, cardinal data on the attribute weights is provided. Decision maker assigns weights for the attributes to indicate their importance levels. Many applications have been developed for this situation, including Linear Assignment Method, Simple Weighted Addition Method, ELECTRE, TOPSIS, Weighted Product method, and Distance from Target method.

For further literature reference about multi-attribute decision making, please refer to the previous chapter where some related works are briefly outlined.

The main purpose of this study is to select a new landfill location that would minimize any environmental damages as well as net cost, and provide the most promising solution in terms of political and public concerns. According to the Phase 2 study (City of Regina, 1989), several possible landfill locations have already been proposed. Since a finite number of alternatives are considered, the study domain is restricted to solve only multi-attribute decision-making problems. In this study, cardinal data is expected to be elicited from the decision maker. Thus, all methods that are implemented in the Multi-Purpose Advisor (MPA) fall into the last category of cardinal data.

3.2 Fuzzy Set Theory

The well-known fuzzy set theory was initiated by Lotfi A. Zadeh (1965) to solve problems with uncertain descriptions of activities and observations. Fuzzy set is defined as a collection of objects (i.e. a set) whose elements have different degrees of belonging to the set. Basic definitions and set theoretic operations for fuzzy set can be found in Zimmermann (1997). Fuzzy set theory is developed for solving problems in which descriptions of activities and observations are uncertain. Wang (1997) has roughly classified fuzzy set theory into five major branches as shown in Figure 3.6. These branches are:

1. Fuzzy mathematics, where classical mathematical concepts are extended by replacing classical sets with fuzzy sets;
2. Fuzzy logic and artificial intelligence, where approximations to classical logic are introduced and expert systems are developed based on fuzzy information and fuzzy reasoning;
3. Fuzzy systems, which include fuzzy control and fuzzy approaches in signal processing and communications;
4. Uncertainty and information, where different kinds of uncertainties are analyzed; and
5. Fuzzy decision-making, which considers optimization or satisfaction problems with soft constraints.

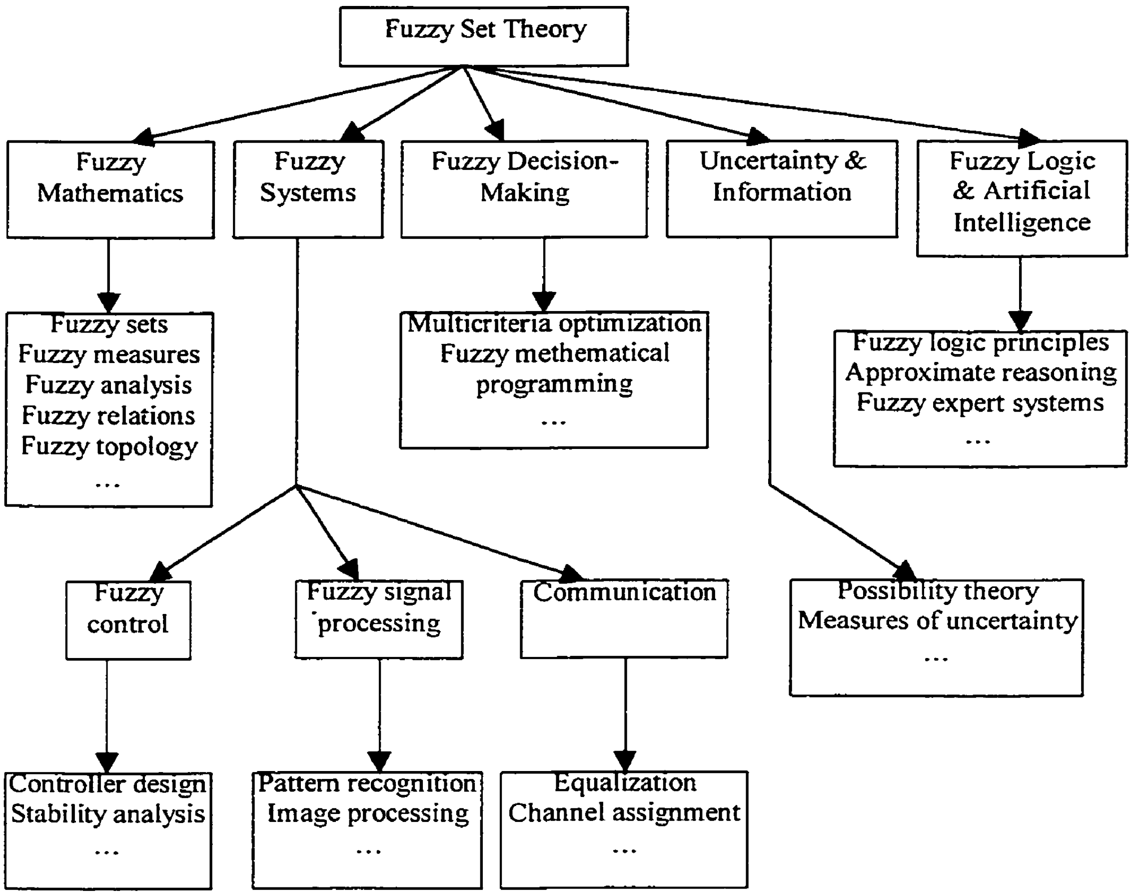

Figure 3.6 Classification of fuzzy set theory (Wang 1997)

These five branches are not independent and there are strong interconnections among them. For example, fuzzy multi-criteria decision support system (MCDSS) is in the class of fuzzy decision-making that deals with satisfaction problems, and it uses the concept from fuzzy mathematics (i.e. fuzzy sets). In this section, the concept of the fuzzy set theory is introduced in order to clarify how it is used in the system.

The fuzzy set theory can be adapted to solve decision-making problems with uncertainty. In general, uncertain data can be categorized into three types (Hwang et al. 1992):

- Imprecise data – the given data is represented in approximate form. For example, the statement of "the maximum speed of a car is about 240 km/h" provides a blurred definition of the car's speed in which the actual speed may either be 238 km/h or 242 km/h;
- Range data – the exact value is not defined for range data; instead, it is known to fall into certain intervals; and
- Linguistic terms – the data that cannot be represented with any scientific measurement, but rather it can only be represented in verbal terms such as "high", "low", and "medium".

Among them, linguistic terms are always encountered in the practical process of data acquisition because human subjective judgment is involved. For example, with the landfill selection problem one of the major criteria for choosing a new location is the risk of groundwater contamination. Some locations may suffer more serious contamination and others less. However, there is no recorded measure for predicting the risk level of groundwater pollution if a landfill is built. Only the linguistic terms are given for an impact analysis. In this case, the analyst might consider using a fuzzy MADM method, such as Kwakernaak's approach (1979), the approach of Cheng et al. (1980), and Chen et al.'s Left and Right Scores (1989). These methods were proposed to solve problems which involve fuzzy data. Nevertheless, those methods are complex, which is a disadvantage. The arithmetic of fuzzy sets requires much more calculation steps and time, and they are not easily understood by the decision-maker or the analyst. None of these fuzzy MADM approaches is suitable for solving problems with more than ten alternatives associated with more than ten attributes (Hwang et al. 1992). Also, some of the methods require all impact values to be presented in the fuzzy format, even though they are crisp in nature. Such an assumption is actually ill defined because it implies that all data in the impact matrix should be based on human judgment, but precise data should not involve subjectivity. In addition, conversion from crisp data into fuzzy format will increase the computational requirements. Thus, many fuzzy MADM methods are used only in academic research and not applicable to real applications. In order to cope with this problem, Nijkamp et al. (1990) and Hwang et al. (1992) suggest that input parameters containing fuzzy information can be converted into crisp values first before applying any MADM methods. Separating fuzzy MADM method into a two-phased procedure can avoid cumbersome computations and many classical MADM methods can be used. The overview of this approach is shown in Figure 3.7.

Applying the fuzzy set theory for fuzzy input transformation includes two steps as shown in Figure 3.8. First, the linguistic-term conversion is performed to convert the verbal

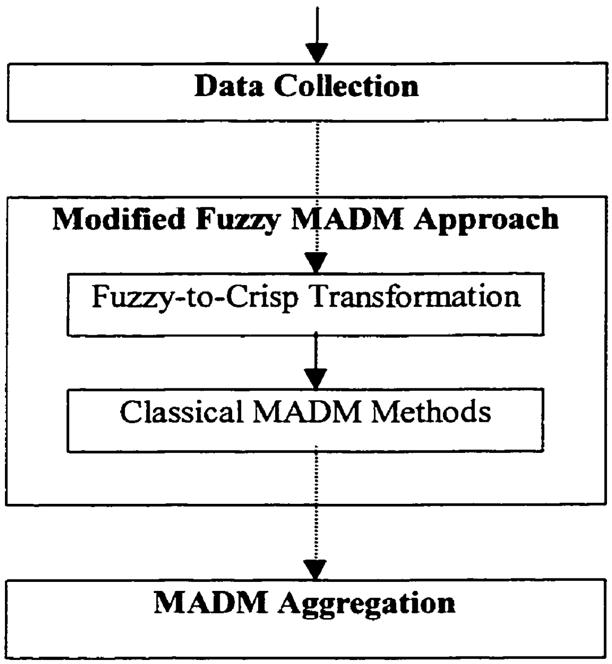

Figure 3.7 Two-phased approach of fuzzy MADM methods.

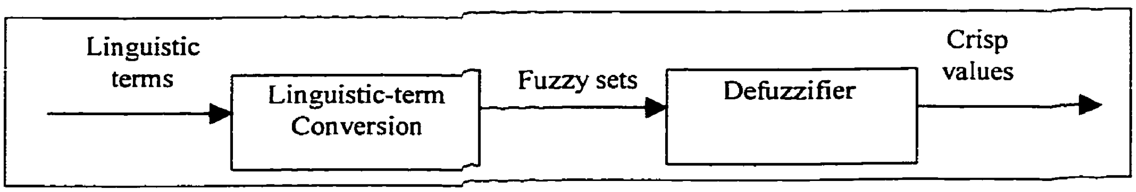

Figure 3.8 Fuzzy-to-Crisp transformation.

terms into a fuzzy set. A fuzzy set is a class of objects with a continuum of membership grades (Zadeh 1965). A membership function is associated with each fuzzy set which assigns to each object a grade of membership. Usually, the membership grades are in [0,1]. When the grade of membership for an object in a set is one, this object is absolutely in that set; when the grade of membership is zero, the object is absolutely not in that set. Precise membership grades do not convey any absolute significance (Hwang et al. 1992). They are context-dependent and can be subjectively assessed. The second step of the input transformation is to convert the fuzzy set into a crisp value. The crisp value is then used as the cardinal data in impact analysis. Usually this conversion is done by taking the fuzzy mean value from the fuzzy set. Cheng et al. (2000) proposed a method of determining the fuzzy mean value according to the α-cut of the fuzzy set. Hwang et al. (1992) also provided a good example by modifying Jain's (1976, 1977) and Chen's (1985) fuzzy ranking approaches. In this thesis, Hwang's approach is adapted for calculating the fuzzy impact values.

3.3 Systematic Fuzzy-to-Crisp Transformation

Many MADM methods are designed for numerical inputs only. In reality information might not always be available in numerical form due to influences of many external factors; and unfortunately, for example, there is not yet a clear measurement for determining the risk of groundwater contamination for a landfill location. Also, people do not provide a recordable value for their preferences in political and public issues. To deal with fuzzy inputs, different fuzzy MADM approaches are proposed as mentioned in the previous section, but most of them have the problem of cumbersome computations.

To address the problem, Nijkamp et al. (1990) and Hwang et al. (1992) suggest the sequential processing between the use of fuzzy data and MADM methods. By using this approach the difficulties mentioned above can be avoided; as well, MADM problems can be meaningfully and efficiently solved in a fuzzy environment. The basic assumption of the proposed approach is that the MADM problem may contain fuzzy and crisp data. In the case of fuzzy data, this study will focus on linguistic terms, but the concept may be extended to other types of data, i.e. imprecise data and range data.

3.3.1 Fuzzy Impact Transformation

The proposed fuzzy MADM approach is composed of two phases. The first phase is fuzzy impact transformation, which consists of two major steps: 1) linguistic-term conversion which transforms the impact values into a fuzzy set if they are verbal terms; and 2) conversion from a fuzzy set to a crisp value set where all the fuzzy sets are assigned crisp scores. The result of this phase is to produce a new impact matrix which only contains numeric data. In the second phase, classical MADM methods can be utilized to determine the ranking order of alternatives. In this section, the procedure of fuzzy impact transformation is described. Analysis of fuzzy to crisp data using MADM methods will be introduced in the next section.

3.3.2 Linguistic-Term Conversion

A numerical approximation system is proposed by Hwang et al. (1992) to systematically transform linguistic terms to their corresponding fuzzy sets. According to Hwang, the

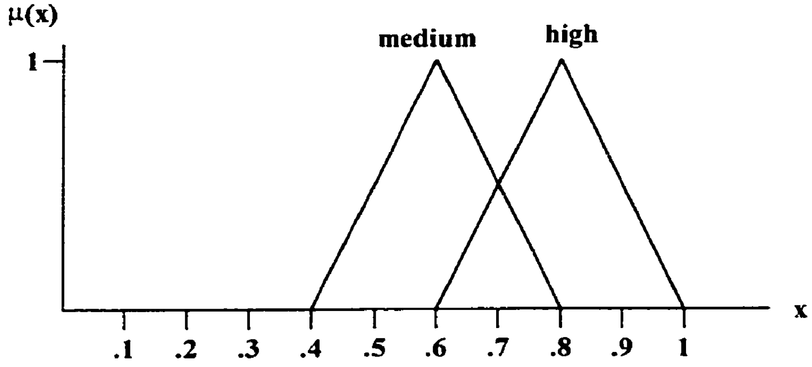

Figure 3.9(a) Scale 1 for the graph of membership function.

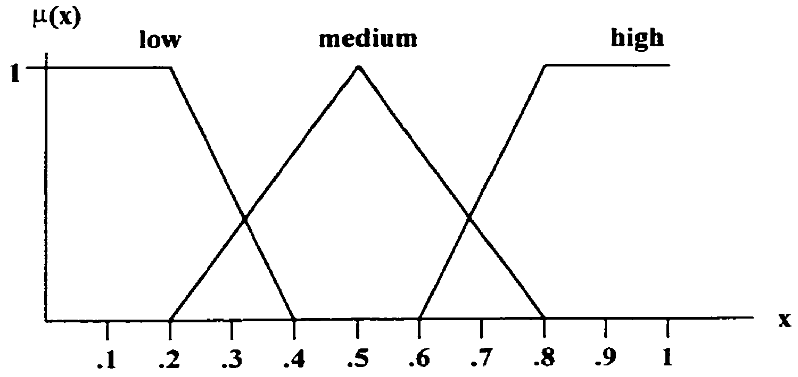

Figure 3.9(b) Scale 2 for the graph of membership function.

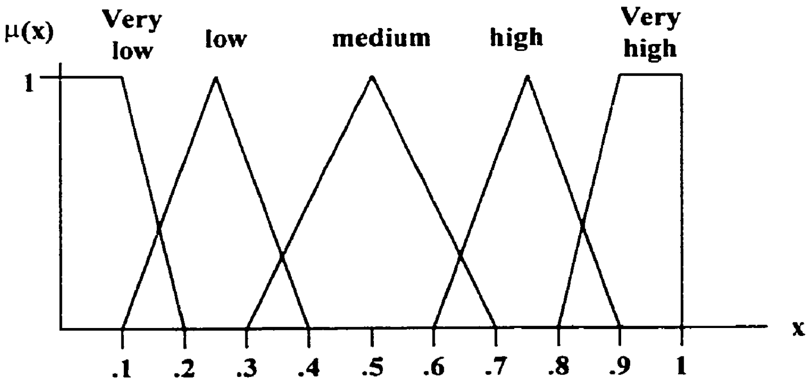

Figure 3.9(c) Scale 3 for the graph of membership function.

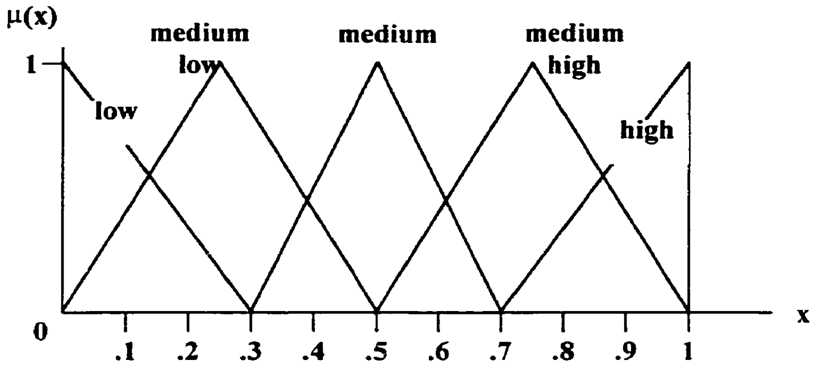

Figure 3.9(d) Scale 4 for the graph of membership function.

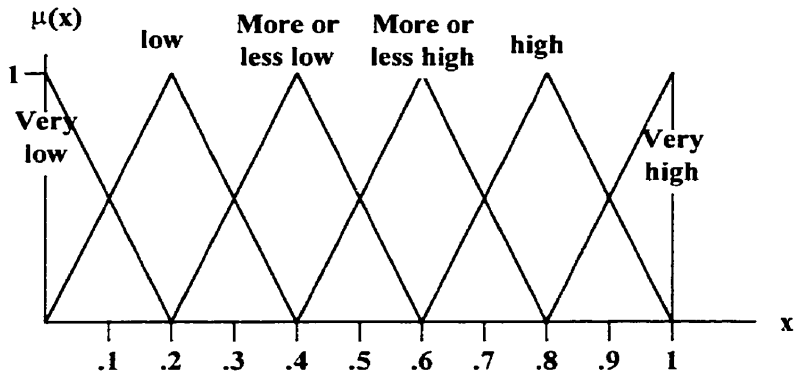

Figure 3.9(e) Scale 5 for the graph of membership function.

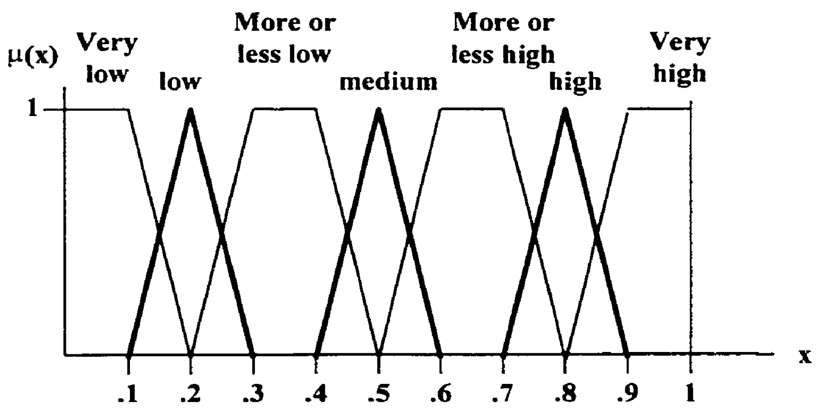

Figure 3.9(f) Scale 6 for the graph of membership function.

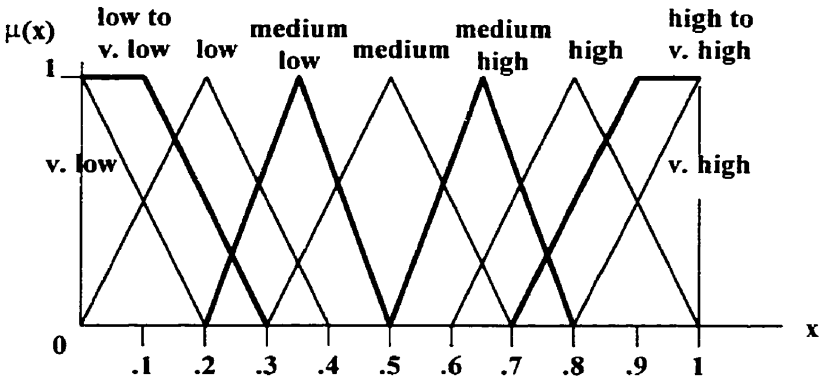

Figure 3.9(g) Scale 7 for the graph of membership function.

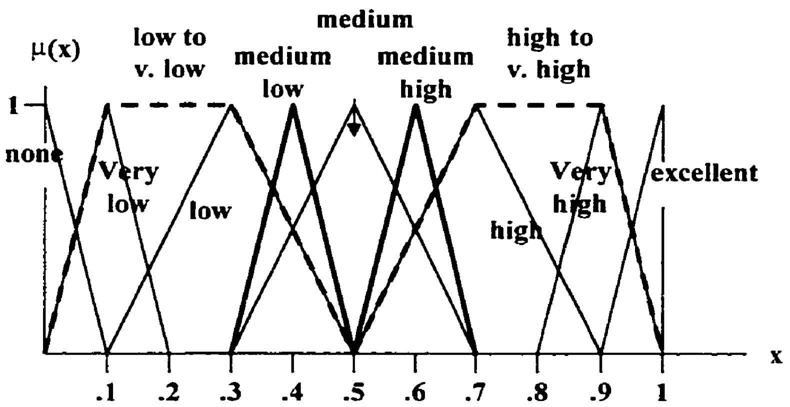

Figure 3.9(h) Scale 8 for the graph of membership function.

transformation requires eight conversion scales as shown in Figure 3.9(a) through 3.9(h). The conversion scales are proposed by synthesizing and modifying the work of Baas et al. (1977), Bonissone (1982), Chen (1988), Efstathiou et al. (1979), Efstathiou et al. (1982), Kerre (1982), and Wenstop (1976). It is assumed that the given figures can adequately cover all expressions of any specific feature – "high" vs. "low". One of the figures will be employed when certain terms are provided. The linguistic terms used in those conversion scales are summarized in Table 3.1. Note that even when the same term such as "high" is used, the fuzzy sets graphed are different from figure to figure. According to Hwang et al. (1992), this phenomenon occurs because the same linguistic term may possess different meanings for different occasions.

In the procedure of the linguistic-term conversion, the principle is to simply select a scale figure that contains all the verbal terms given by the decision-maker and use the membership function set for that figure to represent the meaning of the verbal terms. If the provided verbal terms exist in more than one figure, the simplest one should be picked. For example, given a set of terms "low", "medium", and "very high", Figures 3.9(c), 3.9(f), 3.9(g), and 3.9(h) are the nominee scales. However, Figure 3.9(c) should be selected because it contains all of the words and is the simplest one among the others. Similarly, if "more or less low" and "high" are used, Scale 4 should be selected. The verbal terms used in the eight scales are in the universe U = {"excellent", "very high", "high to very high", "high", "more or less high", "medium", "more or less low", "low", "low to very low", "very low", "none"}. This universe of verbal terms may be suitable to

Table 3.1 Summary of verbal terms used in the Multi-Purpose Advisor.

Scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No. of terms used	two	three	five	five	six	seven	nine	eleven
none								yes
v. low			yes		yes	yes	yes	yes
low-v. low						yes	yes	
low		yes	yes	yes	yes	yes	yes	yes
fairly low				yes	yes		yes	yes
mol low						yes		yes
medium	yes	yes	yes	yes		yes	yes	yes
mol high						yes		yes
fairly high				yes	yes		yes	yes
high	yes	yes	yes	yes	yes	yes	yes	yes
high-v. high							yes	yes
v. high			yes		yes	yes	yes	yes
excellent								yes

v.: very   med.: medium   mol: more or less describe objects (or attributes) such as cost, risk of groundwater contamination, and land value drop, but it may not be applicable to other attributes. For example, to describe the size of a landfill, the possible universe will be {"extremely large", "very large",..., "extremely small"}. This universe and the proposed one are totally different since the meaning of the terms "high" is different from that of "large". Similarly, the meaning of "low" is different from that of "small". To fill the gap, Hwang et al. (1992) suggests that the latter universe can be adjusted to fit the nature of attributes used in a decision problem. Therefore, "very large" can be treated in the same manner as "very high", and "small" as "low". Hwang also states that for any type of attributes, a pair of words can always be found that represents extreme meanings. More examples on pair of words with extreme meanings can be found in Osgood (1975) as well as in Table 3.2. Consequently, a universal linguistic term conversion can be performed in a systematic manner. Such characteristics guarantee the consistency of translating linguistic terms to fuzzy sets.

Not much research has been done to provide guidance for either setting an approximately correct fuzzy scale or determining the right number of conversion scales. Aside from the fact that the proposed scales may involve subjective judgments from Hwang and other researchers, there are still a number of advantages with this conversion method that makes it suitable to be applied in the MCDSS system. Mainly, this method allows any linguistic terms to be converted into a single measurable standard. The linguistic terms are not restricted to only "high" vs. "low" or "good" vs. "bad", but to many universes. Also, such a scale system is simple enough to be understood by the decision-maker, easy to use with the analysts, and still thorough enough for many real-world applications.

Table 3.2 Examples of linguistic universes.

General	**price**	**size**	**distance**	**weight**	**hazardous**	**technique**	**experiences**
high	expensive	large	far	heavy	dangerous	advanced	good
low	cheap	small	close	light	safe	basic	poor

3.3.3 *Conversion from Fuzzy Sets to Crisp Values*

The second step of a fuzzy impact transformation is to convert the fuzzy sets to crisp scores. Related works have been done by many researchers such as Hipel (1985), Hwang et al. (1992), and Cheng et al. (2000). In general, this conversion can be viewed as a searching method for the fuzzy mean value in a fuzzy set. With a set of membership functions as shown in Figure 3.9(a) through 3.9(h), a fuzzy mean value does not necessarily have to be the value which obtains the highest membership grade. In this section, a modified Left-Right scoring approach based on Jain's (1976, 1977) and Chen's (1985) works is introduced and followed by a simple example, which will make the context more understandable. The crisp score of a fuzzy set M is obtained as follows.

In order to determine a crisp score, it is necessary to compare the fuzzy sets with a maximizing fuzzy set (fuzzy max) and a minimizing fuzzy set (fuzzy min) (Hwang et al. 1992). These two fuzzy sets are defined as:

$$\mu_{\max}(x) = \begin{cases} x, & 0 \le x \le 1 \\ 0, & otherwise \end{cases}$$
$$\mu_{\min}(x) = \begin{cases} 1-x, & 0 \le x \le 1 \\ 0, & otherwise \end{cases} \qquad \text{Eq. 3.2 and 3.3}$$

The right score refers to the intersections of the fuzzy set M with the fuzzy max. The right score of M can be determined using:

$$\mu_R(M) = \sup_x[\mu_M(x) \wedge \mu_{\max}(x)] \qquad \text{Eq. 3.4}$$

Similarly, the left score of M can be determined using:

$$\mu_L(M) = \sup_x[\mu_M(x) \wedge \mu_{\min}(x)] \qquad \text{Eq. 3.5}$$

Given the left and right scores of M, the total score of M can be calculated using:

$$\mu_T(M) = [\mu_R(M) + 1 - \mu_L(M)]/2 \qquad \text{Eq. 3.6}$$

Figure 3.10 is used to show an example of determining the crisp score. This figure is similar to Figure 3.9(b). μ_{max} and μ_{min} are computed and presented as the two diagonal dashed lines respectively. Also, the membership functions of M_1, M_2, and M_3 are:

$$\mu_{M_1}(x) = \begin{cases} 1, & 0 \le x < 0.2 \\ \dfrac{0.4 - x}{0.2}, & 0.2 \le x < 0.4 \end{cases}$$

$$\mu_{M_2}(x) = \begin{cases} \dfrac{x - 0.2}{0.2}, & 0.2 \le x < 0.5 \\ \dfrac{0.8 - x}{0.2}, & 0.5 \le x < 0.8 \end{cases}$$

$$\mu_{M_3}(x) = \begin{cases} \dfrac{x - 0.6}{0.2}, & 0.6 \le x < 0.8 \\ 1, & 0.8 \le x < 1 \end{cases}$$

Using Equations 3.4-3.6, the total utility scores are calculated and summarized in Table 3.3. Consequently, the set of μ_{total} can substitute the original linguistic terms and impact matrix with only the crisp values that are formed.

3.3.4 Summary

Performing Fuzzy-to-Crisp transformation in a systematic manner is not an easy task. Hwang et al. (1992) proposed an intuitive algorithm to support such a conversion. The algorithm consists of two steps. For each fuzzy attribute, the linguistic expressions are

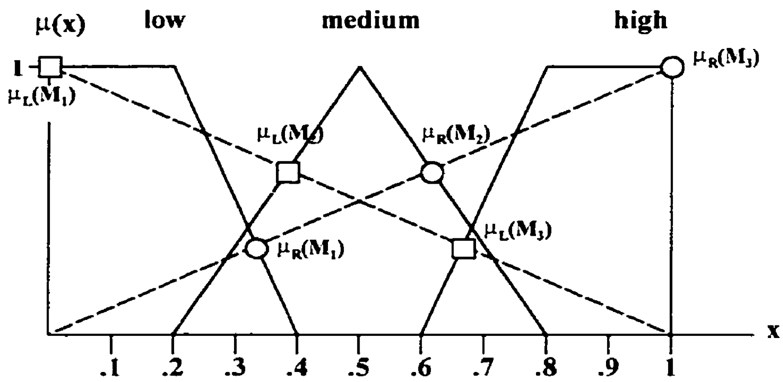

Figure 3.10 Illustration of determining crisp value.

Table 3.3. Sample determination of μ_{total}.

i	$\mu_R(M_i)$	$\mu_L(M_i)$	$\mu_T(M_i)$
1	0.333	1	0.167
2	0.667	0.667	0.500
3	1	0.333	0.834

first transformed into fuzzy sets. This can be done by matching the verbal terms with one of the conversion scales. If more than one scale is identified, the one with the fewest linguistic terms will be adopted. The process continues until all terms under every attribute have been converted to fuzzy sets. Then, crisp scores can be assigned to the fuzzy sets using Equations 3.4, 3.5, and 3.6. After the crisp impact matrix is obtained, the alternatives can be ranked by applying any of the MADM methods introduced in the next section.

3.4 Multi-Attribute Decision Making (MADM) Methods

MADM methods are management decision aids used in evaluating competing alternatives defined by multiple attributes. In this section, five MADM methods are adopted in the MCDSS system. The reason of applying these five methods in this study is because they use the same type of input parameters (i.e. impact matrix and weights), whereas other MADM methods use different ones. For example, the analytical hierarchical process (AHP) uses a set of tables by doing pairwise comparison of 2 alternatives. Since each of the five methods has different characteristics and applicability, their advantages and disadvantages are discussed here. However, before presenting the details of these methods, some basic concepts of decision weight and data normalization should be introduced first.

3.4.1 Weights

Almost all methods and MADM problems require information regarding the relative importance of each attribute, including the methods used in MCDSS. The relative importance is usually given by a set of weights which are standardized to a sum equal to one. Weight set is usually represented as follows:

$$W^T = (w_1, w_2, \ldots, w_n)$$
$$\sum_{i=1}^{n} w_i = 1 \qquad \text{Eq. 3.7}$$

where n represents the number of attributes, T represents the traverse form of a set and W^T is a set of weights with n attributes. The weights can be assigned by the decision maker directly, or by using some other methods such as the eigenvector method or the weighted least square method (Saaty 1977, Chu et al. 1979, Nijkamp et al. 1990). Similar to the problem of assigning impact values, a set of weights can be in either numeric or linguistic forms. In MCDSS, this problem can be solved by using the same concept of fuzzy-to-crisp transformation. Therefore, if a decision maker cannot assign weight in numeric form, a linguistic input is also allowed.

3.4.2 Normalization

According to Hwang et al. (1981), some methods such as ELECTRE and SWA method must apply the normalization method to normalize values in the impact matrix so that any effect introduced by different measurement units is neutralized. Normalization aims at transferring impact values into dimensionless units and providing a comparable platform for the attributes. In MCDSS, two ways of normalization are applied to cope with different MADM methods.

1. Linear Normalization

There are a few versions of linear normalization. The simplest one is to first define the maximum impact value of a certain attribute i. Then the normalized value r_{ij} of the impact matrix becomes:

For impact values of benefit attributes, (i.e. the larger x_i, the greater preference)

$$r_{ij}^{b} = \frac{x_{ij}}{x_i^{*}} \qquad \text{Eq. 3.8}$$

For impact values of cost attributes, (i.e. the smaller x_j, the greater preference)

$$r_{ij}^{c} = 1 - \frac{x_{ij}}{x_i^{*}} \qquad \text{Eq. 3.9}$$

where x_i^{*} is the maximum possible impact value, r_{ij}^{b} represents the impact values of the benefit for alternative j, r_{ij}^{c} represents the impact values of the cost attributes for alternative j, and $0 \le r_{ij}^{b} \le 1$, $0 \le r_{ij}^{c} \le 1$. However, Hwang et al. (1981) mentioned that these two equations over-simplify the normalization process and are not applicable when both benefit and cost attributes are under consideration. He suggested a modified process such that the normalized value r_{ij} can be defined as:

For impact values of benefit attributes,

$$r_{ij}^{b} = \frac{x_{ij} - x_i^{\min}}{x_i^{**} - x_i^{\min}} \qquad \text{Eq. 3.10}$$

For impact values of cost attributes,

$$r_{ij}^{c} = \frac{x_i^{*} - x_{ij}}{x_i^{*} - x_i^{\min}} \qquad \text{Eq. 3.11}$$

where $x_i^{*} = \max\limits_{j} x_{ij}$ and x_i^{min} is the least acceptable impact value of i attribute. The advantages of the definition of r_{ij} by Equations 3.10 and 3.11 are that the scale of measurement varies precisely from 0 to 1 for each attribute. The worst outcome of a certain attribute implies $r_{ij} = 0$, while the best outcome implies $r_{ij} = 1$. In the MCDSS system, Equation 3.10 and 3.11 are adopted.

2. Vector Normalization

   This procedure divides the impact value of each attribute by its norm, so that each normalized value r_{ij} can be calculated as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \qquad \text{Eq. 3.12}$$

   where m is the total number of alternatives. This implies that all attributes have the same unit length of vector. The advantage of this normalization is that all criteria are measured in dimensionless units, thus facilitating inter-attribute comparisons. This process is utilized in the ELECTRE and TOPSIS methods.

The five MADM methods that the MCDSS system adopts include Simple Weighted Addition, Weighted Product method, Cooperative Game Theory, TOPSIS, and ELECTRE. Note that the input parameters (i.e. weight and impact matrix) for these methods are presumably numeric. As mentioned in the previous section, if any set of the inputs consists of fuzzy values or linguistic terms, fuzzy transformation can be used to defuzzify them into crisp values before applying the MADM methods.

3.4.3 Simple Weighted Addition (SWA) method

The SWA method is the simplest MADM method to handle cardinal data (Hwang et al. 1981). Since it is easy to use and easily understood by the decision maker, this method is widely used in many fields. First linear transformation is applied which normalizes the impact matrix. For each alternative, a utility value U_j is determined by multiplying the normalized impact value of each alternative by its importance weight. Then summation is taken of these products. Mathematically, the utility function can be written as:

$$U_j = \sum_{i=1}^{n} w_i r_{ij}, \qquad j = 1,2,\ldots,m \qquad \text{Eq. 3.13}$$

where w_i is the importance weight of the attributes and r_{ij} is the normalized impact matrix. After the utility values are computed for each attribute, the alternative with the highest score (the highest weighted average) is the most preferable one for the decision makers.

The underlying assumption of the SWA method is that attributes are preferentially independent. Therefore, the importance weight of one attribute is not influenced in any way by the weight of another attribute (Fishburn, 1976). Simplicity and ease of use are the main advantages of this method, however, a few disadvantages of using SWA can easily be found. Since complementarity often exists among attributes, the assumption of preferentially independent may be unacceptable, and ignoring the dependence among attributes may cause a misleading result (Hwang et al. 1992). In addition, the greatest disadvantage of this method and of its type (e.g. Linear Assignment method and Hierarchical Additive Weighting method) is that they tend to be ad hoc procedures with little theoretical foundation to support them.

3.4.4 Weighted Product (WP) Method

In the SWA method, addition among impact values was allowed only after the different measurement units were transformed into a dimensionless scale by using linear normalization. However, this transformation is not necessary if attributes are connected by multiplication (Yoon et al. 1995). The WP method was introduced long ago and has been advocated in the last twenty years by Starr (1972) and Yoon (1989). When we use multiplication among impact values, the weights become exponents associated with each impact values; a positive power for benefit attributes, and a negative power for cost attributes. Formally, the utility value U_j of each alternative is given by:

$$U_j = \prod_{i=1}^{n} x_{ij}^{w_j}, \qquad j = 1,2,\ldots,m \qquad \text{Eq. 3.14}$$

where w_j is the importance weight of the i^{th} attribute and x_{ij} is the impact value of the j^{th} alternative. Using this method, the alternative with the largest utility value is considered the most preferable one to the decision maker. Theoretically, the utility value may become infinite due to the characteristic of multiplication. The underlying purpose of this method is to heavily penalize alternatives with poor impact value. The distance between the utility values of the most and second most preferable alternatives would be greater than that derived from SWA method. Although WP method possesses a sound logic and a simple computational process, it has not yet been widely utilized.

3.4.5 Cooperative Game Theory (CGT)

Another method that is similar to the WP method is the Cooperative Game Theory (CGT) developed by Szidarovszky et al. (1978). The CGT may be described as the hybrid of the WP method and TOPSIS (see 3.4.6). It takes advantage of applying multiplication among impact values so that the utility values between two alternatives become more obvious. Conceptually, by using CGT the decision maker looks for a solution that would be as far away from the worst solution as possible. In this case, safety of the solution is guaranteed. CGT is not often seen in the literature for multi-criteria decision-making methods. It was originally used to solve selection problems in corporate firms (Aoki 1984). Using CGT, the decision maker tries to search for the most suitable solution which maximizes the geometric distance from the worst solution. To define a worst solution, the decision maker first specifies a set of minimal acceptable impact levels. Note that the minimal acceptable impact level may not necessarily exist for each attribute. For example, it is difficult for the decision maker to define what the minimal cost would be. If cost is considered as one of the attributes in a MADM problem, the decision maker must assume a minimal cost. One way to avoid this kind of assumptions is to use the worst impact value of each attribute. Given a set of non-dominant alternatives, the set of worst impact value, denoted as A^-, is defined as:

$$\begin{aligned} A^- &= \{(\min_j x_{ij} | i \in I), (\max_j x_{ij} | i \in I') | \ j = 1,2,\ldots,m\} \\ &= \{x_1^-, x_2^-, \ldots, x_i^-, \ldots, x_n^-\}, \end{aligned} \qquad \text{Eq. 3.15}$$

where x_{ij} is the impact value of attribute i and x_i^- is considered as the worst outcome for each attribute. Once the worst solution is defined, the utility values U_i for each attribute can be measured by the following formula (Gershon, 1984).

$$U_j = \prod_{i=1}^{n} |x_{ij} - x_i^-|^{w_i}, \qquad j = 1,2,\ldots,m \qquad \text{Eq. 3.16}$$

where w_i is the importance weight for each attribute. After calculating the utility values, the most preferable alternative can then be defined as the one with the greatest utility; and the result is given by ranking the values in descending order.

Applying a game theory for MADM problems is not a rare case since its concepts and logics of dealing with decision-making problems are common to other MADM methods. For instance, Lau (1996) adopted CGT to the refinement process in the solvent selection system and he stated that CGT could generate a "safe" and low-risk solution for the system. In fact, the rank order produced by CGT provides the most conservative solution for the decision maker, but this characteristic may cause a problem. Due to the fact that multiplying any value by zero equals zero, using CGT will automatically screen out all the alternatives that carry at least one worst impact value. Even if those alternatives might result in better outcomes (impacts) in other attributes, they still will not be considered.

3.4.6 TOPSIS

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a technique that is developed by Hwang et al. (1981). They explain that a MADM problem may be viewed as a geometric system. The m alternatives that are evaluated by n attributes are similar to m points in the n-dimensional space. Therefore, the most preferable alternative should satisfy a condition such that it has the "shortest distance" from the positive-ideal solution and the "longest distance" from the negative-ideal solution. Comparing to CGT, which only takes into account the negative-ideal solution, this method thoroughly visits the available data that are targeted in the MADM problem.

The procedure of determining utility value for each alternative using TOPSIS is shown as follows:

1. First, the impact matrix needs to be normalized so as to render the attributes into dimensionless values environment for inter-attribute comparison, this can be done by using Equation 3.12.

2. A set of weights is selected to form a weighted normalized impact matrix of v_{ij} such that:

   $$v_{ij} = w_i r_{ij}, \qquad i = 1,2,\ldots,n; j = 1,2,\ldots,m \qquad \text{Eq. 3.17}$$

   where w_i is the weight of the attribute i.

3. After v_{ij} is calculated, ideal solution A^* and negative-ideal solution A^- need to be defined as follows.

   $$\begin{aligned} A^* &= \{(\max_j v_{ij} | i \in I), (\min_j v_{ij} | i \in I') | \; j = 1,2,\ldots,m\} \\ &= \{v_1^*, v_2^*, \ldots, v_i^*, \ldots, v_n^*\}, \end{aligned} \qquad \text{Eq. 3.18}$$

   $$\begin{aligned} A^- &= \{(\min_j v_{ij} | i \in I), (\max_j v_{ij} | i \in I') | \; j = 1,2,\ldots,m\} \\ &= \{v_1^-, v_2^-, \ldots, v_i^-, \ldots, v_n^-\}, \end{aligned} \qquad \text{Eq. 3.19}$$

   where I represents the number of benefit attributes and I' represents the number of cost attributes.

4. Once the ideal and negative-ideal solutions are computed, the utility value U_j of each alternative j, which is defined as the relative closeness to the ideal solution (Hwang et al. 1981), can be calculated.

   $$S_j^* = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_j^*)^2}, \qquad j = 1,2,\ldots,m \qquad \text{Eq. 3.20}$$

$$S_j^- = \sqrt{\sum_{i=1}^{n}(v_{ij} - v_j^-)^2}, \qquad j = 1,2,\ldots,m \qquad \text{Eq. 3.21}$$

$$U_j = S_j^- / (S_j^* + S_j^-), \qquad j = 1,2,\ldots,m \qquad \text{Eq. 3.22}$$

where S_j^* is the distance between the impact values of alternative j and the ideal solution, S_j^- is the distance between the impact values of alternative j and the worst solution, and $0 < U_j^* < 1$.

Finally, the alternatives can be ranked according to U_j in descending order and the one with maximum utility value is the most preferable solution. Similar to the advantages of using the SWA method, TOPSIS is a simple and an easily comprehensible method for the decision maker. However, there is a situation where TOPSIS cannot determine a clear solution for the decision maker. Consider a MADM problem with only two attributes that can be presented as a geometric problem in a two-dimensional space (Hwang et al. 1981) as shown in Figure 3.11. The ideal and negative-ideal solutions are defined as P^* and P^-, respectively. Assume that there are two alternatives, P_1 and P_2, which carry the same utility values. In such a case they are considered indifferent and no preferable alternative can be recommended. The decision maker can only choose an alternative by analyzing the trade-off according to their own judgment.

3.4.7 ELETRE with Complementary Analysis

The ELETRE (Elimination et Choice Translating Reality) method, also called an concordance analysis, originated in France (Roy 1968, 1971). It has been continually developed ever since 1968 by Van Delft et al. (1977), Voogd (1983), Crama et al. (1983)

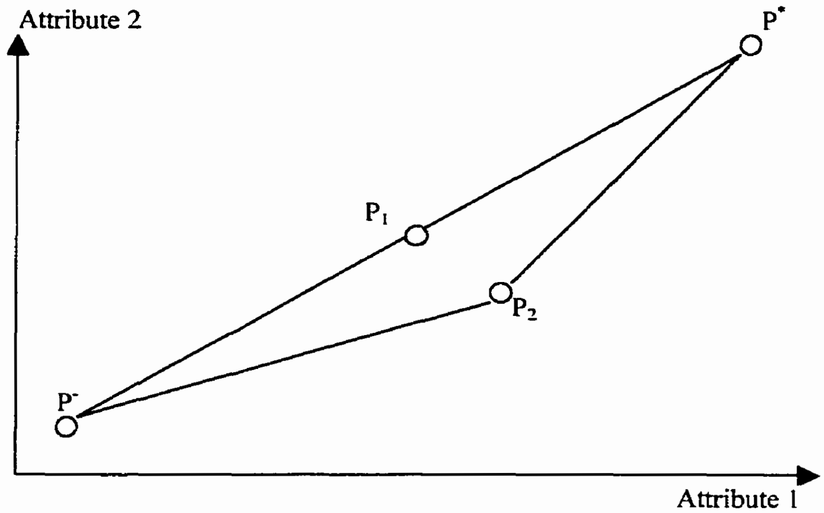

Figure 3.11 Euclidean distances to positive-ideal and negative ideal solutions in two-dimensional space.

and Roy et al. (1986). According to Nijkamp et al. (1990), the basic idea of ELETRE is that the ranking of alternatives is achieved by means of pairwise comparisons. Since the same alternative that is unsatisfactory according to one criterion can be compensated by satisfaction based on another criterion (Nijkamp et al. 1990), simple utility or summation functions may not be useful. Since ELECTRE consists of more computational steps than the previous methods, a brief example is given in Appendix A to illustrate how it is applied. The procedure of using ELECTRE is shown as follows:

1. In ELECTRE, first the weighted normalized impact matrix of v_{ij} is computed to provide a dimensionless environment. This step is the same as the first two steps described in TOPSIS, where $v_{ij} = w_i r_{ij}$.
2. The concordance set $C_{jj'}$ is determined for each pair of alternatives j and j'; i.e. the set of criteria (or attributes) in which the impact of alternative j is better than or equal to that of alternative j'. Similarly, a discordance set $D_{jj'}$ is defined which compares two alternatives in which alternative j performs worse than alternative j'.

   $$C_{jj'} = \{i \mid x_{ji} \geq x_{j'i}\}$$
   $$D_{jj'} = \{i \mid x_{ji} < x_{j'i}\} = I - C_{jj'} \qquad \text{Eq. 3.23 and 3.24}$$

   where x_{ji} and $x_{j'i}$ are impact values with attribute i and I is the set of attributes.
3. Once the concordance and discordance sets are found, concordance ($c_{jj'}$) and discordance ($d_{jj'}$) indices can be calculated respectively. The concordance index is equal to the sum of the weights associated with the i^{th} attribute which are contained in the concordance set. Hence, the formula is shown as follows:

   $$c_{jj'} = \sum_{i \in C_{jj'}} \frac{w_i}{\sum_{k=1}^{n} w_k} \qquad \text{Eq. 3.25}$$

where w_i is the weight of the i^{th} attribute and $0 \le c_{jj'} \le 1$. The concordance index reflects the relative importance of alternative j with respect to j'. A higher value of $c_{jj'}$ indicates that alternative j is preferred to j' as far as the concordance attributes are concerned. In addition, discordance index ($d_{jj'}$) can be calculated such that:

$$d_{jj'} = \frac{\max_{i \in D_{jj'}} | v_{ij} - v_{ij'} |}{\max_{k \in I} | v_{kj} - v_{kj'} |} \qquad \text{Eq. 3.26}$$

where v_{ij} and $v_{ij'}$ are the data in the normalized impact matrix and I is the set of attributes. Note that the information contained in the concordance matrix differs significantly from that contained in the discordance matrix, making the information content of $c_{jj'}$ and $d_{jj'}$ complementary (Hwang et al. 1981). Differences among weights are represented by means of the concordance index, whereas differences among attribute values are represented by means of the discordance index.

4. In the original ELECTRE method, concordance and discordance thresholds are assigned by the analyst in order to perform further comparison (Hwang et al. 1981). Usually the thresholds are set by taking the mean values of all $c_{ii'}$ and $d_{ii'}$. However, Hwang et al. (1992) and Nijkamp et al. (1990) pointed out that setting thresholds is rather arbitrary and can eventually yield only partial prioritization of alternatives. If the number of alternatives and criteria (or attributes) becomes large, finding critical threshold values would be much more difficult. To avoid this, Yoon et al. (1995) suggests that a complementary analysis can be applied with ELECTRE. First, the complementary ELECTRE defines the net concordance index c_j, which measures the difference between Z and Z', where Z is the sum of dominance of alternative j over

the other possible alternatives; and Z' is the sum of dominance of the other possible alternatives over alternative j. Formally, this is expressed as:

$$
\begin{aligned}
Z &= \sum_{\substack{j'=1 \\ j' \neq j}}^{m} c_{jj'}, \\
Z' &= \sum_{\substack{j'=1 \\ j' \neq j}}^{m} c_{j'j}, \\
c_j &= Z = Z'
\end{aligned}
\qquad \text{Eq. 3.27}
$$

Similarly, the net discordance index d_j measures the difference between $\overline{Z}$ and $\overline{Z'}$, where $\overline{Z}$ is the sum of weakness of alternative j in comparison to the other possible alternatives; and $\overline{Z'}$ is the weakness of the other possible alternative over alternative j. Formally, this is expressed as:

$$
\begin{aligned}
\overline{Z} &= \sum_{\substack{j'=1 \\ j' \neq j}}^{m} d_{jj'} \\
\overline{Z}' &= \sum_{\substack{j'=1 \\ j' \neq j}}^{m} d_{j'j} \\
d_j &= \overline{Z} - \overline{Z}'
\end{aligned}
\qquad \text{Eq. 3.28}
$$

Using Equations 3.27 and 3.28, sets of net concordance and discordance indexes are obtained. The most preferable alternative is defined as the one which consists of a highest value of c_j and a lowest value of d_j. If both of these conditions are not satisfied, an average ranking procedure should be used for further aggregation (Yoon et al. 1995). Average ranking procedure will be discussed in the next section. An advantage of using complementary ELECTRE is that the tradeoff among attributes is compensatory. It fully utilizes the information contained in the decision matrix. However, the major disadvantage is the complexity of the method. Since its computational procedures are quite elaborate, the amount of calculations can increase exponentially as the number of alternatives increases.

3.4.8 Summary

In this section, five different MADM methods have been introduced. These include SWA, WP, CGT, TOPSIS, and complementary ELECTRE. They are classical MADM methods that handle cardinal input parameters. Each of them has its advantages and disadvantages. In order to utilize each method's advantages and compensate their weakness, it is recommended to combine them to solve problems. Indeed, there is one method that has not been covered in this study, but which is also widely used—the analytic hierarchy process (AHP). AHP is a hierarchical SWA method developed by Saaty (1980). Many commercial systems have adopted this method for impact analysis. However, AHP requires much more subjective information from the decision-maker and data collection is sometimes difficult. Moreover, AHP uses a set of matrices to compare the impact of alternatives on each criterion, rather than using the impact matrix that has been introduced in this section. Implementing AHP in MCDSS would be problematic. Therefore, AHP is excluded from the MCDSS system.

Due to the different characteristics of the five MADM methods, the outcomes from applying them to solve a decision-making problem might be diverse. If the diversity is small, then the outcome is considered reliable. If the outcomes are inconsistent, further

Table 3.4 Determination of ranking index.

M_1	Most favorable set	Second most favorable	Third most favorable	Least favorable
Position	1	2	3	4
Alternative (A_j)	A_3	A_2	A_1, A_5	A_4
Average Index	1	2	3.5	5

aggregations have to be done. Different approaches of MADM aggregation are discussed in the next section.

3.5 MADM Aggregation

The MADM methods in the previous section try to simultaneously find a set of preference orders of alternatives. Due to the different conceptual assumptions of the methods, the set of orders may not be the same. Thus, three ordering techniques are introduced for further aggregation, which include the average ranking procedure, the Borda method, and the Copeland method. The average ranking procedure ranks alternatives according to their mean values, while in the other two methods ranking is done by voting. In this section, an example is given along with the methods to illustrate how to use them.

3.5.1 Average Ranking Procedure

The average ranking procedure is the simplest technique among the three aggregation methods. This technique is based on the concept of statistical calculation and ranks the alternatives according to the average rankings from the MADM methods. First the rank position of each alternative is taken as its index value. Table 3.4 shows an example of determining index values for 5 alternatives A_j with the rank order of $A_3 > A_2 > A_1, A_5 > A_4$. Note that A_1 and A_5 are in the same rank position, which means that they are not different from each another. In this case, their average index values are assigned as the mean number of their positions, which is $(3 + 4) / 2 = 3.5$. After that, the average index numbers are calculated. The summary of all index values from different MADM

Table 3.5. Summary of index values in Average Ranking Procedure.

	MADM Methods				**Mean Rankings**
	$\mathbf{M_1}$	$\mathbf{M_2}$	$\mathbf{M_3}$	$\mathbf{M_4}$	
$\mathbf{A_1}$	3.5	2	5	2	3.125
$\mathbf{A_2}$	2	3	4	4	3.25
$\mathbf{A_3}$	1	4	1	1	1.75
$\mathbf{A_4}$	3.5	5	3	5	4.125
$\mathbf{A_5}$	5	1	2	3	2.75

methods is shown in Table 3.5 and the mean ranking for each alternative is determined in the last column. According to these mean rankings, the alternatives are finally ranked in ascending order from smallest to largest. In the example shown in Table 3.5, the final rank order is A3 > A5 > A1 > A2 > A4.

3.5.2 Borda Method

The Borda method is based on the concept of voting. It compares each pair of alternatives separately and forms a NxN matrix. For each pair of alternatives A_j and $A_{j'}$, the number of votes is defined as the number of "supporting" methods in which A_j is more preferable than $A_{j'}$. For example, using the first 2 rows in Table 3.5, the numbers of votes for A_1 and A_2 are determined. According to methods M_2 and M_4, A_1 is better than A_2; while according to methods M_1 and M_3, A_2 is better than A_1. Hence, A_1 gets 2 votes from a set of methods $\{M_2, M_4\}$ compared with A_2. Conversely, A_2 has 2 votes from $\{M_1, M_3\}$ compared with A_1. Then a NxN matrix X is generated such that:

$x_{jj'} = 1$, if A_j receives more votes than $A_{j'}$,

$x_{jj'} = 0$, otherwise.

The resulting matrix using data from Table 3.5 is shown in Table 3.6. For example, it was determined that A_1 receives 2 votes compared with A_2, and A_2 also receives 2 votes compared with A_1. According to the rules for the matrix X, x_{12} and x_{21} are both 0 because the comparing alternatives A_1 and A_2 receive the same number of votes.

The last column S_j in Table 3.6 indicates the number of "wins" that A_j has received against other alternatives. It is calculated by summing the numbers in each row. Hence,

Table 3.6. NxN matrix used in Borda and Copeland methods.

	A_1	A_2	A_3	A_4	A_5	S_j
A_1	0	0	0	1	0	1
A_2	0	0	1	1	0	2
A_3	1	1	0	1	1	4
A_4	0	0	0	0	0	0
A_5	0	1	0	1	0	2
S'_j	1	2	1	4	1	

the alternative with the highest S_j is considered the most preferable. For example, according to Table 3.6 the rank order should be $A_3 > A_2, A_5 > A_1 > A_4$, where A3 is the most preferable because it has the highest summed value of 4.

3.5.3 Copeland Method

The Copeland method is another technique that is based on a voting concept. Indeed, this method is an extension of the Borda method. It is believed that the aggregation utility of A_j does not only depends on the number of "wins", but the number of "losses" also needs to be taken into account. The number of "losses", denoted as S'_j, is used to compensate the utility value of S_j. Using the previous example in Table 3.6, S'_j is calculated by summing the values of each column of the matrix. The aggregation utility is simply defined as the difference of S_j from S'_j. For example, the value of S_j and S'_j for alternative A_1 are both 1; therefore, the utility of A_1 is $1 - 1 = 0$. This is repeated for all alternatives. As with the Borda method, the Copeland method ranks the alternatives in descending order of their aggregation utilities from largest to smallest. The rank order in this example becomes $A_3 > A_5 > A_1, A_2 > A_4$.

Although using these aggregation methods may still result in inconsistencies among the rankings, some useful patterns can easily be observed by the decision-maker according to the analyzed information. In the above example, the rank orders of the average ranking procedure and the Copeland method are exactly the same, while the Borda method is slightly different from the others. However, it is still possible to conclude that $A_3 > A_5 > A_1 > A_4$ and $A_3 > A_2 > A_4$. If the decision-maker only looks for the most preferable solution, which is often the case in the real world, this conclusion is clear enough to suggest A_3 as the best choice.

3.6 Summary

This chapter focuses on solving MADM problems with fuzzy input parameters. Many methods have been developed in the past twenty years. However, some of them are applicable to certain situations because of their constraints; while others are not applicable to real-world problems because of their complexity. To avoid these problems, Hwang et al. (1990) suggested the separation of fuzzy inputs from MADM methods. The separation not only preserves the meaning of the original content (i.e. input parameters), but also improves the applicability of fuzzy MADM methods and reduces the amount of computation. In the case of the MCDSS system, five MADM methods are proposed in order to deal with decision problems. They aim at providing a consistent result on ranking alternatives in order to increase confidence of the decision. If the rank orders from all MADM methods are approximately the same, reliability of the result is increased. If the rank orders are significantly different, a procedure of MADM aggregation must be applied. Three methods have been introduced for MADM aggregation. If these methods cannot generate a satisfactory outcome, it can be concluded that the given alternatives cannot be compared.

4. Implementation of MCDSS

Based on the proposed fuzzy MADM methods that have been discussed in the last chapter, a multi-criteria decision support system called Multi-Purpose Advisor (MPA) is implemented to handle the decision problems with discrete alternatives. In this case, the MPA is used to deal with the landfill selection problem in Regina, where impact evaluation in a fuzzy environment must be performed. This system is implemented in Visual Basic 6.0, which is a graphical object-oriented development toolkit derived from the Basic language. The event-driven programming model makes it easy to learn and use by application developers. By providing a set of intrinsic visual tools, Visual Basic can help simplify the programming steps for a complex project and shorten the development time. In this chapter, the structural framework of the MPA system is provided. Each of the implemented components is described. After that, a walkthrough of the system is provided along with several screenshots to show how the MPA can be used.

4.1 Structural Framework of the Multi-Purpose Advisor (MPA)

A system framework has been constructed to explain how the fuzzy MCDA is implemented into the Multi-Purpose Advisor (MPA). In this framework, the MPA is divided into six modules as shown in Figure 4.1. These modules include Graphical User Interface (GUI), I/O and Process Controller, Data Validation, Fuzzy Set Module, MCDA Module, and Aggregation Module. Besides GUI, each of the modules consists of several

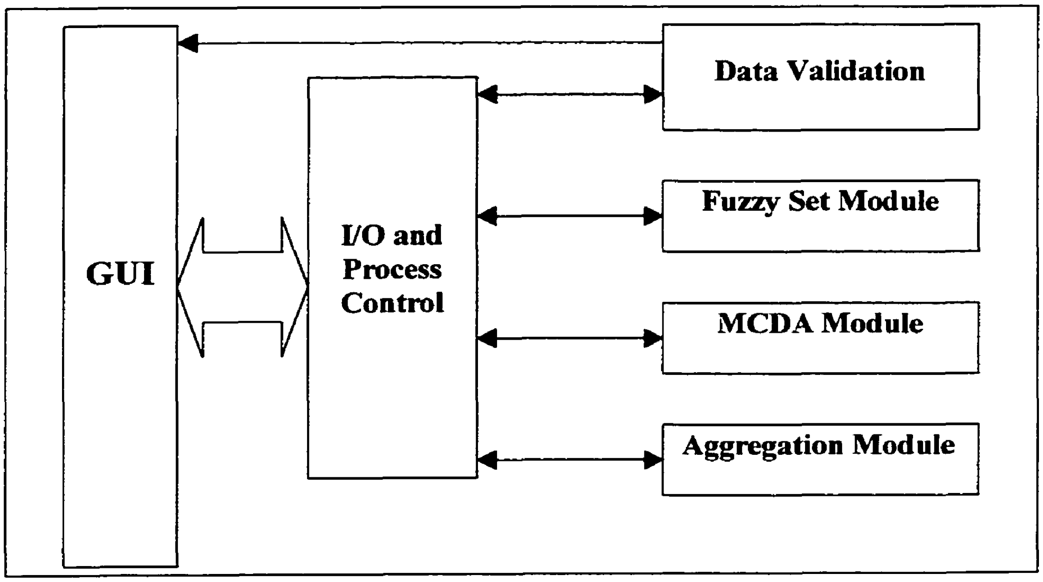

Figure 4.1. Structural Framework of the fuzzy MCDSS

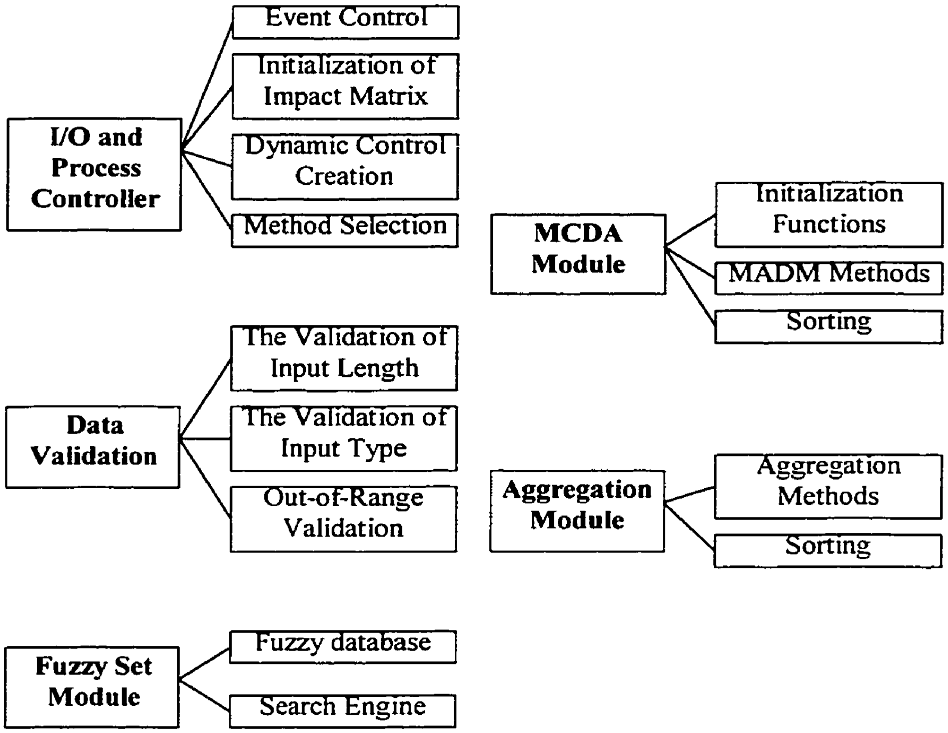

Figure 4.2. Main functional components for the modules

process components. A brief description for each module is presented in this section and their main components are presented in Figure 4.2.

4.1.1 Graphical User Interface (GUI)

Graphical user interface allows interaction between a user and the system. According to Eom (1999), many MCDSS developers have changed their focus from improving the analysis methods of the system to enhancing the visual functions of the system in order to improve the accuracy of input parameters. Such change of focus shows the importance of GUIs in contemporary society. In the GUI module of MPA development, instead of focusing on interpreting user's input using different graphical functions, our goal is to provide a simple and easy-to-use GUI to enhance user friendliness of the system.

4.1.2 I/O and Process Controller

This module represents the core of the system, which controls the flow of processes throughout program execution. It waits for user's input from GUI and performs the corresponding actions. Four main components are included in this module:

Event control – A function or procedure is invoked if an event is detected. An event refers to the moment when the user performs certain control action. For example, if the user "clicks" on a button or "changes" an input parameter, the event control will trigger the corresponding functions.

Initialization of impact matrix – Initializing an impact matrix requires three groups of information from the user, including the dimension of the matrix, the range and type of each criterion, and the range and type of the weight. After the system receives the above information, an object of impact matrix can be dynamically created.

Dynamic control creation – Some of the controls in the MPA are generated dynamically. Particularly, after the user has initialized the dimension of the impact matrix, the system needs to create a set of variables to hold the input parameter information. Different input data types require different variables. For instance, if the input parameter is numeric, a textbox should be provided for user's input. If the parameter is of linguistic type, a pull-down menu should be generated.

Method selection – Using the system, the user can choose different combinations of the MADM methods and aggregation methods. Since the result from the aggregation methods are based on the output from the MADM methods, selecting different combination of methods would greatly influence the final ranking order. Although in most cases, the user might want to apply as many methods as possible, selecting fewer methods can significantly shorten the computation time, especially when the problem is large. In the application case, all MADM methods are selected for solving the selection problem.

4.1.3 Data Validation

This module evaluates the user input and informs the user if the input data is invalid. For example, when the system requests the user for the size of criteria, the user is expected to input an integer within the range of 2 to 99 where this range is pre-set in the system. If the input provided is either not an integer or out of the given range, the system alerts the user by displaying an error message. The validation functions are grouped into three categories as shown in Figure 4.2. These functions include:

The validation of input length – It is used to check the number of characters or digits in the input to a control. Usually when the maximum length of input is reached, the remaining data input should be blocked out.

The validation of input type – In the system, the type of input parameter may be integer, float value, or string. If the user input includes data with invalid input type, an error message should be displayed to inform the user.

The out-of-range validation – When impact matrix and weights are initializated, the maximum and minimum values are set for each of the input parameters. The user is not allowed to provide data outside this range.

4.1.4 Fuzzy Set Module

Since the MPA system allows linguistic input from the user, the fuzzy set module plays an important role for interpreting those data. This module is used to transform the linguistic inputs into a set of crisp values which are acceptable by the MADM methods. The main components in this module include:

Fuzzy database – In order to perform fuzzy-to-crisp transformation, 8-scale membership function graphs are used to interpret the input data (Hwang et al. 1992). The procedure of transformation is mentioned in Chapter 3 and the scales are shown in Figures 3.10 to 3.17. To implement this transformation, a simple database is needed to store data that represents these membership function graphs.

Search engine – When linguistic inputs are involved, this search engine will be triggered to seek the matching numeric values. The search method consists of two steps. Given a set of linguistic terms, the engine first need to search from the fuzzy database for a membership function graph that is the most suitable one to describe these terms. Once the membership function graph is found, the engine will then match the terms to appropriate fuzzy sets so that a set of crisp values can be determined.

4.1.5 MCDA Module

This module is mainly composed of the classical MADM methods and the sub-functions that are involved for their computation. These functions are grouped into three different components described below:

Initialization functions – These include all the functions that have to be executed before applying each of the MADM methods. For example, when applying the Simple Weighted Addition (SWA) method, a linear transformation is required to normalize the impact matrix. Also, vector normalization is needed for both the TOPSIS and ELECTRE methods.

MADM methods – Given a numeric impact matrix and a weight vector, the MADM methods can determine a utility value for each of the alternatives. The detailed description of these methods is provided in Section 3.4.

Sorting – After computation, each MADM method generates a set of utility values. These values are sorted in either descending or ascending order according to the characteristics of the method. For instance, in SWA method the most preferable alternative is defined to be the one with the highest utility value; therefore, a descending sort should be used.

4.1.6 Aggregation Module

Similar to the MCDA module, a set of aggregation functions is stored here. This module consists of two components: 1) Aggregation methods and 2) Sorting. The aggregation methods analyze the outcomes of the MADM methods and try to combine them into one rank order. If the same ranking had resulted from the MADM methods, it would not be changed here. The sorting component consists of the same functions as those in the MCDA module. It re-arranges the order of alternatives based on the result from the aggregation methods.

4.2 Operation of the MPA system

In order to illustrate how the MPA system operates, a process flowchart is presented as shown in Figure 4.3. Using the MPA system is straightforward. When the system is executed, it first asks the user for the size of the MCDM problem. The user has to provide the number of alternatives and criteria considered in the problem. For example, Figure 4.4 shows that the problem consists of 12 alternatives and 11 criteria. Given such information, the system will dynamically generate a 11x12 impact matrix. Also, the user needs to decide which MADM methods he/she likes to use. The five MADM methods presented in Chapter 3 are included in the system. Once the selection has been made, the system will display another window for further initialization of the impact matrix.

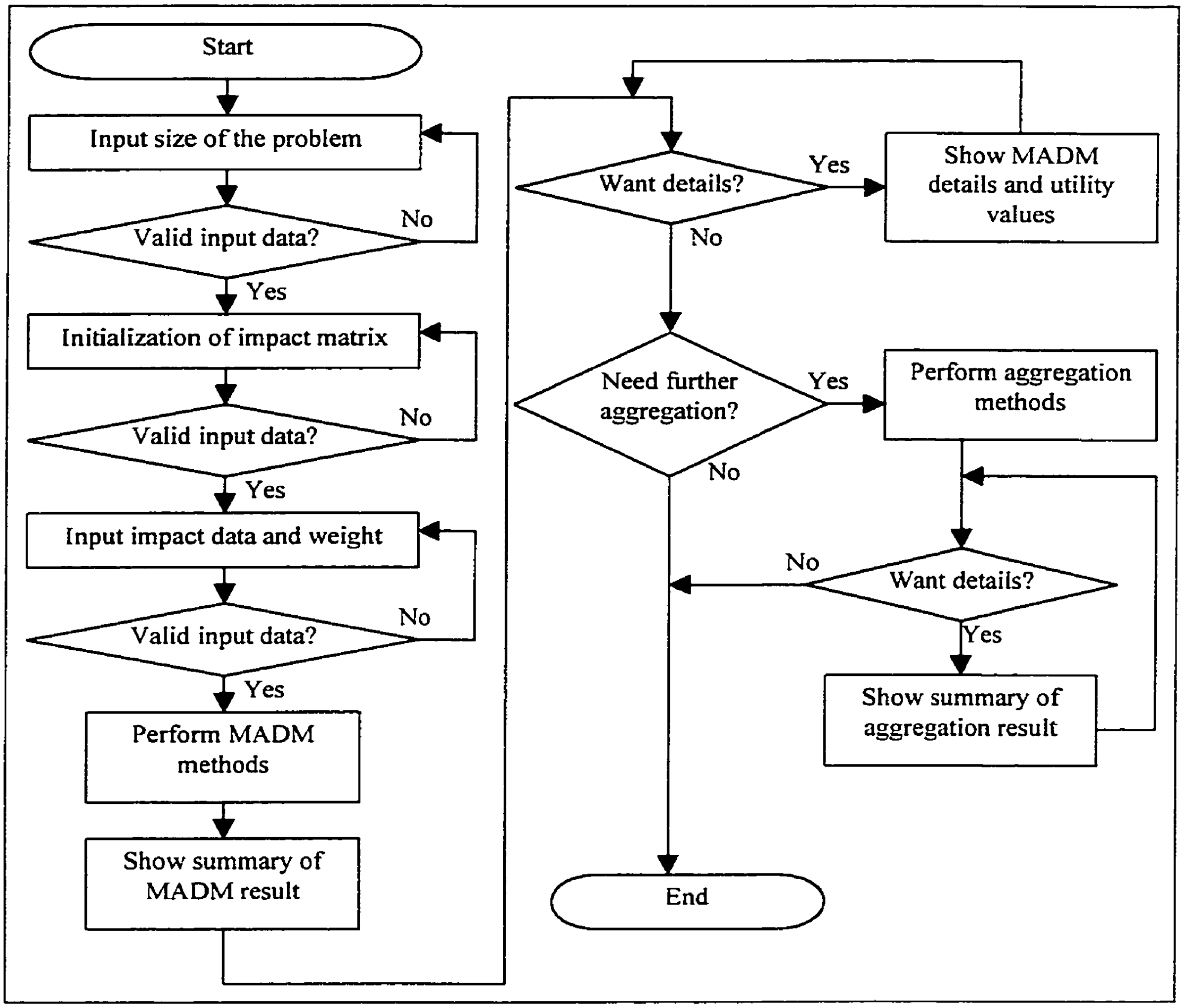

Figure 4.3. Process flowchart of the MPA system.

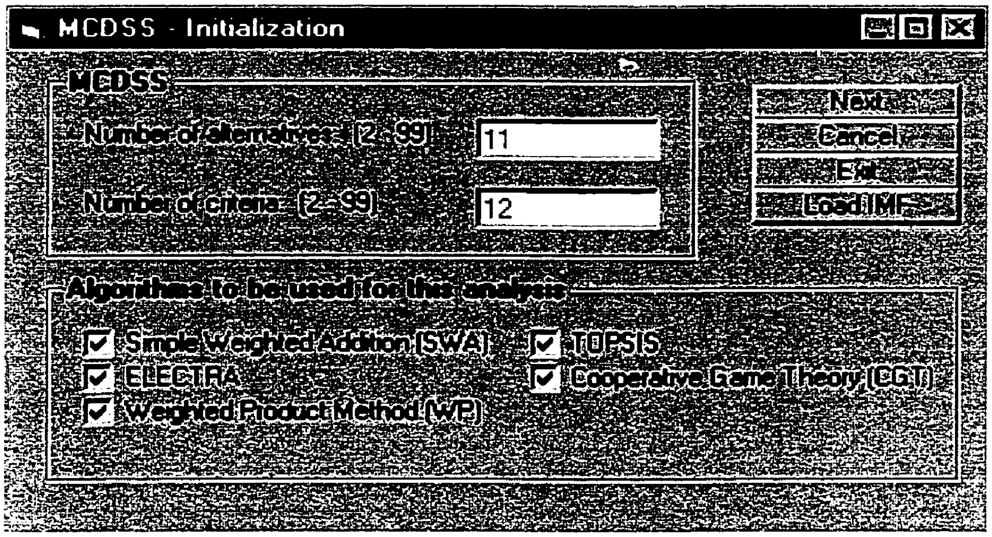

Figure 4.4. Initialization for the size of the problem.

Figure 4.5 and 4.6 show initialization of the criteria and alternatives, respectively. In Figure 4.5, the user has to specify the data type of the input parameters with respect to different criteria. Either "fuzzy number" or "real number" can be chosen here. If "real number" is selected, the user must specify the maximum and minimum values for the matrix inputs. If "fuzzy number" is selected instead, it means that the input parameters on this criterion are presented in linguistic terms. Hence, the pairing terms that express two extreme meanings with respect to the criterion must also be provided. For example, the "Public" criterion in Figure 4.5 has "low" and "high" as its pairing terms, while the hydrogeology (hydrogeo.) criterion uses "bad" and "good" as its pairing term. Figure 4.6 presents the next initialization window for the alternatives. Providing information in this window is optional but it helps to further clarify the alternatives. Under alternative, (25, 26) indicates a site section number which will be discussed in greater detail in Section 5.4.2.

After the initialization processes, an impact matrix is constructed and appears in the next window. As shown in Figure 4.7, the user can input impact values into the textboxes, or select different linguistic terms from the pull-down menus. The terms in the pull-down menus are generated systematically according to the information obtained from the criteria initialization. In addition, a short label is tagged to each input control to provide useful hints to the user. For example, in Figure 4.7 a label appears on the screen to show the valid range of the weight input, e.g. min = 1 and max = 100.

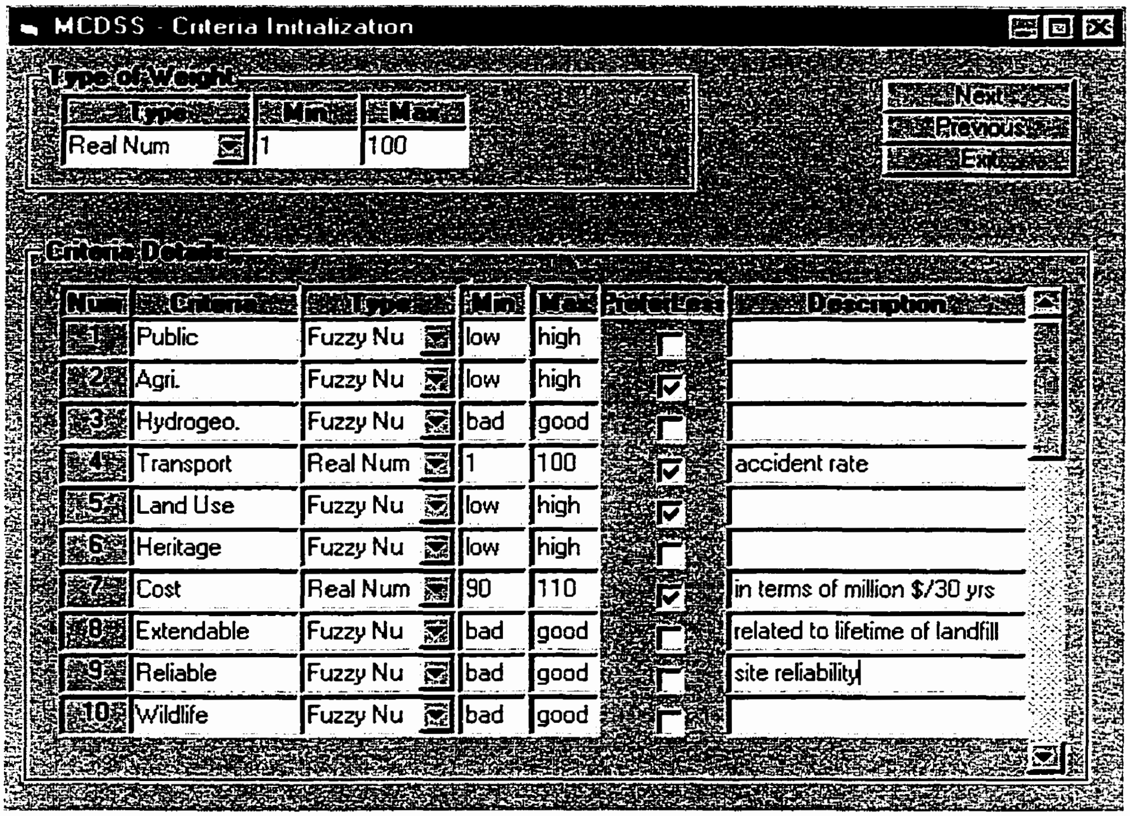

Figure 4.5. Initialization for the criteria of landfill selection.

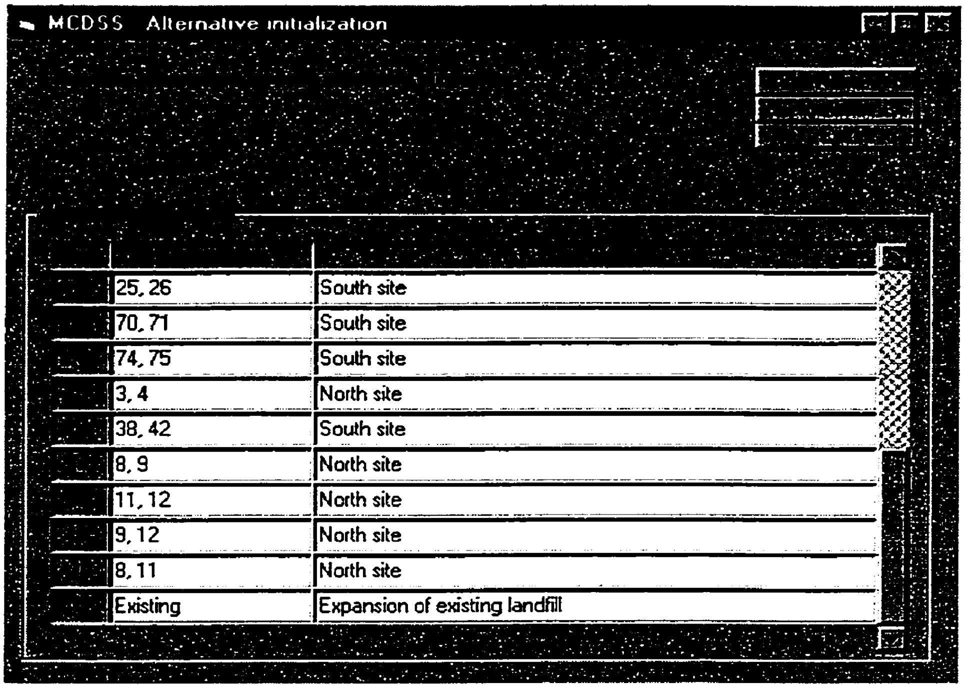

Figure 4.6. Initialization for the landfill-siting alternatives.

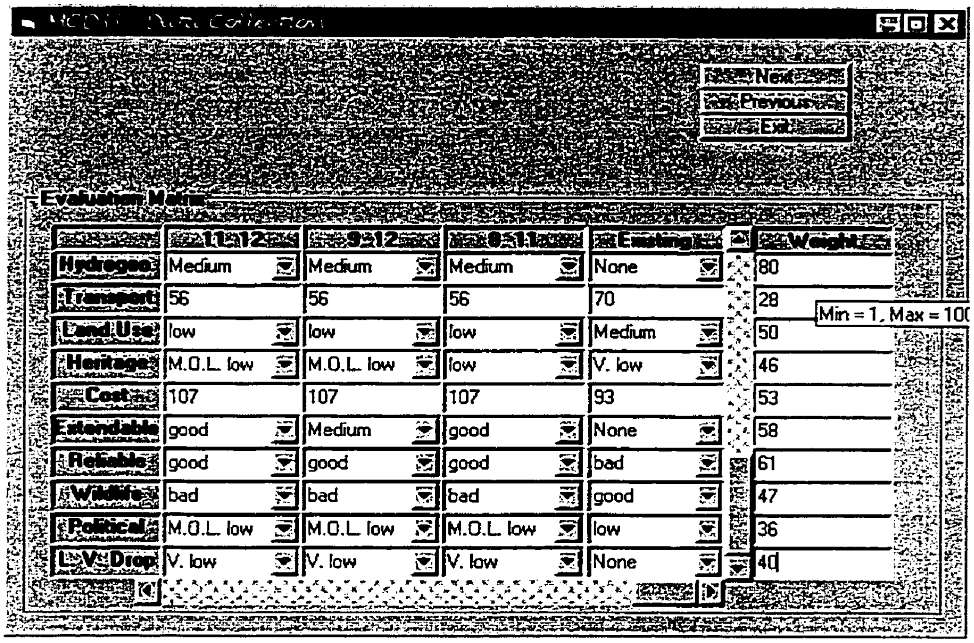

Figure 4.7. Inputs of impact matrix.

Once the input parameters are analyzed by the MADM methods, the result will be summarized as shown in Figure 4.8. In order to interpret the rankings in this figure, the user needs to understand the meaning of the following symbols.

"[n]" – This symbol indicates an alternative where n represents its index number.

">>" – This symbol implies the meaning of "is better than" or "is more preferable than", depending on the situation when the system is used.

"," – This symbol implies the meaning of "is in the same preference level as".

For example, Figure 4.8 shows that the ranking of SWA method is:

[6] >> [2] >> [1] >> [8] >> [10] >> [9] >> [3] >> [4] >> [7] >> [5] >> [11].

From this ranking, it can be found that the 6^{th} alternative is considered the most preferable one, whereas the 11^{th} alternative is the least preferable. Since using index numbers to indicate the alternatives might be confusing, an additional window is provided as shown in Figure 4.9 to present the resulting details for each method. The details include description for each alternative, its rank order using the MADM method, and the utility value after calculation.

Lastly, if the rankings from the MADM methods appear to be different from each other, further aggregation methods can be used. The aggregation result is presented in the window shown in Figure 4.10. Similar to Figure 4.8, this window shows a summary of the result from different aggregation methods, and the details of each ranking is presented in another window. Figure 4.10 also summarizes the methods that have been used throughout the impact evaluation. The details of the aggregation methods can be found in Chapter 3.

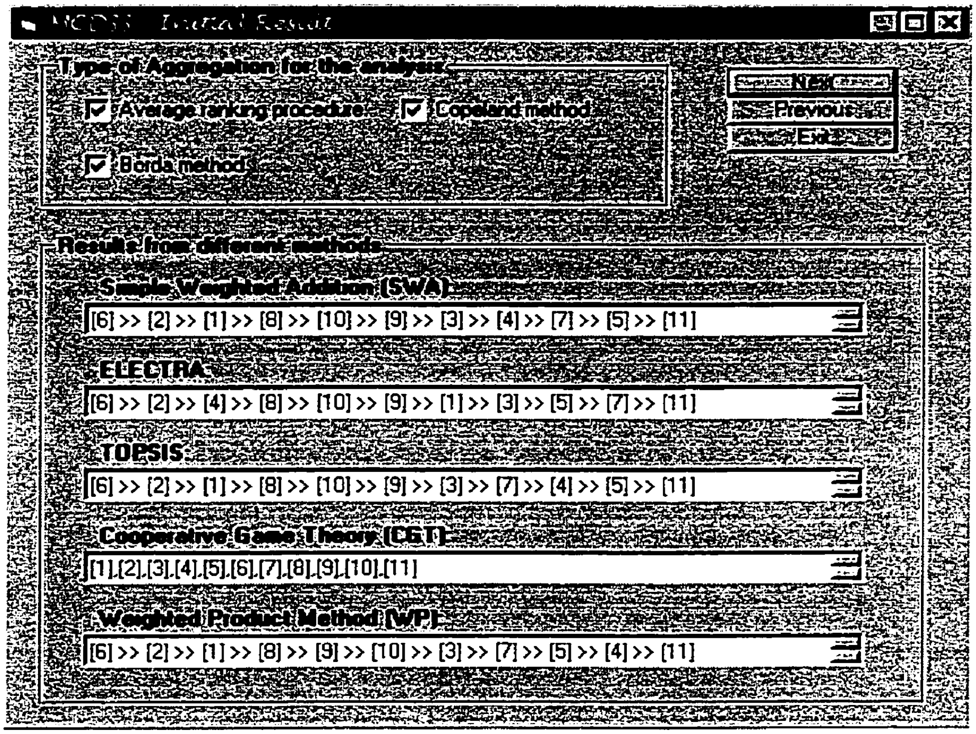

Figure 4.8. Results from different MCDM methods.

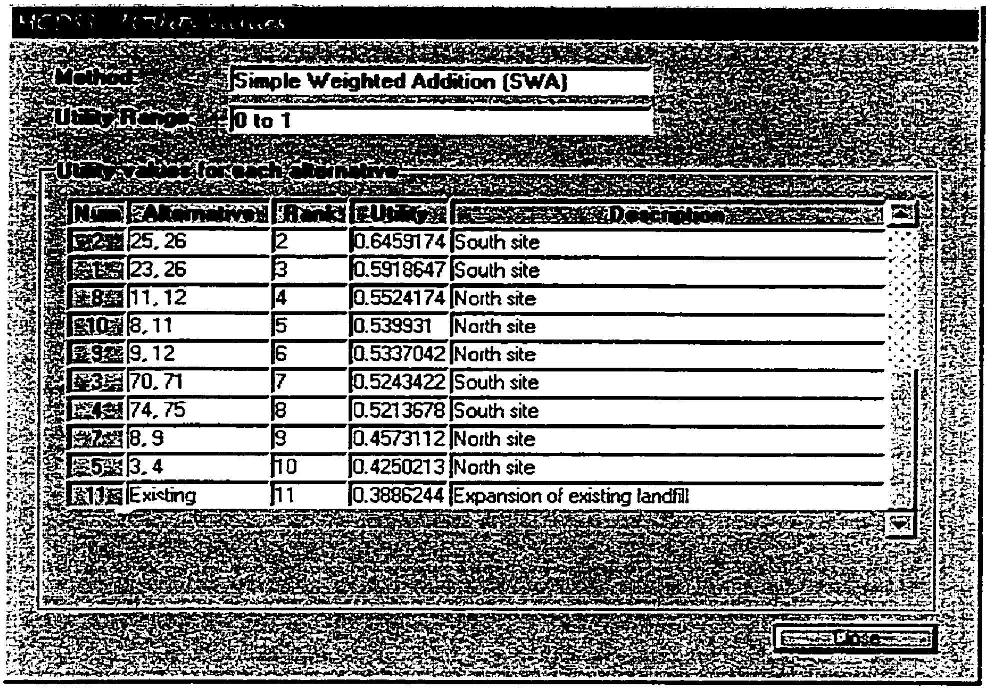

Figure 4.9. Utility values calculated for each alternative.

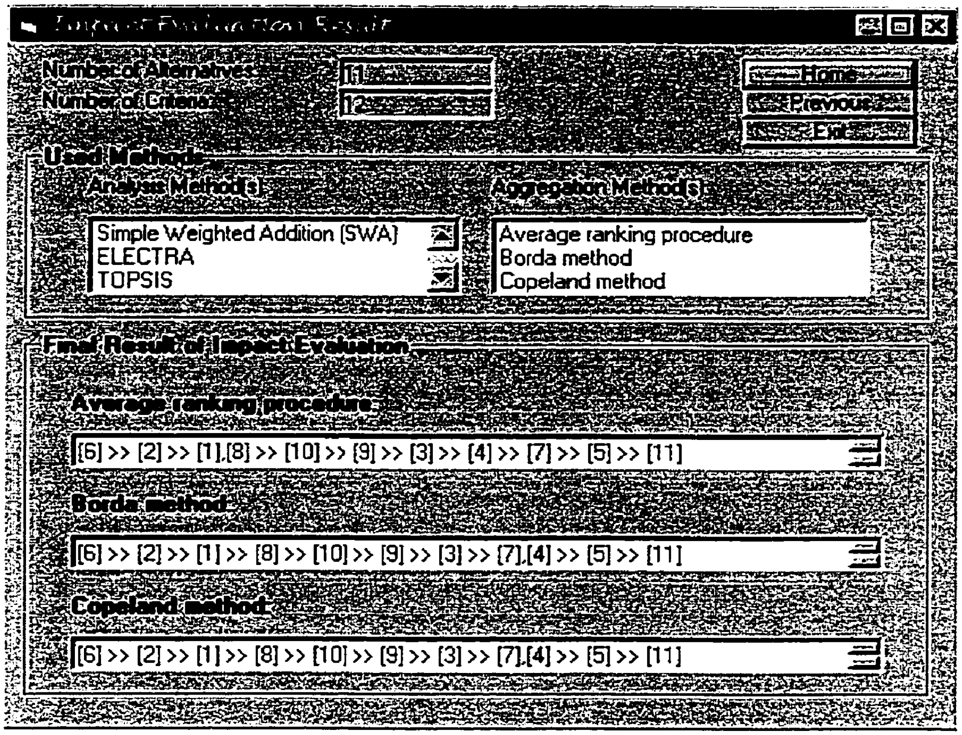

Figure 4.10. Results from different aggregation methods.

5. Application to Solid Waste Management in the City of Regina

5.1 Background

According to an estimation (City of Regina, 2000), the population in the City of Regina is about 187,500. There is only one landfill in the city, located northeast of Regina, to handle 138,750 tonnes of waste as of 1998. The waste generation rate is 0.74 tonnes/person/yr. Compared to that in 1988 (SERM 1999, City of Regina 1999), which was 1.23 tonnes/person/yr, the waste generation rate has been reduced by almost 40%. This fact alone proves that the city of Regina has done an exceptional job in solid-waste management. Since the early 1980's, the city has been concerned about the possible environmental impacts that the existing landfill may cause. Specifically, the existing landfill consists of two major problems -- the risk of contaminating groundwater and its limited capacity. In 1983, Phase 1 of the Regina Waste Management Study was completed to evaluate the existing landfill site and to find various alternative sites. Later, Phase 2 of the study which was conducted in 1986, aimed at re-evaluating the alternative landfill sites and provided recommendations in association with the new landfill location. Aside from the planning of a new landfill, the city of Regina has also promoted many programs to help reduce waste generation in order to prolong the lifetime of the existing landfill. These programs, some of which were promoted as early as 1990, include the Big Blue Bin paper recycling program, backyard composting, the Garbage Reduction Zero Waste program, and other similar special waste programs. Moreover, the city also targets the community education systems to help more people understand the importance of waste reduction. Further details on these programs are provided in the latter part of this chapter.

5.2 Groundwater Contamination

In general, the existing landfill confronts two major problems. First, the landfill is close to its maximum capacity and is going to expire within the next 10 years. It is essential that a new landfill be built before the expiry date. More importantly, the existing landfill has caused groundwater contamination because it is located on top of the Regina Aquifer. This problem has been addressed since the early 1980's. In 1981, a sensitivity analysis on the risk of aquifer contamination was conducted (City of Regina 1983) to evaluate impact of the existing landfill and other industrial activities. After 1984, a leachate monitoring well was installed at the existing landfill to collect the data on the groundwater quality, location, elevation and flow. In 1990, the Environmental Protection Branch initiated the Regina Aquifer Groundwater Monitoring Project (Ballagh, 1998). The project found that the existing landfill might be one of the sources of contamination in the aquifer. Ballagh (1998) also suspected that the landfill has contaminated the groundwater over the last thirty years and the contamination has become worse every year. In addition, this aquifer provides about 10% of drinking water for the residents in the city. If leachate leaks out of the landfill and results in groundwater contamination, the drinking water of both urban and rural areas will be seriously affected. Fortunately, even though the risk exists, no sign of significant groundwater pollution has yet been discovered.

5.3 Historical Data of SWM facilities in the City of Regina

In the past, the city of Regina has used different types of solid waste management (SWM) facilities. The landfill is the only one that has been available since 1884 (City of Regina 1999). The first disposal ground in Regina was developed in 1885, with a total area of 40 acres. It was in service until 1945. At the same time, a new site was opened and located at Mount Pleasant Park. The site was about 80 acres in size with waste being placed on about 55 acres. In 1961, the Mount Pleasant site was closed and the operation of the Fleet Street Landfill began. This landfill covers an area of approximately 240 acres (City of Regina 1999). The current landfill uses roughly 148 acres, with the adjacent property being used for agricultural purposes. Table 5.1 summarizes the total area and number of service years of these three landfills. Note that even though the second landfill was bigger than the first one in size, it was only in operation for 16 years. A reasonable conclusion can be drawn that the population growth rapidly increased during this time period. In addition, Table 5.1 shows that the approximate waste generation rate increases every year. However, the waste-filling ratio for the existing landfill has decreased slightly because many advanced techniques have been introduced in the last 50 years. For instance, a shredder system was built in 1974 with a capacity of approximately 20 to 30 tonnes per hour. This system can help increase the density of the garbage and lower the volume of the material going to the landfill. However, as a result of two explosions in the shredder in 1985 and 1986, it was closed down permanently.

Another facility that had been used in the City of Regina is the incinerator. In 1954, a new incinerator was built which was operated 24 hours a day, giving it a 95 tonnes per

Table 5.1. Solid waste disposal rates in the city of Regina.

	Year of Operation	Area (acres)	Years of Service (yr)	Waste Filling Ratio (acres/yr)
First Landfill	1885-1945	40	60	0.7
Second Landfill	1945-1961	55	16	3.4
Existing Landfill	1961-present	148	49	3.0

day capacity. It reduced the capacity of garbage to as low as 10% of its original size and helped extend the lifetime of a landfill. However, many problems occurred when using the incinerator. Mainly the toxic air that was vented from the incinerator and the residual remains produced serious air pollution. Consequently it was phased out in the 1980's because of both public rejection and environmental impacts. Due to consideration of the limited capacity in the existing landfill, different analyses on solid waste incineration have been conducted. In the Phase 2 study (City of Regina, 1989), different methods of incineration were evaluated by a cost-benefit analysis. The report stated that incineration required a higher cost and was not applicable to Regina. Later Jardine (1994) also prompted an investigation on re-evaluating the option of incineration in order to extend the lifetime of the landfill, and he concluded that incineration is economically not a viable alternative.

Besides the sanitary landfill, a recent trend of implementing SWM facilities has focused on waste diversion. Prior to 1990, there were limited recycling opportunities for residents. However, in the last several years, the city has undertaken a number of initiatives in recycling and waste diversion. These programs can be divided into two categories:

1. General recycling programs, which include:
   - Big Blue Bin program encompassing 12 locations that collect all forms of paper;
   - Backyard Composting that encourage residents to compost the organic waste in their backyard;
2. Special waste programs, which include

- Paint Disposal and Recycling program that collects paint and paint products for re-use;
- Household Hazardous Waste program that allows disposal of household hazardous materials in a safe manner.

The 4 programs are operated by the Solid Waste Division of the city of Regina and target the residential sector. A large component of these initiatives, as well as the general focus of the division, is public education. The education component is emphasized in the existing programs, and the division provides general information on recycling and diversion. Other programs that are introduced in the province include:

- Pesticide Container Collection program which provide Saskatchewan farmers with a system to collect and recycle used pesticide containers;
- Scrap Tire program which collect tires and recycles them from harmful waste into useful products;
- Beverage Container Collection and Recycling program which recycle the empty, non-refillable beverage containers made from aluminum, tin, plastic, glass and cardboard (aseptic);
- Used-Oil Recycling program collects used-oil and refines it into a product with the same original qualities.

The results of these waste diversion programs are encouraging and a significant amount of refuse is diverted into a variety of useful sources. Moreover, in 1999 an implementation of the Garbage Reduction Zero Waste was fully implemented in City Hall. The Department of Public Works was to "lead by example" and to develop work procedures on diverting products from the waste stream (City of Regina 1999). This program achieved a 350% increase in the diversion of fine office paper and a 50% reduction of solid waste generation.

Although various waste reduction programs have been implemented, the problems of groundwater contamination and limited capacity of the sanitary landfill still existed. The problem under consideration is whether we should develop a new landfill at another location, or expand the existing one. If new landfill development was to be considered, where should the new site be located that would cause the minimal adverse impact to the city? Applying the proposed fuzzy MADM methods can help solve this landfill selection problem.

5.4 MADM Initialization

5.4.1 Definition of Alternatives

Since a thorough investigation has already been done in the Phase 2 study (City of Regina 1989), the possible landfill locations are determined based on some of the results. This section explains how the possible sites are defined. Initially, 76 candidate areas were found. A screening process is performed to reduce the number of candidate areas to 11 alternatives for the impact evaluation using the proposed fuzzy MADM approach. In the study, the domain is restricted to approximately 16 km from the city of Regina municipal boundary because alternative sites beyond this boundary would provide few advantages and serious disadvantages in cost and access. Three major constraints were first considered in the screening process, which include:

- Hydrogeological suitability—this constraint aims at selecting an area where the problems of surface water and groundwater pollution are minimal.
- Airport restrictions—this constraint is set according to Transport Canada's guidelines and restrict landfills to areas beyond 8 km of a jet port to prevent bird hazards to the aircraft.
- Urban development—this constraint restricts a landfill to be located outside the urban areas to avoid any land use conflicts and to minimize disruption to local residents.

After exclusion of certain areas according to these constraints, the remaining areas were examined in order to identify potential sites. These areas are divided into a number of quarter sections and a list of factors was used to exclude undesirable quarter sections (City of Regina, 1989). These includes:

- Urban development—no residence on property; no urban or proposed non-compatible development within 500m;
- Natural environment—no major slough on property; no licensed well within 1000m
- Topography—no significant topographical features such as coulees, sloughs, and slopes on property;
- Utilities—no utility bisects property;
- Visual—at least 800m away from provincial highway;
- Access—at most 3.2km from provincial highway;
- Site size—at least a quarter section of area.

Initially, 76 quarter section sites were found that fit the requirements as shown in Figure 5.1 (a)-(d). These candidate sites are indicated as the shaded, numbered squares. Further screening process proceeded in order to reduce the number of candidates.

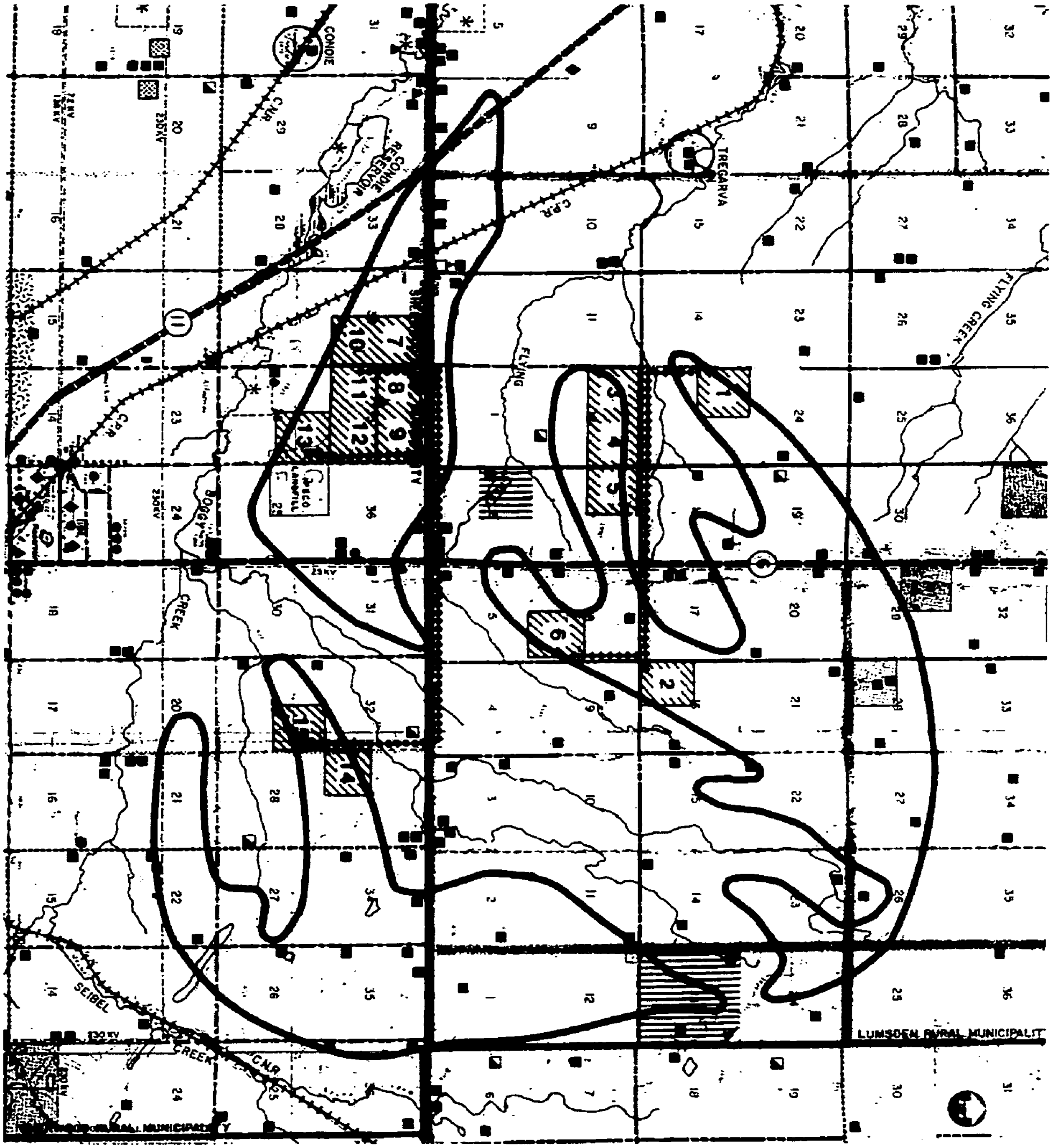

Figure 5.1(a) Potential landfill sites in the city of Regina.

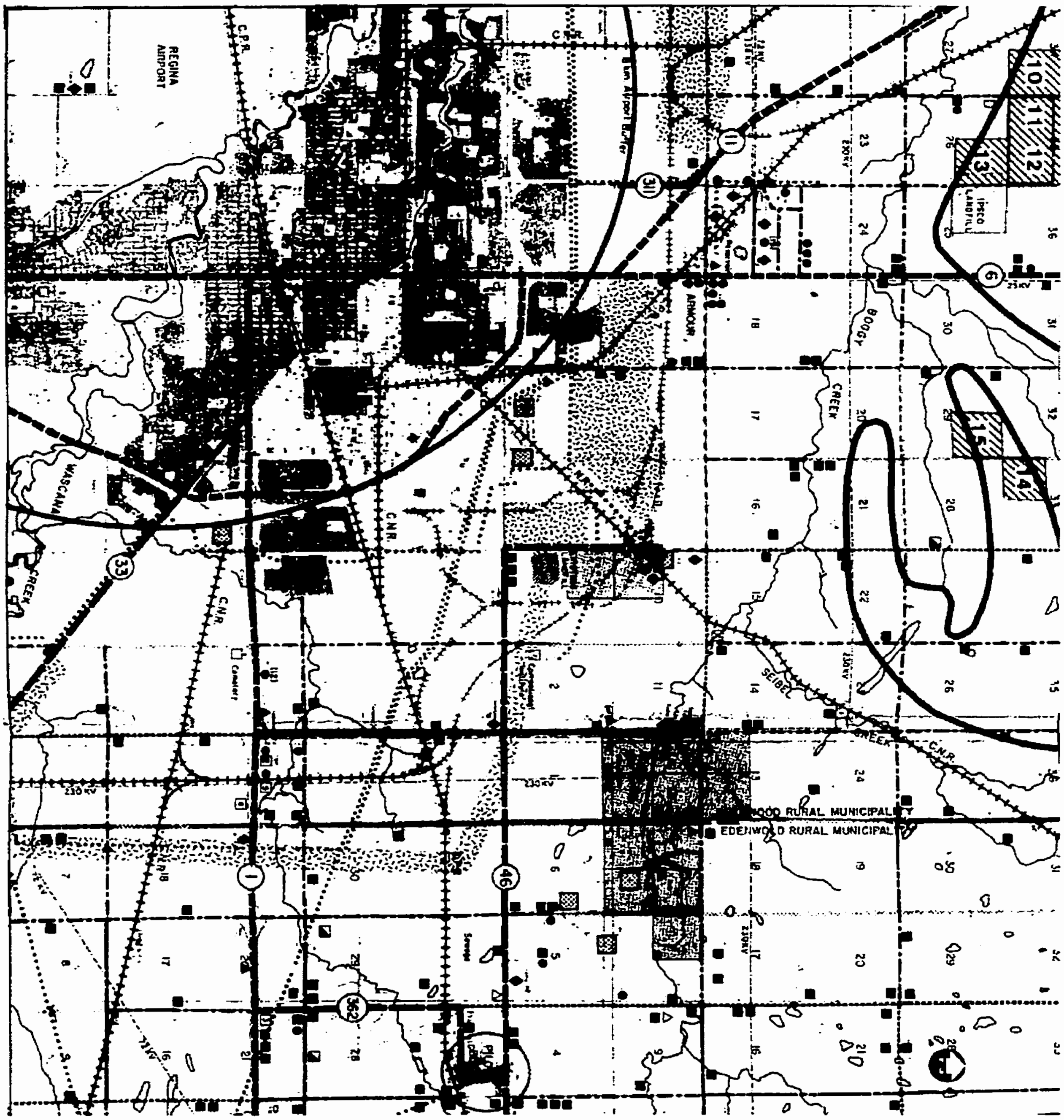

Figure 5.1(b) Potential landfill sites in the city of Regina.

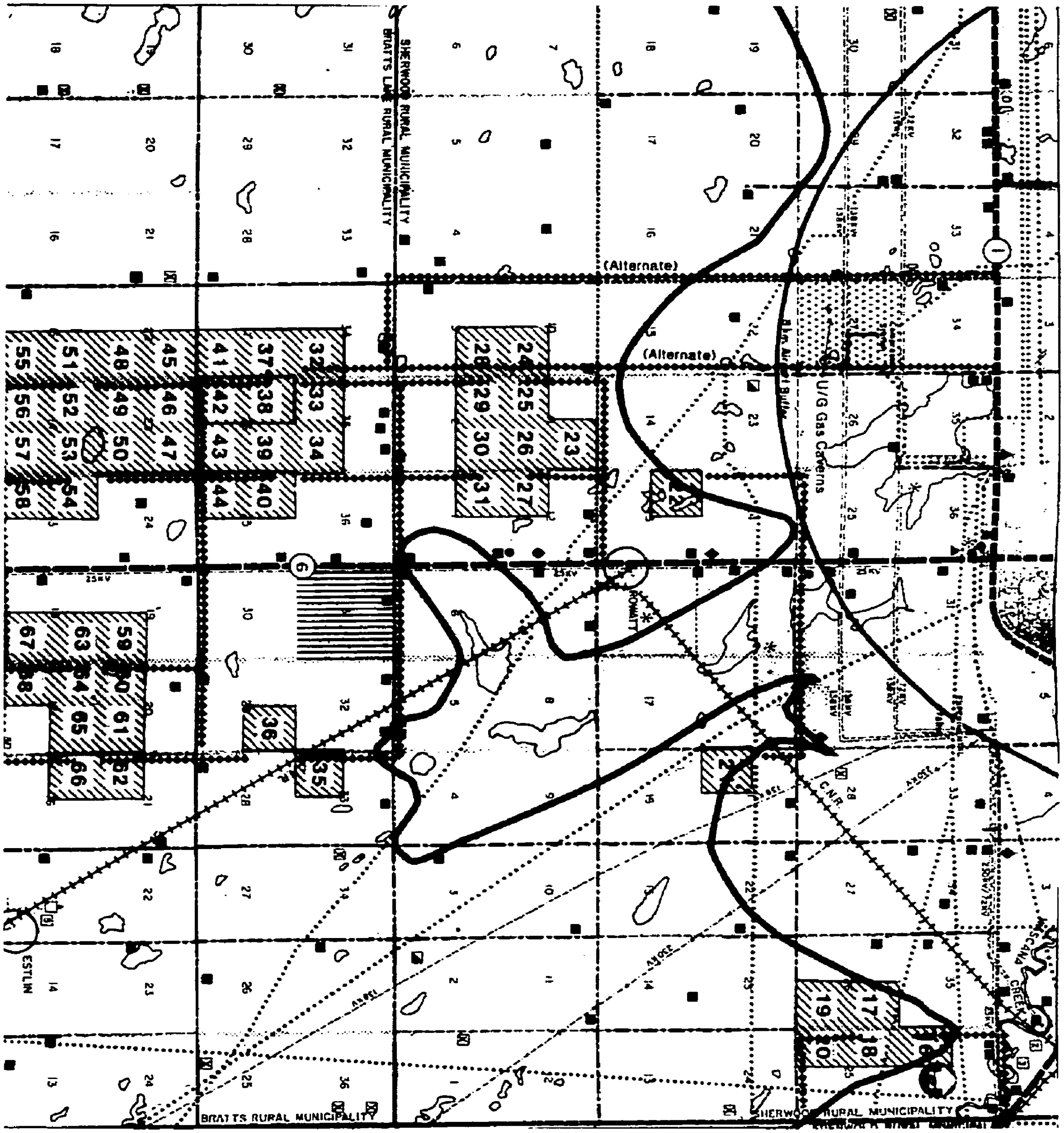

Figure 5.1(c) Potential landfill sites in the city of Regina.

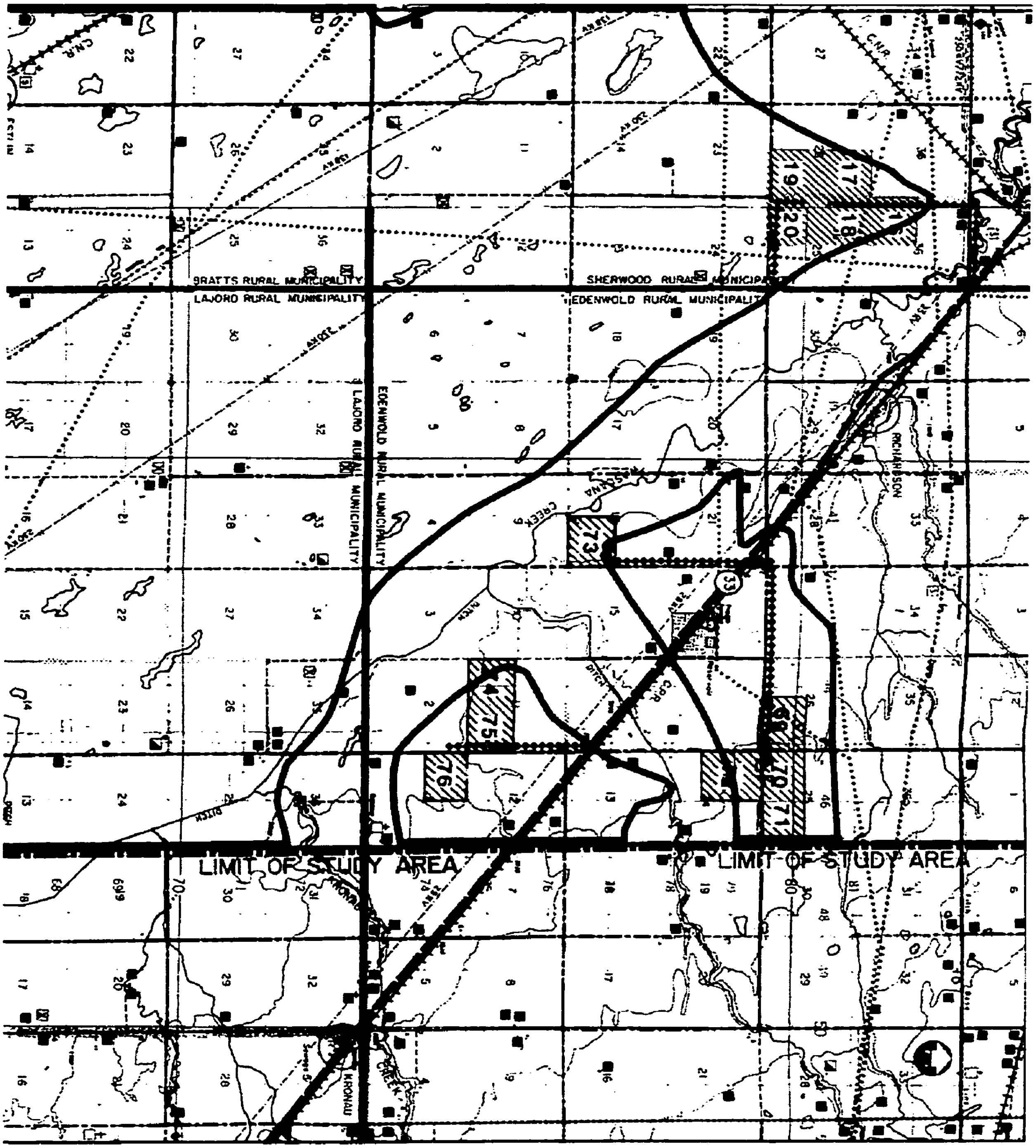

Figure 5.1(d) Potential landfill sites in the city of Regina.

5.4.2 Screening of Alternatives

To allow greater flexibility in a landfill site development, the site area was expanded to a one half section and 48 potential sites were identified. These potential sites are denoted as Region (X, Y), where X and Y are the numbered quarter section sites indicated in the maps. For example, according to the Phase 2 study (the City of Regina 1989), Region (11, 12) is one of the potential sites that is shown in Figure 5.1(a). Among the 48 sites, it was found that some of them were dominant alternatives. These dominant alternatives have the same characteristic such that each of them is absolutely advantageous in all criteria than the other alternatives (City of Regina 1989). A comparative evaluation was performed in the Phase 2 study to limit the number of alternatives. The evaluation factors (or criteria) include:

- Social environment
- Land use
- Agriculture
- Transportation
- Natural environment
- Engineering

After the screening process, only 10 sites were identified. These sites are then defined as the alternatives to be used in this study. As well, the choice of expanding the existing landfill was strongly requested by rural jurisdictions. Therefore, a total of 11 alternatives are specified in this MADM problem.

5.4.3 Definition of Criteria

5.4.3.1 Characteristics of Criteria

In MADM problems, defining attributes (or criteria) is the most important task. Hwang's deductive or inductive approach (Hwang et al. 1992) is helpful as it suggests construction of a hierarchy tree according to the desired objectives. However, Hwang also advises that the number of tree levels considered should be reasonable. Too many levels in the hierarchy might result from inclusion of insignificant criteria, whereas a shallow tree might be due to objective generalization. These two situations would lead to incorrect results; therefore, the analyst should verify the appropriateness of the criteria carefully.

Verification of the criteria hierarchy can be done by interaction with the decision maker. In this study, a criteria hierarchy that is believed to thoroughly express the essential tasks for the landfill selection problem is specified as shown in Figure 5.2. The top level describes the main objective, which is to identify a new landfill location for the city of Regina. To do that, four major criteria are considered, namely economical, agricultural, environmental, and societal impacts. These criteria are then divided into a total of 13 sub-criteria. Most of them are revised from the previous studies conducted by the city of Regina in 1983 and 1989 (City of Regina 1983, 1989) and the rest are new additions according to relevant literature and the public's opinion. These criteria are discussed as follows:

Under economical impacts, three criteria are considered:

(i) Total net cost

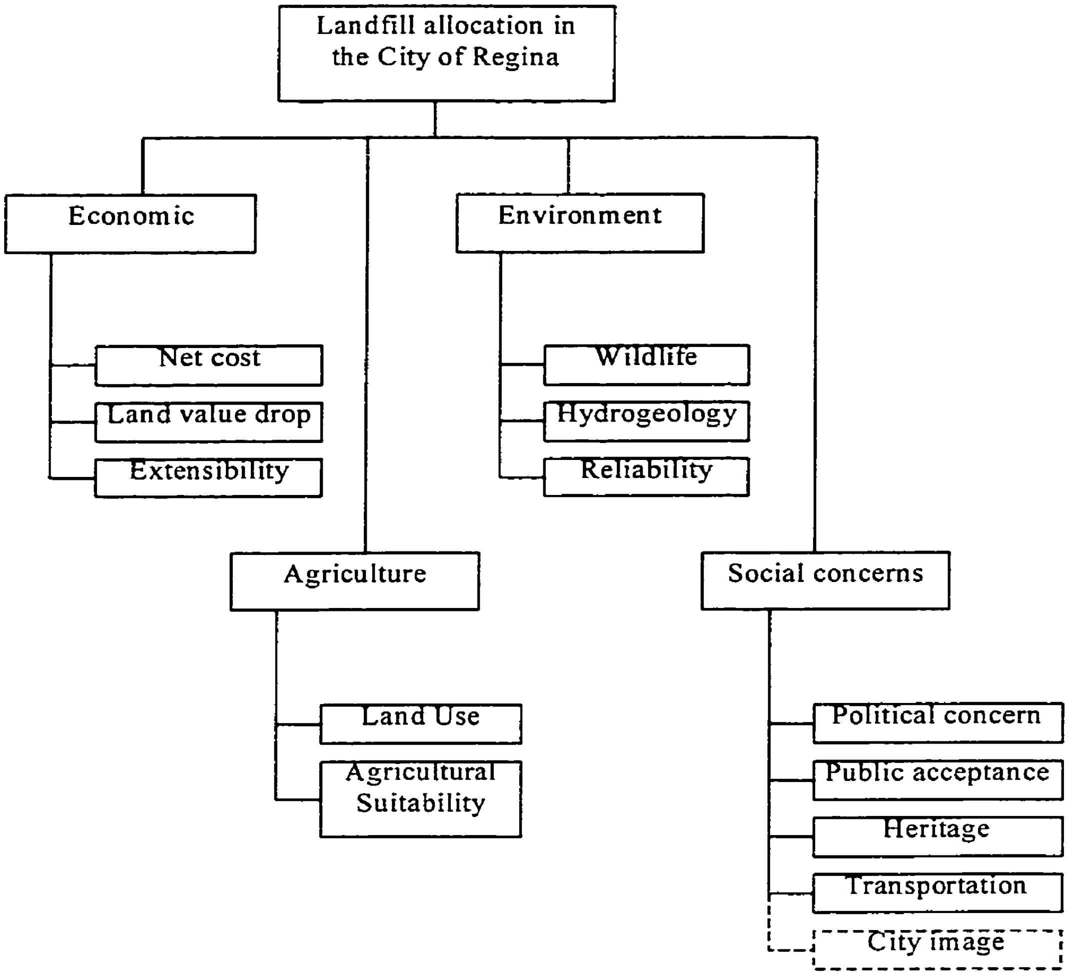

Figure 5.2 A hierarchy of attributes of evaluating landfill site in the city of Regina.

Cost is certainly one of the criteria in most MADM problems, but how can it be defined in this study? In studies conducted in Phase 1 and 2 (City of Regina 1983, 1989), the total net cost was one of the factors in the trade-off analysis. This cost was determined by the estimated net cost derived in the first year of the study period. Although the cost estimation can probably be used directly for the impact evaluation, the studies involved a few non-realistic assumptions which can lead to unsatisfactory results. For example, as Chi stated (1997), the cost presented in the Phase 2 study only shows the short-term effects, whereas landfill allocation is actually a long-term investment. Furthermore, it was shown in the Phase 2 study that the dynamic constraints were not being considered. For instance, the costs for recycling and composting facilities were fixed in the study, but in reality the related costs are likely to increase in the future due to more comprehensive protection requirements. Also, re-scheduling the routes for different solid-waste loading trucks greatly influence the operating and maintenance costs. These problems make the estimation of a net cost extremely difficult. Since the Phase 2 study implicitly neglected these dynamic factors mentioned above, the cost function adopted in the study might not be applicable in later years.

In contrast to the results of studies done in Phases 1 and 2, Chi (1997) introduced an inexact mixed integer linear programming (IMILP) model for cost estimation. Instead of calculating the total net cost in the first year of the planning horizon, Chi's model was developed to estimate the minimal net cost over a period of 30 years. The model was capable of incorporating dynamic factors such as the development period of different facilities and the waste stream allocation. Using Chi's IMILP model to determine the estimated costs for the possible landfill sites can provide a more reasonable result; therefore, it is used directly in the impact matrix.

(ii) Land value drop

In the past, the landfill has presented a bad image to the general public. A landfill can generate groundwater contamination, bad odors, dust, and attract rats and birds. Although advanced technology can help improve the conditions, the negative impression still remains. Consequently, when a new landfill is built, it will affect the land value of the surrounding area. The drop varies from one location to another, depending on the distance of the land from the landfill site, and the original purpose of the land. Furthermore, if implementation of the proposed landfill site excludes the facilities that can prevent the previously mentioned problems, the drop in land value will be more dramatic.

(iii) Extensibility

Once a site is allocated, it is expected to be occupied for a long period of time. In order to determine the flexibility of a landfill's life span, this criterion focuses on assessing the potential expandable size of each landfill. Such expandable size is defined according to the number of quarter section sites next to it. For example, Region (38, 42) is one of the potential sites as shown in Figure 5.1a. This location is considered a highly extensible site because it is surrounded by other potential regions, which are the shaded, numbered areas in the map. The greater the expandable size is, the more preferable such a potential site becomes.

Similarly, under agricultural impacts, two sub-criteria concerns are:

(iv) Land use

In terms of city expansion, the city of Regina is divided into different zones and assigns land use strategies for them based on the changing needs of residents, businesses and expected future trends. Therefore, it might be more preferable to construct a new landfill in an industrial area than building it in an agricultural area or commercial area. Moreover, a landfill should be sited as far from the rural residents as possible. Proposed locations that are near any residences will most certainly result in strong objections from its residents, which might eventually lead to failure of landfill implementation.

(v) Agricultural suitability

According to the Phase 2 study (City of Regina 1989), most of the lands in the Regina area consists of heavy clay soils that represent some of the best agricultural land in Saskatchewan. In addition, Saskatchewan has very little potential for expanding its farmland acreage as almost all the lands suitable for agriculture have already been developed. If a landfill is built in an agricultural area, it will cause the loss of prime land. More importantly, allocating a landfill site on good farmland would probably create frustration and annoyances among the landowners and the agricultural community.

For environmental impacts, the three criteria to be considered are:

(vi) Wildlife Habitat

A landfill may very likely cause destruction of any wildlife habitation. Although there are not many endangered species in the Regina area, this impact should nevertheless not be neglected. In the case of minimizing the effects on the habitat, a potential landfill site should be located at an area where the population of wildlife is minimal. However, it is difficult to obtain such statistical information. Instead of assessing the impact by determining certain wildlife's population, four factors are observed and analyzed. These factors, which can be observed from an aerial map in order to estimate the impact on wildlife habitat, are critical wildlife areas, native reserves, chaparrals, and wetlands.

(vii) Hydrogeology

The risk of groundwater contamination is always a subsequent problem to any landfill. According to Postigo (1999), there is a sign that the Condie aquifer, which also happens to be lying on top of the Regina aquifer, continues to be polluting slowly. One of the possible sources of pollutant comes from the lecheate in the existing landfill. If leakage of the landfill lining occurs, the groundwater will be seriously contaminated and 10% of the drinking water in Regina will be polluted. To reduce such a risk of contamination and to protect the aquifers such as the ones at Condie and Regina, a new site should be allocated at a dry land or a place where the least amount of groundwater flow occurs. Hence, expanding the existing landfill is not a preferable choice due to this impact.

(viii) Reliability

Similar to hydrogeology, the impact of reliability of the existing landfill is worse than other potential ones. In this study, the impact of reliability refers to the maintenance required for the facilities in a landfill. Assessing the reliability of a landfill relies on two factors: the lifetime of a landfill and the water resources in the surrounding area. In terms of life span, the existing landfill has been in service for about forty years and it will be close to termination in ten years. In order for the related facilities to improve its reliability, frequent maintenance is needed. Also, siting a new location near water resources such as wetlands, creeks, and rivers would require an increase in maintenance costs (City of Regina 1989).

Other criteria grouped under societal impacts include:

(ix) <u>Political concern and Public acceptance</u>

In a technical impact assessment, the political concerns and public acceptance factors are usually difficult to account for. However, they are included in the MADM approach because it allows for subjectivity from the decision-maker or the analyst (Hwang et al. 1992). To assess the political and public impacts, a survey was conducted to collect different opinions. Results from this observation are described in a later section.

(x) <u>Heritage</u>

Heritage properties contain valuable information and represent significant contributions from past generations. Some potential heritage resources can be found within the Regina boundary and they might need to be reserved. For this reason it is considered not preferable to allocate a new landfill near the potential resources. With this criterion, the heritage impact can be determined according to archaeological remains as well as with historical trails and structures.

(xi) Transportation

This criterion is applied in order to deal with the safety of the sections of provincial highway, used to travel from the city to each alternative site. The potential for traffic accidents generated by the landfill site is also a risk factor. Data was obtained according to the Phase 2 study (City of Regina 1989), where the accident rate is defined as the number of accident events per million vehicle kilometers.

(xii) City Image

City image is determined based on two factors. The first factor involves conflict between each potential site and the natural landscape. It is more preferable to allocate a landfill where no local resident is able to see it. Another factor involves the movement of the hauling trucks. After waste collection from the municipalities, the trucks need to access the highway in order to head back to the landfill. The existence of hauling trucks on the highways may create a negative impression to tourists or the general public. Hence, it is to be expected that the trucks should be able to access certain highways where there is less traffic.

5.4.3.2 Revising Criteria

The set of criteria described in the above section has been verified during interviews with various people in Regina and several comments were obtained. The people who were interviewed act as the interest group or the decision makers in this study. Two of them are the personnel in the Solid-Waste Management Division in the City of Regina, four of them work in Saskatchewan Environment and Resource Management, and the others are the local residents in Regina. Most of the interest group agreed with the criteria and stated that the information was enough to thoroughly cover the landfill selection problem. However, three specific questions were raised which led to further investigation. Some commented that the criterion of the hydrogeological impact needed to be sub-divided into several components, including surface water drainage, flood potential, and hydrology. Due to the fact that too much information would be required, if hydro-geological impacts are subdivided into several components, and data about some components, e.g. hydrology, would be diffcult to determine, it was concluded that the groundwater impact remains as is.

Another question was summarized from the comments of a few of interviewees. They stated that the presented criteria might not be enough, and more criteria needed to be added to the impact matrix, including soil type, proximity to an airport, all-weather access, meteorology, impacts on air quality, litter control, and the NIMBY (Not In My Back Yard) effect. In response to this question, it was later discovered that the soil type and proximity to the airport were already included in the alternative screening process. Therefore, these two criteria were not applicable to the impact matrix. For the other additional criteria mentioned above, except for the NIMBY effect, they are more likely to be defined as considerations to be encountered in the later implementation stage. As for the NIMBY effect, it is always a problem in solid-waste management. By reviewing the interviewees' opinions and the public comments recorded in the Phase 2 study, where almost 100 percent of the public strongly objected to a new site in their area, it is safe to conclude that this effect is difficult to resolve and hence it is ignored in this MADM analysis.

Furthermore, important facts pointed out by 3 different interviewees, who stated that the impact of the city image might not be an appropriate factor for landfill site selection since there was no dependency between them. This statement was reviewed in the later stage where the impact matrix was determined and the result showed an agreement with it. Thus, this criterion of city image was deleted. Further details about the criteria are described in the next section.

5.5 Input Parameters of Impact Matrix

According to the previous section, an impact matrix is determined for the 11 alternatives in association with the 12 criteria. The impact values are obtained by analyzing different types of sources, which are comprised of different levels of subjectivity. The results from data acquisitions are shown in Appendix B and described in the following sections. The data are organized in order from low to high subjectivity.

5.5.1 Data from Research and Analysis

In order to obtain the most satisfactory results that can confidently reflect the existing situation, the impact values should be presented with a high degree of reliability. However, most of the data in the impact matrix cannot simply be obtained from the decision makers or the domain experts. A series of analysis in association with each criterion has to be done. In this case, the reports of waste management study (City of

Regina 1983, 1989) have provided valuable information that can be used as input parameters. The information involves comments on the landfill issues from different groups, and the public in the past, and assessment details for each criterion. To construct the impact matrix in this study, some of the input data is taken from the Phase 2 study (City of Regina 1989) directly, such as land use, agricultural suitability, hydrogoeology, heritage, and transportation.

To estimate the total net cost of landfill development, Chi (1997) used IMILP as an optimization modeling method. As mentioned earlier, this model incorporates dynamic factors such as development of related facilities and waste stream allocation. In this study, the cost criterion is based on the results from Chi's work with respect to the following considerations:

- In the proposed fuzzy MADM approach, the valid types of input parameters are presented as numeric values or linguistic terms. Since Chi's result (Chi 1997) on the total net costs for different locations are originally presented as interval values, their mean values are taken instead as input parameter to the impact matrix in this study.
- The results from Chi (1997) only indicate the net cost of landfills located at the south of Regina, the north of Regina, and the existing site, respectively. To accept the cost criterion, the alternatives of an impact matrix are categorized into three groups, according to the soil characteristics and distance from the city. These three groups include the South Site group, the North Site group, and the existing site.
- Regions (23, 26), (25, 26), (38, 42), (70, 71), and (74, 75) are defined as the South Site group. Regions (3, 4), (8, 9), (11, 12), (9, 12), and (8, 11) are defined as the

North Site group. And the existing site is the sanitary landfill that is located on Fleet Street, north of McDonald Street, Regina (City of Regina 2000).

- Opinions from representatives in the Environmental Protection Branch were obtained, which agree with separation of South Site group, North Site group and existing site as mentioned in the above consideration.
- Soil characteristics of each location are verified according to the Phase 2 study, which suggests that the sites in the same group are approximately the same.
- The distance of each potential site from the city is verified and the result concludes that they are an approximate match, in the same group, except that Regions (70, 71) and (74, 75) are obviously further from the city than other sites in the South Site group.

5.5.2 Data from Interviews with Experts

Data from an analysis requires complex calculation formula and methods, and the result tends to be more technical. However, in MADM problem some of the input parameters may not be obtainable from analytical calculations. For example, the population of the different wildlife could be used as the input data of the impact on wildlife habitat, but determining this value is impossible. In this case, interviews with domain experts are necessary. Domain experts are able to estimate input parameters and the estimates are more reliable than those of the decision maker and the analyst. The impacts that are acquired from interviews with experts include estimates on wildlife habitat, site reliability, and drop in land value.

5.5.3 Data from Questionnaires

With physical planning, the opinions of public and local authorities are important. Since they are the actual decision makers in this kind of problem, their opinions are valuable, but can also be conflicting. In order to provide a more realistic result in this landfill selection problem, the public and political concerns are included in the impact assessment. A survey was conducted to ask the local residents to locate the most preferable and non-preferable disposal sites. Assuming that the public was only concerned about the approximate location of the potential sites, they were given three options to each of these questions, namely the north site, the south site, or expansion of the existing landfill. Their opinion served as inputs on public impact. A sample survey is shown in Appendix C. The same questionnaires were provided to the representatives of the Environmental Protection Branch, who are considered as the interest group from the political side. Hence, the opinions of two interest groups were obtained: 1) the public group that express the public's point of view; and 2) the political group that was presented by the Environmental Protection Branch. After analyzing the survey results, it is concluded that the public group would prefer a new landfill site to be located at the north site, whereas the political group would prefer a site to be located at the south site. In addition, most of the people in both groups did not agree with the option of expanding the existing landfill.

5.5.4 Data from Observation

The last type of data acquisition in this study is observation by the analyst, this type of data may be subjective but are important. Whether or not the analyst can understand the problem is the key to whether significant impact data can be generated that reflect the real situation. In this study, site extensibility is the only impact that is obtained based on the analyst's observation. The judgment for this impact was made according to the number of quarter sections, where these sections were initialized as potential landfill sites before the screening process and whether sites considered is available for extension.

5.6 Processing Information from Survey

5.6.1 Input Parameters of Weights

MADM methods require information on attributes that are to be obtained from the decision makers (Hwang et al. 1987). It is referred to as the weights of considered criteria. Among all weight assessment techniques, fuzzy set theory is applied to transform the linguistic terms obtained from decision makers into weights. As mentioned in the previous section, a survey was conducted in order to perform weight assessment. The results from the survey are divided into two groups. Group A presents the data obtained from local residents, whereas group B characterizes the opinions from the local authority. In group A, a total of 40 local residents were contacted from the east, west, south, and north of Regina as shown in Table 5.2. The purpose of this was to avoid the possible NIMBY effect, where the residents only want the landfill to be located as far away from them as possible. Fortunately, by analyzing the results from group A, it seems that there is no sign of such a phenomenon – residents only want the landfill to be located as far away from them as possible. A reason might be derived that the municipal residents would not mind landfill development near them, as long as it is out of their line

Table 5.2. Number of survey conducted.

	Group A (Local residents)				Group B
	East	South	West	North	(Local Authority)
Survey #	10	12	9	9	4
Total		40			4

of vision and the problems such as bad smells and wind litters remain minimal. This result is totally opposite to that obtained from group B of the local jurisdictions (City of Regina 1989), where the NIMBY effect is strong and they simply do not want a landfill to be built near their regions.

5.6.2 Processing Input Parameters

The results from the survey on weight assessments are all recorded in verbal terms. In both groups A and B, since one person's opinion can be totally different from another, the results are varied. Therefore, directly applying linguistic terms as input parameters to the MADM analysis is impossible. A simple two-step approach is used to solve this problem. First the systematic fuzzy-to-crisp transformation that is introduced in Chapter 3 can be adopted. Using the concept of fuzzy set theory, the information can be converted into representative numeric data. For example, Table 5.3 shows the qualitative values of weights obtained from one resident in group A. By using fuzzy-to-crisp transformation, the set of verbal terms {"very low", "low", ..., "very low"} can be converted into a numeric set of {0.137, 0.333, ..., 0.137} without losing any meaning. Hence, the weight of public impact in this example is 0.137, and the weight of agricultural impact is 0.333. Details in the fuzzy-to-crisp transformation are described in Chapter 3, and the same procedure is used in each survey.

After finding the numeric values, the final weight for each criterion can then be calculated by taking the average from the survey results. The weight assessments for groups A and B are presented in Table 5.4 and 5.5, respectively. The standard deviations

Table 5.3. Conversion from linguistic terms to numeric values

	Public	Agriculture	Hydrogeology	Transport	Land Use	Heritage
Verbal terms	Very low	Low	Extremely High	Very low	Low	High
Numeric values	0.137	0.333	0.954	0.137	0.333	0.667
	Cost	**Extensibility**	**Reliability**	**Wildlife**	**Political**	**Land Value Drop**
Verbal terms	Low	MOL high	MOL high	High	Very low	Very low
Numeric values	0.333	0.843	0.843	0.667	0.137	0.137

Table 5.4. Weight assessment from Group A of municipal residents.

	Public	Agriculture	Hydrogeology	Transport	Land Use	Heritage
Average value	0.616	0.533	0.799	0.278	0.499	0.458
Std Dev.	0.220	0.244	0.216	0.220	0.225	0.236
Conf. Interval	0.068	0.075	0.067	0.068	0.070	0.073
	Cost	**Extensibility**	**Reliability**	**Wildlife**	**Political**	**Land Value Drop**
Average value	0.529	0.579	0.613	0.473	0.359	0.400
Std Dev.	0.219	0.266	0.207	0.259	0.226	0.242
Conf. Interval	0.068	0.082	0.064	0.080	0.070	0.075

Table 5.5. Weight assessment from Group B of local authority.

	Public	Agriculture	Hydrogeology	Transport	Land Use	Heritage
Average value	0.903	0.499	0.791	0.460	0.488	0.487
Std Dev.	0.102	0.205	0.146	0.150	0.171	0.359
Conf. Interval	0.100	0.201	0.144	0.140	0.168	0.352
	Cost	**Extensibility**	**Reliability**	**Wildlife**	**Political**	**Land Value Drop**
Average value	0.607	0.817	0.783	0.624	0.585	0.512
Std Dev.	0.233	0.106	0.095	0.143	0.342	0.130
Conf. Interval	0.228	0.104	0.093	0.140	0.335	0.128

and the confidence intervals in the tables are also provided as referential data. Note that the opinions of the public are expected to vary widely, which explains why the standard deviation for each parameter in Table 5.4 is so large. On the other hand, it can be observed that the standard deviation in Table 5.5 is smaller under some criteria, even though the number of people is much smaller than that in Table 5.4. This is probably due to the fact that, after the long-term study for the landfill allocation problem (City of Regina 1983, 1989), the representatives in the local authority already have a general agreement on which criteria should be considered a priority.

5.6.3 Validation of Input Parameters

A few statistical tests have been performed in order to study how municipal residents responded in the survey and to validate the independence of the input parameters in terms of the interrelationships among the given criteria. In this section, the chi-square test and the correlation function are introduced. Chi-square is used to verify whether or not there is a relationship between two sets of data, whereas the correlation function verifies whether the relationship is linear. An example is given to illustrate how to apply each of these techniques and description of the validated result follows.

5.6.3.1 Chi-square (χ^2) test

Chi-square is a non-parametric test that roughly estimates the degree of confidence of relationship between two attributes. It investigates the pattern of frequencies between them using a null hypothesis test and the result can be used to determine the confidence of the relationship between two attributes. Assume that a sample of size N can be classified into p classes by the first attribute and into q classes by the second. To perform the chi-square hypothesis test, a contingency table is first constructed. A contingency table is a frequency table where two attributes are present simultaneously. The frequencies of individuals in each classification can be expressed as n_{pq} so that the value of chi-square χ^2 can be formulated as follows (Kanji, 1993):

$$\chi^2 = \sum_{i=1}^{p}\sum_{j=1}^{q}\frac{(n_{ij} - n_{i\bullet}n_{\bullet j}/N)^2}{n_{i\bullet}n_{\bullet j}/N}$$

$$n_{i\bullet} = \sum_{j=1}^{q} n_{ij}, \qquad i = 1,2,\ldots,p \qquad \text{Eq. 5.1}$$

$$n_{\bullet j} = \sum_{i=1}^{p} n_{ij}, \qquad j = 1,2,\ldots,q$$

where N is total number of frequencies. Once χ^2 is computed, it compares with the critical value which can be found using the table of χ^2 distribution with (p-1)(q-1) degrees of freedom. If χ^2 exceeds the critical value, the null hypothesis is rejected and the two attributes are dependent on each other. Otherwise if χ^2 is smaller than the critical value, it can be concluded that the two attributes are independent.

Since the size of the data set has to be sufficiently large in order to perform this statistical test, only data from group A are examined. The χ^2 test is carried out to find out if and how many pairs of attributes are related to each another. For example, it is necessary to check whether the location of the residents can influence the weight assessment. Correlation among data from group A on the attributes of public acceptance of the landfill site and residential locations are tested using the chi-square test. Recall that the universe of weight inputs is {"excellent", "very high", … , "very low", "none"}. This universe can be divided into three distinct classes:

- H indicates the set of input {"excellent", "very high", "high to very high", "high"}
- M indicates the set of input {"more or less high", "medium", "more or less low"}
- L indicates the set of input {"low", "low to very low", "very low", "none"}

Once H, M, and L are defined, a contingency table n_{pq} can be constructed as shown in Table 5.6. Applying Equation 5.1, the value of χ^2 = 10.711 is obtained. To obtain the critical value, the degrees of freedom is first determined, which is $(4-1)(3-1)=6$. Therefore, by looking up the table of χ^2 distribution, the critical value with 95% of a confidence interval is 12.592. Since χ^2 is smaller than the critical value, it can be concluded that the null hypothesis is not rejected and there is no relationship between the two attributes of location of residence with their acceptance of a landfill site.

A similar test is performed for each pair of criteria in the impact table, and the results are summarized in Table 5.7. The test shows that for some of the data, significant results that is greater than the critical value of 9.488 with 95% of a confidence interval are generated. Each pair of attributes (or criteria) with high χ^2 implies that they have a relationship with one another. In particular, χ^2 in (i, v), (v, viii), and (ix, x) in the table contains the greatest values which even exceeds the critical value with 99% of a confidence interval (i.e. 13.28). These data is circled in Table 5.7.

Using the chi-square test, the relationships among a set of criteria can be identified. If the null hypothesis is rejected, a statistically significant relationship between the two criteria is concluded. According to the result shown in Table 5.7, there is sufficient evidence to

Table 5.6. Contingency table of public acceptance of location.

		Public Acceptance			Total ($n_{\bullet q}$)
		H	**M**	**L**	
Location	**East**	4	3	3	*10*
	South	1	6	5	*12*
	West	0	4	5	*9*
	North	0	3	6	*9*
	Total ($n_{p\bullet}$)	*5*	*16*	*19*	*40*

Table 5.7. The result of chi square test for each pair of criteria.

i	Public Acceptance	vii	Total Net Cost
ii	Agriculture	viii	Site Extensibility
iii	Hydrogeology	ix	Reliability
iv	Transportation	x	Wildlife Habitat
v	Land Use	xi	Political Concern
vi	Heritage	xii	Land Value Drop

Critical value = 9.488

	i	ii	iii	iv	v	vi	vii	viii	ix	x	xi	xii
i		2.171	7.969	5.000	**15.985**	6.048	1.597	4.279	1.473	4.300	2.350	2.698
ii			5.778	5.715	7.110	3.479	1.086	8.879	7.328	8.482	8.809	4.819
iii				6.678	9.183	2.667	3.019	3.059	4.691	2.470	5.752	3.903
iv					2.876	4.464	1.523	4.523	7.600	3.224	9.078	6.450
v						9.760	6.451	**16.131**	2.080	2.506	6.522	5.096
vi							8.557	1.466	2.093	4.001	4.960	1.122
vii								12.582	0.954	3.628	9.740	4.822
viii									9.752	8.530	7.659	1.108
ix										**17.475**	5.291	2.264
x											1.424	3.452
xi												4.276
xii												

conclude that relationships exist on three pairs of criteria, including the relationships between:

1) Public Acceptance and Land Use,
2) Site Extensibility and Land Use, and
3) Wildlife Habitat and Reliability.

Although the relationship between two criteria can be found using the chi-square test, the result does not indicate how strong the relationship is. In the next section, Pearson's product moment correlation is introduced to perform further analysis and determine the strength of the relationship.

5.6.3.2 Correlation function

Correlation calculations do not discriminate between *X* and *Y*, but rather quantify the relationship between the two attributes (Cohen and Cohen, 1983). In this study, Pearson's product moment correlation coefficient is applied to evaluate the linear relationships among each criterion. The formula is shown as follows:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad \text{Eq. 5.2}$$

where r_{xy} is the correlation coefficient; x and y are two attributes; *n* is the size of data set; $\bar{x}$ and $\bar{y}$ are their mean values. If r_{xy} falls into the range from 0 to 1 ($0 < r_{xy} < 1$), there might exist a relationship between the two attributes which tend to increase or decrease together. Conversely, if r_{xy} falls into the range from –1 to 0 ($-1 < r_{xy} < 0$), there might exist an inverse relationship between the attributes. In addition, there are four possible explanations for the situation where r_{xy} equal 0, which are:

- The x attribute helps determine the value of the y attribute;
- The y attribute helps determine the value of the x attribute;
- Another attribute influences both x and y; and
- x and y don't really correlate at all, and the observation of such strong correlation happens just by chance.

The purpose of using a correlation function is to determine if there exists a linear relationship between two attributes. Judging from the interpretation of the value of r_{xy}, it is not expected that r_{xy} would be either 1 or –1 since both values represent existence of an absolute linear relationship between two attribute. To demonstrate the computation of r_{xy}, a portion of the survey results from group B is captured and listed in Table 5.8. This table shows the responses of the local authority to the importance level of criteria of public acceptance and agriculture. Using Equation 5.2, the value of r_{xy} can be determined as follows:

$$\sum_{i=1}^{4}(x_i-\bar{x})(y_i-\bar{y}) = (-0.153)(-0.249) + (0.051)(0.168) + (0.051)(0.168) + (0.051)(-0.089)$$

$$= 0.051$$

$$\sum_{i=1}^{4}(x_i-\bar{x})^2 = (-0.153)^2 + (0.051)^2 + (0.051)^2 + (0.051)^2 = 0.031$$

$$\sum_{i=1}^{4}(y_i-\bar{y})^2 = (-0.249)^2 + (0.168)^2 + (0.168)^2 + (-0.089)^2 = 0.126$$

Therefore, $r_{xy} = \dfrac{0.051}{\sqrt{(0.031)(0.126)}} = 0.816$

Table 5.8. Sample calculation of correlation coefficient of r_{xy}.

i	1	2	3	4	Average
Public acceptance (x)	0.750	0.954	0.954	0.954	0.903
Agriculture (y)	0.250	0.667	0.667	0.410	0.499
$x_i - \bar{x}$	-0.153	0.051	0.051	0.051	N/A
$y_i - \bar{y}$	-0.249	0.168	0.168	-0.089	N/A

The result shows that there might be a linear relationship between the importance level of public acceptance and agriculture. Note that according to Equation 5.2 the size of n in Group B is only 4, which is much smaller than the required data size in this statistical test ($n >= 30$). Therefore, the result from the above calculation is used for demonstration only. However, the correlation function can be applied to Group A of municipal residents where the size of n equals 40. Table 5.9 summarizes the value of r_{xy} for each pair of criteria. The overall result shows very weak linear relationship among the attributes previously identified to be interdependent. In particular, the most significant value of r_{xy} occurs when comparing the criteria of public acceptance and land use, where r_{xy} equals 0.602. Furthermore, it can be seen that most r_{xy} are positive values. A conclusion drawn from this observation suggests that there is no evidence indicating that an increase of importance level of one attribute would lead to the decrease of another.

In the previous section, the chi-square test was performed and the result showed that relationships among the criteria do indeed exist. The pairs of criteria with significant chi-square results are also circled in Table 5.9. It can be observed that most of these pairs, especially (i, v) and (ix, x), have a higher r_{xy} than the others. (i, v) represents the relationship between public acceptance and land use, whereas (ix, x) represents the relationship between site reliability and the wildlife habitat. Although the latter is identified using both the chi-square test and the correlation function, it is questionable

Table 5.9. Result of correlation coefficient to show linear relationship among the criteria.

i	Public Acceptance	**vii**	Total Net Cost
ii	Agriculture	**viii**	Site Extensibility
iii	Hydrogeology	**ix**	Reliability
iv	Transportation	**x**	Wildlife Habitat
v	Land Use	**xi**	Political Concern
vi	Heritage	**xii**	Land Value Drop

	i	**ii**	**iii**	**iv**	**v**	**vi**	**vii**	**viii**	**ix**	**x**	**xi**	**xii**
i	1.000	0.164	0.189	0.437	0.602	0.401	-0.029	0.068	0.067	-0.004	0.381	0.126
ii		1.000	0.192	0.383	0.175	-0.040	0.210	0.170	0.208	0.321	0.358	0.339
iii			1.000	0.002	0.280	0.110	0.153	0.054	0.109	0.073	-0.250	0.094
iv				1.000	0.414	0.400	0.127	0.260	0.448	0.494	0.394	0.322
v					1.000	0.557	0.183	0.079	0.263	0.391	0.231	0.289
vi						1.000	-0.137	-0.151	0.116	0.238	0.199	0.018
vii							1.000	0.471	0.362	0.172	0.272	0.107
viii								1.000	0.459	0.260	0.252	0.020
ix									1.000	0.600	0.133	0.140
x										1.000	0.153	0.278
xi											1.000	0.084
xii												1.000

why the weight on site reliability can affect that of wildlife habitat. No explicit reason can be obtained to explain this phenomenon. Since only a few weak relationships were found among the criteria, a final conclusion drawn on the survey data is that the data set is reliable and relatively independent, and can be used to represent public opinion on assessing weights of criteria's weights for landfill selection.

5.6.4 Summary

This section presents the procedure of how to initiate the impact matrix in solid waste management in the city of Regina. Because of the groundwater problem and the limited life span of the existing landfill, it is necessary to allocate a new site. According to Phase 2 study (City of Regina 1989), the possible locations of new sites were narrowed down to 11. Regions (23, 26), (25, 26), (38, 42), (70, 71), and (74, 75) are located in southern Regina, whereas Regions (3, 4), (8, 9), (11, 12), (9, 12), and (8, 11) are located in northern Regina. In addition, expansion of the existing landfill is considered an alternative as well. 12 criteria are identified for the selection process, and their details are discussed in this chapter. A survey has been conducted in order to determine the importance weight for each criterion. Also, two statistical analyses are performed to validate the survey data. The chi-square test is used to identify whether or not a relationship exists between each pair of criteria. It is found that with 99% of a confidence interval relationships exist on the following pairs: (1) public acceptance and land use, (2) land use and site extensibility, and (3) site reliability and wildlife habitat. Further analysis was carried out to determine the strength of these relationships using the correlation function. The result showed that there is no linear relationship between the pair of alternatives of (2), and only weak linear relationships exist among those of (1) and (3). It is concluded that even though interrelationships exist among some criteria, the survey result is robust and hence the weights are validated.

5.7 Results of the Interest Groups

Using MCDSS, the rankings from MADM methods are obtained. The results for groups A and B are summarized in Tables 5.10 and 5.11, respectively. Detailed outputs are shown in Appendix D. It can be seen from these tables that the analyzed results from both groups are very close; hence, it can be concluded that no major conflict exists between the decisions of the two interest groups—the public and the city of Regina. Since most of the alternatives contain at least one worst point under certain criteria, the result from CGT shows no preference among all the alternatives except for Region (74, 75). This implies that allocating a new landfill at Region (74, 75) might be the "safest" choice and would not lead to a worst impact under any criteria. Besides CGT, all other methods result in complete rank orders, which means that no two alternatives fall into the same preference level. Since the rankings of the methods are different from each other, an MCDA aggregation is carried out and the result is shown in Tables 5.12 and 5.13.

Table 5.12 presents the aggregated results of Group A. It can be seen that, after aggregation, the rankings are roughly consistent with each other. In fact, the same ranked order is produced when both Borda and Copeland methods are used. This is probably due to the fact that the same concept applies to both of them. According to the rankings,

Table 5.10 Summary of Group A results from MADM methods.

Public Point of View (Group A)											
	Preference level										
	1	2	3	4	5	6	7	8	9	10	11
SWA	38, 42	25, 26	23, 26	70, 71	74, 75	11, 12	8, 11	9, 12	8, 9	Existing	3, 4
ELECTRE	38, 42	25, 26	74, 75	11, 12	23, 26	9, 12	8, 11	70, 71	8, 9	Existing	3, 4
TOPSIS	38, 42	25, 26	23, 26	70, 71	11, 12	8, 11	9, 12	74, 75	8, 9	Existing	3, 4
CGT	74, 75	All									
WP	38, 42	25, 26	23, 26	70, 71	11, 12	9, 12	8, 11	74, 75	8, 9	3, 4	Existing

Table 5.11 Summary of Group B results from MADM methods.

Political Point of View (Group B)											
	Preference level										
	1	2	3	4	5	6	7	8	9	10	11
SWA	38, 42	25, 26	23, 26	70, 71	11, 12	74, 75	8, 11	9, 12	8, 9	Existing	3, 4
ELECTRE	38, 42	25, 26	74, 75	11, 12	9, 12	8, 11	70, 71	23, 26	8, 9	Existing	3, 4
TOPSIS	38, 42	25, 26	23, 26	11, 12	9, 12	70, 71	8, 11	74, 75	8, 9	Existing	3, 4
CGT	74, 75	All									
WP	38, 42	25, 26	23, 26	11, 12	70, 71	9, 12	8, 11	74, 75	8, 9	3, 4	Existing

Table 5.12 Summary of Group A results from MADM Aggregations.

Public Point of View (Group A)											
	Preference level										
	1	2	3	4	5	6	7	8	9	10	11
ARP	38, 42	25, 26	23, 26	70, 71	11, 12	8, 11	74, 75	9, 12	8, 9	Existing	3, 4
Borda	38, 42	25, 26	23, 26	70, 71	74, 75	11, 12	9, 12	8, 11	8, 9	Existing	3, 4
Copeland	38, 42	25, 26	23, 26	70, 71	74, 75	11, 12	9, 12	8, 11	8, 9	Existing	3, 4

Table 5.13 Summary of Group B results from MADM Aggregations.

Political Point of View (Group B)											
	Preference level										
	1	2	3	4	5	6	7	8	9	10	11
ARP	38, 42	25, 26	23, 26	11, 12	70, 71	9, 12	8, 11	74, 75	8, 9	Existing	3, 4
Borda	38, 42	25, 26	23, 26	11, 12	70, 71	74, 75	9, 12	8, 11	8, 9	Existing	3, 4
Copeland	38, 42	25, 26	23, 26	11, 12	70, 71	74, 75	9, 12	8, 11	8, 9	Existing	3, 4

it is obvious that the most preferable landfill location is at Region (38, 42), whereas the most non-preferable site is located at Region (3, 4). According to the impact matrix provided in Appendix B, the criteria that support landfill allocation at Region (38, 42) include agriculture, hydrogeology, heritage, cost, site extensibility, reliability, and political support. In particular, this area offers the greatest protection to known aquifers and surface drainage courses, so that the groundwater problems would not exist. The least preferable site, Region (3, 4), is located further north of Regina. Although it has agricultural advantages and the land value drop would not be much affected, the risk of groundwater contamination is quite significant. Other criteria on this site show no advantage in comparison with the other sites. In particular, the site extensibility of Region (3, 4) is smaller than that of the other regions.

All of the aggregation results agree that the three most preferable sites are located in southern Regina, which are Regions (38, 42), (25, 26), and (23, 26). However, if only the north area is considered, Region (11, 12) becomes the best choice. Among all the northern sites, Region (11, 12) has the shortest distance from a nearby industrial landfill—IPSCO. The number of residence within 1km from this site is also lower than the others. Aside from these advantages, there is not much difference among Regions (11, 12), (8, 11), (9, 12), and (8, 9).

In group B, similar conclusions can be made as presented in Table 5.13. The three most preferable sites are located at Regions (38, 42), (25, 26), and (23, 26), whereas the least preferable one is at Region (3, 4). If the southern sites were not considered, Region (11,

12) would be the most preferable. In addition, group B seems to prefer that the new landfill be located at the south end of Regina. As shown in Table 5.13, almost all south sites are among the top rankings. A possible reason can be drawn that the local residents might wish to avoid any conflict between a new landfill and the aquifer system, and the south region is the ideal location since there is no aquifer below the ground.

According to the results from both groups A and B, expansion of the existing landfill is not recommended because it is ranked second to last, despite the fact that this option is the most cost-effective alternative. Since the total net cost of this option is less than those for other alternatives and the land value of the surrounding area might not be changed it is clear that concerns about groundwater contamination overwhelm the cost factors.

5.8 Comparison of Results from MCDA with Previous Study

The result from this MCDA study is compared with that in the Phase 2 study (City of Regina, 1989), and some interesting findings are observed. Unlike the MADM methods used in this study, a trade-off analysis was applied in the Phase 2 study. Its purpose was to delimit the number of alternatives one by one according to a few criteria. First the potential sites were divided into groups where each group belonged to a rural municipality. A brief comparative evaluation was performed in order to select a preferred site from each group. These selected sites were then used in the detailed comparative evaluation so that a preferred site at the south and north ends of Regina were chosen, respectively (City of Regina 1989). Phase 2 concludes that the most preferable site, located at the north end of Regina, is at Region (11, 12), and that the preferable site at the south end of Regina is at Region (38, 42). In this MCDA study, if the alternatives are divided into a north and south region, the same result can be generated such that Region (11, 12) in the north and Region (38, 42) in the south are the most preferable.

5.9 Comparison of the Results from Different MADM Methods

In this study, it is found that the results from the MADM methods vary slightly because each method has its underlying assumptions. Sometimes these assumptions may not be applicable to the particular situations. For instance, it can be seen that the CGT method did not provide a representative ranking to the interest groups. According to Szidarovszky (1978), CGT can aid the decision maker in avoiding an alternative that would give the worst impact value according to any of the criteria. In other words, it would suggest the alternative which is furthest away from the worst to the decision maker. However, such an alternative may not be the most desirable one. For instance, the result from CGT in this study shows that Region (74, 75) is the alternative which is furthest away from the worst. Based on the results from other methods and the impact values shown in Appendix B, however, Region (74, 75) is obviously not the most desirable landfill location. In fact, another study has been conducted to compare if the result would be different when the CGT method is excluded. When CGT is not applied, the rankings from the other MADM methods will be similar but the result from MADM aggregations will be changed. It will affect the ranked order of Regions (8, 11), (9, 12), (11, 12), (23, 26), and (70, 71). Reviewing the results from SWA and TOPSIS, it is found that the utility values for these alternatives are close. This might imply that their preference level for both interest groups could be the same.

5.10 Advantages and Disadvantages of Multi-Criteria Decision Support System

Multi-criteria decision support system (MCDSS) provides decision makers with powerful capabilities in analyzing, exploring and comparing a set of incompatible alternatives. It can help them gain insight on the problem as well as confidence when making a decision. Besides the solid waste management problem, MCDSS can be used for a wide variety of multi-attribute selection problems. The size of alternatives and criteria would no longer be an issue. Since various MADM methods are employed, the result from one method can be cross-validated with those from other methods. Aggregation techniques are also utilized to analyze rankings and suggest an overall conclusion. All these mechanisms are integrated in order to provide a reliable and consistent result.

Regardless of the advantages of how MCDSS is able to help decision makers, there is still a major concern on the unproven assumptions of applying MADM methods. Conceptually, MADM problems always involve subjective parameters such as public and political concerns. Because of that, some researchers might argue that the results obtained from the MADM methods would not be meaningful. It is possible to find an ideal compromise solution using a particular method for a decision maker or an interest group, but a different solution could just as well result when another method is used. While possible, such inconsistent results among the two interest groups have not been observed in this study.

5.11 Comparison of the Multi-Purpose Advisor and Different Systems

According to Buede (1996), there are more than 30 decision support systems that have been developed to solve MADM problems. In this section, a review of MCDA software by Eom (1999) is presented to show the variety of such products. Several of them have been selected to compare with the Multi-Purpose Advisor (MPA). These software include Expert Choice (Expert Choice Inc.), Criterium Decision Plus (Sygenex Inc.), VISA (SPV Software Products), and Logical Decision (Logical Decision Inc.).

5.11.1 Comparison of System Complexity

The MPA consists of five MADM methods. The user can select a single or multiple MADM method(s) that he/she is confident with and analyze the data. On the other hand, most of the commercial systems consist of one or two methods only. Expert Choice and Criterium are based on the analytic hierarchy process (AHP), which is another popularly used MADM method (Saaty, 1980). Logical Decision is based on a set of modified AHP methods, while VISA employs a highly visual interactive approach. Since the MPA is a theory-oriented system, and the other commercial systems are user-oriented, the MPA compares favorably with the others in terms of system complexity. Moreover, none of the commercial systems are capable of handling linguistic inputs. Systems that deal with fuzzy inputs can be found in other non-commercial products such as fuzzy DRASTIC (Chen et al. 1997).

5.11.2 Comparison of Usability

The MPA is simple and easy-to-use, and the period of time that it takes users to understand and use this system is much shorter than others that have similar functions. However, it does not support input of data in a file. For instance, the MPA uses only a data-collection window as shown in Figure 4.7 to obtain data on the impact matrix and its weight and the user has to type in the data. In Expert Choice, data can be obtained through a "Treeview" window, or other windows for different pairwise comparisons. These commercial systems, which have existed on the market for years, spend more time and effort on improving the user interfaces. By providing enhanced visual functions in these systems, it is easier to obtain accurate parameter inputs and as a consequences, users will be more confident in the decision support results. Hence, users may feel more comfortable using the commercial products rather than the MPA. Excluding the MPA, however, Eom (1999) has done experiments to compare the user-friendliness among the commercial products. Eom suggested that Expert Choice and VISA are the most user-friendly MCDA products.

5.11.3 Comparison of Ease of Use

Although the MPA does not have graphical representations that can analyze a cluster of data individually, like some of the other systems do, its step-by-step procedure is simple enough to guide users through the decision-making analysis. The only difficulty that might be encountered is when the user needs to initialize the input type and range for each criterion. To initialize a problem in the MPA, the user is asked for information such as the type of input data (either fuzzy or numeric data), the range of data, the name of criterion, and its description which is optional. Compared with other systems where such information is presumed using the MPA may be more time-consuming at the present version.

6. Conclusions

6.1 Summary

Multi-Purpose Advisor (MPA), a decision support system, is primarily developed to solve the landfill selection problem in the city of Regina. Regina is faced with two major SWM problems: (1) the sanitary landfill has a life span of approximately 10 years according to the present waste generation rate; and (2) there exists high risk of groundwater contamination beneath the existing landfill. Due to these two problems, the city of Regina is concerned about allocating a new landfill. Possible sites had been proposed but rejected by rural jurisdictions mainly because of the NIMBY (not in my back yard) effects. Since many conflicts occur from different aspects, an investigation is undertaken in this study to confirm the necessity and suitability of a new landfill allocation. Instead of applying the tradeoff analysis used in the Phase 2 study (City of Regina 1989), five MADM methods are used. These include the Simple Weighted Addition, Weighted Product, Cooperative Game Theory, TOPSIS, and ELECTRE methods. Opinions and comments, which were needed as part of the input parameters, were obtained locally and divided into two groups. Group A represents the opinions of local residents in Regina and group B represents that of the local authority. Although the results according to these two groups vary slightly, they both show that the preferred landfill site should be located at the south end of Regina. Such a conclusion is agreeable with the results from the previous studies.

Among the possible landfill locations, Region (38, 42) is the most preferable one, according to both interest groups of the municipal residents and the local authority of the City of Regina. This site is located at the south end of Regina, where no potential aquifer problem is detected. Region (25, 26) would be the second alternative to the decision maker if Region (38, 42) is rejected. In addition, if the south sites are not considered, Region (11, 12) is a preferred alternative located at the north end and near the IPSCO landfill. Expansion of the existing landfill, on the other hand, is not recommended because its adverse impacts on many factors are higher than for other alternatives. It is ranked the second last choice. By conducting a survey, it is realized that more than 90 percent of the surveyed municipal residents would rather build a new landfill somewhere else in order to avoid the risk of groundwater contamination.

The MPA system is used to overcome particular difficulties in selection problems. For instance, it is possible to handle linguistic inputs by adopting a fuzzy set theory. Using the MPA system, the landfill selection process becomes stable and systematic. MCDM aggregation is also applied to guarantee consistency of the outcomes from different MADM methods. Moreover, implementing intuitive methods in the system is possible and easy to do. While decision makers would struggle with problems that consists of many conflicting factors, multi-criteria decision support system (MCDSS) should be able to compromise them and generate a satisfactory result.

Although the MPA system has been implemented for solving SWM problems, it can be used to deal with other selection problems of various sizes. Although five MADM methods are implemented, computation time of the system is significantly shorter than other commercial products. The computing result also includes an array of utility values for each alternative in order to compare the degree of preferences among them. In terms of usability, since MCDSS was initially designed for research purposes, its interface might not be as user friendly as those of the commercial products. However, it is simple enough so that an inexperienced user should be able to run the system without any difficulties.

6.2 Future Extensions

6.2.1 Solid Waste Management

In SWM, landfill allocation is only one of the many problems that are encountered. It can be foreseen that other challenging problems await further exploration. For example, it has only been realized in the recent decades that waste diversion is the optimal solution for waste treatment. Although different strategies have been proposed in the past that have successfully reduced the waste generation rate, the amount of solid waste that piles up in the landfill each year is quite significant. In particular, the lack of municipal residents' participation is still an unresolved problem. Contributions from researchers are strongly needed to develop efficient approaches to further decrease the rate. In addition, landfills cause a reduction of useful land, which might not be a feasible alternative to some countries such as Britain (Read et al. 1997). Several techniques of landfill recovery have been introduced to solve such a problem, but they are still at the infant stage. Hence, landfill recovery may be another challenging field that researchers can get involved with in the future.

Another direction for future research is to integrate the MADM approach, linear programming models, and geographic information system (GIS) in order to reduce subjectivity in the landfill selection process. Linear programming and GIS are techniques that are often used to deal with SWM problems. The results obtained from them provide reliable sources for the input to the impact matrix in MCDSS. Therefore, they can be used to enhance the quality of input parameters. In this study, inputs are still strongly subjective based on the analyst's opinions.

6.2.2 Multi-Criteria Decision Support System (MCDSS)

According to Eom (1999), many new MCDSS have paid a great deal of attention to the capabilities of the user interface. They visualize input parameters as different graphical objects. These objects generate an interactive environment for the decision maker who are then able to provide inputs with a certain degree of accuracy. To expand the functionality of the multi-purpose advisor (MPA), improvement of visual representation and graphical input analysis can be done.

As mentioned in the previous chapter, the MPA system is flexible enough so that a new MADM method can be added easily. Flexibility is needed since different MADM methods are implemented as individual modules. If a new method is added to the system, a new module can be created which will work independently to compute utility values like other modules. For example, some commercial systems apply the AHP or modified

AHP method, while others use the Bayesian decision analysis. These methods may be treated as different modules so that they can be included in the MPA system.

In this study, the MPA system assumes that individuals in each interest group have reached a common ground on the average impact weights. However, such an assumption might not be practical and, in extreme cases, the result might not satisfy any member in the group. In order to provide a compromise for such a situation, techniques for group support system can be investigated and integrated with MCDSS. Related researches can be found in Bose et al. (1997) and Zapatero et al. (1997). Also, a web-based DSS may be a challenging area for researchers because the Internet provides an easier way to communicate and share information. Developing a web-based DSS could support group decision making without the barrier of physical distances.

References

Al-Shemmeri T., Al-Kloub B., and Pearman A. "Computer Adied Decision Support System for WaterStrategic Planning in Jordan," European Journal of Operation Research. Vol. 192, pp455-472, 1997.

Aller L., Bennett T., Lehr J.H., and Petty R.J. "DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings," U.S. Environmental Protection Agency. EPA-600/2-85/018, 1985.

Aoki M. The Co-operative Game Theory of The Firm. NY:Oxford University Press. 1984.

Baas S.M., and Kwakernaak H. Rating and Ranking of Multiple Aspect Alternative Using Fuzzy Sets. Automatica. Vol. 13, pp47-58, 1977.

Badri M.A. "Combining the analytic hierarchy process and goal programming for global facility location-allocation problem," International Journal of Production Economics. Vol. 62, pp237-248, 1999.

Ballagh D. Groundwater Quality Analysis of the Condie Aquifer. Prepared for Environmental Protection Branch, Saskatchewan Environment and Resource Management. 1998.

Belton V., Hodgkin J. "Facilitators, Decision Makers, D.I.Y. Users: Is Intelligent Multicriteria Decision Support for All Feasible or Desirable?" European Journal of Operational Research. Vol. 113, pp247-260, 1999.

Bisdorff R. "Logical Foundation of Fuzzy Preferential Systems with Application to the ELECTRE Decision Aid Methods," Computers and Operations Research. Vol. 27, 7-8, pp673-687, 2000.

Bohanec M. DEX: An Expert System Shell for Multi-Attribute Decision Making, User's Manual. Jožef Stefan Institute, Report DP-5896, 1990.

Bohanec M. Introduction to DEX. Jožef Stefan Institute, Report DP-6240, 1991.

Bonissone P.P. A Fuzzy Set Based Linguistic Approach: Theory and Applications. In: Approximate Reasoning in Decision Analysis. M.M. Gupta and E. Sanchez (eds.), North-Holland, pp329-339, 1982.

Bose U., Davey A.M., Olson D.L. "Multi-attribute Utility Methods in Group Decision Making: Past Applications and Potential for Inclusion in GDSS," Omega. Vol 25, pp691-706, 1997.

Briassoulis H., Installe M. "An Integrated, Multistage, Multicriteria Methodology for Siting Hazardous Waste Management Facilities," Journal of Solid Waste Technology and Management, Vol. 23, 3, pp.155, 1996.

Buede D. "Second Overview of the MCDA Software Market," Journal of Multi-criteria Decision Analysis. Vol 5, 4, pp312-216, 1996.

Chang D.Y. Applications of the extent analysis method on fuzzy AHP, European Journal of Operational Research. Vol. 95, 3, pp649-655, 1996.

Chang N.B., Wang S.F. "A Fuzzy Goal Programming Approach for the Optimal Planning of Metropolitan Solid Waste Management Systems," European Journal of Operational Research. Vol. 99, 2, pp303-321, 1997a.

Chang N.B., Wen C.G., Cheng Y.L. "A Fuzzy Multi-Objective Programming Approach for Optimal Management of the Reservoir Watershed," European Journal of Operational Research. Vol. 99, 2, pp289-302, 1997b.

Chen S.H. "Ranking Fuzzy Numbers with Maximizing Set and Minimizing Set," Fuzzy Set and Systems. Vol. 17, 2, pp113-129, 1985.

Chen S.M. "A New Approach to Handling Fuzzy Decision-Making Problems," in Proceedings of the 18th International Symposium on Multiple-Valued Logic. Spain, pp72-76, 1988.

Chen S.J., and Hwang C.L. Fuzzy Scoring of Fuzzy Number – A Direct Comparison Index. 1989.

Chen W.Y., Kao J.J. "Fuzzy DRASTIC for Landfill Siting," in Proceedings of the Thirteenth International Conference on Solid Waste Technology and Management. Philadelphia, PA, U.S.A. 1997.

Cheng S., Chan C.W., Huang G.H. "Multiple Criteria Decision Analysis for the Planning of Solid Waste Management Systems," CD of Proceedings of 4th International conference on engineering design and automation (EDA 2000), Orlando Florida, 2000.

Cheng Y.M., and McInnis B. "An Algorithm for Multiple Attribute, Multiple Alternative Decision Problem Based on Fuzzy Sets with Application to Medical Diagnosis," IEEE Transaction on System, Man, and Cybernetics. Vol. SMC-10, pp645-650, 1980.

Chi G. Integrated Planning of a Solid Waste Management System in the City of Regina. Master Thesis in the University of Regina, 1997.

Chu A.T.W., Kalaba R.E., and Spingarn K. "A Comparison of Two Methods for Determining the Weights of Belonging to Fuzzy Sets," Journal of Optimization Theory and Applications. Vol. 27, pp.531-538, 1979.

City of Regina. Regina Waste Management Study Phase 1, 1983.

City of Regina. Waste Management Study Phase 2, 1989.

City of Regina. Annual Report. Solid Waste Division, 1999.

City of Regina (2000) – School project (WebPage).
URL at www.cityregina.com/schoolprojects/city_facts.shtml.

Cohen, J. & Cohen, P. Multiple Regression/Correlation for the Behavioral Sciences 2nd ed. : Hillsdale, NJ: Erlbaum Associates, 67-69, pp490-497, 1983.

Crama Y., Hansen P. "An Introduction to the ELECTRE Research Programme," in Hansen P. (ed.), Essays and Surveys on Multiple Criteria Decision Making. Springer, Berlin, pp31-42. 1983.

Efstathiou J., and Rajkovic V. "Multiattribute Decision Making Using a Fuzzy Heuristic Approach," IEEE Transaction on Systems, Man, Cybernetics. Vol. SMC-9, pp326-333, 1979.

Efstathiou J., and Tong R. "Ranking Fuzzy Sets: A Decision Theoretic Approach," IEEE Transaction on Systems, Man, and Cybernetics. Vol. SMC-12, pp655-659, 1982.

Eom S.B., Min H. "The Contributions of Multi-criteria Decision Making to the Development of Decision Support Systems Subspecialties: An Empirical Investigation," Journal of Multi-criteria Decision Analysis. Vol 8, 5, pp239-255, 1999.

Fishburn P.C. "Utility independence on subsets of product sets," Operations Research. Vol. 24, pp245-255, 1976.

French S. "Multi-Attribute Decision Support in the Event of a Nuclear Accident," Journal of Multi-Criteria Decision Analysis, Vol. 5, pp39-57, 1996.

Garavelli A.C., Gorgoglione M., Scozzi B. "Fuzzy Logic to Improve the Robustness of Decision Support Systems under Uncertainty," Computers #38, Industrial Engineering. Vol. 37, 1-2, pp477-480, 1999.

Gershon M. "The Role of Weights and Scales in the Application of Multiobjective Decision Making," European Journal of Operational Research. Vol. 15, pp244-250, 1984.

Haastrup P., Maniezzo V., Mattarelli M., Rinaldi F.M., Mendes I., Paruccini M. "A Decision Support System for Urban Waste Management," European Journal of Operational Research. Vol. 109, 2, pp330-341, 1998.

Haslinger J., Neittaanmaki P. "Finite Element Approximation for Optimal Shape Design: Theory and Numerical Realization," Application in Mathematical Optimization. Vol. 14, pp187-201, 1988.

Hinloopen E., Nijkamp P. "REGIME methode voor ordinele multicriteria analyse," Kwantitative Methoden, Vol. 7, 22, pp61-78.

Hipel K.W. "Fuzzy Set Methodologies in Multicriteria Modelling," in Gupta M.M. and Sanchez E. (eds), Fuzzy Information and Decision Processes, North-Holland, New York, pp279-287, 1982.

Hokkanen J., Salminen P. "The Choice of a Solid Waste Management System by Using the ELECTRE III Decision-Aid Method," in M. Paruccini (eds.), Applying Multiple Criteria Aid for Decision to Environmental Management. London, Kluwer Academic Publishers, 1993.

Hokkanen J., Salminen P. "Choosing a Solid Waste Management System Using Multicriteria Decision Analysis," European Journal of Operational Research. Vol. 98, 1, pp19-36, 1997.

Hong I., Vogel D.R. "Data and Model Management in a Generalized MCDM-DSS," Decision Science, 22, pp1-25, 1991.

Huang, G.H., Liu L., Chakma A., Wu S.M., Wang X. H., Yin Y.Y. "A Hybrid GIS-Supported Watershed Modeling System," Hydrological Science Journal, Vol. 44, 4, pp597-610, 1999.

Huang G.H., Wu, S.M., Guo H.C. "An Interactive Inexact-Fuzzy Approach for Multiobjective Planning of Water Environmental Systems," Water Science and Technology, Vol. 36, 5, pp235-242, 1997.

Hwang C.L., Yoon K. Multiple Attribute Decision Making: Methods and Applications. Springer-Verlag, New York, 1981.

Hwang C.L., Lin M.J. Group Decision Making Under Multiple Criteria: Methods and Applications. Springer-Verlag, New York, 1987.

Hwang C.L., Chen S.J. Fuzzy Multiple Attribute Decision Making: Methods and Applications. Springer-Verlag, New York, 1992.

Hwang F. An Expert Decision Making Support System for Multiple Attribute Decision Making. Ph.D. Thesis, Dept. of Industrial Engg, Kansas State University, 1987.

Ioannis G. "A Multiobjective Programming Model for Locating Treatment Sites and Routing Hazardous Wastes," European Journal of Operational Research. Vol. 104, 2, pp333-342, 1998.

Isabel G., Salvador C. "Ambiguity in Multicriteria Quality Decisions," International Journal of Production Economics. Vol. 38, 2-3, pp215-224, 1995.

Jain R. Decision Making in the Presence of Fuzzy Variables. IEEE Trans. on Systems, Man, and Cybernetics. Vol. SMC-6, pp698-703, 1976.

Jain R. A Procedure for Multi-Aspect Decision Making Using Fuzzy Sets. International Journal of System Science. Vol. 8, pp1-7, 1977.

Jardine B. Municipal Solid Waste Incineration Preliminary Analysis for the City of Regina. Reported in Faculty of Engineering, University of Regina. 1994.

Kanji G.K. 100 Statistical Tests. Sage Publ., London, 1993.

Karagiannidis A., Moussiopoulos A. "Application of ELECTRE III for the Integrated Management of Municipal Solid Wastes in the Greater Athens Area," European Journal of Operational Research. Vol 97, 3, pp439-449, 1997.

Keeney R.L., Raiffa H. Decisions with Multiple Objectives. New York: Wiley. 1976.

Kerre E.E. "The Use of Fuzzy Set Theory in Electrocardiological Diagnostics," in Gupta and E. Sanchez (eds.), Approximate Reasoning in Decision Analysis. M.M., pp277-282, 1982.

Kwakernaak H. "An Algorithem for Rating Multiple-Aspect Alternatives Using Fuzzy Sets," Automatica. Vol. 15, pp615-616, 1979.

Lau P. An Architectural Framework for Construction of A Flexible Expert System for Engineering Selection. MSc Thesis in University of Regina. 1996.

Lee E.S., Li R.L. "Comparison of Fuzzy Numbers Based on the Probability Measure of Fuzzy Events," Computer and Mathematics with Applications. Vol. 15, pp887-896, 1988.

Maniezzo V., Mendes I., Paruccini M. "Decision Support for Siting Problems," Decision Support Systems. Vol. 23, 3, pp273-284, 1998.

Miettinen, K., Mäkelä, M.M and Männikkö, T. "Optimal Control of Continuous Casting by Nondifferentiable Multiobjective Optimization," Computational Optimization and Applications Vol. 11, pp177-194, 1998a.

Miettinen, K. and Mäkelä, M.M. "Theoretical and Computational Comparison of Multiobjective Optimization Methods NIMBUS and RD," Report 5/1998, University of Jyväskylä, Department of Mathematics, Laboratory of Scientific Computing, Jyväskylä, 1998b.

Mollaghasemi M., Pet-Edwards J. Technical Briefing: Making Multiple-Objective Decisions, IEEE Computer Society Press, California, 1997.

Morton S. "Management decision systems; computer-based support for decision making," Boston, Division of Research, Graduate School of Business Administration, Harvard University, 1971.

Nijkamp P., Rietveld P., and Voogd H. Multicriteria Evaluation in Physical Planning, North-Holland, Amsterdam, 1990.

Norbis M., Smith J.M. "An Interactive Decision Support System for the Resource Constrained Scheduling Problem," European Journal of Operational Research. Vol. 94, pp54-65. 1996.

Osgood C.E., Suci G.J., and Tannenbaum P.H. The Measurement of Meaning (9th ed.). University of Illinois Press, Urbana. 1975.

Paruccini M., Matarazzo B. "The Use of MAPPAC and PRAGMA Methods to Support Decision on Industrial Waste Management," in M. Paruccini (eds.), Applying Multiple Criteria Aid for Decision to Environmental Management. London, Kluwer Academic Publishers, 1993.

Pinco Postigo T.R. Groundwater Quality of Condie Aquifer: A Graphical Analysis. BASc Project Report in Faculty of Engineering, University of Regina, 1999.

Read A.D., Phillips P. "Landfill as a Future Waste Management Option in England: The View of Landfill Operators and Decision Makers," in the Proceedings of the Thirteenth International Conference on Solid Waste Technology and Mangement. Chester, PA, 1997.

ReVelle C. "Research Challenges in Environmental Management," European Journal of Operational Research. Vol. 121, 2, pp218-231, 2000.

Rogers M, Bruen M. "A New System for Weighting Environmental Criteria for Use within ELECTRE III," European Journal of Operational Research. Vol. 107, 3, pp552-563, 1998.

Roy B. Classement et choix en presece de points de vue multiples (la methode ELECTRE), R.I.R.O., Vol. 2, pp57-75, 1968.

Roy B. Problems and Methods with Multiple Objective Functions. Mathematical Programming Vol. 1, pp239-266, 1971.

Roy B., Present M., and Silhol D. "A Programming Method for Determining which Paris Metro Stations should be Renovated," European Journal of Operations Research, Vol. 24, pp318-334, 1986.

Saaty T.L. “A Scaling Method for Priorities in Hierarchical structures,” Journal of Mathematical Psychology. Vol. 15, pp.234-281, 1977.

Saaty T.L. The Analytical Hierarchical Process. New York: Wiley. 1980.

Sarkis J. “A Comparative Analysis of DEA as a Discrete Alternative Multiple Criteria Decision Tool,” European Journal of Operational Research. Vol. 123, 3, pp543-557, 2000.

Sen T.K., Moore L.J., Hess T.J. “An Organizational Decision Support System for Managing the DOE Hazardous Waste Cleanup Program,” Decision Support Systems. Vol. 29, 1, pp89-109, 2000.

SERM (1999) – Recycling Initiatives (WebPage).
URL at www.serm.gov.sk.ca/environment /recycle/initiatives.php3

Starr M.K. Production Management. Englewood Cliffs, NJ: Prentice-Hall. 1972.

Szidarovszky F., and Yakowitz S. Principles and Procedures of Numerical Analysis. NY: Plenum Press. 1978.

Van Delft A., Nijkamp P. Multicriteria Analysis and Regional Decision-Making. Martinus Nijhoff: The Hague. 1976.

Voogd H. Multicriteria Evaluation for Urban and Regional Planning. Pion Ltd. London. 1983.

Wang L.X. A Course in Fuzzy Systems and Control. New Jersey: Prentice Hall. 1997.

Wenstop F. “Fuzzy Set Simulation Models in a Systems Dynamic Perspective,” Kybernetes. Vol. 5, 1976, pp209-218.

Yager R. “Fuzzy Decision Making Including Unequal Objectives,” Fuzzy Sets and Systems Vol. 1, pp87-95, 1978.

Yoon K. A Reconciliation among Discrete Compromise Situatons. Journal of Operational Research Society. Vol. 40, pp681-686, 1989.

Yoon K.P., Hwang C.L. Multiple Attribute Decision Making: An Introduction. California: Sage Publication. 1995.

Zadeh L.A. “Fuzzy Sets,” Information and Control, Vol. 8, pp338-353, 1965.

Zapatero E., Smith C.H., Weistroffer H.R. “Evaluating Multiple Attribute Decision Support Software,” Journal of Multi-criteria Decision Analysis. Vol 6, pp201-214, 1997.

Zimmermann J. Fuzzy Set Theory and Its Applications. Boston: Kluwer Academic Publishers. 1997.

Appendix A. Example of Using ELECTRE

This example demonstrates how to apply the ELECTRE method. In this example, the normalized impact matrix and weight are given as follows:

Criteria (i)	**Alternatives (j)**			**Weights (w_i)**
	1	**2**	**3**	
1	0.6	0.8	1.0	0.2
2	1.0	0.4	0.2	0.5
3	0.8	1.0	0.6	0.3

Step 1: Generate the weighted normalized matrix using the equation $\mathbf{v_{ij} = w_i r_{ij}}$.

Criteria (i)	**Alternatives (j)**		
v_{ij}	**1**	**2**	**3**
1	0.12	0.16	0.20
2	0.50	0.20	0.10
3	0.24	0.30	0.18

e.g. $v_{11} = w_1 * r_{11} = 0.6 * 0.2 = 0.12$

Step 2: Calculate the concordance set $C_{jj'}$ and discordance set $D_{jj'}$.

Pair of alternatives (j, j')	Concordance set $C_{jj'}$	Discordance set $D_{jj'}$
(1, 2)	2	1, 3
(1, 3)	2, 3	1
(2, 1)	1, 3	2
(2, 3)	2, 3	1
(3, 1)	1	2, 3
(3, 2)	1	2, 3

Step 3: Calculate the concordance and discordance indices.

Pair of alternatives (j, j')	Concordance index $c_{jj'}$	Discordance index $d_{jj'}$
(1, 2)	0.5	0.2
(1, 3)	0.8	0.2
(2, 1)	0.5	1.0
(2, 3)	0.8	0.3
(3, 1)	0.2	1.0
(3, 2)	0.2	1.0

e.g. $c_{12} = \sum_{i \in C_{12}} \frac{w_i}{\sum_{k=1}^{n} w_k} = \frac{0.2}{0.2+0.5+0.3} = 0.5$

$$d_{12} = \frac{\max_{i \in D_{12}} | v_{i1} - v_{i2} |}{\max_{k \in I} | v_{k1} - v_{k2} |} = \frac{\max(| 0.12 - 0.16 |, | 0.24 - 0.30 |)}{\max(| 0.12 - 0.16 |, | 0.50 - 0.20 |, | 0.24 - 0.30 |)}$$

$$= \frac{0.06}{0.30} = 0.2$$

Step 4: Calculate the net concordance and discordance indices using complementary analysis.

Alternatives (j)	Net concordance index c_j	Net discordance index d_j
1	0.6	-1.6
2	0.6	0.1
3	-1.2	1.5

e.g. $c_1 = \sum_{\substack{j'=1 \\ j' \neq j}}^{m} c_{1j'} - \sum_{\substack{j'=1 \\ j' \neq j}}^{m} c_{j'1} = (0.5 + 0.8) - (0.5 + 0.2) = 0.6$

$$d_1 = \sum_{\substack{j'=1 \\ j' \neq j}}^{m} d_{1j'} - \sum_{\substack{j'=1 \\ j' \neq j}}^{m} d_{j'1} = (0.2 + 0.2) - (1.0 + 1.0) = -1.6$$

Since the most preferable alternative is defined as the one which consists of a highest value of c_j and a lowest value of d_j, it can be concluded that the ranking of this example is $1 > 2 > 3$.

Appendix B. Impact Matrix of the Landfill Selection Problem in the City of Regina

		Alternatives					
		(23, 26)	(25, 26)	(70, 71)	(74, 75)	(3, 4)	(38, 42)
Criteria	**Public**	Medium	Medium	Medium	Medium	High	Medium
	Agriculture	High	Medium	High	Low	Low to Medium	Low
	Hydrogeology	Extremely Good	Extremely Good	Medium	Very Bad	Very Bad	Extremely Good
	Transportation	98	99	80	68	50	81
	Land Use	Low	Low	Low	Low	Medium	Medium
	Heritage	Low	Low	Medium	Medium	Low	High
	Cost	95	95	95	95	107	95
	Extensibility	Medium	Good	Bad to Medium	Very Bad	Bad to Very Bad	Very Good
	Reliability	Good	Good to Very Good	Medium	Good	Good	Very Good
	Wildlife	Medium	Medium	Medium	Medium	Bad	Medium
	Politic	Very High	Very High	High	High	Medium to Low	Very High
	Land Value Drop	Medium	Medium	Very Low	Very Low	Low	Medium

		Alternatives				
		(8, 9)	(11, 12)	(9, 12)	(8, 11)	Existing
Criteria	**Public**	High	High	High	High	Low
	Agriculture	Medium	Medium	Medium	Medium	Extremely Low
	Hydrogeology	Medium	Medium to Good	Medium	Medium	Extremely Bad
	Transportation	56	56	58	56	70
	Land Use	Medium	Low	Low	Low	Medium to High
	Heritage	Low	Medium to Low	Medium to Low	Low	Very Low
	Cost	107	107	107	107	93
	Extensibility	Medium	Medium to Good	Medium	Good	Extremely Bad
	Reliability	Good	Good	Good	Good	Bad
	Wildlife	Medium to Bad	Bad	Medium to Bad	Medium to Bad	Good
	Politic	Medium to Low	Medium to Low	Medium to Low	Medium to Low	Low
	Land Value Drop	Very Low	Very Low	Very Low	Very Low	Extremely Low

Appendix C. Sample Survey for Selection of Regina Landfill Site

Survey:

Survey Form Number: _________

Name: _____________________

Personal Information:

Q1. Are you working?

Yes No

Q2. If you are working, is your job related to solid waste management or city planning?

Yes No

Q3. Which area in the City of Regina are you living in now?

East South West North Central

Waste Management:

Q1. In Regina, only one landfill is operating for domestic, industrial, and commercial waste disposal. If this landfill is full, which of the following locations do you think is the best location for the new landfill? Please circle your answer.

1. South (about 11 km from south end of Regina)
2. North (about 8 km from north end of Regina)
3. Expansion of Existing landfill (located at fleet street in east Regina)
4. Any of the above

Q2. Where would you not prefer the landfill to be located?

1. South (about 11 km from south end of Regina)
2. North (about 8 km from north end of Regina)
3. Expansion of Existing landfill (located at fleet street in east Regina)
4. None of the above

Q3. The following factors are the criteria for landfill selection.

1. Social Impact (public acceptance)
   Residences in surrounding area
   Resistance impact from residences (eg. Noise, dust, odor)
2. Agricultural
   Disruptions of farm operations
3. Hydrogeology
   Risk to groundwater / aquifer contamination
4. Transportation
   Distance from waste centroid to landfill
5. Public image
   Conflict to tourists' traffic
6. Land Use
   Conflict to potential site development
7. Heritage
   Potential for heritage resource impact
8. Cost
9. Site Capacity
10. Reliability and maintenance over years (mainly compare new vs existing landfill)
11. Critical wildlife habitats
12. Political issues 1 (government, provincial, and city authorities)
13. Political issues 2 (local jurisdictions support)
14. Land value drop

Do you think there are any other criteria for a landfill selection? If your answer is yes, please list them.

Q4. Please rate the following criteria in terms of their importance for landfill selection, by circling the given scale below:

Public acceptance	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Agricultural	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Hydrogeology	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Transportation	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Public Image	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Land Use	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Heritage	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Cost	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Site Capacity	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Reliability and maintenance over years	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Critical wildlife habitats	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Political issues	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high
Land value Drop	Minimum effect	Very low	Low to very low	Low	More or less low	Medium	More or less high	High	High to very high	Very high	Extremely high

Appendix D. Results Obtained from the MPA

Group A. Public Points of View:

MADM RESULTS	
Method:	**SWA**
Utility Range:	0 to 1

Location	Rank	Utility	Note
38, 42	1	0.700	South site
25, 26	2	0.625	South site
23, 26	3	0.572	South site
70, 71	4	0.548	South site
11, 12	5	0.547	North site
74, 75	6	0.543	South site
8, 11	7	0.540	North site
9, 12	8	0.537	North site
8, 9	9	0.477	North site
Existing	10	0.421	Expansion of existing landfill
3, 4	11	0.388	North site

MADM RESULTS	
Method:	**ELECTRE**
Utility Range:	**1 to 11**

Location	Rank	Utility	Note
38, 42	1	1.000	South site
25, 26	2	2.500	South site
74, 75	3	3.000	South site
11, 12	4	3.500	North site
9, 12	5	5.500	North site
8, 11	5	5.500	North site
70, 71	6	7.500	South site
23, 26	6	7.500	South site
8, 9	7	9.000	North site
Existing	8	10.000	Expansion of existing landfil
3, 4	9	11.000	North site

MADM RESULTS
Method: TOPSIS
Utility Range: 0 to 1

Location	Rank	Utility	Note
38, 42	1	0.661	South site
25, 26	2	0.581	South site
23, 26	3	0.544	South site
11, 12	4	0.538	North site
9, 12	5	0.527	North site
70, 71	6	0.523	South site
8, 11	7	0.522	North site
74, 75	8	0.463	South site
8, 9	9	0.446	North site
Existing	10	0.387	Expansion of existing landfill
3, 4	11	0.334	North site

MADM RESULTS
Method: CGT
Utility Range 0 to infinite

Location	Rank	Utility	Note
74, 75	1	0.075	South site
23, 26	2	0.000	South site
25, 26	2	0.000	South site
70, 71	2	0.000	South site
3, 4	2	0.000	North site
38, 42	2	0.000	South site
8, 9	2	0.000	North site
11, 12	2	0.000	North site
9, 12	2	0.000	North site
8, 11	2	0.000	North site
Existing	2	0.000	Expansion of existing landfill

MADM RESULTS
Method: WP
Utility Range: 0 to 1

Location	Rank	Utility	Note
38, 42	1	0.106	South site
25, 26	2	0.075	South site
23, 26	3	0.060	South site
11, 12	4	0.042	North site
70, 71	5	0.040	South site
9, 12	6	0.039	North site
8, 11	7	0.034	North site
74, 75	8	0.022	South site
8, 9	9	0.020	North site
3, 4	10	0.013	North site
Existing	11	0.004	Expansion of existing landfill

AGGREGATION RESULTS
Method: ARP
Utility Range: 1 to 11

Location	Rank	Utility	Note
38, 42	1	1.020	South site
25, 26	2	1.820	South site
23, 26	3	2.820	South site
11, 12	4	3.620	North site
70, 71	5	4.020	North site
9, 12	6	4.620	North site
8, 11	7	5.020	North site
74, 75	8	5.200	South site
8, 9	9	7.420	North site
Existing	10	8.420	Expansion of existing landfill
3, 4	11	8.820	North site

AGGREGATION RESULTS
Method: Borda Method
Utility Range: 0 to 10

Location	Rank	Utility	Note
38, 42	1	10.000	South site
25, 26	2	9.000	South site
23, 26	3	8.000	South site
11, 12	4	7.000	North site
70, 71	5	5.000	South site
74, 75	5	5.000	South site
9, 12	6	3.000	North site
8, 11	6	3.000	North site
8, 9	7	2.000	North site
Existing	8	1.000	Expansion of existing landfill
3, 4	9	0.000	North site

AGGREGATION RESULTS
Method: Copeland Method
Utility Range: -10 to 10

Location	Rank	Utility	Note
38, 42	1	10.000	South site
25, 26	2	8.000	South site
23, 26	3	6.000	South site
11, 12	4	4.000	North site
70, 71	5	1.000	South site
74, 75	6	0.000	North site
9, 12	7	-2.000	North site
8, 11	8	-3.000	North site
8, 9	9	-6.000	North site
Existing	10	-8.000	Expansion of existing landfill
3, 4	11	-10.000	North site

Group B. Political Points of View:

MADM RESULTS			
Method:	**SWA**		
Utility Range:	**0 to 1**		

Location	**Rank**	**Utility**	**Note**
38, 42	1	0.697	South site
25, 26	2	0.632	South site
23, 26	3	0.577	South site
70, 71	4	0.557	South site
74, 75	5	0.550	South site
11, 12	6	0.527	North site
8, 11	7	0.523	North site
9, 12	8	0.514	North site
8, 9	9	0.446	North site
Existing	10	0.424	Expansion of existing landfill
3, 4	11	0.355	North site

MADM RESULTS			
Method:	**ELECTRE**		
Utility Range:	**1 to 11**		

Location	**Rank**	**Utility**	**Note**
38, 42	1	1.000	South site
25, 26	2	2.500	South site
74, 75	2	2.500	South site
11, 12	3	4.500	North site
23, 26	4	6.000	South site
9, 12	4	6.000	North site
8, 11	4	6.000	North site
70, 71	5	7.500	South site
8, 9	6	9.000	North site
Existing	7	10.000	Expansion of existing landfill
3, 4	8	11.000	North site

MADM RESULTS	
Method:	**TOPSIS**
Utility Range:	**0 to 1**

Location	Rank	Utility	Note
38, 42	1	0.647	South site
25, 26	2	0.599	South site
23, 26	3	0.558	South site
70, 71	4	0.554	South site
11, 12	5	0.544	North site
8, 11	6	0.536	North site
9, 12	7	0.529	North site
74, 76	8	0.490	South site
8, 9	9	0.425	North site
Existing	10	0.389	Expansion of existing landfill
3, 4	11	0.298	North site

MADM RESULTS	
Method:	**CGT**
Utility Range	**0 to infinite**

Location	Rank	Utility	Note
74, 75	1	0.106	South site
23, 26	2	0.000	South site
25, 26	2	0.000	South site
70, 71	2	0.000	South site
3, 4	2	0.000	North site
38, 42	2	0.000	South site
8, 9	2	0.000	North site
11, 12	2	0.000	North site
9, 12	2	0.000	North site
8, 11	2	0.000	North site
Existing	2	0.000	Expansion of existing landfill

MADM RESULTS	
Method:	**WP**
Utility Range:	**0 to 1**

Location	Rank	Utility	Note
38, 42	1	0.087	South site
25, 26	2	0.068	South site
23, 26	3	0.054	South site
70, 71	4	0.034	South site
11, 12	5	0.031	North site
9, 12	6	0.029	North site
8, 11	7	0.026	North site
74, 75	8	0.019	South site
8, 9	9	0.015	North site
3, 4	10	0.009	North site
Existing	11	0.003	Expansion of existing landfill

AGGREGATION RESULTS
Method: ARP
Utility Range: 1 to 11

Location	Rank	Utility	Note
38, 42	1	1.020	South site
25, 26	2	1.720	South site
23, 26	3	2.487	South site
70, 71	4	4.220	South site
11, 12	4	4.220	North site
8, 11	5	4.687	North site
74, 75	6	4.700	South site
9, 12	7	4.887	North site
8, 9	8	7.420	North site
Existing	9	8.420	Expansion of existing landfill
3, 4	10	8.820	North site

AGGREGATION RESULTS
Method: Borda Method
Utility Range: 0 to 10

Location	Rank	Utility	Note
38, 42	1	10.000	South site
25, 26	2	9.000	South site
23, 26	3	8.000	South site
70, 71	4	7.000	South site
74, 75	5	6.000	South site
11, 12	6	5.000	North site
9, 12	7	3.000	North site
8, 11	7	3.000	North site
8, 9	8	2.000	North site
Existing	9	1.000	Expansion of existing landfill
3, 4	10	0.000	North site

AGGREGATION RESULTS
Method: Copeland Method
Utitlity Range: -10 to 10

Location	Rank	Utility	Note
38, 42	1	10.000	South site
25, 26	2	8.000	South site
23, 26	3	6.000	South site
70, 71	4	4.000	South site
74, 75	5	2.000	South site
11, 12	6	0.000	North site
9, 12	7	-3.000	North site
8, 11	7	-3.000	North site
8, 9	8	-6.000	North site
Existing	9	-8.000	Expansion of existing landfill
3, 4	10	-10.000	North site