

**Integrated Decision Support System for Infrastructure Privatization
under Uncertainty using Conflict Resolution**

by

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Abstract

Infrastructure privatization decisions have an enormous financial and social impact on all stakeholders, including the public sector, the private sector, and the general public. Appropriate privatization decisions, however, are difficult to make due to the conflicting nature of the objectives of the various stakeholders. This research introduces a multi-criteria decision-making framework for evaluating and comparing a wide range of privatization schemes for infrastructure facilities. The framework is designed to resolve conflicts that arise because of the varying points of view of the stakeholders, and accordingly, determine the most appropriate decision that satisfies all stakeholders' preferences. The developed framework is expected to help in re-engineering the traditional conflict resolution process, particularly for construction conflict resolution and infrastructure privatization decisions. The framework provides decision support at the management level through three successive decision support processes related to 1. Screening of feasible solutions using the Elimination Method of multiple criteria decision analysis (MCDA); 2. Analyzing the actions and counteractions of decision makers using conflict resolution and decision stability concepts to determine the most stable resolution; and 3. Considering the uncertainty in decision maker's preferences using Info-gap Theory to evaluate the robustness of varying uncertainty levels of the decisions. Based on the research, a procedure and a decision support system (DSS) have been developed and tested on real-life case studies of a wastewater treatment plant and a construction conflict. The results of the two case studies show that the proposed DSS can be used to support decisions effectively with respect to both construction conflicts and infrastructure

privatization. The developed system is simple to apply and can therefore save time and avoid the costs associated with unsatisfactory decisions. This research is expected to contribute significantly to the understanding and selecting of proper Public-Private-Partnership (PPP) programs for infrastructure assets.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

According to the World Bank (Houskamp and Tynan, 2000), since 1980, a growing number of countries have encouraged greater involvement of the private sector in infrastructure systems. In addition to citing the main advantage of creating a competitive environment that will reduce the overall cost, proponents of privatization have argued that the private sector will be more efficient and better at financing the large investment needed. These claims have not been supported by evidence from comparative studies or independent scientific reviews with respect to the actual performance of the public and private sectors. This lack of evidence is especially notable in the water industry due to its lack of a systematic methodology for choosing the most appropriate privatization scheme, particularly since the majority of the contracts in question are confidential.

Infrastructure privatization has a wide variety of alternative approaches ranging from partial operational contribution of services or materials to complete ownership and management of assets. The selection and evaluation of a proper model for optimization is a crucial part of any

infrastructure system. The most popular approach used in the selection of a scheme is the competitive method. To date, there have been no systematic processes or selection criteria to guide decision makers (DMs) in the public sector when they are trying to make an informed selection. Privatization contracts are generally ambiguous, and in particular, they lack specific details for dispute resolution procedures (Catley-Carlson, 2002).

Multi-Criteria Decision Analysis (MCDA) methodologies provide a comprehensive set of decision tools that may help to guide privatization selection decisions. These methods have been found to be highly useful in scientific research and in practical problem solving. When used together with the Graph Model for Conflict Resolution and the Information Gap Theory, they may yield a remarkable tool for dealing with the uncertain negotiation-based process of privatization. This research, as such, develops a systems methodology for evaluating and comparing a wide range of privatization methods and schemes. The methodology establishes multiple criteria that reflect stakeholders' preferences when comparing alternative solutions. Various MCDA studies are carried out in order to determine optimum privatization schemes that satisfy stakeholders' requirements.

1.2 Research Motivation

The National Science Foundation (NSF, 2004) has estimated the total US investment in civil infrastructure systems at \$ 20 trillion. In Canada, recent studies by the National Round Table on the Environment and the Economy have estimated that water and sewer infrastructure will require significant investment in excess of \$ 50 billion for upgrading or restoring to an acceptable level. Only half of the cost will be recovered from user fees (Li, 2001). Many of these infrastructure

systems are eroding due to aging, excessive demands due to population increase, lack of maintenance and rehabilitation due to government inefficiency, and expenditure cuts. However, the demand for these services continues to rise dramatically. The renewal of aging infrastructure systems is a difficult proposition at all government levels due to the eroded quality of the infrastructure; the high cost of maintenance, rehabilitation, expansion; and other financial constraints. Many governments are recognizing their inability to effectively provide infrastructure service and are searching for alternatives to managing and financing these essential services. Hence, they are opening the door partially or completely for private investors to participate in this crucial area. Various Public-Private-Partnership (PPP) programs have been adopted by some governmental authorities and are playing a growing role in the implementation of infrastructure rehabilitation, with both successes and failures.

Infrastructure projects possess unique characteristics; they differ with respect to function, uncertainty, risk, and cost. Although PPP systems of privatization show a high potential for success and have been adopted in many countries, they could lead to disaster if they are not properly studied, selected, and implemented. The proper evaluation and selection of PPP programs is crucial.

To date, public-sector decision makers (DMs) have lacked both a complete set of selection criteria and a systematic process for determining appropriate decisions. Furthermore, these decision-making processes need to reflect stakeholders' values, avoid any unnecessary risk, and use a systematic dispute resolution procedure to support quality selections.

Without the implementation of a proper rational and comprehensive selection process for choosing the optimum alternative and avoiding future disputes, the extensive expansion of privatization could lead to failure. To date, the selection process is not systematically executed. It lacks an organized, systematic process for matching the appropriate privatization scheme with the specific needs of the public sector.

In general, the selection process suffers from the following procedural problems (Catley-Carlson, 2002; Gleick et al., 2002):

- The selection process does not consider the effects of all related criteria and variables that could affect infrastructure projects.
- Most contracts used are ambiguous.
- Most privatization procedures lack detailed procedures for resolving disputes when the projects are implemented, such as specifying who resolves disputes and setting out rules and procedures for dispute resolution.
- The selection process has an increased potential for political conflict (e.g., disagreements with foreign investors).
- The selection process lacks a clear procedure with criteria known in advance.
- Because of the ambiguity of the contracts, the private sector can raise the cost of its proposals, so that the public sector pays much more than initially expected.
- The selection process lacks risk assessment models (Catley-Carlson, 2002).

A key purpose of this research is to develop a framework to enable the DMs in the public sector to make better decisions when evaluating and selecting appropriate privatization schemes in order to save time and money for the public sector.

1.3 Research Objectives and Scope

The objectives of this research are to provide an understanding of the procedure for privatization selection and evaluation, and to develop a decision support framework to help DMs in the public sector decide upon the appropriate privatization schemes that satisfy stakeholders' requirements.

Specific objectives include the following:

- Identifying the various Public Private Partnership (PPP) schemes used in the privatization process;
- Developing systems methodologies by integrating MCDA and Graph Model techniques for evaluating and comparing a wide range of PPP schemes, considering all stakeholders' values;
- Integrating information gap theory (Info-gap Theory) for dealing with missing information or future uncertainty associated with infrastructure projects;
- Experimenting with various MCDA tools, genetic algorithms (GAs), conflict resolution methods, and info-gap theory to develop an encompassing model for optimizing privatization decisions.
- Developing and testing a decision-support system (DSS) based on real-life water/wastewater infrastructure privatization case studies;

- Experimenting with various MCDA tools, genetic algorithms (GAs), conflict resolution methods, and info-gap theory to develop an encompassing model for optimizing privatization decisions.

The following aspects and concepts are utilized in the design of the proposed DSS:

1. Consider both numeric and non-numeric criteria that are important in the selection of a proper privatization scheme.
2. Use a filter or a pre-processor to eliminate or screen out infeasible alternatives.
3. Use an appropriate MCDA method, such as the elimination method, to compare and rank feasible alternatives.
4. Incorporate the Graph Model for Conflict Resolution into the DDS for carrying out strategic analyses.
5. Extend the Graph Model methodology with Genetic Algorithms (GAs) optimization as an approach to optimizing decisions when the number of feasible solutions is large.
6. Extend the DSS to consider the impact of uncertainty on decision-making using the Info-gap Theory approach.
7. Implement the proposed decision methodology in a new, user-friendly, DSS, and experiment with case studies in wastewater infrastructure and construction conflict to test and improve it.

The research was developed to be useful in infrastructure privatization projects as well as in any multi-criteria decision-making process. Figure 1.1 provides a flow chart for the privatization

process. The present research focuses on Steps 2 and 3, which are the most critical for appropriate privatization decisions.

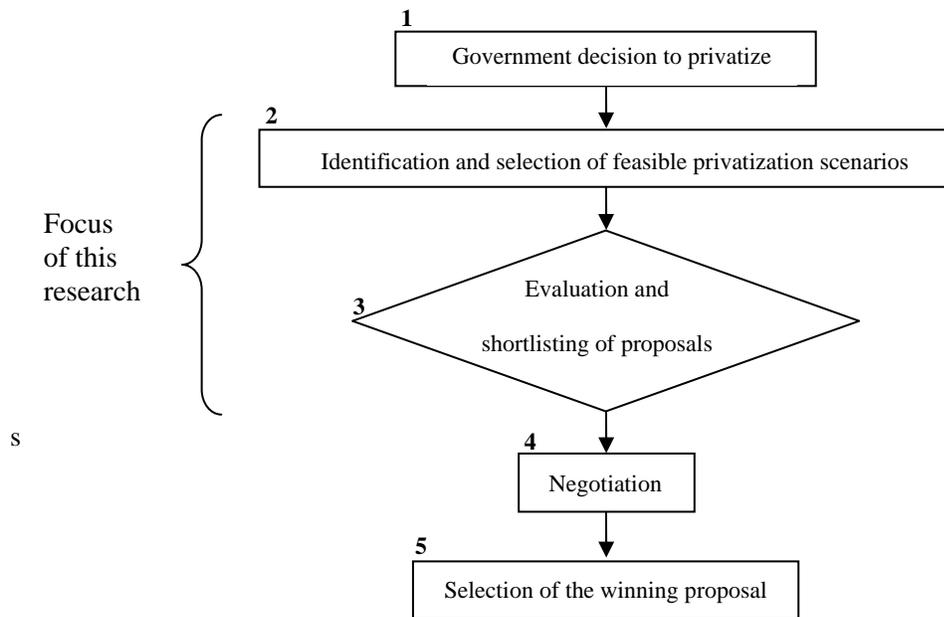


Figure 1.1: Stages of the Privatization Process

1.4 Research Methodology

This research develops a comprehensive decision-making methodology for evaluating and selecting the privatization method that best satisfies stakeholders' preferences. To achieve the desired objectives, the research follows the methodology depicted in Figure 1.2.

- **Step 1: Literature Review**

A comprehensive literature review is conducted with respect to the following:

1. Privatization methods in infrastructure projects with examples,
2. MCDA methods and their processes,

3. Conflict resolution techniques, and
4. Optimization tools.

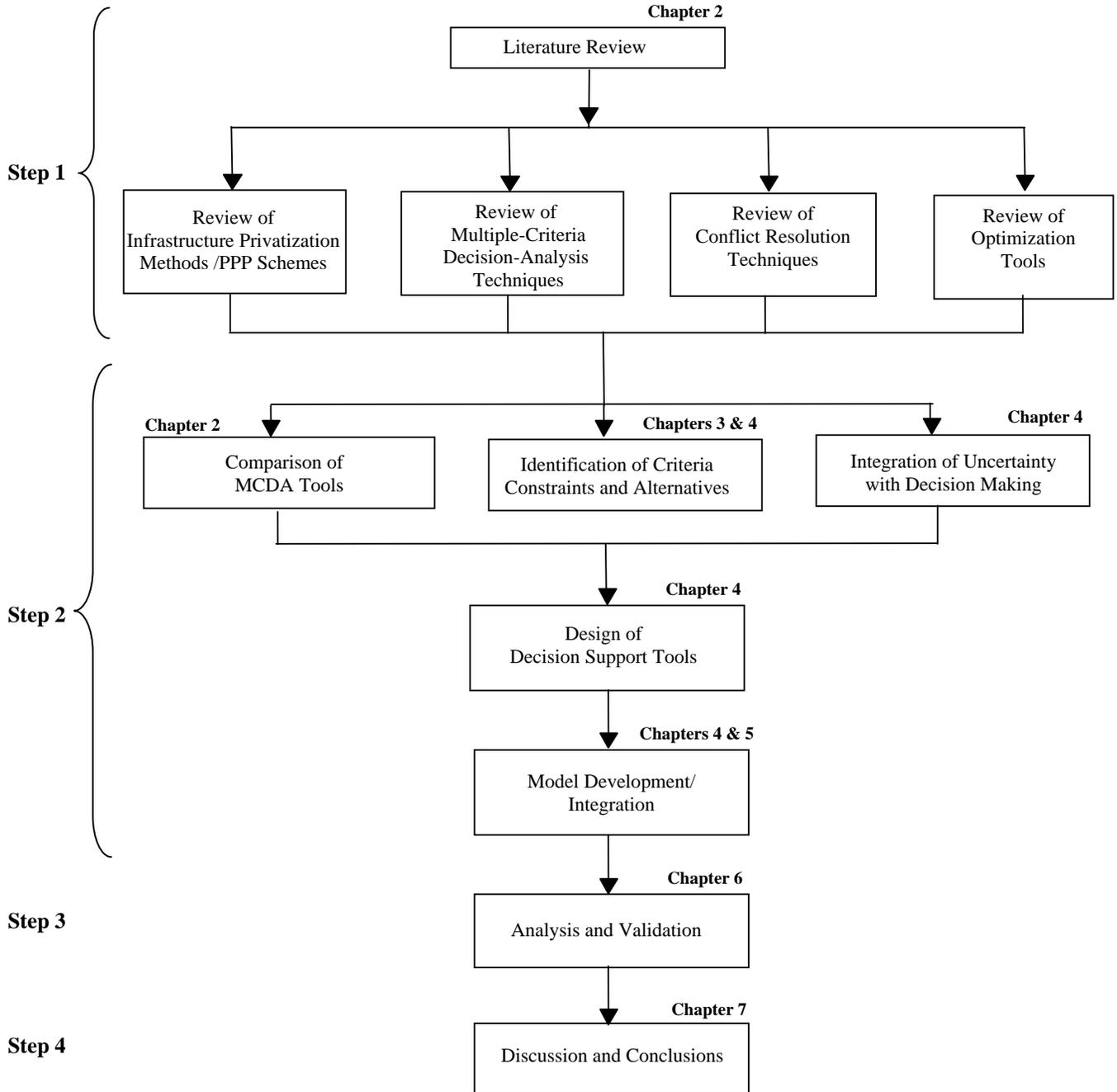


Figure 1.2: Research Framework

- **Step 2: Procedure**

The following procedure needs is implemented:

1. Problem identification;
2. Identification of criteria, constraints, and alternatives;
3. Design of a model of a decision support tool for selecting the best privatization scheme using MCDA, the Graph Model for Conflict Resolution, and the Information Gap Theory; and
4. Experimenting with the artificial intelligence tool of Genetic Algorithms for decision optimization.

- **Step 3: Analysis and Validation**

The model is analyzed and validated using case studies in different appropriate sectors.

- **Step 4: Discussion and Conclusions**

The results are discussed, conclusions are drawn, and recommendations are made for future work.

1.5 Thesis Organization

Chapter 2 presents a review of the literature about decision-making tools, in particular, Multiple Criteria Decision Analysis (MCDA) techniques, followed by a review of advanced decision support tools for optimizing decisions and dealing with conflict, uncertainty and lack of information, such as the Graph Model for Conflict Resolution (GMCR), Info-gap theory, and Genetic Algorithms (GAs). Chapter 3 discusses infrastructure privatization, present various forms of Public-Private-Partnerships (PPP), and concludes with a brief description of the advantages and disadvantages of privatization. Chapter 4 presents the framework of the proposed decision

support system, followed by experimentation using the main components of the developed DSS: MCDA, the Graph Model for Conflict Resolution, info-gap theory, and GAs. Chapter 5 then, presents the implementation stage of the developed DSS model as prototype software, as well as its main components, input, and output, using a case study of a construction conflict for validation. Chapter 6 is devoted to the application of the DSS for infrastructure privatization using a case study of the Hamilton Wastewater Treatment Plant. The way in which the developed prototype can be used to suggest the best privatization option is explained. Finally, Chapter 7 is a review of this study and the conclusions that can be drawn, along with recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the fundamentals of decision-making, particularly Multi-Criteria Decision Analysis also known as Multiple Criteria Decision Analysis (MCDA). It then presents a comprehensive review of MCDA models for evaluating and comparing different infrastructure privatization schemes. It provides a review of various MCDA techniques and procedures, together with a survey of existing decision-supporting software. This section is followed by a review of advanced decision support tools for optimizing decisions and dealing with conflict, uncertainty, and lack of information, such as the Graph Model for Conflict Resolution (GMCR), Information Gap Theory (Info-gap Theory), and Genetic Algorithms (GAs).

2.2 Multi-Criteria Decision Analysis

Some simple and relatively unimportant decisions can be made based on a single governing factor called a single criterion. However, given the complex interactions among the economical, social, and political aspects of modern life, it becomes difficult, if not impossible, to solve real-life problems without a consideration of multiple factors. Therefore,

an MCDA process is involved. Recently, there has been a growing interest in using MCDA tools in many domains, where they provide the capability of dealing with complex decision problems.

MCDA is the process of reaching a decision through the consideration of available alternatives, guided by many measures, rules, and standards, called criteria (Zeleny, 1981). Criteria can be quantitative, clear, and easy-to-measure, such as marks, size, and price, or qualitative and hard-to-measure, such as satisfaction, colour, and taste. Even when criteria are of the former type, conflict may arise among the decision makers (DMs) about their priorities and preferences with respect to the criteria. Accordingly, an appropriate decision process should consider both types of criteria and also take into account the variability in DMs' preferences.

2.2.1 The Structure of MCDA

The process of structuring MCDA problems has received a great deal of attention. von Winterfeldt and Edwards (1986) called problem structuring the most difficult part of decision aid. Keeney (1992) and Hammond et al. (1999) proposed a systematic analysis method, called value-focused thinking, which provides an excellent approach to this aspect of MCDA.

Despite the variations in the terminology and notation used by different researchers, the general process of multiple-criteria decision aid is defining objectives, arranging them into criteria, identifying all possible alternatives, and then measuring consequences. A

consequence is a direct measurement of the success of an alternative according to given criterion (e.g., cost in dollars and volume in cubic metres).

The basic format of a typical MCDA problem established by carrying out the above processes is shown in Figure 2.1. In this figure, $A = \{A^1, A^i, \dots, A^3, \dots, A^n\}$ is the set of alternatives, and $Q = \{1, 2, \dots, j, \dots, q\}$ is the set of criteria. The consequence for criterion j of alternative A^i is expressed as $C_j(A^i)$, which can be shortened to c_j^i when there is no possibility of confusion. It should be kept in mind that, altogether, there are n alternatives and q criteria.

		Alternatives (A)					
		A_1	A_2	...	A_i	A_n
Criteria (Q)	1						
	2						
	.						
	.						
	j				c_j^i		
	.						
	.						
	q						

Figure 2.1: The Structure of MCDA

2.2.2 Multiple-Criteria Decision-Making Process

The decision-making process in MCDA is defined as a dynamic process that involves a complete search of information (Zeleny, 1981). The basic steps in the decision-making process are shown in Figure 2.2.

The decision-making procedure shown in Figure 2.2 is general and can be used with both single and multiple criteria. For MCDA, these steps are explained as follows:

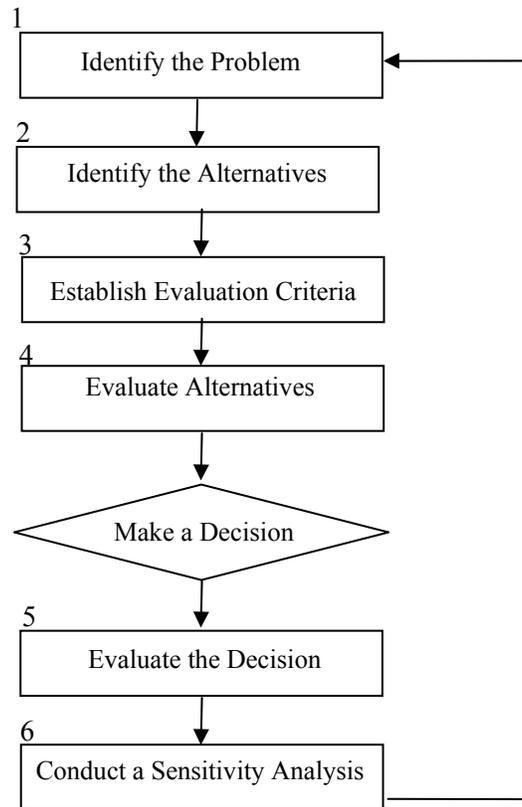


Figure 2.2: Decision-Making Process

- **Step 1: Identify the Problem**

A typical approach to problem definition in the civil service is to hold a series of meetings over a period of time until the task is accomplished. Different group decision techniques can be employed:

- Brainstorming technique: This technique provides creative collaboration by means of the presentation of a large number of ideas. However, due to its open discussion atmosphere,

some group members may influence the discussion trend, and accordingly, the final decision may become a compromise agreement.

- Nominal Group Technique (NGT): As the term “nominal” (meaning silent and independent) suggests, NGT refers to a process that brings individuals together but does not allow them to communicate verbally. The advantages of this technique are that it minimizes influences and treats participants equally through voting (Hwang, 1987). However, this technique limits creativity, diversity, and synergy.

- Research survey: A research survey can take various forms, including telephone and face-to-face interviews, as well as mailed or web-based questionnaires. A survey can cover a large geographic area and provide anonymity. However, the respondents may misinterpret questions, which may distort the results.

- The Delphi method: This technique is based on collecting ideas from intensive questionnaires that provide feedback from respondents interspersed with controlled opinion feedback (Hwang, 1987). This method is tedious and consumes a considerable amount of time and effort.

- **Step 2: Identify the Alternatives**

The second step is to specify the alternatives or options. Alternatives are often formulated on a go or no-go basis and are not final. They can always be revised. For example, project funding is often conducted in this way.

- **Step 3: Establish Evaluation Criteria**

The criteria and sub-criteria are the measures of performance by which the alternatives will be judged. Before criteria are finalized, a provisional set of criteria needs to be assessed against a range of qualities. These qualities include completeness, redundancy, operability, mutual independence of preferences, double counting, size, and impact occurring over time. Organizing the criteria in a hierarchical way facilitates scoring the alternatives against the criteria and examining the overall results at the level of the objectives. This hierarchical representation is often referred to as a value tree, as shown in Figure 2.3 (Dodgson et al., 2000). The process of assigning weights to the criteria is fundamental to the effectiveness of an MCDA study. Often the weights are derived from the views of a group of people.

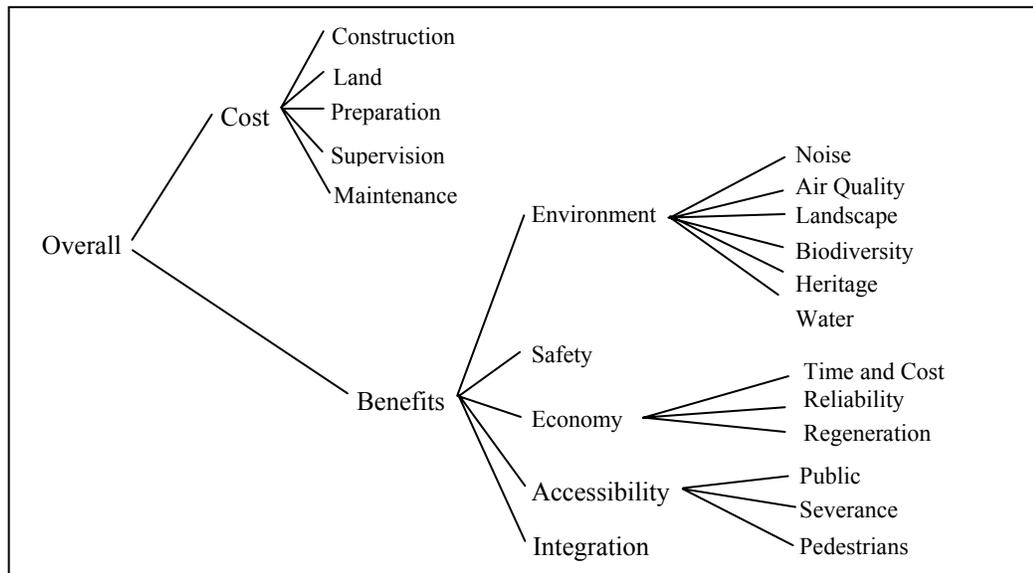


Figure 2.3: Example of Hierarchical Criteria (Dodgson et al., 2000)

With respect to the obtaining of alternatives and criteria, it is worth mentioning Keeney’s approach of “Value-Focused Thinking” (Keeney, 1992), in which he introduces long-term values as principles for evaluating the actual or potential consequences of actions that reflect

short-term values. The long-term values range from ethical principles that must be upheld to guidelines for preferences among choices.

- **Step 4: Evaluate Alternatives**

To evaluate the alternatives, a consistent numerical scale for the assessment of criteria needs to be set up so that better levels of performance lead to higher score values. One possibility (global scaling) is to assign a score of 0 (worst level) to 100 (best level). Another way is to approach the issue indirectly by eliciting from the DM a series of verbal pairwise assessments expressing a judgment of the performance of each alternative relative to each of the others, as used in the Analytic Hierarchy Process (AHP) (Dodgson et al., 2000). Another approach is Elimination Methods (MacCrimmon, 1973; Radford, 1989). This technique offers the capability of ranking the decision criteria in an order of preference without using quantitative weights.

There are two types of preference expressions: weights, which are based on criteria, and values, which are based on consequences (Chen, 2006; Chen et al., 2007). With respect to consequences, a standard feature of multi-criteria analysis is a performance matrix, or consequence table, in which each column describes an option or alternative and each row gives the performance of the alternatives against each criterion. The individual performance assessments are often numerical but may also be expressed ordinally, as “bullet point” scores, or by color-coding. Table 2.1 shows a simple example. The table is used by an owner to decide which contractor (bid) to choose. It shows the performance of a number of the different bidding contractors with regard to a set of criteria thought to be relevant to the owner’s choice among different contractors’ bids. These criteria are previous experience,

resources availability, reputation, financial strength, number of drawbacks, and price. As can be seen, some of these criteria are measured using cardinal numbers (price, number of drawbacks), some are expressed in binary terms (a tick indicates the presence of a particular feature), and one is shown in qualitative terms (financial strength).

Table 2.1: Performance Matrix

		Alternatives				
		Contractor A	Contractor B	Contractor C	Contractor D	Contractor E
Criteria	Previous experience		√	√		
	Resources availability		√	√	√	
	Reputation	√		√		
	Financial strength	*		*		
	Number of drawbacks	3	3	1	5	2
	Price (\$)	50,000	45,000	47,000	38,000	42,000
√: the presence of a feature; *: the best financial strength; : the next best; all contractors that scored less than best or next best have been eliminated						

A value represents the preferences of a DM with respect to a consequence. There are several ways for a DM to express preferences based directly on consequences. Among them, the best known are utility-theory-based definitions (Fishburn, 1970; Keeney and Raiffa, 1976) and outranking-based definitions (Roy, 1985). It should be kept in mind that some MCDA methods do not usually distinguish between consequences and preferences. For example, Nijkamp et al. (1983) gave scores the same meaning as preferences based on consequences. Some normalization methods can be regarded as transformations from consequences to preferences.

Consequences, which represent objective measures of alternatives based on criteria, may be numerical data or simply nominal. Consequences must be distinguished from values. In determining consequences, the DM should not think of his or her opinion (what preferences, contributions, impact, or satisfaction are associated with a consequence). Values are refined

data obtained by processing consequences according to the needs and objectives of the DM. The relationship between consequences and values can be expressed as

$$v_j^i = f_j(c_j^i) \quad (2.1)$$

where v_j^i and c_j^i are value and consequence, respectively, and $f_j(.)$ is a mapping from consequence to the relevant value. Greater values of v_j^i indicate increased preference.

- **Step 5: Evaluate the Decision**

A decision can be evaluated by an examination of different results throughout the decision process. Essential objectives, criteria, and DMs' preferences should be logically reflected in the decision.

- **Step 6: Conduct a Sensitivity Analysis**

A sensitivity analysis provides a means of examining the extent to which vagueness about the input or disagreements among people make any difference in the final overall results. An important characteristic of MCDA models is that they are often remarkably insensitive to many specific scores and weights. This feature is often easily demonstrated through a sensitivity analysis.

2.3 MCDA Methods

MCDA techniques are distinguished from one another principally in terms of how they process the basic information in the performance matrix. Some of the MCDA techniques that are most relevant to the evaluation of an infrastructure proposal are the merit points systems, linear additive models, linear goal programming, the multiple attribute utility theory, and the

analytical hierarchy process (Ababutain, 2002). These techniques are discussed briefly in the following sections. For a discussion regarding other approaches to solving MCDA problems, one can refer to research by authors such as Belton and Stewart (2001), Hipel (1992), Hipel et al. (1993, 1999), Hobbs and Meier (2000), Roy (1996) and Saaty (1980, 2001).

2.3.1 Merit Points Systems

The merit points systems (MPS) method is the most common professional technique used for evaluating infrastructure and construction bid proposals. Many large agencies, such as the United States Army Corps of Engineers and the World Bank, utilize this technique in making infrastructure decisions, such as determining qualified bidders (Ababutain, 2002). This method is based on assigning relative weights to the relevant criteria. The next step is establishing a relationship between the total score of those features and the bid price. The winning bid will be the one that receives the lowest number of price-per-merit points. An example of the way this method is used is shown in Table 2.2.

Table 2.2: A Merit Point System Example

Technical Feature	Points			
	Total	Bid A	Bid B	Bid C
1. Previous experience	25	20	15	25
2. Equipment availability	15	12	12	10
3. Reputation for completing projects on time	20	15	10	10
4. Staff qualifications	15	15	12	10
5. Reputation for quality	25	12	7	10
Total points	100	74	56	65
Bid price (\$)		500,000	450,000	470,000
Price per merit point (\$)		6,756.7	8,035.7	7,230.7
Rank		1	3	2

A revised form of MPS could be established through the assignment of merit points to the bid price along with other technical features. In this case, the highest number of points is assigned to the lowest price. Accordingly, the winning bid is the one that scores the

maximum number of points. Although this model is easy to use and apply, it suffers from the drawbacks of subjectivity used in assigning points and the lack of established relationships between different attributes.

2.3.2 Linear Additive Models

A linear additive model is used when the criteria are independent of one another and when uncertainty is not formally built into the MCDA model. The linear model shows how an alternative's values based on many criteria can be combined into one overall value. The value score for each criterion is multiplied by the weight of that criterion, and then the weighted scores are added together. However, this simple arithmetic is appropriate only if the criteria are mutually independent, and it makes sense to add weighted values across criteria for a given alternative.

In linear additive models, MCDA techniques commonly apply two stages of numerical analysis to a performance matrix that has cardinal criteria expressed as values:

- Scoring: the expected consequences of each alternative are assigned numerical values.
- Weighting: for each criterion, a numerical weight is assigned to define its relative contribution to the final decision. The overall preference score or value for each alternative is simply the weighted summation of its values for all the criteria. Letting the preference value for alternative i on criterion j be represented by v_j^i and the weight for each criterion be w_j , then for q criteria, the overall score, v^i , for the i th alternative, is

$$v^i = w_1 v_1^i + w_2 v_2^i + w_3 v_3^i + \dots + w_q v_q^i = \sum_{j=1}^q w_j v_j^i \quad (2.2)$$

Thus, scoring and weighting are the most challenging aspects of MCDA techniques.

The above method is suitable if all data can be expressed quantitatively. For some decision problems, criteria or alternatives are hard to express entirely in a quantitative form or are not feasible in different situations. It is then recommended that the Elimination Method be used, which has the advantage of allowing the alternatives to be ranked without using quantitative weights. An example illustrating this method is presented in Section 4.4.1.

2.3.3 Linear Goal Programming

Linear goal programming (LGP) is a branch of a widely used set of decision-making techniques called mathematical programming. It is based on specifying an objective function for each of the selection criteria that emphasizes quantitatively what is to be achieved while considering any constraints (economical, social, political, or technical) on the project. LGP is utilized to find a "satisfying" solution to a decision problem that meets a set of aspiration levels rather than maximizing all objectives (Forgionne, 1990). The best proposal or scheme is the one that optimizes (maximizes or minimizes) the desired output while considering the predetermined constraints.

Although this method of decision-making is straightforward and has been used in many operational research studies, it suffers from many drawbacks, such as the difficulty the ordinary decision maker has in formulating complex functions and constraints. This lack of skill explains the absence of mathematical programming for widespread use at the professional level (Libretore, 1987; Ababutain, 2002). In addition, many objective functions and constraints in infrastructure projects, such as social benefits and the environmental impact, are hard, if not impossible, to quantify in a straightforward manner. To overcome

these disadvantages, many research studies propose combining other decision-making techniques with LGP (Lotfi et al., 1992; Al-Ariami, 1993; Khoramshahgol and Steiner, 1988; Ababutain, 2002).

2.3.4 Multiple Attribute Utility Theory

The breakthrough in multiple attribute utility theory (MAUT) is the work of Keeney and Raiffa (1976). They developed MAUT, in which a set of procedures allows DMs to evaluate alternatives against multi-criteria. Their procedures contain three building blocks: the performance matrix, the procedures to determine whether criteria are independent of each other, and the methods of estimating the parameters in a mathematical function. The third characteristic allows the estimation of a single number index, U , to express the DM's overall valuation of an alternative in terms of the value of its performance based on each of the separate criteria.

What makes the Keeney and Raiffa model potentially demanding to apply is, first, that it takes uncertainty formally into account, building it directly into the decision-support models, and, second, that it allows attributes to interact with one another in ways other than a simple, additive fashion. It does not assume mutual independence of criteria. Although well regarded and effective in its most general form, it is relatively complex and annoying to implement and highly subjective, time consuming, costly, and frustrating to apply (Forgionne, 1990; Ababutain, 2002).

2.3.5 The Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) was developed by Thomas L. Saaty (1980, 1990) in the 1970s. It is one of the most popular methods used for making a decision when there are multiple alternatives and criteria (Zahedi, 1986; Golden et al., 1989; Shim, 1989). AHP uses procedures for deriving the weights and the scores achieved by alternatives, which are based, respectively, on pairwise comparisons between criteria and between alternatives. Thus, for example, in assessing weights, the DM is posed a series of questions, each of which asks how important one particular criterion is relative to another for the decision being addressed.

The strengths and weaknesses of the AHP have been the subject of substantial debate among specialists in MCDA (Barzilai, 1997, 1998; Zahedi, 1986; Golden et al., 1989; Shim, 1989; Goodwin and Wright, 1998; and French, 1988). More recently, Saaty (2001) has developed the Analytic Network Process (ANP), which is a generalization of AHP.

2.3.6 Outranking Methods

Outranking methods originated in France through the work of Bernard Roy and his colleagues starting in 1960 (Roy, 1973, 1985, 1996), and have been applied to a fair degree in some European countries (Roy and Vanderpooten, 1996). They depend on the concept of outranking, where one alternative outranks another if it outperforms the other with respect to enough criteria of sufficient importance (as reflected by the sum of the criteria weights). All alternatives are then assessed in terms of the extent to which they exhibit sufficient outranking with respect to the full set of alternatives being considered, as measured against a pair of threshold parameters (Dodgson et al., 2000). The main concern voiced about the

outranking approaches is that they are dependent on rather arbitrary definitions of what precisely constitutes outranking and of the ways the threshold parameters are set and later manipulated by the DM (Dodgson et al., 2000).

2.3.7 Fuzzy Sets

A different response to the imprecision that surrounds much of the data on which the decision-making process is based has been to look at the popular field of fuzzy sets developed by Zadeh (1972, 1973). Fuzzy sets attempt to capture the idea that the natural language of discussion is not precise. Examples of fuzzy expressions are “fairly attractive” or “rather expensive”, not simply “attractive” or “expensive”. Fuzzy arithmetic then tries to capture these qualitative assessments using the idea of a membership function, through which an expression (e.g., “fairly”, “mostly”, “very”) belongs to the set of “attractive” alternatives, with a given degree of membership lying between 0 and 1.

Fuzzy MCDA models develop procedures for aggregating fuzzy performance levels using weights that are sometimes also represented as fuzzy quantities. More details and examples can be found in Chen and Hwang (1992) and also Roy (1985, 1996). However, some researchers have criticized these methods as being difficult for non-specialists to understand and therefore unlikely to be of much practical use in government for the foreseeable future (French, 1988).

2.3.8 MCDA Software Survey and Results

Decision support systems (DSS) are computer-based systems that furnish interactive support during the decision-making process. During the search for the best decision, they allow the user to retrieve data, test alternative solutions, and analyze and explore the impact of these changes. Jelassi and Foroughi (1989), Thiessen and Loucks (1992), and Kilgour et al. (1995) provide overviews and comparisons of existing decision- and negotiation- support systems (a name for DSSs developed for use in negotiations). DSSs gain their unique recognition from their capability of dealing with decisions that require human judgment and that cannot be solved by the computer alone (Olson and Courteny, 1992).

A summary of a survey conducted by the *OR/MS Today* journal with respect to the decision analysis software available on the market is shown in Table 2.3. The study found that 19 companies produce 28 different packages. Many of the vendors of multiple packages have developed very robust interfaces between their products. These features allow a user to implement a particular package for its intended purpose and then efficiently share the required information with another specialized product.

The survey led to a number of conclusions (Maxwell, 2002):

- The vast majority of the software is written for use with the Windows operating system. Three packages (Analytica, Netica, and TreePlan) have Mac OS versions. Netica has a version that runs under both the LINUX and Solaris operating systems. Three packages (Joint Gains, Opinions-Online, and Web-HIPRE) are offered as web-based applications.

- Ten of the packages have variants designed to support group elicitation, and eight packages support decentralized group activities.
- Some of the packages indicate limitations on the model size and complexity that the software will support. Potential users should research these constraints carefully in the context of the types of models they are intending to construct.
- In general, decision analysis software has one of the two emphases:
 1. the elicitation and analysis of complex multi-criteria value functions, focusing on the second and fourth stages of the decision-analysis process, or
 2. the elicitation and analysis of uncertainties, emphasizing the third and fourth stages.

The split across packages is roughly even, with 15 vendors offering approaches for eliciting value functions graphically and 10 vendors indicating they can do so for probabilities. One package, Expert Choice 2000, 2nd Edition, indicates that it supports the entire spectrum of elicitation graphically, as well as displaying analysis results graphically. In fact, the vast majority of the packages indicate that analysis results can be displayed graphically.

- With regard to a software package's ability to support sensitivity analysis, 10 vendors indicate that their software has the capability of defining the probabilities and/or weights as variables, and 21 vendors indicate that their software supports graphical sensitivity analysis.

Table 2.3: Decision Analysis Software Survey (Maxwell, 2002)

Product	Applications							Hard Constraints			Specific applications
	Trade-offs among multiple objectives	Analysis of uncertainty	Probabilistic dependencies	Risk aversion	Sequential decision making	Multiple stakeholders	All of the above in one model	Number of alternatives?	Number of levels in value or decision tree?	Number of states of a node in a tree?	
Analytica	y	y	y	y	y	y	y	y	y	y	Business models
cdpGEO 1.0	y	y	n	y	n	y	n	n	n	n	Resource allocation, portfolio management
Criterion DecisionPlus (CDP) 3.0	y	y	n	y	n	y	n	n	n	n	Resource allocation, discrete choice, portfolio management
Crystal Ball 2000	n	y	y	n	n	n	n	n	n	n	Financial analysis, budgeting and cost estimation, forecasting
DATA 4.0	y	y	y	y	y	y	y	y	y	y	Cost-effectiveness analysis of healthcare options, environment
Decision Explorer	y	y	n	y	y	y	-	y	-	y	Strategy development, stakeholder analysis, project definition
Decision Programming Language (DPL)	y	y	y	y	y	n	y	y	n	y	Strategic business modeling under uncertainty
DecisionPro 4.0	y	y	y	y	y	y	y	n	n	n	-
The DecisionTools Suite	y	y	y	y	y	n	n	-	y	y	Portfolio investment analysis, drilling decisions in oil and gas
EQUITY	y	y	n	n	n	y	y	y	n	n	Resource allocation
Expert Choice 2000, 2nd Edition	y	y	y	y	-	y	n	n	n	n	Resource allocation, IT portfolio management, project mgmt
Frontier Analyst	y	n	n	n	n	n	-	-	-	-	Performance measurement and resource allocation
HIVIEW	y	y	n	n	n	y	y	n	n	n	Evaluation of alternative MCDA
Hi Priority	y	n	n	y	n	y	y	n	y	n	Resource allocation, R&D budgeting, mergers
Impact Explorer	y	y	n	y	y	y	-	y	-	-	Risk analysis, option prioritization
Joint Gains	y	n	n	n	n	y	y	n	n	n	Multiple stakeholder negotiations
Logical Decisions for Windows 5.1	y	y	n	y	n	y	y	n	n	-	Discrete choice, multiple stakeholders, engineering design
Netica	y	y	y	y	y	y	y	n	n	n	-
NoRegrets	y	n	n	y	n	y	y	n	y	n	Multiple stakeholder negotiation support
OB Run	y	n	n	y	n	n	y	y	y	n	Discrete choice with scenarios or stakeholders
OnBalance	y	n	n	y	n	y	y	n	y	n	Discrete choice scenario or stakeholders
Opinions-Online	n	n	n	n	n	y	y	n	n	n	Course evaluation, participatory policy analysis, voting
PRIME Decisions	y	y	n	n	n	n	y	n	n	n	Evaluation of discrete choices under incomplete information
Risk Detective	y	y	y	y	y	y	y	n	n	y	All
TreePlan	n	y	y	y	y	n	n	-	-	-	Sequential decision problems under uncertainty
WINPRE	y	y	n	n	n	y	y	y	y	n	Evaluation of discrete choice alternatives under incomplete info.
Web-HIPRE	y	n	n	n	n	y	y	n	n	n	Evaluation of discrete choice alternatives, multiple stakeholders

- The ability to exchange data with commercial applications, such as EXCEL and ACCESS, continues to increase. One package, Decision Explore, provides XML-based import and export functionality. Approximately five packages indicate that they support Monte Carlo simulation as a method for solving their models, and a significant number indicate that linear programming is now integrated into their tools. Netica continues to offer algorithms that present probability distributions for a network using data, subjective techniques, or a mixture of both. In addition, a number of packages advertise improved sensitivity analysis capabilities.
- For problems involving multiple stakeholders and multiple competing attributes, tools that emphasize group support and value elicitation are probably most appropriate. Problems involving large uncertainties, diagnosis, complex interdependencies, or risk analysis would benefit most from tools such as Influence Diagrams, Bayesian Networks, or one of the Monte Carlo modeling tools.

Whichever tools are selected, they should be intuitive to the user and should support easy iteration during the various stages of the decision-analysis process (Maxwell, 2002).

2.4 The Graph Model for Conflict Resolution

Infrastructure privatization is a complex multiple-criteria decision having multiple decision makers (DMs). It usually involves a resolution of a conflict among different concerned stakeholders with different socio-economic, political and technical backgrounds and interests.

Dealing with such decisions is very serious: any mistake can cause a catastrophe and, in many cases, irreversible damage.

Finding the best tool for resolving social and economic conflicts, such as ones dealing with infrastructure privatization, is the aim of many researchers worldwide. They have developed many formal modeling techniques for systematically studying conflicts that have two or more DMs, each of whom can have multiple objectives. In particular, the graph model for conflict resolution (Fang et al., 1993) constitutes an expansion and reformulation of conflict analysis (Fraser and Hipel, 1984), which, in turn, is an extension of metagame analysis (Howard, 1971). Other related techniques for describing human conflict include drama theory (Howard, 1994, 1999), which allows one to consider the role of emotions in conflict resolution, and hypergame analysis (Fraser and Hipel, 1984; Bennett, 1980; Wang et al., 1988). These approaches to strategic decision-making situations can be considered as belonging to a branch of game theory that is quite distinct from more traditional methods based on the classical work of von Neumann and Morgenstern (1953). Hipel et al. (1993) furnish an overview of the use of game theory models in engineering decision making while Hipel et al. (1999) explain the roles of the graph model for conflict resolution and of other operational research tools for refining and selecting courses of action to solve a given problem within a systems engineering context (Sage, 1991, 1992). The final decision in a graph model represents a compromise solution that brings different parties to a reasonably common ground.

2.4.1 The Graph Model Methodology

The graph model methodology consists of three main stages (Fang et al. 1993): modeling, stability analysis, and output interpretation, including sensitivity analyses.

a) Modeling

The first step is modeling. The graph model for conflict resolution represents a conflict as moving from state to state (the vertices of a graph) via transitions (the arcs of the graph) controlled by the decision makers (DMs). A graph model for a conflict consists of a directed graph and relative preferences for each DM taking part in the dispute. Let $N = \{1, 2, 3 \dots n\}$, denotes the set of DMs, and $S = \{s_1, s_2, s_3, \dots, s_n\}$ denotes the set of states, or possible scenarios of the conflict. A collection of finite directed graphs $G = \{G_1, G_2, \dots G_n\}$, where $\{G_i = (S, A_i), i \in N\}$, can be used to model the course of the conflict, where the nodes are the states, and the arcs are the state-to-state transitions controlled by the DMs. If DM i can unilaterally move in one-step from state s to state s' , there is an arc with an orientation from s to s' in A_i .

Formally, for each DM, $i \in N$, $A_i \subset S \times S = \{(s_1, s_2) : s_1, s_2 \in S, s_1 \neq s_2\}$ is the set of state transitions or arcs controlled by DM i . For $s_1, s_2 \in S$ and $s_1 \neq s_2$, (s_1, s_2) is an arc in DM i 's directed graph (S, A_i) if DM i can cause, in one step, a transition from state s_1 to state s_2 . In this case, s_2 is reachable for i from s_1 . One of the states in each conflict is the status quo, or initial state (designated as s_0), and the conflict evolves as individual DMs unilaterally cause transitions among states.

The other component of a graph model is each DM's preferences among states. A DM's preference can be expressed in a relative sense by pairwise comparisons of states, through which a DM prefers one state to another or is indifferent between them. In general, for each DM, $i \in N$, a preference relation \succeq_i expresses each DM's preferences over S . The \succeq_i can be decomposed into a pair of binary relations $\{\succ_i, \sim_i\}$.

Conventionally, DM i strictly prefers s_1 to s_2 , written $s_2 \succ_i s_1$, if and only if $s_2 \succeq_i s_1$ but not $s_1 \succeq_i s_2$. Also, DM i is indifferent between s_2 and s_1 , then $s_1 \sim_i s_2$, if and only if $s_2 \succeq_i s_1$ and $s_1 \succeq_i s_2$. These preference relationships possess the following properties:

1. \succ_i is asymmetric: for any $s_1, s_2 \in S$, $s_1 \succ_i s_2$ and $s_2 \succ_i s_1$ cannot hold true simultaneously.
2. \sim_i is reflexive and symmetric: for all $s_1, s_2 \in S$, $s_1 \sim_i s_1$, and if $s_1 \sim_i s_2$ then $s_2 \sim_i s_1$.
3. $\{\succ_i, \sim_i\}$ is complete: for all $s_1, s_2 \in S$, then at least one of $s_1 \succ_i s_2$, $s_2 \succ_i s_1$, or $s_1 \sim_i s_2$ is true.

Preference information can be either transitive or intransitive. The Graph Model can handle both transitive and intransitive preferences. However, in most real-life conflicts, DMs' preferences can be assumed to be transitive, and thus expressed as a ranking of the states from most to least preferred, where ties are allowed.

Based on DM i 's preferences over states, the set S , can be partitioned into two sets, relative to a particular $s \in S$, as follows:

$\Phi_i^+(s) = \{s_m \in S : s_m \succ_i s\}$ is the set of all states s_m , that DM i prefers to state s ; and

$\Phi_i^\leq(s) = \{s_m \in S : s \succeq_i s_m\}$ is the set of all states s_m , that DM i finds equally or less preferred to state s .

In the Graph Model, DM i 's reachable list $R_i(s)$, is the set of all states that DM i can unilaterally reach from state $s \in S$, in one step. Hence, the concept of unilateral improvement is built upon a DM's preferences and on his or her reachable list. Accordingly, $R_i(s)$ can be divided into two subsets:

$R_i^+(s) = R_i(s) \cap \Phi_i^+(s)$ is the set of unilateral improvements from state s for DM i ; and

$R_i^\leq(s) = R_i(s) \cap \Phi_i^\leq(s)$ is the set of unilateral disimprovements from state s for DM i .

b) Stability Analysis

The stability analysis of a conflict is carried out through a determination of the stability of each state for every DM. A state is stable for a DM iff (if and only if) that DM has no incentive to move from it unilaterally under a particular behavioural model, usually referred to as a stability definition or solution concept. A possible resolution or equilibrium in the graph model is a state which all DMs find to be stable under that particular stability definition.

A stability definition or solution concept defines how DMs may behave in a conflict in which each DM aims to achieve his or her goals. Because people may behave differently under conflict, a rich range of solution concepts have been defined. Solution concepts reflect different styles of behaviour (Fang et al., 1993) that incorporate a DM's level of foresight,

willingness to make strategic concessions, risk attitude, and knowledge of others' preferences (Kilgour et al., 2001). Table 2.4 outlines the solution concepts available for the Graph Model.

Detailed definitions of these solution concepts are given in Chapter 4, Section 4.4.3.

Table 2.4: Solution Concepts and Human Behavior (Hipel et al., 2002)

Solution Concepts	Stability Description	Characteristics			
		Foresight	Knowledge of Preference	Strategic Risk	Dis-improvement
Nash Stability (R)	Decision maker cannot unilaterally move to a more preferred state	Low	Own	Ignores risk	Never
General Metarationality (GMR)	All decision maker's unilateral improvements are sanctioned by subsequent unilateral moves by others	Medium		Avoids risk; conservative	By opponents
Symmetric Metarationality (SMR)	All decision maker's unilateral improvements are still sanctioned even after a possible response by the original decision maker to sanctioning		All	Takes some risks; strategies	Never
Sequential Stability (SEQ)	All decision maker's unilateral improvements are sanctioned by subsequent unilateral improvements by others	Variable		Accepts risk; strategies	Strategic
Limited Move Stability (L_h)	All decision makers are assumed to act optimally within a specified number (h) of states transitions				
Nonmyopic (NM)	Limiting case of limited move stability as the number of state transitions increases to infinity	High			

Fang et al., (1993) define and mathematically compare the solution concepts listed in Table 2.4 within the framework of the Graph Model. These solution concepts are applicable to models with two or more DMs. The first column gives the names of the solution concepts, and their acronyms. The second column contains a brief description of the way the solution concept is defined. The last four columns characterize the solution concepts qualitatively, according to the four criteria of foresight, knowledge of preferences, strategic risk, and disimprovements.

c) Output Interpretation and Sensitivity Analyses

The findings from the stability analysis stage can be interpreted in terms of the real-world conflict by analysts, actual DMs, or interested parties. New insights or information may sometimes justify recalculation; one can make appropriate changes in the model and re-analyze it before continuing with the study. In sensitivity analyses, changes in the model parameters are made systematically to assess the robustness of the stability results. In other words, sensitivity analyses are used to answer “what if” questions.

2.4.2. The Decision Support System GMCR II

Software packages have been designed to assist in interactive decisions involving multiple DMs . Some are based on metagame analysis, such as CONAN (Howard, 1989) and INTERACT(Bennett et al., 1994), others are based on conflict analysis, such as Decision Maker (Decision Maker, 1996) and SPANNS (Meister and Fraser, 1994). Recently, a DSS software has been based on the Graph Model for Conflict Resolution (Fang et al., 1993), namely GMCR II (Hipel et al., 1997; Fang et al., 2003a, b). The advantages of GMCR II, which will be used in this research, are that it is embedded with an engine that utilizes the Graph Model for Conflict Resolution methodology, and its mathematical solution concepts help support the decision-making process and resolve conflict among different players concerned with a competing decision.

GMCR II is a powerful analysis program that applies the concepts developed in the Graph Model for Conflict Resolution. It calculates the stability results of the solution definitions listed in Table 2.4. GMCR II (Hipel et al., 1997; Fang et al., 2003a, b) is written in C++ and is implemented on a Windows operating system platform. It offers three functionalities: easy

modeling management, convenient and effective *analysis* procedures, and *display of results*.

Figure 2.4 depicts the structural design of the software. It consists of a modeling subsystem, an analysis engine, and an output interpretation subsystem.

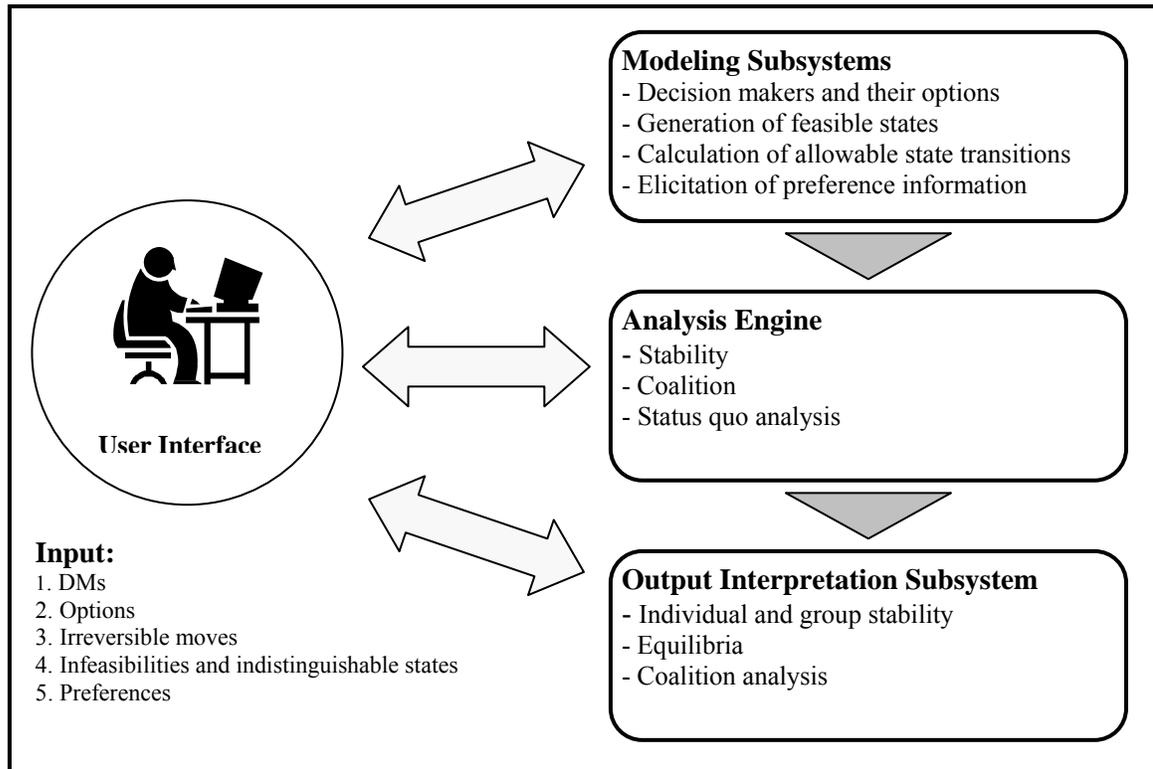


Figure 2.4: Structure of GMCR II

The input is the basic information concerning the conflict under analysis, such as the parties involved; their options; specification of infeasible states; preferences for the generated feasible states; and other special information, including irreversibility among states.

The modeling subsystem processes this information and generates the necessary information for the analysis engine. For every DM involved in the conflict, the engine performs a stability analysis for each feasible state in the conflict for each solution concept in Table 2.4 and then calculates the equilibria. The output interpretation subsystem responds to user requests by

controlling which output is displayed via the user interface on the monitor. More details about the use of GMCR II can be found in Fang et al. (2003a, b) and Hipel et al. (1997).

2.5 Information Gap Theory

This section introduces the idea of using information gap (info-gap) modeling (Ben-Haim, 1985, 1995, 1996, 1998, 1999, 2001a,b, 2006) into infrastructure privatization decision analysis and decision making. It is used in the formal consideration of the uncertainty that exists between what we know about a system and what we would like to know (Mack, 1971). This process will enable the DM to predict how credible and robust the privatization decision is with respect to the uncertainty caused by the lack of related information. Decision making under uncertainty is particularly important in privatization decisions in which some stakeholders are uncertain about their preferences among the options.

2.5.1 Uncertainty and MCDA

Uncertainty has been tackled through various approaches, including interval judgments (Saaty and Vergas, 1987), fuzzy logic (Zadeh, 1972, 1973), information gap models (Ben-Haim, 1996), stochastic differential equations (Cox and Miller, 1965), Bayesian techniques (Ludwig, 1996) and multi-attribute utility theory (Keeney and Raiffa, 1976). With the exception of multi-attribute utility theory, commonly referred as MAUT, and fuzzy sets theory, there has been little formal treatment of uncertainty in MCDA. However, the use of MAUT is restricted to problems involving probabilistic choice, in which case, a cardinal von Neumann-Morgenstern utility function applies (von Neumann and Morgenstern, 1953; Luce

and Raiffa, 1957). Detailed discussions of these uncertainty methods are given by Morgan and Henrion (1990), Zadeh (1972), and Restrepo et al. (1993).

The info-gap model is completely non-probabilistic; it captures a DM's preferences and attitude toward risk without resorting to "non-intuitive probabilistic concepts of gambling and indifference between lotteries" (Barzilai, 1997). Information gap theory utilizes convex modeling, which is particularly valuable since utility functions are not required (only value functions are necessary) and robust alternatives can be identified. Other advantages of using this approach are its ability to quantify the robustness of privatization alternatives (policies) with respect to uncertainty, and to identify policy alternatives that, while capable of coping with attribute variability, still achieve minimum requirements with respect to stakeholders' values. Hipel and Ben Haim (1999) explain how info-gap models can be used in environmental and water resources management.

2.5.2 Methods of MCDA with Uncertainty

Because of the different types of available information (e.g., probabilistic/non-probabilistic, cardinal/ordinal, deterministic/stochastic), different MCDA techniques have been developed as shown in Table 2.5 (Levy, 2001). Which technique to use depends on the features of the decision problem. For example, ELECTRE methods (Roy, 1973) employ information in a fuzzy context, the AHP approach (Saaty, 1990) elicits ratio judgments, and the Elimination Methods (MacCrimmon, 1973) require only ordinal ranking.

Table 2.5: Features of a Decision Problem and MCDA (Levy, 2001)

Techniques	Optimal Control	Cost-Benefit Analysis	Elimination Methods	MAVT	Internal Methods	Entropy Measures	Bayesian	MAUT	Information gap
Feature of the Problem									
Type of Impact									
Economic impact	X	X	X	X	X	X	X	X	X
Social impact			X	X	X		X	X	X
Environmental impact			X	X	X		X	X	X
Distribution of impact			X	X	X			X	X
Feasibility									
Technical & operational			X	X				X	X
Legal & public policy			X	X			X	X	X
Type of Problem									
Physical system model	X		X	X			X		X
Societal system model		X		X	X		X	X	X
Type of Tradeoffs									
Compensatory	X	X	X	X	X	X	X	X	X
Non-compensatory			X				X		
Type of Uncertainty									
Probabilistic uncertainty	X	X			X	X	X	X	
Non-uncertainty									X
Type of Information									
Quantitative (Cardinal)	X	X	X	X	X	X	X	X	X
Qualitative (Ordinal)			X		X				
Type of Analysis									
Extinction analysis	X					X	X	X	X
Hierarchical analysis	X	X	X	X	X	X	X	X	X

Techniques for decision making under certainty include Optimal Control Theory, Cost-Benefit Analysis (CBA), Elimination Methods, and Multi-Attribute Value Theory (MAVT). The remaining five approaches in Table 2.5 – Interval Methods, Entropy Techniques, Multi-Attribute Utility Theory (MAUT), and Information Gap Methods – apply to decision-making under uncertainty.

It should be noted that all nine techniques listed in Table 2.5 could be used to help make decisions when the criteria are expressed in dollars. However, the treatment of decision

consequences in purely monetary terms has attracted considerable criticism, particularly with respect to socio-environmental values and applications (Sagoff, 1988).

2.5.3 Decision Robustness

One important concept that should be considered in dealing with uncertainty and information gap theory is the robustness phenomenon (i.e., how robust a privatization decision is in lieu of missing or lack of information). Richards (1996) defines robustness as an insurance policy that is almost certain to pay off, but the amount of the payoff is not guaranteed. A robustness approach will not provide the optimal answer; rather, it offers insights that can lead to more adaptive and flexible strategies.

The simplest set of robustness measures is the ratio of the number of “good” alternatives, options, or outcomes left open after an action is selected to the number of “good” alternatives open prior to taking the action (Gupta and Rosenhead, 1968). For example, in a planning situation in which the set of all alternatives is denoted by S , and the set of all acceptable alternatives is represented by S^* (a subset of S), the set of alternatives attainable if the i th alternative (a_i) is selected is denoted by S_i , and S_i^* represents the set of all acceptable alternatives if a_i is chosen (Figure 2.5).

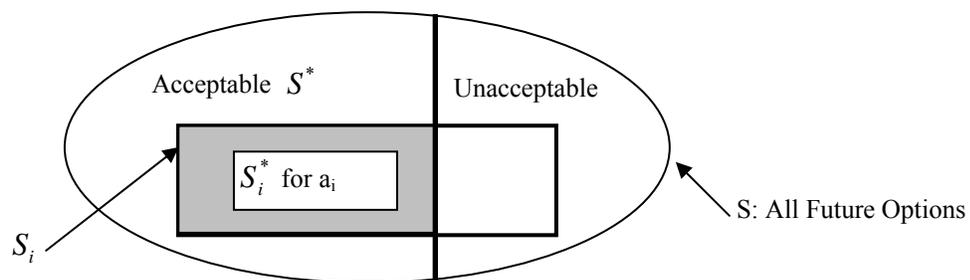


Figure 2.5: Categorization of Future Alternatives (Rosenhead, 1989)

Rosenhead (1989) defines the robustness of an action (alternative) a_i as

$$\text{Robustness} (a_i) = \frac{(S_i^*)}{(S^*)} \quad (2.3)$$

$$(S_i^*) \leq (S^*), \quad (2.4)$$

the robustness of any initial decision must lie between 0 and 1. The higher the robustness of an initial decision, the more acceptable the outcomes that remain open.

2.5.4 Satisficing and Bounded Rationality

Simon (1957, 1958, 1961, 1979) proposed a rationality framework for decision analysis called satisficing (a combination of the words “satisfactory” and “sufficient”). A DM who chooses the best available alternative according to some criteria is said to optimize; one who chooses an alternative that meets (or exceeds) specified criteria is said to satisfice. Of course, the satisficing solution is not guaranteed to be either unique or in any sense “best”.

March (1978), Simon (1979), and March and Simon (1958) have noted that satisficing involves a bounded rationality in that decisions occur in a limited time frame, DMs are unable to acquire all the information they need, and DMs are not aware of all the information they need to know to make a decision. The term “bounded rationality” implies “somewhat less than perfect rationality” (Lewandowski et al., 1989). Experience shows that DMs usually satisfice, both in terms of failing to examine all the available information and also in the sense of choosing an alternative as soon as one has been found to meet minimum requirements against the criterion of concern (Rajabi, 1997).

2.5.5 Convex Models of Uncertainty

The overwhelming volume of literature in the field of economics and the environment hold that decision making under uncertainty is probabilistic (Levy, 2001). However, in many large infrastructure projects and environmental problems, lack of information, expertise, and time to perform a probabilistic analysis are common as most of these problems are unique and have their own characteristics. Information gap theory provides the solution for this type of non-probabilistic uncertainty.

Convex models of uncertainty are used to answer these questions; they require fewer assumptions and less data than probabilistic models for their formulation and verification. Accordingly, somewhat weaker assertions, with “starker interpretation” (Ben-Haim, 1999), will be accessible with convex models than with probabilistic models. Nonetheless, meaningful results can be obtained.

In the literature, the mathematical formulation of convex models emerged in control theory (Schweppe, 1973), the seismic design of structures (Drenick, 1968), nuclear measurements (Ben-Haim, 1985), and mechanical analysis (Ben-Haim and Elishakoff, 1990). This formulation matches the idea of the perception of uncertainty that is common among economists and environmental managers. Hipel and Ben-Haim (1999), and Ben-Haim and Hipel (2002) used the term “information gap” models, or simply, info-gap, in place of convex models to emphasize the fact that “uncertainty is the complement of knowledge”.

2.5.6 Information Gap Theory/Convex Modeling

The following example, which analyzes phosphorus levels in Lake Erie (Levy, 2001), describes the information gap theory and its convex modeling technique. Assume that the nominal (typical/anticipated) phosphorus level in Lake Erie is given by $\bar{P}(t)$, a known function, and the actual phosphorus level, $p(t)$, deviates by an unknown amount from the expected phosphorus level $\bar{P}(t)$. This information may be quantified in an information-gap model of uncertainty. Consider the set of all phosphorous functions $P(t)$ whose deviation from the nominal function $\bar{P}(t)$ is bounded by α :

$$R(\alpha, \bar{P}) = \{P(t) : |P(t) - \bar{P}(t)| \leq \alpha \}, \quad \alpha \geq 0 \quad (2.5)$$

$R(\alpha, \bar{P})$ is a set of functions that contains all phosphorus functions consistent with the prior information, where α is the uncertainty parameter, expressing the (unknown) phosphorus level.

As explained by Ben-Haim (1996), this information uncertainty model, $R(\alpha, \bar{P})$, is a family of nested sets for $\alpha \geq 0$. This means that $R(\alpha, \bar{P}) \subseteq R(\beta, \bar{P})$ if $\alpha \leq \beta$. For fixed α , the set $R(\alpha, \bar{P})$ represents a degree of uncertain variability in the lake's phosphorus level $P(t)$. The greater the value of α , the greater the possible variation of phosphorus, so α , the uncertainty parameter, expresses the information gap between what is known, $\bar{P}(t)$, and what needs to be known for an ideal solution, the exact function $P(t)$. Robustness to uncertainty underlies the convex modeling approach: specified goals are attained, while at the same time the DM's immunity to uncertainty is maximized.

Convex modeling (Hipel and Ben-Haim, 1999) is a vivid theory of uncertainty motivated by a severe lack of information. It does, nonetheless, have its own particular subtlety. It is simple enough to express the idea that uncertainty may be either pernicious or propitious. That is, uncertain variation may be either adverse or favorable: the robustness function is the greatest level of uncertainty consistent with no failure, while the opportunity function is the least level of uncertainty, which entails the possibility of sweeping success. If q is a vector of parameters such as time, design variables, and model parameters, the robustness and opportunity functions can be expressed as the maximum or minimum of a set of α values:

$$\hat{\alpha}(q) = \max \{ \alpha : \text{minimal requirements are satisfied} \} \quad (2.6)$$

$$\hat{\beta}(q) = \min \{ \alpha : \text{sweeping success is obtained} \} \quad (2.7)$$

The robustness function $\hat{\alpha}(q)$ is the immunity against failure, so a large value of $\hat{\alpha}(q)$ is desirable. In contrast, the opportunity function $\hat{\beta}(q)$ is the immunity against sweeping success, so a small value of $\hat{\beta}(q)$ is desirable.

Quite often, the degree of success is assessed by a scalar reward function $R(u)$, which depends on the vector q of actions, decisions, and model parameters as well as on an uncertainty u whose variations are described by an information-gap model $U(\alpha, \hat{u})$. The minimal requirement in Equation 2.6 is that the reward be less than a critical value r_c . Likewise, the sweeping success in Equation 2.7 is the attainment of the wildest-dream reward r_w . The robustness and opportunity functions can be expressed more explicitly as

$$\hat{\alpha}(q, r_c) = \max \{ \alpha : \min_{u \in U(\alpha, \hat{u})} R(q, u) \geq r_c \} \quad [\text{Robustness function}] \quad (2.8)$$

$$\hat{\beta}(q, r_w) = \min \{ \alpha : \max_{u \in U(\alpha, u)} R(q, u) \geq r_w \} \quad \text{[Opportunity function]} \quad (2.9)$$

As explained elsewhere (Hipel and Ben-Haim, 1999), the robustness function $\hat{\alpha}(q, r_c)$ decreases monotonically in the minimum required reward r_c . This tendency expresses the trade-off between demanded reward and immunity to uncertainty: if a large reward is required, then only low immunity to uncertainty is possible. Conversely, the opportunity function $\hat{\beta}(q, r_w)$ increases monotonically in the wildest-dream reward r_w : sweeping success cannot be attained at low levels of ambient uncertainty. This principle is illustrated in Figure 2.6. An illustration of the use of uncertainty is presented in Chapter 4.

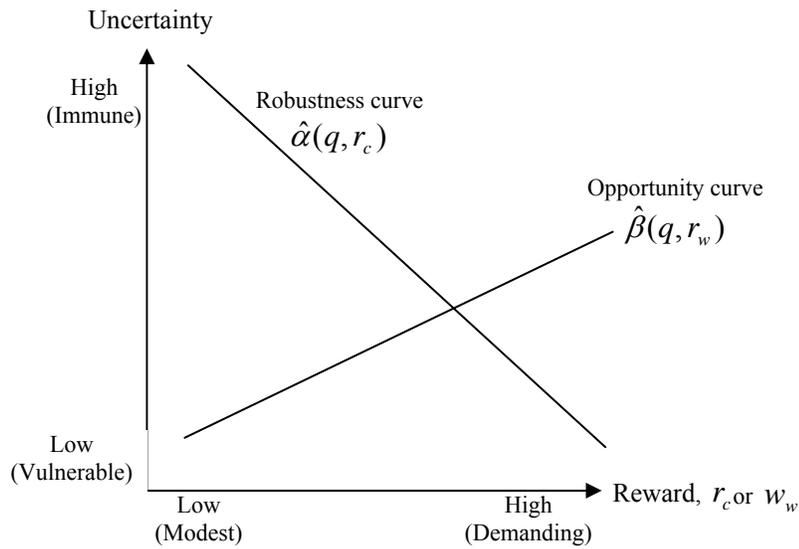


Figure 2.6: Robustness and Opportunity Curves (Schematic) (Hipel and Ben-Haim, 1999)

2.5.7 Convex Models and MCDA

Suppose that prior knowledge exists about nominal (anticipated) attribute levels for an alternative j , i.e., the vector $\bar{x}_j = (\bar{x}_{1j}, \bar{x}_{2j}, \dots, \bar{x}_{nj})$ is known, but very little is known about how the actual attribute values deviate from these nominal levels. Then a convex model determines the robustness to variability of the j th policy alternative by considering the following three components (Levy, 2001):

- A decision model to evaluate the overall value of each alternative, $V(x_i)$: in this section, an additive value function model is employed.
- The failure criteria, or conditions under which the alternative does not meet minimum requirements: the failure region may be written as $V(x_i) < u_{cr}$.
- The uncertainty model, or quantification of the variability inherent in the attribute levels: for the j th alternative, uncertainty can be modeled as a solid sphere centered at the point $\bar{x}_j = (\bar{x}_{1j}, \bar{x}_{2j}, \dots, \bar{x}_{nj})$, with radius α . This set, of the form

$$S_j(\alpha, \bar{x}_{ij}) = \{ x_j : \sum_{i=1}^n (x_{ij} - \bar{x}_{ij})^2 \leq \alpha^2 \}, \quad (2.10)$$

is more likely to contain actual attribute levels as α increases.

If J is defined to be the set of decision alternatives, of which the DM must select one, then the evaluation of policy alternative $j \in J$ is described by a vector of indicators, $\bar{x}_j = (\bar{x}_{1j}, \bar{x}_{2j}, \dots, \bar{x}_{nj})$, where n is the number of indicators and x_{ij} is the performance level of alternative j on indicator i . Let $v_i(\cdot)$ be the value function for indicator i . Then, an amalgamation rule combines consistency-scaled component (marginal) value functions,

$v_i(x_{ij})$, into an overall index of value or worth, $V(x_j)$. This result is achieved most often using a linear additive model, in which overall value is the weighted sum of scaled indicators:

$$V(x_j) = \sum_{i=1}^n k_i v_i(x_{ij}), \quad j = 1, 2, 3, \dots, m. \quad (2.11)$$

The constant k_i rescales the indicators to be comparable while at the same time indicating their relative importance. For the linear additive model to be a valid representation of the overall objective, the indicators should be preferentially independent (Keeney and Raiffa, 1976), meaning that the level of any specific indicator does not depend on the levels of the other indicators.

2.6 Genetic Algorithms for Multicriteria Optimization

With recent advances in the artificial intelligence branch of computer science and the fast growth in computer technology, a new breed of optimization techniques, Genetic Algorithms (GAs), has emerged. GAs are search algorithms, developed by Holland (1975), which are based on the mechanics of natural selection and genetics and which search through decision space for optimal solutions (Goldberg, 1989). Impressed by the adaptive capabilities of living organisms to solve problems posed by their environment, Holland set out to abstract and explain the adaptive process of natural systems and to design artificial system software that retains the important mechanisms of natural and artificial systems. He developed a programming technique that operates in the same way populations evolve by following the general principle of “survival of the fittest”.

Due to their perceived benefits, GAs have successfully been used to solve several engineering problems. Applications include the optimization of a contractor's markup strategy (Hegazy and Moselhi, 1994); steel truss roof optimization (Koumouisis and Georgiou, 1994); resource scheduling (Chen et al., 1996); time-cost trade-off optimization (Li and Love, 1997); and resource allocations and management (Hegazy, 1999; Hegazy and Kassab, 2003). GAs are different from the traditional optimization procedures in the following respects (Goldberg, 1989):

- During the search, GAs work with a group of possible solutions at the same time. In contrast, the traditional optimization procedures usually work with only one solution.
- GAs work with the coding of the parameter set and not with the parameters themselves, thus allowing the use of a wide variety of parameters as decision variables.
- GAs do not require gradient information about the objective function, which can be very difficult to obtain in many engineering problems.
- GAs improve the search process in an adaptive manner using probabilistic transition rules, which guide a search easily toward a set of solutions, with improvement likely.

These differences make GAs more robust for solving optimization problems.

GAs are rooted in both genetics and computer science. Hence, the terminology used in GA literature is a mix of both and requires explanation (Goldberg, 1989). The strings in artificial genetic systems are "chromosomes" in biological systems. Chromosomes are composed of genes, which may take on a number of values called "alleles". In an artificial genetic search, strings are composed of characters (bits), which take on different values (1 or 0).

2.6.1 Basic Genetic Algorithms

As shown in Figure 2.7, a standard genetic algorithm evolution process consists of the following steps (Hegazy and Kassab, 2002):

1. Initialize a population of genes.
2. Evaluate each gene in the population.
3. Apply genetic algorithm operators (e.g., crossover and mutation) to generate offspring.
4. Evaluate the offspring and delete members of the population to make room for the new genes if the offspring are fitter.
5. If the stopping criterion is met, then stop and keep the best gene; otherwise, go back to Step 3.

In evolution, the problem each species faces is to search for beneficial adaptations to a complicated and changing environment. In other words, each species has to change its chromosome combination to survive in the living world. In GAs, a string represents a set of decisions (chromosome combination), which are a potential solution to a problem. Each string is evaluated on its performance with respect to the fitness function (objective function). The ones with better performance (fitness value) are more likely to survive than the ones with worse performance. Then, the genetic information is exchanged between strings by crossover and is perturbed by mutation. The result is a new generation with (usually) better survival abilities. This process is repeated until the strings in the new generation are identical or until specified termination conditions are met.

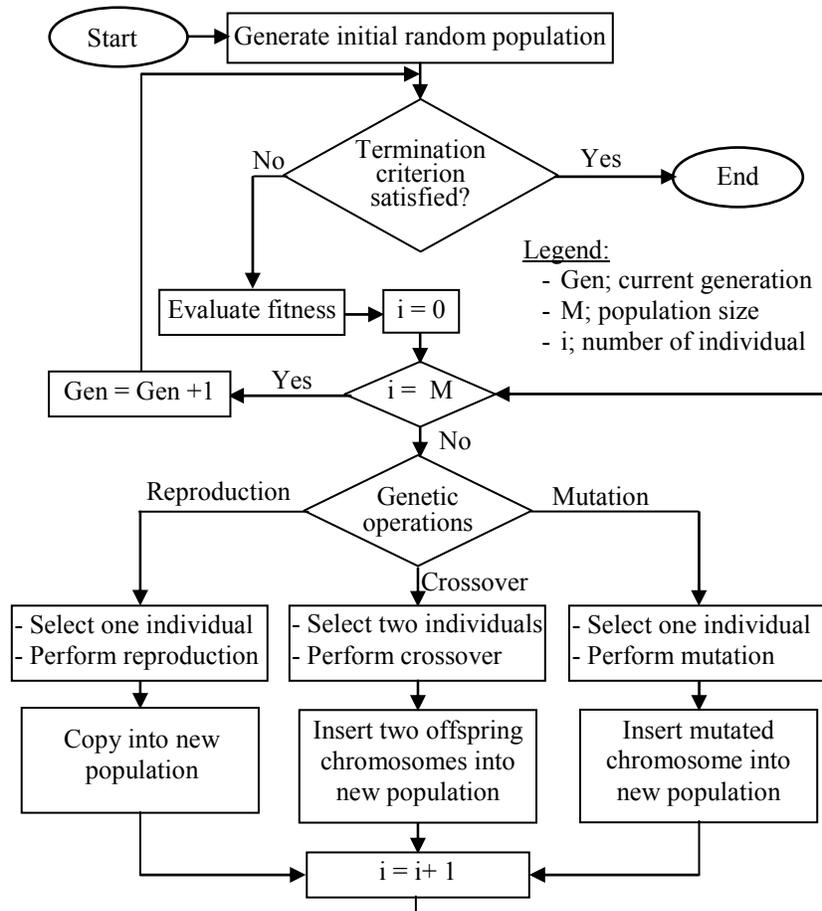


Figure 2.7: Basic GA Flowchart (Son and Skibniewski, 1995)

2.6.2 Genetic Algorithms Operations

The reproduction operations of GAs represent the way in which a solution evolves. Basic GAs have three main operations: reproduction, crossover, and mutation (Goldberg, 1989).

- **Reproduction:** The reproduction process allows individual chromosomes to be copied for possible inclusion in the next generation. The chance that a chromosome will be copied is based on the chromosome's fitness value, calculated from an objective function. For each generation, the reproduction operator chooses chromosomes that are

placed into a mating pool, which is used as the basis for creating the next generation. Because the total number of chromosomes in each generation is kept constant, chromosomes with lower fitness values are eliminated (Al-Tabtabi and Alex, 1999).

- Crossover:** Crossover (marriage) is by far a more common process (Caudill, 1991). The system selects two parent chromosomes, exchanges their information, and produces new chromosomes for the offspring. Each of the two parent genes is randomly selected, and the GA then calculates whether crossover should take place or not using a parameter called “crossover probability”. This parameter usually ranges from 0.6 to 1.0 (Al-Tabtabi and Alex, 1999). To produce offspring chromosomes, the exchange of information between the two parent chromosomes is accomplished through a random process, as depicted in Figure 2.8.

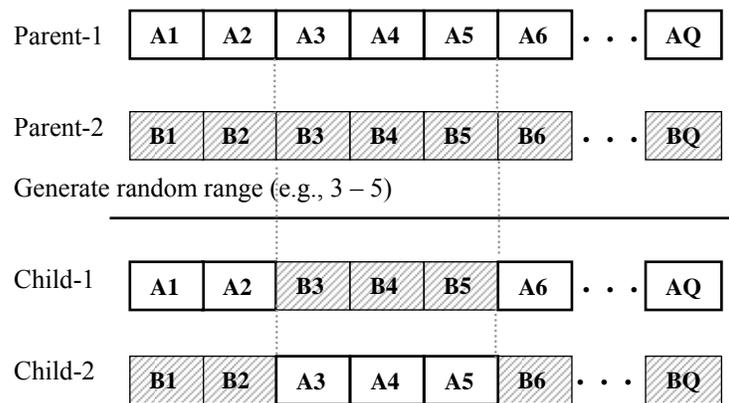


Figure 2.8: Two-Point Crossover

- Mutation:** Reproduction and crossover alone can obviously generate a staggering number of different strings. However, depending on the initial population chosen, there may not be enough variety of strings to ensure that the GA searches the entire problem space. This difficulty is overcome through the introduction of a mutation operator.

Mutation helps prevent the population from stagnating by maintaining diversity throughout the GA's iterations. The GA has a mutation probability (usually less than 5%) that dictates the frequency at which mutation occurs (Goldberg, 1989; Holland, 1975). During mutation, a portion of the chromosome changes at random to generate a new bit, as shown in Figure. 2.9.

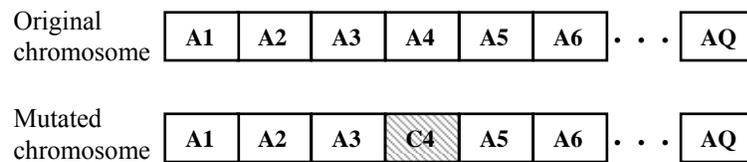


Figure 2.9: Chromosome Mutated by Changing Gene Value at Random Locations

2.6.3 Other Genetic Algorithm Options

The basic GA uses binary coding (i.e., 0 or 1) to represent the problem variables and also uses three operators (reproduction, crossover, and mutation) for the evolution process. Other options can be applied such as using real coding instead of binary coding and two operators instead of three, namely “crossover” and “mutation”. These two options are discussed in the following subsections.

a) Real-Coded GAs

The genes might be coded using real-number representation as opposed to the binary coding. In addition to improvements in speed arising from the avoidance of the coding and decoding processes usually required with binary-coded GAs, real-coded GAs have other advantages. One of the main ones is the non-existence of redundant values in chromosomes, which occurs with binary coding. When the binary alphabet is used for coding a parameter belonging to a finite discrete set, some codes may be redundant (i.e., their decoding corresponds to values

that do not belong to the domain of the parameter) (Vairavamoorthy and Ali, 2000). For example, in the design of a water distribution system, if the number of commercially available diameters is 10, then when binary coding is used, a minimum of 4 bits are needed for coding the elements of the set of diameters. If codes 0000 to 1001 are used to represent the 10 diameters, then the codes 1010 to 1111 are redundant values that do not represent any diameter. These redundant values are inevitably generated when the crossover and mutation operators are applied.

Another advantage of real-coded GAs is that they avoid the problem associated with the Hamming cliff, which is associated with binary coding (Herrera et al., 1995). The Hamming cliff effect is produced when the binary coding of two consecutive values differs in each one of their bits. For example, the strings 011111 and 100000 represent the values 31 and 32, respectively, and the value of each one of their positions is different. The Hamming cliff may produce problems, such as convergence towards local optima (Goldberg, 1991).

b) Steady-State GAs

The steady-state evolutionary approach means that only one chromosome is replaced at a time, rather than an entire "generation" being replaced (i.e., the reproduction process). This steady-state approach has been shown to work as well as or better than the traditional replacement method (Rogers and Prügel-Bennett, 2000).

The reproduction process among the population members takes place by either crossover or mutation. In crossover, two members of the population are chosen randomly in such a way that the probability of a member being selected is proportional to its relative merit to produce

a single child (Gaudill, 1991). Without violating the diversity of the random process, this method ensures that the best chromosomes have a higher likelihood of being selected. In the mutation process, one chromosome is randomly selected from the population, and then some of its information is arbitrarily changed. Once an offspring is generated by either method, it is evaluated in turn and can be retained only if its fitness is higher than that of others in the population, as shown in Figure 2.10.

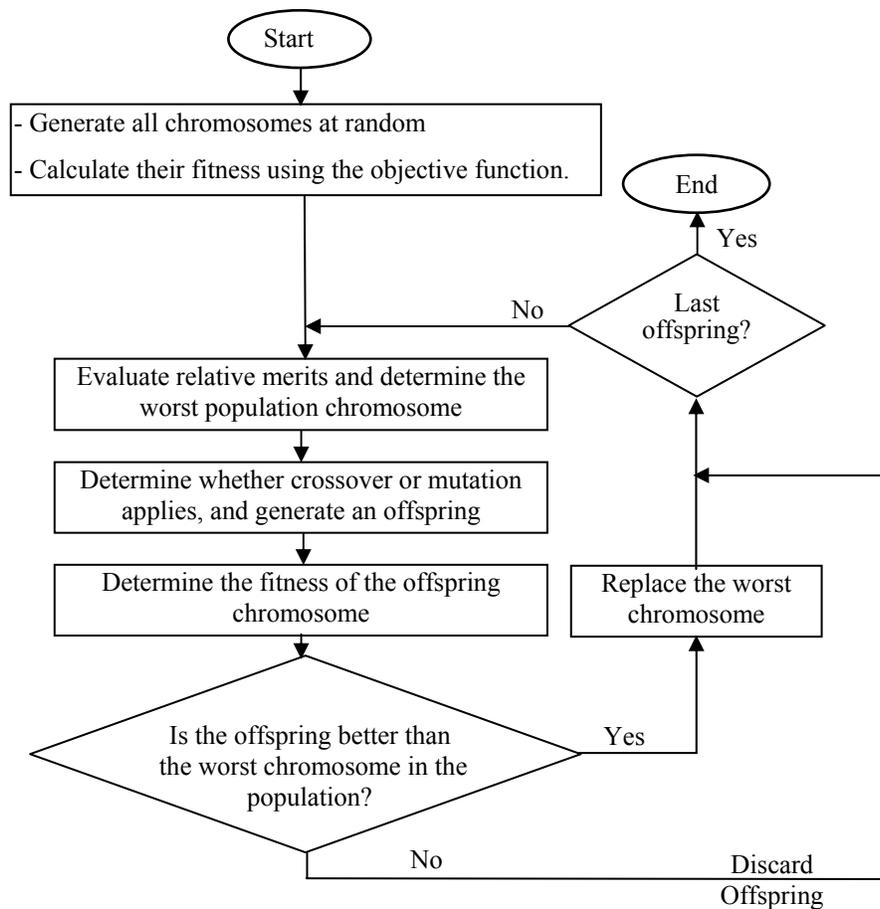


Figure 2.10: Steady-State GA Procedure (Kassab, 2001)

Throughout the process, the entire population soon improves since fitter offspring chromosomes replace unfit parents (Gaudill, 1991; Bishop et al., 1991). In this case, the

number of generations equals the number of individual trials divided by the size of the population.

2.7 Summary

This chapter reviews the literature that defines existing methods used in the decision-making process. In particular, Multi-Criteria Decision Analysis (MCDA) tools, the Graph Model for Conflict Resolution, the Info-gap Theory, and Genetic Algorithms (GAs) are discussed.

MCDA techniques are effective tools for handling complex problems such as infrastructure management decisions because they can handle both the qualitative and quantitative aspects of the problem. Both traditional and non-traditional methods are presented. Because conflicts often exist among stakeholders, the Graph Model for Conflict Resolution is introduced together with its methodology and solution concepts that can handle different kinds of human behaviour. Then, to deal with uncertainties with respect to stakeholders' preferences due to missing information, information gap theory is presented to show its strength in identifying the most robust decision that satisfies the goals of all stakeholders. Finally, the techniques of a non-traditional optimization tool, the GA, are explained. The above decision-making tools are incorporated into the integrated decision support system (DSS) presented in Chapter 4, which is applied to the case studies discussed in Chapters 5 and 6.

CHAPTER 3

PRIVATIZATION

3.1 Introduction

In recent years, in sectors such as transportation, water and power, an international trend has evolved toward involving the private sector in infrastructure systems management and operations. Among the factors that have triggered the trend toward deregulation are aging infrastructure, escalating demands on infrastructure services due to population growth, the scarcity of governmental resources, the increase in globalization, and the realization by governments that they are unable to provide efficient services. These factors are operating around the world and have opened the door for private investors in more than 100 countries (Thobani, 1999) to finance, manage, and own infrastructure projects that were once considered to be the sole responsibility of the governments.

This chapter discusses infrastructure privatization, and, in particular, privatization of facilities such as water, wastewater, and power systems. It examines forms of Public-Private-Partnerships (PPP), and concludes with a brief description of the advantages and disadvantages of privatization.

3.2 Private-Sector Involvement in Infrastructure Privatization

According to the World Bank, many developing countries have encouraged the private sector to participate in infrastructure facilities, and between 1990 and 1999, more than 30 developing countries have had at least one project completed by the private sector, as shown in Table 3.1 (Roger, 1999).

Table 3.1: Investment in Infrastructure Projects with PPP in Developing Countries (US \$ billions)

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Telecommunication	6.6	13.1	7.9	10.9	19.5	20.1	33.4	49.6	53.1
Energy	1.6	1.2	11.1	14.3	17.1	23.9	34.9	46.2	26.8
Transport	7.5	3.1	5.7	7.4	7.6	7.5	13.1	16.3	14
Water and sanitation	0	1	1.8	7.3	0.8	1.4	2	8.4	1.5

Source: Roger (1999)

Governments implement infrastructure privatization for different reasons. Sanchez (1998) points out the following main reasons:

- Economic

Public funds are in short supply. Governments are facing a scarcity of the resources intended to finance infrastructure projects, and the gap between their infrastructure needs and available resources is growing. The symptoms of this problem range from poorly maintained transportation, water and wastewater, and power facilities to the partial or complete lack of essentials for life, such as drinking water, wastewater removal, and electricity networks.

Challenged by these problems, many governments around the world have found complete or partial privatization to be a viable solution to their funding shortfall. These governments have started to implement policies and regulations to ease the way for the

private sector to participate in public-service sectors, such as the deregulation of infrastructure systems and the letting of public services as concessions.

- Pragmatic

The private sector is very well known for its efficiency and innovation, especially in the field of customer-oriented service. It is capable of overcoming restrictions and obstacles, especially in the design-construction phase. Additionally, because of its nature as a profit-driven sector, it has the incentive to operate its facilities more efficiently, even with budget restrictions that allocate a percentage of the revenue to its target return on investment. However, for privatization critics, this feature represents a major drawback, especially for essential human services such as drinking water or sewage systems and even electricity.

- Commercial

Capital markets and innovative infrastructure financing mechanisms are expanding, as investors in many countries are diversifying their portfolios to achieve higher returns.

- Social

Proponents of privatization believe that it can help satisfy unmet basic human needs. For example, in Third World countries, private companies will increase the total supply of water to make a profit.

- Ideological

Privatization is also based on the belief idea that smaller government is better.

Given these factors, governments around the world are increasingly turning to private financing to ease the burden on their budgets and to encourage better risk sharing,

accountability, monitoring, and management in the provision of infrastructure assets and services (Roger, 1999; World Bank, 2003).

Globally, the decision to privatize water has been driven by several factors. For example, in the United States and Canada, the decision to privatize began mainly as pragmatic and now is strongly ideological, as can be seen in the public policy push to privatize water on the part of libertarian and free-market policy institutions (Gleick et al., 2002). In Europe, privatization efforts were at first ideologically driven, but are increasingly characterized as having commercial and pragmatic advantages (Beecher, 1997). In developing countries, privatization efforts can be described as primarily financial and pragmatic, although some argue that social benefits are also significant (Global Water Partnership, 2000). As well, in recent years, several countries with a strong anti-capitalist ideology have chosen to explore water privatization for pragmatic reasons; China and Cuba, for example, have both recently awarded contracts to private companies to develop and operate municipal water-supply systems and to build wastewater treatment plants (Gleick et al., 2002).

3.3 Water Privatization

Water and wastewater have traditionally been managed by governments and financed by the public sector and by user fees. However, due to the factors mentioned previously, governments are starting to push the private sector to become involved in this essential field, as confirmed in Figure 3.1. Privatizing water-supply and wastewater systems can also involve strong capitalistic incentives. The World Bank estimates that new investments required to provide water infrastructure over the next decade will exceed \$60 billion US

per year (Gleick et al., 2002). In the USA, the American Water Works Association released a study suggesting that \$250 billion may be needed over the next 30 years just to update and maintain the existing drinking water system (American Water Works Association, 2001). In Canada, a report released by the National Round Table on the Environment and the Economy (Li, 2001) suggests that \$50 billion CAD will be required in order to maintain and operate existing water and sewer utilities, with only half of the cost being recovered from the users. In addition, \$90 billion CAD will be needed over the next 20 years.

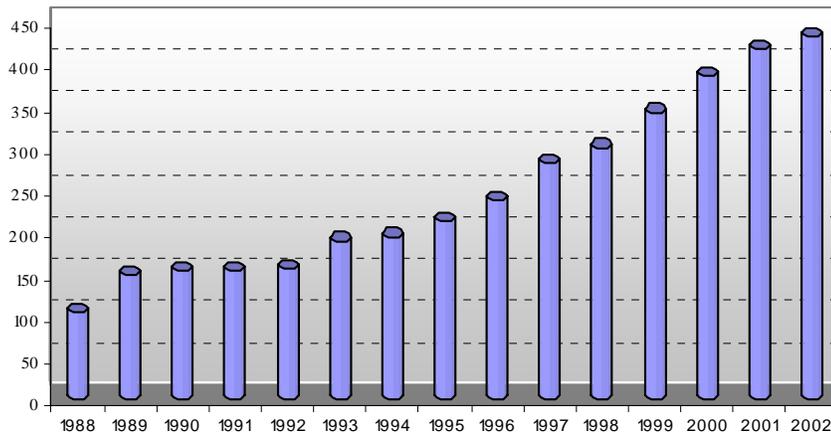


Figure 3.1: Number of Individuals Using Water from PPP (in millions) (Owen, 2002)

While privatizing water and wastewater systems is not a new idea and many forms of privatization have long existed in different parts of the world, the concept has resurfaced more prominently in recent years for a number of reasons:

- Many public water agencies have been unable to satisfy the most basic need for clean water for all humans.
- Major multinational corporations have greatly expanded their efforts to take over responsibility for a larger portion of the water service market than ever before.

- Several recent highly publicized privatization efforts have failed or have generated serious controversy.
- The rapid rise in the standard of living and an increasing population have left no room for error, poor decisions, or mismanagement of these essential services.

The privatization of water encompasses a variety of possible water-management arrangements. Privatization can be partial, leading to so-called Public-Private-Partnerships (PPPs), or complete, leading to the total elimination of government responsibility for water systems. At the extreme end of the scale, private water companies build, own, and operate water systems around the world, with annual revenues of approximately \$300 billion CAD (Gopinath, 2000). Such increasing involvement of the private sector has important implications for the supply of water and for human well-being. Along with increasing water privatization, there is also rapidly growing opposition among local community groups, unions, human rights organizations, and even public water providers (Gleick et al., 2002).

3.4 History of Privatization

Private involvement in water supply and its related systems has a long history. In the United States (USA) in the early 1800s, municipal services were often provided by private organizations. Toward the latter half of the nineteenth century, access and service problems started to surface, which led many municipalities to begin a move toward public control and management. This trend continued in the nineteenth and twentieth centuries until by 2000, public ownership of water infrastructure reached about 85% (Gleick et al.,

2002; Beecher et al., 1995). In France, in the nineteenth century, the trend moved in the opposite direction: municipalities that had previously been responsible for providing water service began to contract services to private operators (Gleick et al., 2002).

However, for most of the world, major privatization efforts are still a relatively new phenomenon, with major transfers taking place only over the last 10 to 15 years. By the end of 2000, at least 93 countries had partially privatized water or wastewater services (Brubaker, 2001). Nevertheless, less than 10% of water is currently managed by the private sector (LeClerc and Raes, 2001).

Recently, European nations have implemented a variety of approaches. In 1989, in the United Kingdom (UK), for example, water supply and sewerage systems were entirely privatized through an asset sale (Bakker, 2004). In France, on the other hand, the Operation and Maintenance (O&M) and Build-Own-Transfer (BOT) forms have been successful. Germany and Italy are also exploring different forms of privatization. It should be noted that service providers in all four countries initially tried to keep prices low, but they have recently imposed large price increases in order to upgrade their plants and distribution systems (Gleick et al., 2002).

The USA and Canada have moved more slowly toward privatization. The USA has long had a mix of privately owned and publicly regulated water and wastewater utilities, although an estimated 85% of residences still receive water from public agencies. With the failure of a few pioneering privatization decisions, such as in Hamilton, Canada, and the corruption scandals in large corporations such as Enron, voices calling for full

privatization have become less active, especially when it comes to vital services such as water and electricity. Recently, in Canada, many have called on the government to think carefully before considering any privatization decision. For example, in a recent book entitled *Eau Canada: the Future of Canada's Water*, edited by Bakker (2007), more than 16 articles by well-known academic and non-academic experts and researchers warn the public and government about choosing the wrong path in water privatization.

In Third World countries, public water and wastewater services were the norm until the late twentieth century, when it became apparent that public water systems were consistently failing to provide universally good water and wastewater services and that the losses involved in wastewater treatment can be as high as 50%. Because of these failures, governments are increasingly seeking private-sector involvement ranging from minor subcontracts to full privatization.

3.5 Major International Water Privatization Business

Due to the large potential for profit from water service industries, many companies around the world have started to explore this business opportunity, as shown in Table 3.2. However, a few companies have dominated the main international water markets. Vivendi SA and Suez Lyonnaise des Eaux (now called Ondeo) are two companies that have participated in water ventures in more than 120 countries and claim to have provided water for more than 100 million people (FTGWR, 2000). Other companies have major water interests, including Thames Water and United Utilities in the UK, Bechtel and Enron in the USA, and Aguas de Barcelona in Spain.

Table 3.2: Global Water Privatization Market (Owen, 2002)

Region	Population (2000)	Completed privatization	Potential by 2015
North America	310 m	14%	65%
Middle & South America	519 m	16%	25%
Western Europe	389 m	38%	75%
Central & Eastern Europe	341 m	4%	20%
Middle East & Africa	1039 m	3%	10%
Southeast Asia & Australasia	2041 m	4%	11%
Middle & south Asia	1335 m	? %	7%

3.6 Forms of Privatization

Despite the growing debate about privatization, considerable misunderstanding and misinformation exists about what the term itself means. Privatization can take the form of many different arrangements, agreements, and models. Only the most absolute form transfers full ownership of an operation to the private sector. Much more common forms leave public ownership of water resources unaffected and include transferring some operational responsibility for water supply or wastewater management from the public to the private sector. Privatization also does not, or should not, release public agencies from their responsibility for environmental protection, public health and safety, or monopoly oversight.

Privatization can vary from a completely public to a completely private operation, with many variations in between. Some water system functions are more suitable for privatization than others. Table 3.3 lists several functions that could be assigned to either private or public enterprises, in combinations ranging from completely public to completely private operations.

Different countries have adopted different privatization alternatives for private-sector participation. Table 3.4 shows scenarios that could be developed using different combinations of the above-mentioned privatization functions with different participation.

Table 3.3: Possible Water-System Functions for Privatization

1	Capital improvement planning and budgeting
2	Finance of capital improvements
3	Design of capital improvements
4	Construction of capital improvements
5	Operation of facilities
6	Maintenance of facilities
7	Pricing decisions
8	Management of billing and revenue collection
9	Management of payments to employees or contractors
10	Financial and risk management
11	Establishment, monitoring, and enforcement of water quality and other service standards

Table 3.4: Examples of Privatization Forms (Catley-Carlson, 2002; Owen, 2002; Smith, 1999)

Contract Task	Privatization Forms												
	Asset Sale	Service Contracts	Management Contracts	Leasing	Pre-financing	O & M ¹	BLT/BLTM ²	Concession	BOT/BOOT ³	BTO/BTSM ⁴	BOO/BOOR ⁵	LROT ⁶	DBFO ⁷
Ownership	Pr ⁸	P ⁹	P	P	P	P	Pr	P	P	P	Pr	P	P
Investment	Pr	P	P	P	Pr	P	Pr	Pr	P	Pr	Pr	Pr	Pr
Operation	Pr	Sh ¹⁰	Pr	Pr	Sh	Pr	P	Pr	Pr	Pr	Pr	Pr	Pr
Billing	Pr	P	Sh	Pr	Sh	Sh	P	Pr	P	Pr	Pr	Pr	Pr
Commercial Risk	Pr	P	P	Sh		P	Sh	Pr	Sh	Sh	Pr	Pr	Pr
Duration (Years)	-	1-2	3-5	8-15	15	5	10-30	20-30	10-30	10-30	20-30	10-30	20-30
Examples	London UK	Mexico City	Gaza City	Guinea	Germany	Atlanta	Germany	Berlin	Sydney	Thailand	Melbourne	Malaysia	Hong Kong

1- Operation and Maintenance; 2- Build-Lease-Transfer-Maintain; 3- Build-Own-Operate-Transfer; 4- Build-Transfer-Service-Maintain; 5- Build-Own-Operate-Remove; 6- Lease-Renovate-Operate-Transfer; 7- Design-Build-Finance-Operate; 8- Private; 9- Public; 10- Shared: Public/Private.

Smith (1999) describes some of the privatization forms as follows:

- **Management Contracts**

Existing services and utilities are commonly privatized through the medium of management contracts, whereby the private sector takes over responsibility for the operation and maintenance of an existing facility that has previously been operated by the public sector. This arrangement may be especially useful when the public sector has a facility in need of upgrading or renovation but does not have the necessary funds available to carry out the work.

- **Build, Lease, Transfer (BLT)**

In this model, the facility is typically designed, financed, and constructed by the private sector and is then leased back to the government for a predetermined period at a pre-agreed rental. Rental costs are commonly based on the costs of construction and financing and, according to Trosa and Schreiner (1994), will usually represent about 9-10% of the investment costs. During the period of the lease, legal ownership of the facility rests with the private-sector partner, and at the end of the leasing period, the government typically has the option of renewing the lease, of buying out the private sector partner for a lump sum, or of simply walking away from the deal, leaving the facility in private-sector hands. The operation and maintenance of the utility during the lease period is typically the government's responsibility and, when operation and maintenance forms part of the original deal, the project may be described as build, lease, transfer, maintain (BLTM). The BLT model has been considered for use in different countries, such as Germany for the construction of motorways (Trosa and Schreiner,

1994), the United States for the construction of prisons (Havens, 1994), and Mexico for the procurement of power stations (Hollihan, 1994).

- **Pre-financing**

The pre-financing model is similar in many respects to the leasing model, but the major difference is that with the pre-financing model, the private sector initially finances and constructs the project, with the government paying off the full cost, including the financing charges, by a series of pre-agreed annual lump-sum payments over an agreed period (typically about 15 years). With this model, it is usual for the government to provide the land free of charge and also to prepare the initial route alignments in the case of roads and to obtain the necessary planning permissions. The government may prepare the final detailed design, with tenders being invited for financing and construction only, or the final design may be entrusted to the construction company on a design, finance, and construct basis.

Tenders for the work are therefore comprised of an offer to finance and construct the works according to an agreed-upon specification in exchange for a laid-down series of lump-sum payments over an agreed time period. As in the case of the leasing model, the government may either operate the facility itself or may contract out the operation and maintenance to the private sector.

With this approach, it is common for the ownership of the completed facility to pass to the government, and for the payments to begin immediately upon completion of the

construction work. Therefore, there is considerable incentive for the work to be completed in the shortest possible time. As with the leasing model, this approach has advantages because the developer's risk is normally limited to cost and time overruns on the construction contract and to fluctuations in the costs of providing the necessary capital. The German government has begun a program of 12 major motorway contracts using this model, totalling about 151 km at an estimated cost of about DM 3.89 billion (PFI, 1995).

- **Mixed Models**

A combination of the leasing and pre-financing models has been used for the redevelopment of the A2 motorway between Helmstedt and Berlin in Germany (Trosa and Schreiner, 1994). For this project, ownership of the scheme passed to the government immediately after construction, and the annual payments from the government depend on traffic flow. Payments are calculated based on the number of vehicles using the road, with different types of vehicles generating different fees.

The risks for the developer and for the government are thus significantly changed when this approach is used. Since payments are based on traffic flow, if traffic flow is lighter than predicted, then the developer suffers, but if traffic flow exceeds expectations, then government expenses increase. Payments are therefore much more difficult to anticipate and to plan for (Trosa and Schreiner, 1994).

- **Concession-Based Methods**

A wide variety of techniques have been developed based on the concept of a fixed-term concession, using various combinations of private-sector resources to design, construct, finance, and operate facilities. The concession makes provision for the ownership of the facility to be vested in the host government, which may occur either upon completion of the construction work or at the end of the concession period, depending on the terms of the concession agreement. It should be noted, however, that, in some cases, even if legal ownership is transferred upon completion of the construction phase, the operator is frequently required to be deemed to be the owner for taxation purposes. Upon completion of the concession period, the host government generally takes over responsibility for operation and maintenance of the facility.

It is common for the concession period to include the design and construction period. As discussed earlier, concession-based approaches are among the oldest form of Public-Private-Partnership programs. The terminology and acronyms used to describe concession-based projects are not, however, always used consistently, and different projects, which apparently use the same terms, may vary significantly in the actual contractual arrangements. On the other hand, a number of terms are virtually synonymous. The principal variants in most common use are explained in the following sections.

- Build, Operate, Transfer

Build, Operate, Transfer (BOT), is often used as a generic term for concession-based agreements in which the facility is designed, financed, operated, and maintained by the concession company for the period of the concession, typically between 10 and 30 years. The United Nations Industrial Development Organization (UNIDO) has produced detailed guidelines that discuss all aspects of the BOT family of approaches (UNIDO, 1996).

Under the "standard" BOT agreements, the concessionaire's involvement with the project terminates at the end of the concession period, and at this point, all operating rights and maintenance responsibilities revert to the host government. Legal ownership of the utility may or may not rest with the concession company. In many projects, legal ownership of the constructed facility is required to pass free of charge to the host government immediately upon completion of construction, but the concessionaire retains the right to operate the utility for the full concession period, effectively as a licensee.

Walker and Smith (1995) contend that the Hong Kong Cross Harbour Tunnel, first conceived in 1958 and eventually opened in 1972, is probably the world's first modern-day BOT project. More recently, British contractor John Laing entered into a joint venture in the late 1960s with the Spanish company Ferrovial for the construction and operation of a 109-km motorway between Bilbao and San Sebastian in Spain under the provisions of the Spanish government's Toll Motorway Construction Plan. Armstrong

(1994) reports that the 35-year concession was awarded in 1968, and the road opened to traffic in 1976. According to Armstrong, support provided by the Spanish government included:

- A guarantee of 75% of the funds borrowed in international capital markets;
- Subject to a premium of 0.2% per annum, a supply of foreign currency for the settlement of principal and interest, at the same exchange rate as that prevailing on drawdown, in respect of funds borrowed from capital markets;
- An interest-free advance, equal to the difference in revenue between actual receipts and those for the target traffic density, subject to repayment only when traffic density exceeds the target by 5%; in consideration of this support, net dividends were capped at 10%.

- Build, Own, Operate, Transfer

Build, Own, Operate, Transfer (BOOT) describes the earliest concession model, although the late Turkish Prime Minister, Turgut Ozal, is popularly cited as originating the phrase (Smith, 1999) "BOOT" in the 1980s in connection with proposals for the construction of power plants in Turkey. In this model, ownership of the utility rests with concessionaires until the end of the concession period, at which point, both ownership and operating rights are transferred free of charge to the host government. Host governments often consider legal ownership of the concessionaires to be undesirable, particularly when the utility is of strategic importance.

- Build, Transfer, Operate; Build, Transfer, Service, Maintain

Build, Transfer, Operate (BTO) and Build, Transfer, Service, Maintain (BTSM) are technically terms that could be applied to any project in which ownership of the facility passes back to the host government upon completion of the construction phase. In practice, the terms tend to be used for projects in which the host government takes possession of and pays for the completed facility once construction has ended, with the developer being responsible for maintenance and operation of the plant for the period of the concession. This approach has been used for projects such as chemical waste treatment and waste recycling plants, which usually require very specific expertise for the design and operation but for which the revenue stream is difficult to predict with any degree of accuracy. Payment for the operation of the facility is often a combination of a fixed and predetermined "availability charge" covering the fixed costs of the facility, supplemented by a further variable charge depending on the extent of use.

- Build, Own, Operate

The goal of the build, own, operate (BOO) approach is, of course, outright privatization, but BOO projects are sometimes let on a concession basis for a fixed period of time with no provision for transfer of ownership back to the host government. In projects of this nature, the developer is responsible for the design, funding, construction, operation, and maintenance of the facility during the concession period, at the end of which several options might apply. Typically, the project agreement might provide for one or more of the following options:

- Renegotiation of the original agreement for a further concession period;

- Negotiation of a new agreement on a renovate-operate basis;
- Purchase of the facility by the host government, who may then, of course, let a separate lease, renovate, operate, and transfer the concession;
- Termination of the facility, in which case, the developer may be responsible for decommissioning, demolition, and reinstatement of the site; in this case, the project may be defined as build, own, operate, remove (BOOR).

An example of a project of this type is the \$25 million AUD, Yan Yean Water Treatment Plant constructed outside Melbourne (Australia) by a Transfield-North West Water joint venture; the plant is required to be removed and the site reinstated at the end of the 25-year concession period (Young and Sidwell, 1996).

- Lease, Renovate, Operate, Transfer

The Lease, Renovate, Operate, Transfer (LROT) approach may be used when a host government already owns a facility that requires modernization and improvement, or it may be used as a "follow-up" to an existing concession once it reaches the end of the concession period. In this case, the private-sector operator pays a rental to the government, undertakes to renovate the utility to a pre-agreed standard, and in exchange, is granted a concession to operate the facility for a fixed period of time and to charge a fee for the service. The private-sector partner is responsible for financing and carrying out any required refurbishing work in addition to regular maintenance during the concession period. This approach has been widely used in some parts of the world,

such as for government-owned car parks and vehicular tunnels in Hong Kong and for water and sewage treatment plants in Malaysia.

- Design, Build, Finance, Operate

Design, Build, Finance, Operate (DBFO) is a term coined by the UK Highways Agency to describe its concession-based road schemes let under the Private Finance Initiative. The basis of the "standard" DBFO contract is defined by the Highways Agency (1995) in the following terms:

The private sector partner (the DBFO concessionaire) will be

- Responsible for the design, construction, maintenance (i.e., capital, routine, and winter maintenance), and operation of the project road;
- Responsible for financing the project;
- Granted a long-term right of access (probably 30 years) to the project road by the Secretary of State for those purposes;
- Paid by the Department for delivery of specified services in the form of payments over the life of the contract.

In addition to the free provision of any necessary land, the public sector contribution is likely to include some or all of the following, depending on the detailed requirements of particular projects:

- A right of access to the project road without charge;
- DBFO payments, which are expected to include traffic-related payments, usually based on shadow tolls (payments made by government to the private sector operator

of a road based, at least in part, on the number of vehicles using the road, first proposed in the UK by the Conservative government in 1993); lane-closure charges; and additional payments for initiatives designed to improve safety.

Significant features of the DFBO contracts are as follows:

- No rights of ownership are conferred on the developer, neither does the developer at any point acquire any interest in the land. The Secretary of State remains the highway authority throughout the contract period.
- The DBFO contractor is given merely a right of access to the road, and effectively, a "licence" to operate it, normally for a period of 30 years.
- Five years before the end of the operation period, a joint inspection is held to identify any work which the operator is required to carry out before the road is handed back to the Highway Agency.
- Payment is made on the basis of traffic flow at predetermined "shadow tolls". The level of the shadow tolls forms an element of the DBFO tender.
- Some protection is offered in the form of increased payments in the event that the public-sector partner changes the conditions under which the road operates (e.g., if other competing roads are upgraded during the contract period, thus reducing traffic flow).

- Design, Construct, Manage, Finance; Design, Build, Finance, Operate, Manage

Design, Construct, Manage, Finance (DCMF) and Design, Build, Finance, Operate, Manage (DBFOM) are terms used in connection with projects let by the British Private

Finance Initiative (PFI). These projects are very similar in many ways to build, own, and operate concessions.

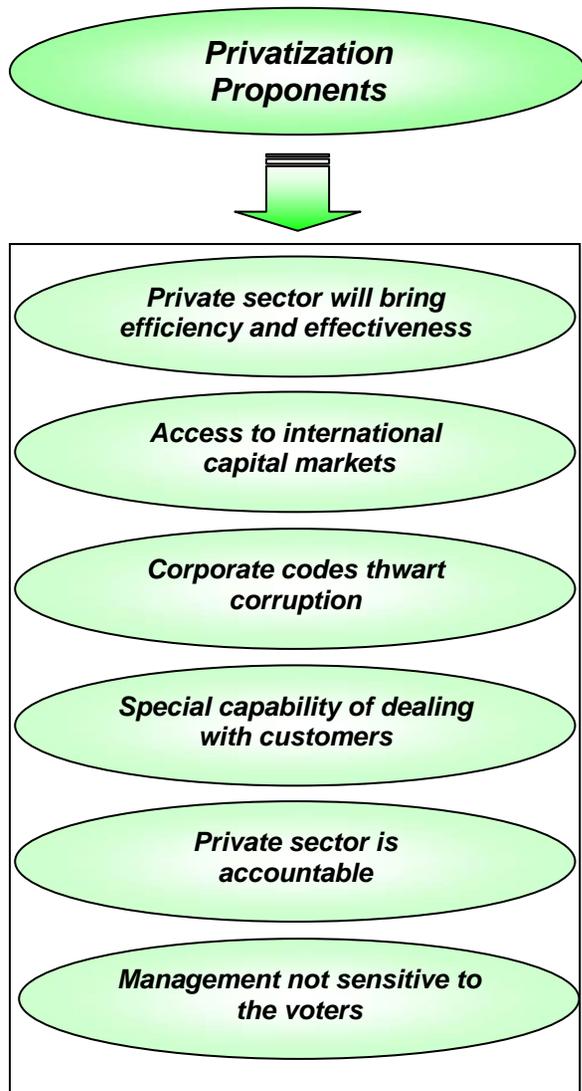
3.7 The Advantages and Drawbacks of Privatization

Infrastructure privatization and, in particular, water and wastewater privatization, has been the subject of extensive controversy. Supporters include as governments, who hope to ease the burden of providing financial and administrative support for these services; private agencies looking for new opportunities in business markets; and researchers who have found in the idea an interesting new method for solving development problems in different parts of the world. On the other hand, many groups, such as environmentalists, researchers, unions, and in many cases, the direct customers, have criticized the trend toward privatization and have been totally or in part opposed to the idea of privatization as having no potential good for society. They believe the privatization agenda to be a game, with the sole beneficiary, a corporation hungry for profit and the sole loser, the public.

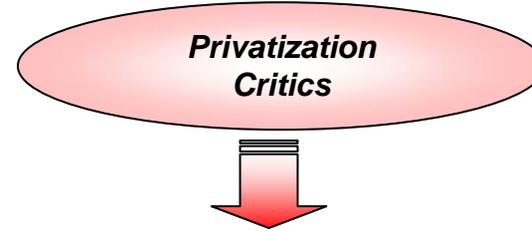
Conflict among the groups has been seen in many places, from conferences to legislatures and violent public demonstrations. Pro-privatization groups and oppositions groups each have their own points to support their views. Figure 3.2 lists a summary of the arguments put forward by both sides.

3.8 Summary

The extensive cost of infrastructure systems and the strong movement toward privatization require governments to have a comprehensive systematic selection process that addresses



VS



- Corporations have to make profits
- Improvements in efficiency reduce water sales and revenues
- Efficiency programs are eventually ignored or even cancelled

- Private corporations will bring money and the interest increases user costs
- Privatization companies are mostly international
- National sovereignty will be questioned

- Corporations are corrupt
- PUMP (Hamilton waste water plant disaster), Enron, World Com

- Poor cannot pay
- Privatization will lead to higher costs for water and water services

- Privatization contracts are ambiguous
- Almost all past privatization cases ended in disputes

- Privatization contracts often fail to guarantee ecosystem water requirements
- Privatization may be irreversible
 - Long-term contracts
 - The loss of internal skills and expertise
 - Management expertise, engineering knowledge, and other assets in the public domain may be lost forever

Figure 3.2: Summary of Arguments between Privatization Proponents and Critics

all the key issues of selecting a successful proposal, such as possible alternatives, stakeholders' values, and relevant criteria.

In this chapter, a discussion of the infrastructure privatization trend and its history was presented, in particular, with respect to the privatization of facilities such as water, wastewater and power systems. Forms of Public-Private-Partnerships (PPP) were examined, and a brief description of the advantages and disadvantages of privatization was provided.

CHAPTER 4

DECISION SUPPORT SYSTEM FOR INFRASTRUCTURE PRIVATIZATION

4.1 Introduction

This chapter presents the framework of the proposed decision support system. It begins with a description of the main characteristics of the infrastructure privatization problem, followed by a presentation of the main components of the decision support system (DSS), along with its concepts and experimental tests.

4.2 Characteristics of the Privatization Problem

As with any decision-making problem, a privatization decision requires careful identification and analysis of suitable privatization alternatives, stakeholders' needs, and assessment criteria. The main functions that can be privatized are ownership, investment, operation, billing, and maintenance. Various combinations of these functions produce different Public-Private-Partnership (PPP) alternatives. Each of these alternatives suits specific circumstances and stakeholders' preferences to different degrees. Accordingly, the three main components of the

privatization problem are privatization schemes and alternatives, stakeholders and their preferences, evaluation criteria, and ranking of preferences. These components are identified further in the following subsections.

- **Privatization Schemes and Alternatives**

As presented in Chapter 3, many privatization scenarios have been described in the literature. The basic water system functions that can be privatized are shown in Table 3.3. Combinations of these basic functions produce hundreds of different PPP alternatives; each suits specific circumstances and stakeholder preferences. The alternatives cover a wide range, from the British model of full privatization that sells and transfers the complete infrastructure-asset, through the French model that privatizes infrastructure management and keeps asset ownership in government hands, to the “full” public infrastructure, with a wide variety of PPP scenarios in between.

- **Stakeholders (Decision Makers) and their Preferences**

As a basis for the comparison and evaluation of privatization scenarios, five main interest groups of privatization stakeholders are listed in Table 4.1, based on the extensive privatization literature survey presented in Chapter 3. The first is the provincial government, which is currently the biggest investor in infrastructure projects in the water and wastewater management field. The second is the municipality or local government that owns and operates its own infrastructure facilities. The third is the employees of the current central and local water and wastewater facilities, who are normally represented by a powerful union. The fourth group is the consumers who make use of water services. The fifth is the environmental groups,

who focus on environmental protection. This group is gaining substantial strength due to its influence on public opinion. The key preferences of each decision maker (DM) are shown in the right-hand column in Table 4.1

Table 4.1: Stakeholder Groups in Privatization (Loxely, 1999; Kay and Metz, 2001; Park, 1999; the World Bank Group, 1999; Catley-Carlson, 2002; Gleick et al., 2002; Owen, 2002)

Interest Groups	Descriptions	Major Preferences
Provincial Government	It has full responsibility for the privatization of public infrastructure and partial responsibility at the local level. It is accountable to the public and tries to reach a compromise between the interests of provincial governmental departments and those of local governments.	Reduce government subsidies
Municipality	This group can be the municipal government of a city or rural area. It may wish to privatize its infrastructure assets and thereby increase business efficiency. It prefers to manage them directly for regional development.	Private partners to have less influence
Employees	This group is concerned about privatization due to fear of loss of job security after privatization. It is also interested in enhancing its own technical skills, increasing efficiency, and excluding political intervention.	Job security
Public Users/ Consumers	This group is generally concerned about service quality, system management, and cost and strongly demands improvement in efficiency. In addition, it is concerned about the trade-off between the public interest and creation of monopolies due to privatization.	High quality and low cost
Environmental Groups	This group is concerned about environmental protection and about pointing out damage that may be caused by the profit-driven private sector.	Less environmental impact

- **Evaluation Criteria**

Based on the literature reviews in Chapters 2 and 3, six different categories of criteria that cover the qualitative and quantitative aspects of privatization have been compiled for this study, namely, public and social, technological, operational and administrative efficiency, economic, environmental, and political, along with their associated criteria or subcriteria. The subcriteria in each category are shown in the right-hand column of Table 4.2 and can be appropriately expanded or revised, as required for a given situation.

Some of these evaluation criteria are numeric (quantitative) in nature, such as economic criteria or subcriteria. Other criteria are not numeric (qualitative) in nature such as the public and social aspects, technology, operational efficiency, environmental effects, and political

criteria. For this thesis, through the use of proper decision-analysis tools, extra effort therefore been made to remove the subjectivity associated with the assessment of these criteria.

Table 4.2: Privatization Criteria and Subcriteria. (UNIDO, 1996; Loxely, 1999; Lobina and Hall, 2001; Kay and Metz, 2001; Park, 1999; the World Bank Group, 1999; Catley-Carlson, 2002; Gleick et al., 2002; Owen, 2002)

Evaluation Criteria	Subcriteria
Public and Social	Concerns about low-income users Increase in service coverage Governmental ability to control fees Reduction in the inequality in infrastructure between regions Consumers' opportunity to supervise and provide feedback Integrated provincial development
Technology	Technological development Expertise of employees Introduction of advanced technology Long-term accumulation of technology
Operational Efficiency	Improvement in efficiency due to competition Prevention of bureaucratization Elimination of political intrusion Elimination of corruption Welfare of employees Job security
Economic Aspects	Securing investment resources Reducing government subsidies Monopoly and profits Cost reduction due to competition Recognition of the economies of scale Degree of risk transfer
Environmental Effects	Applicability of strict environmental standards Establishment of efficient environmental regulation systems Regional management of local infrastructure Consumers' involvement and observation
Political	Percentage of foreign ownership Trade with another country Access to specific areas (e.g., industrial)

- **Ranking of Preferences**

Different stakeholders have different preferences for each criterion and its attributes. For example, the provincial government prefers supporting “reduction in government subsidies”, while the municipalities do not like the idea of the private sector interfering in their essential services. In addition, in the case of the British model of full privatization and asset sale, job security is the main concern of the employees’ group. Accordingly, the stakeholders’ preferences are classified into six levels that represent the various degrees of acceptance or

rejection as follows: 1 = very bad, 2 = bad, 3 = normal, 4 = good, 5 = very good and 6 = excellent. This numerical score facilitates the process of data management and manipulation on a spreadsheet.

4.3 Design of the Proposed Decision Support System

Based on the literature reviews carried out in Chapters 2 and 3, a decision support system (DSS) for infrastructure privatization has been structured. The main components are shown in Figure 4.1, and the development of each component is described in the following sections.

Figure 4.2 provides more details about the DSS components shown in Figure 4.1.

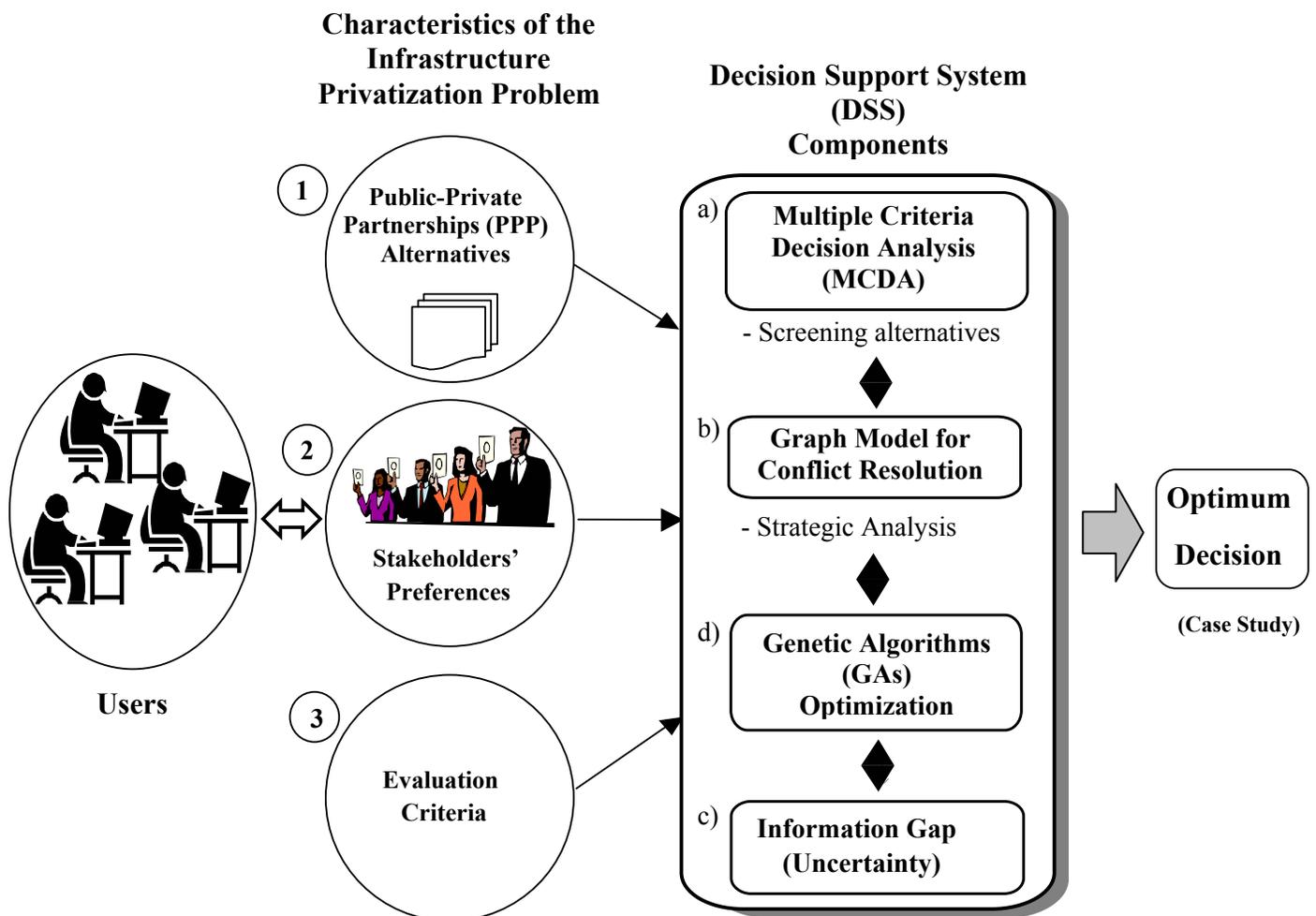


Figure 4.1: Components of the Decision Support System

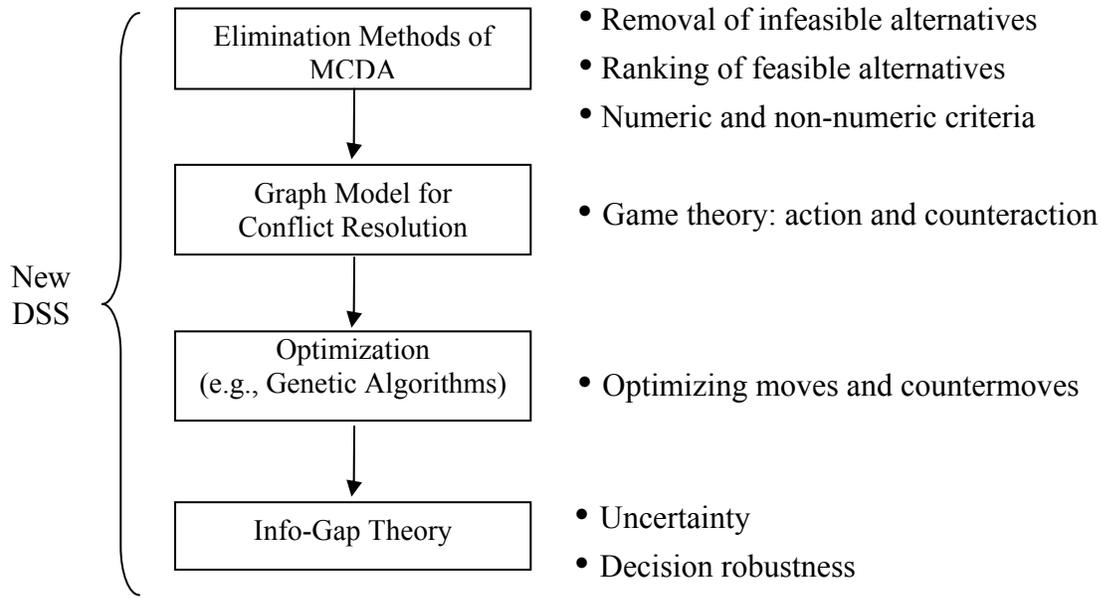


Figure 4.2 Considerations in the Design of the Proposed DSS

The advantages of the DSS design include the following:

1. Use of the Graph Model for Conflict Resolution approach as a basis for the proposed DSS; the graph model technique is implemented in a more transparent way;
2. Consideration of both numeric and non-numeric criteria within the Elimination Method of MCDA;
3. Extension of the Graph Model with Genetic Algorithms (GAs) optimization as a new way to calculate stability and thereby optimize decisions;
4. Extension of the GA-Graph Model to consider the impact of uncertainty in the decision makers' payoff values using the Info-Gap theory approach
5. Implementation of the proposed “GA-Graph Model-Info-Gap” approach in a new friendly computer system and experimentation with it in case studies.

4.4 Components of the Proposed Decision Support System

The privatization problem is clearly described using the identified PPP alternatives, criteria, stakeholders, options, and preferences, as described in Section 4.2. To establish the credibility of this framework for decision making, the main techniques shown in Figure 4.2 were experimented with. These techniques include the Elimination Method for Multiple Criteria Decision Analysis (MCDA), the Graph Model for Conflict Resolution, the Genetic Algorithms technique for optimization, and the Information Gap Theory for uncertainty assessments. An examination of each method is presented below.

4.4.1 MCDA: The Elimination Method

Privatization decision problems are often complex, with many criteria and alternatives to be considered. Measures of progress towards objectives cannot be expressed entirely in quantitative form or are not feasible in certain situations. Under these circumstances, a series of techniques under the general title of Elimination Methods (MacCrimmon, 1973; Radford, 1989) offer the ability of ranking the privatization alternatives in order of preference without using quantitative assessments and weights. The advantage of the selected Elimination Method in the case of privatization is that it provides the ability to eliminate some of the alternatives that do not meet certain threshold values of acceptance. This feature is especially useful in privatization problems because stakeholders can have specific acceptance thresholds or a logical combination of many thresholds. Background information and examples illustrating these methods can be found in MacCrimmon (1973) and Radford (1989).

The Elimination Method in MCDA constitutes a generalization of the “preference tree” method originally suggested by Fraser and Hipel (1988) and later reported on by Hipel and Meister (1995). Although Fraser (1993) suggested the use of the preference tree in MCDA, the following description provides a correct approach for defining the methodology based on the option prioritization idea of Fang et al. (2003a).

Definitions:

Mathematically, the Elimination Method can be defined as follows:

Alternatives: Let A be the set of alternatives given by

$$A = \{A^1, A^2, \dots, A^i, \dots, A^n\}, \text{ where } n \geq 2$$

Criteria: Let Q be the set of criteria given by

$$Q = \{1, 2, \dots, j, \dots, q\} \text{ where } q \geq 2$$

Evaluation: The elimination method works for either consequences or values (Section 2.2).

For explanation purposes, the procedure is explained using consequences.

c_j^i = the consequence of criteria i with respect to alternative A^i , such that for every i, j , and k ,

one of the following holds:

$c_j^i > c_k^i$: criterion j is better satisfied by either alternative A^i if a higher value of j is desirable, or A^k , otherwise

$c_j^i < c_k^i$: criterion j is better satisfied by alternative A^k , if a higher value of j , is desirable, or A^i otherwise

$c_j^i = c_k^i$: criterion j is equally satisfied by alternatives A^j or A^k .

It should be note that these values do not actually need to be determined but are simply a convenient way of distinguishing between more desirable and less desirable features of an alternative. The criteria can be inherently cardinal or ordinal.

Preference Statements (threshold statement): A preference statement Ω is of the form

$$c_j^i \text{ R } c_t^i$$

where R is one of the equivalence relations $<$, \leq , $=$, $>$, or \geq ; while c_t^i is a threshold consequence and distinguishes the consequences of a criterion for which a set of alternatives are desirable. It splits a set of alternatives based on a particular criterion consequences. In addition, depending on the actual threshold consequences given, it is possible that some alternatives will be ranked equally.

Conditional Preference Statement: A conditional preference statement Ω^c is

$$\Omega^c: \Omega' \text{ IF } \Omega'', \text{ or}$$

$$\Omega^c: \Omega' \text{ IFF } \Omega'',$$

where IFF means “If and only if”, and where Ω' and Ω'' are preference statements.

A conditional preference statement is like a preference statement except that the existence or form of the left-hand side (LHS) depends on the truth of the right-band side (RHS). In the Elimination Method, the user is asked to provide a priority ordered set of preference statements for the DM. Each preference statement takes a truth value, either True (T) or False (F), at each particular alternative. The relative importance of a preference statement is reflected by its position in the tree (list): a statement that occupies a higher place in the tree (list) is more important in determining the decision maker’s preferences.

The order of preferences of the alternatives can be determined in the following way:

Let $\{\Omega_1, \Omega_2, \dots, \Omega_k, \}$ be the list of preference statements; then an alternative $A^1 \in A$ is preferred to $A^2 \in A$ iff $\exists j, 0 < j \leq k$, such that

$$\begin{aligned} \Omega_1(A^1) &= \Omega_1(A^2) \\ \Omega_2(A^1) &= \Omega_2(A^2) \\ &\vdots \\ \Omega_{j-1}(A^1) &= \Omega_{j-1}(A^2) \\ \Omega_j(A^1) &= T \text{ and } \Omega_j(A^2) = F \end{aligned}$$

Similarly, A^2 is preferred to A^1 if T and F are reversed in the last line. If there is no such j , then A^1 and A^2 are indifferent. In summary, A^1 is preferred to A^2 if and only if the first statement on which A^1 and A^2 have different truth values is true for A^1 and false for A^2 .

Preference statements are expressed in terms of options and logical connectives. A preference statement can be non-conditional, conditional, or bi-conditional. A non-conditional statement is expressed as a combination of available options, joined by connectives, including the conjunction “and” or “&” and the disjunction “or”. In this sense, non-conditional preference statements are no different from direct specification statements.

A conditional or bi-conditional statement consists of two non-conditional statements connected by an “IF” or “IFF”, respectively. The truth value of a conditional or bi-conditional statement at a state depends on the truth values of its two non-conditional components according to the conditional or bi-conditional truth table defined in mathematical logic (Rubin, 1990) (Table 4.3).

Table 4.3: Truth Table

A	B	-A	A & B	A/B	B IF A	B IFF A
T	T	F	T	T	T	T
T	F	F	F	T	F	F
F	T	T	F	T	T	F
F	F	T	F	F	T	T

For example, according to the conditional truth table, the statement “Technical Transfer must be $\geq 8\%$ IF Foreign Shareholders $\leq 20\%$ ” is True at any alternative that satisfies the statement and at any alternative for which the option “Foreign Shareholders $> 20\%$ ” is selected (which makes it false).

The Elimination Method’s capacity to handle complicated logical combinations of options is very useful in practice, as most DMs’ preferences tend to be expressed in a few rather simple statements. Generally speaking, the Elimination Method can express richer and more flexible preference information in an ordinal fashion that overcomes many difficulties encountered in getting cardinal information, and hence is recommended to users who feel comfortable with this methodology.

Once the preference statements for the problem are set and listed in an ordinal fashion, a ranking scheme is used to classify the alternatives by assigning a “score” $\Psi(A^i)$ to each alternative according to its truth values when the preference statements are applied. These scores are in their highest value at the top of the tree (or list) and decrease the further down they are on the tree branches (or list). If k is assumed to be the total number of statements that have been provided, and $\Psi_j(u)$ denotes the incremental score for alternative (A^i) based upon the statement Ω_j , then $0 < j \leq k$. Define

$$\Psi_j(A^i) = \begin{cases} 2^{k-j} & \text{if } \Omega_j(A^i) = T \\ 0 & \text{otherwise} \end{cases}$$

and

$$\Psi(A^i) = \sum \Psi_j(A^i)$$

The alternatives can then be sorted according to their scores, which will produce exactly the same ranking as the tree presentation. Again, it should be emphasized that the cardinal “score” plays only a temporary role in determining the ranking.

The above mathematical definitions for the Elimination Method can be illustrated linguistically using the problem characteristics described in previous sections (Tables 4.1 and 4.2). As shown in Figure 4.3, for simplicity, only five alternative privatization schemes are used. To apply the Elimination Method, these steps are followed:

1. Rank the criteria from most important at the top to least important at the bottom (based on brainstorming). Then, score each alternative with respect to each criterion (numeric and non-numeric scores are possible) as shown in Figure 4.3a.
2. Specify the threshold level of acceptance for each criterion (Figure 4.3a). For example, politically, the percentage of foreign shareholders of a concession should not exceed 50%.
3. Starting with the top criterion, put an X against any alternative that fails to meet the evaluation factor or minimum threshold level for the criterion under construction (Figure 4.3b). For example, the leasing alternative fails against the criterion of providing Technology Transfer (its score is 8%, which is less than the stipulated 10% threshold).
4. Continue with Step 3 for all of the criteria. The final results are displayed in Figure 4.3b.
5. Rank the alternatives according to their compliance with the elimination rules.

6. To break ties, the alternative that violates more criteria should be ranked lower.
7. Continue this procedure until all of the alternatives have been checked.

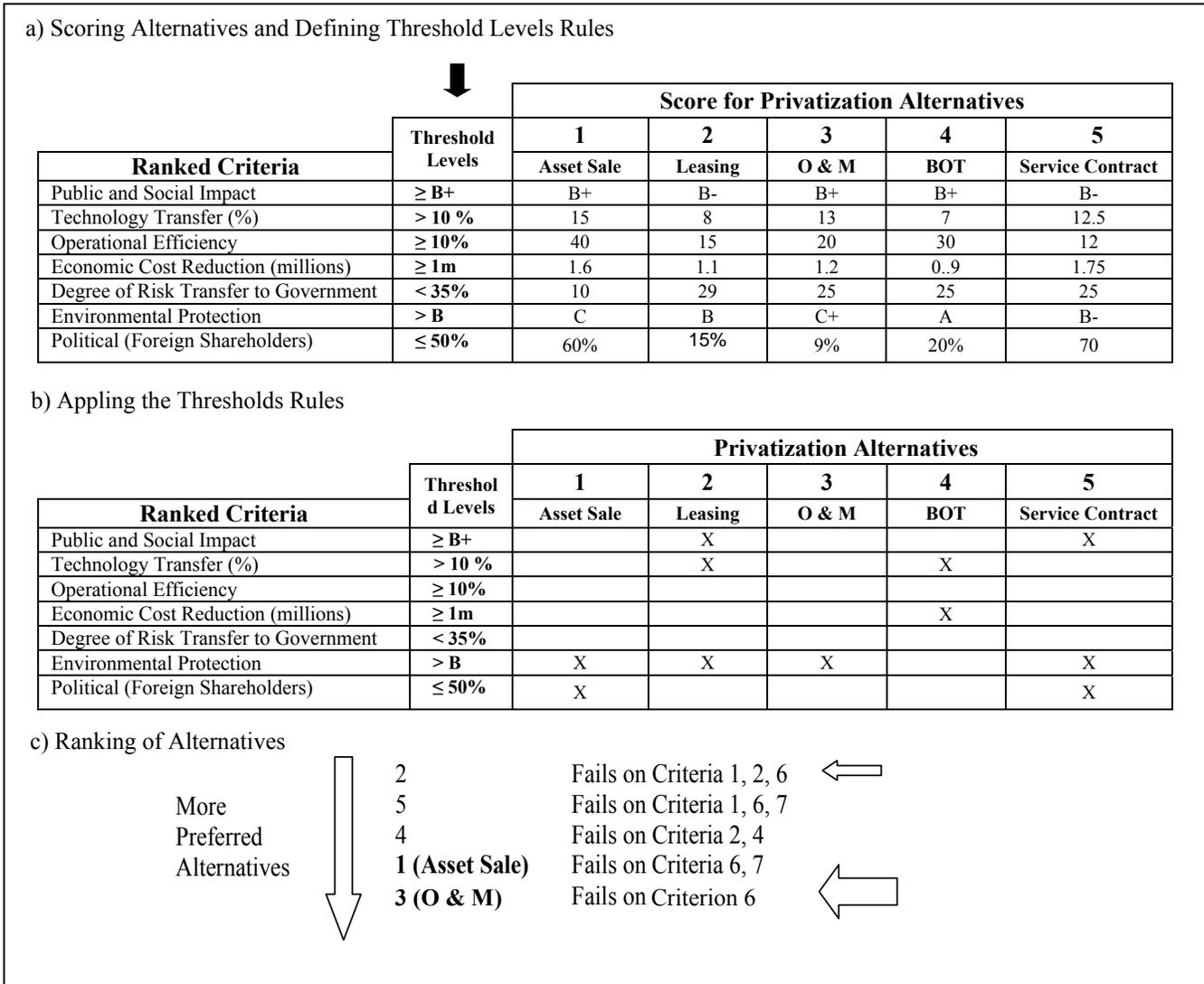


Figure 4.3: Elimination Method Example

As can be seen from this example, the strength of this technique is its simplicity in identifying and eliminating less desirable alternatives. In addition, the user can use richer rules that have combined and/or conditional thresholds. Thus, this technique is utilized in the proposed DSS model as a pre-processor which can be used in the initial stage to eliminate privatization

alternatives that are not meeting specified rules or thresholds and to rank the remaining alternatives.

A tree presentation of the Elimination Method for a particular DM relies on the splitting of any set of alternatives into two subsets so that any alternative in the first subset is preferred to any alternative in the second subset. This splitting process is applied successively to subsets defined by the truth or falsity of the preference statements in sequence, forming a decision tree. If the process continues long enough, a complete ranking is achieved. Whenever a subset of alternatives is to be split (i.e., at each level of the preference decision tree), a preference statement serves as the criterion governing this bifurcation. However, and as shown in the next example, a few preference statements can represent a rather complex tree.

Using sufficiently complex preference statements, any ordering of the alternatives can be represented by the Elimination Method and its corresponding preference statement tree decision. However, some rankings may require many statements. Nevertheless, the Elimination Method proves itself especially useful for large models, in which the DMs' preferences typically fall into regular and consistent patterns. Moreover, experience suggests that it closely reflects the way many people express their preferences about the outcome of a conflict.

The preference tree presentation that corresponds to the set of preference statements given in Figure 4.3 is shown in the upper part of Figure 4.4, and the alternatives are ranked according to the scored values at the bottom of the figure. It should be noted that the figure shows only

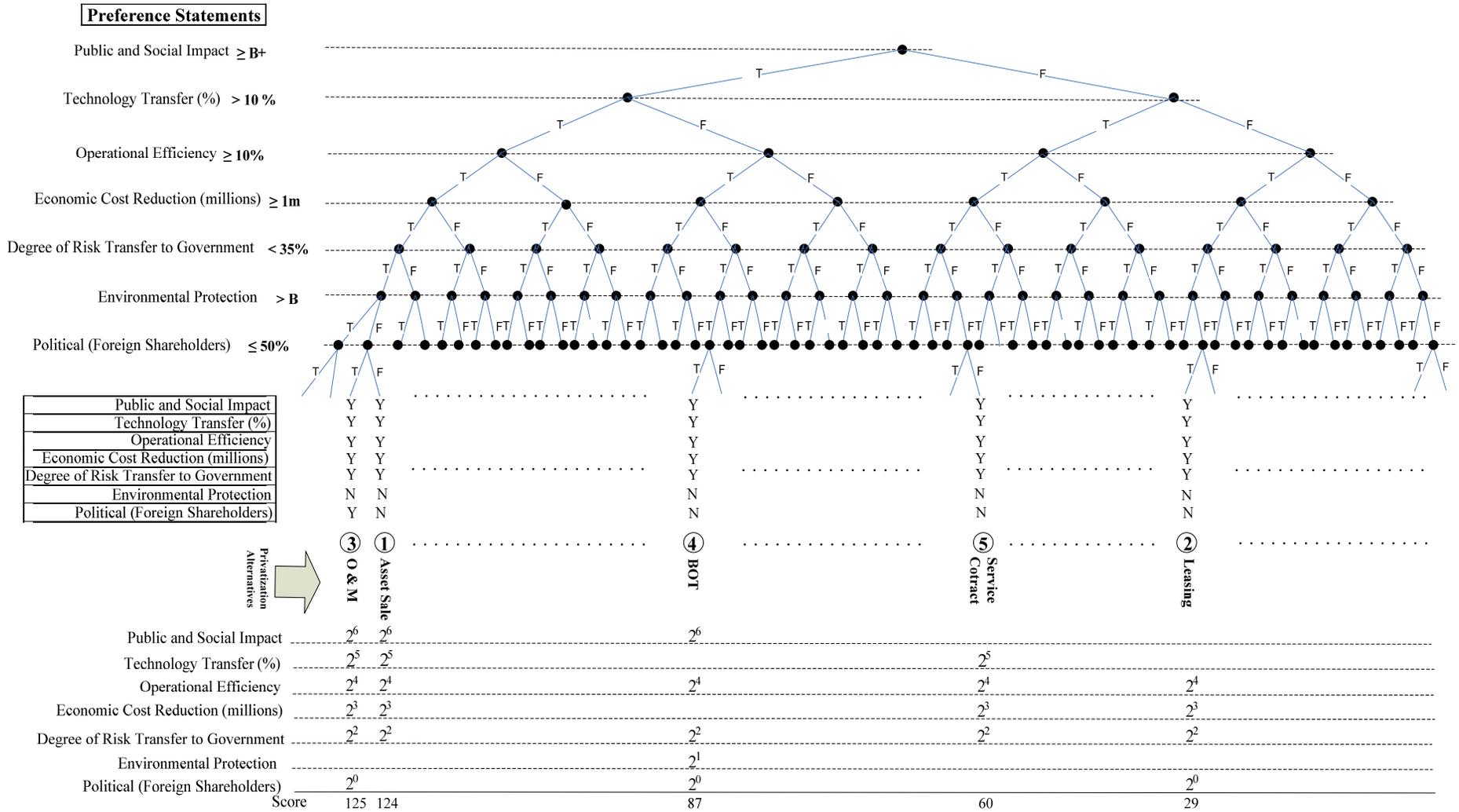


Figure 4.4: The Presentation of Elimination Method and Preference Statements Prioritizing

the leaves that correspond to the alternatives under study. As can be seen in Figure 4.3, the preference statements are a compact representation of a preference tree.

As shown in the example in Figure 4.4, the scores given at the bottom and the preference statement tree at the top list the states from the most preferred on the left to the least preferred on the right. To assign the scores, a methodology is implemented through the assigning of a value of 2^s for each branch, where s takes the value of $S = j-1$, which starts from zero at the lowest level and increases by increments of 1 as one climbs up the branch nodes to reach the upper node with a value of $S = n-1$, where n is the number of preference statements. In the example in Figure 4.4, the lowest branch of the preference statement “Political (Foreign Shareholders) $\leq 50\%$ ” is assigned a score of $2^0 = 1$, and the next level of branch node with the statement “Environmental Protection $> B$ ” is assigned a score of 2^1 . This trend continues until the last upper branch node, which is assigned a score value of $2^{i-1} = 2^{7-1} = 2^6 = 64$.

4.4.2 Extended Elimination Method

After the prescreening using the Elimination Method, a short list of the more preferred alternatives is ready for more detailed analysis, in which more criteria and sub-criteria can be used, and these criteria can be evaluated according to each stakeholder’s viewpoint. To carry out a more detailed study, one could use the Elimination Method or another suitable MCDA method such as the weighting score method (Edwards, 1977); the Analytical Hierarchical Process (AHP) (Saaty, 1980); the Analytical Network Process, (Saaty, 2001) which is an expanded version of the AHP procedure; or Electre (Roy, 1996).

For the example in Figure 4.3, one can argue that the Elimination Method compares alternatives based on their independent performance for each criterion, regardless of how good that alternative is with respect to another important criterion. For example, Alternative 5 in Figure 4.3 does very poorly with respect to foreign ownership but extremely well with regard to cost reduction. Therefore, in some circumstances a lower performance in a less important criterion would be compensated for to some extent by a superior performance against a more important concern. To help overcome this difficulty, logical statements using conjunctive (and), disjunctive (or), and conditional (if; if and only if) connections among criterion thresholds can be employed. The example given in Figure 4.5, which uses the same evaluations as those listed in Figure 4.3a, illustrates how this method is carried out in practice.

The decision maker involved in the evaluation process in the example in Figure 4.3 might argue that the highest importance is that the public and social impact of a privatization decision on the public must be greater than or equal to B-, combined with the parameter that protecting the environment must have a rating of B or better. This most preferred statement with respect to meeting criterion thresholds is listed at the top of the left-hand column in Figure 4.5b. The next level of priority for a performance statement shown on the left in Figure 4.5b is that if the foreign shareholders own 20% or less of the project, then the technical transfer should be greater than or equal to 8%, in order to give more flexibility to local shareholders. Next, the decision maker specifies that if the environmental protection is less than or equal to B-, then the economic cost reduction must be greater than 1.7 million dollars. The lowest ranked preference statement on the left in Figure 4.5b is that operational efficiency must be greater than 15% or the economic cost reduction must be greater than or equal to 1.3 million dollars.

a) Scoring Alternatives and Defining Thresholds (See Figure 4.3a)

b) Applying the Thresholds Rules

Ranked Statements	Privatization Alternatives				
	1	2	3	4	5
	Asset Sale	Leasing	O & M	BOT	Service Contract
Public and Social Impact \geq B- and Environmental Protection \geq B	X		X		X
If Foreign Shareholders \leq 20% then Technical Transfer must be \geq 8%				X	
If Environmental Protection \leq B- then Economic Cost Reduction $>$ 1.7M	X		X		
Operational Efficiency $>$ 15% or Economic Cost Reduction \geq 1.3M		X	X		X

c) Ranking of Alternatives

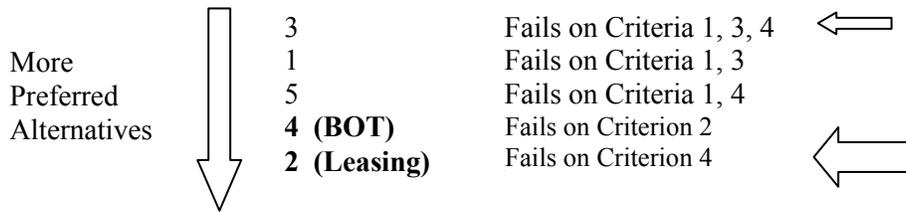


Figure 4.5: Evaluation of Alternatives Using Logical Statements about Thresholds for Criteria

In summary, using logical statements in the Elimination Method requires the following steps:

1. Develop a preference statement by linking preference thresholds for criteria using conjunctive, disjunctive, and conditional logical connections.
2. List these preference statements from most important at the top to least preferred at the bottom.
3. Apply the Elimination Method as previously performed.

Following this procedure, the alternatives are ranked as shown in Figure 4.5c.

When the final ranking of alternatives in Figure 4.5c are compared to the ranking in Figure 4.3c, one can see that the ordering has been substantially changed. For example, leasing (Alternative 2) is the highest ordered alternative in Figure 4.5c and the lowest in Figure 4.3c.

The reason for these changes can be understood through an examination of the performance statements listed on the left in Figure 4.5b. It can be seen, for instance, that “Foreign Shareholders” has been moved from the least preferred criterion on the left in Figure 4.3b to a higher level in Figure 4.5b, where it is part of a conditional preference. An explanation for this move may be that the government is encouraging higher local ownership but may have to support the local owners technologically in order to improve the technical transfer mechanism such as providing subsidies or tax breaks.

It can also be seen that in both situations the BOT (Alternative 4) is ranked fairly high because it does well with respect to the environment even though the technical transfer is low and the cost reduction is the lowest among all of the alternatives. On the other hand, the O & M (Alternative 3) drops from highest (Figure 4.3c) to the lowest position (Figure 4.5c) largely due to its poor environmental record, even though it does well with respect to national investments. Using the same procedure, a new preference decision tree representing extended Elimination Methods can be developed, as shown in Figure 4.6.

The foregoing and other insights that can be gleaned from a comparison of the two analyses clearly show how preferences, as reflected in the ranking of criteria or preference statements, can dramatically affect the final results. Depending on their value systems, different stakeholders would rank their preference statements in different orders and thereby alter the findings accordingly. Hence, conflict must be directly addressed in infrastructure privatization projects.

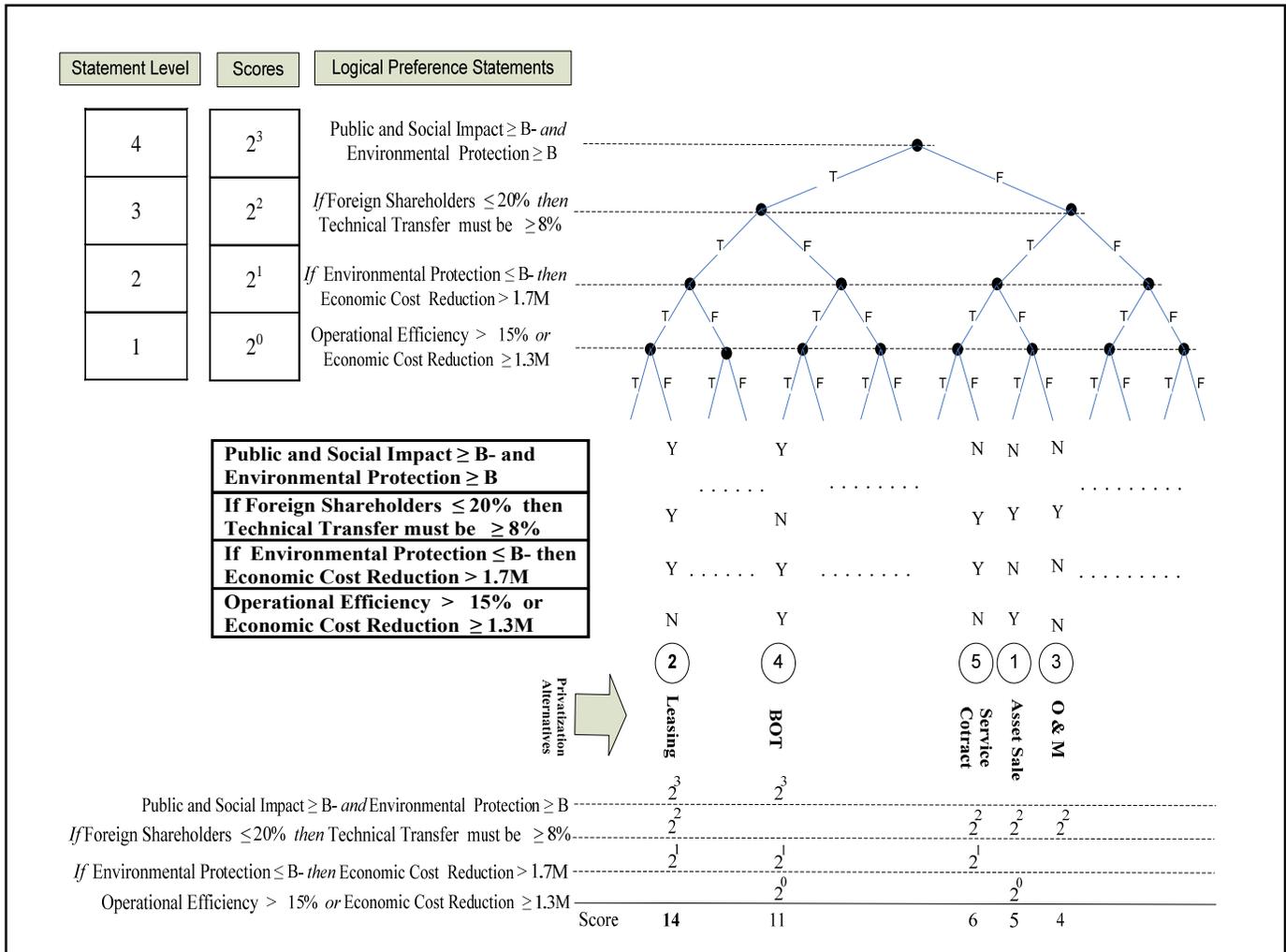


Figure 4.6: The Presentation of Elimination Method and Logical Preference Statements Prioritizing

4.1.1 The Graph Model for Conflict Resolution

The application of the Graph Model for Conflict Resolution to the famous game of Prisoner's Dilemma is employed to explain its capabilities and how it can be conveniently applied in practice to real world disputes, including privatization, constructions, environmental and other kinds of conflicts. The graph model uses mathematical logic and set theory to describe conflict situations in a graphical form (Hipel et al., 2002). Fang et al. (1993) provide background material on the graph model for conflict resolution, while Harary et al. (1969), and Berge (1973) furnish descriptions of Graph theory. The basis of the graph model is found in classical

game theory (von Neumann and Morgenstern, 1953), metagame analysis (Howard, 1971), and conflict analysis (Fraser and Hipel, 1984).

- **Modeling**

Within the graph model paradigm, any conflict involves decision makers (DMs), their options, and their preferences. For simplicity, the Graph Model for Conflict Resolution is explained using the well-known “Prisoner’s Dilemma” dispute. This simple problem has been extensively studied in order to gain insight into human behavior in conflict situations, when one must decide whether or not to cooperate with another person (Rapoport et al., 1976; Axelrod, 1984; Fraser and Hipel, 1984). In this conflict, two individuals suspected of being partners in a crime are arrested and placed in separate cells so that they cannot communicate with one another. The district attorney does not have sufficient evidence to convict them for the crime. Consequently, to obtain a confession, the district attorney presents each suspect with the following offers:

1. If one of them cooperates (C) with his partner (i.e., does not confess) and the other does not cooperate (D) (i.e., confesses), the one who cooperates receives a stiff 10-year sentence while the other can go free for proving that they committed the crime.
2. If both prisoners do not cooperate with each other (i.e., both confess), both receive reduced sentences of 5 years.
3. If both cooperate by keeping silent, each receives a lesser charge of carrying a concealed weapon, leading to one year of incarceration in prison.

Because each decision maker (DM) in the Prisoner’s Dilemma possesses two strategy choices represented by C and D, the four possible states or scenarios that can take place when each

DM selects a strategy are written as CC, CD, DC, and DD, in which the left and right letters in each pair represent the strategy selection of the first prisoner (DM 1) and the second prisoner (DM 2), respectively. A tree representation of the four decision states is shown on the left-hand side in Figure 4.7. From left to right in this figure, DM 1 choices are shown as strategy C or D. For each of these two strategy selections by DM 1, the second DM can also choose either C or D. The final result is the four states listed in four columns as states 1, 2, 3 and 4 or equivalently, as states CC, CD, DC, and DD, respectively.

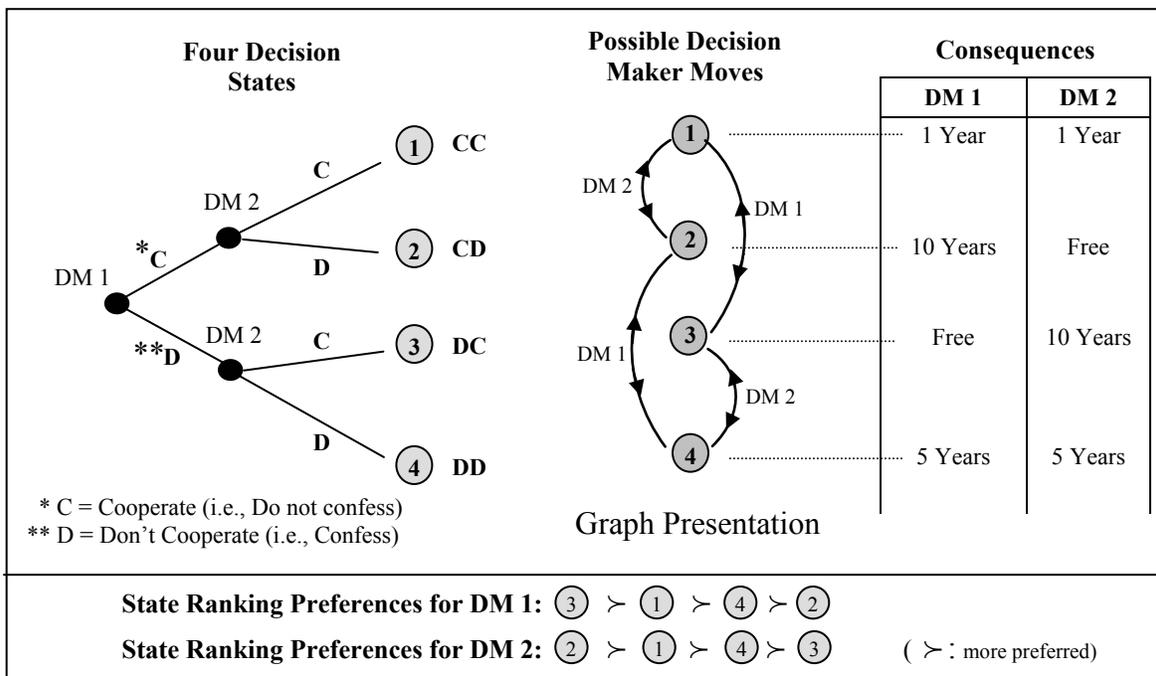


Figure 4.7: Graph Representation of the Prisoners' Dilemma

The modeling and analysis of the Prisoners' Dilemma are explained below in Steps 1 to 3, and in Step 4, respectively.

The manual calculations of the different stability concepts and equilibria for this conflict are as follows:

Step 1: Determine the decision makers and options in the conflict

As mentioned previously, this conflict (game) has two decision makers (DMs); because each DM in the Prisoner's Dilemma possesses two strategy choices, represented by C and D, the four possible states or scenarios that can take place when each DM selects a strategy are written as CC, CD, DC, and DD, for which the left and right letters in each pair represent the strategy selection of the first prisoner (DM 1) and the second prisoner (DM 2), respectively, as shown on the left in Figure 4.7 and at the bottom of Table 4.4.

Table 4.4: List of Decision Makers, Options and Possible States

Decision Makers/Option	States			
	1	2	3	4
Prisoner 1				
Cooperate	Y ^a	Y	N	N
Prisoner 2				
Cooperate	Y	N	Y	N
Normal form notation	(CC)	(CD) ^b	(DC)	(DD)
Payoff function for prisoner 1, P1 = (75, 0, 100, 50) for States 1, 2, 3, and 4, respectively.				
Payoff function for prisoner 2, P2 = (75, 100, 0, 50) for States 1, 2, 3, and 4, respectively.				

(a) Y: Yes, N: No

(b) C: Cooperate, D: Do not cooperate

For example, State 2 has the option of CD, which represents the case of DM 1 cooperating and DM 2 not cooperating.

Step 2: Determine the feasible states

From Table 4.4, the total number of possible states is $2^n = 2^2 = 4$, where n is the number of DMs in the game. There is no infeasible state to remove.

Step 3: Construct the Graph Model for the DMs

The middle portion of Figure 4.7 portrays the integrated graph model for this dispute. The graph model depicts how the conflict could move from one state to another, in which a node represents a state and an arc stands for the DM (written on the arc) who controls the movement from one state to another. Accordingly, four states with node numbers 1, 2, 3, and 4 represent states CC, CD, DC, and DD, as do the four columns (from left to right) of Ys and Ns in the center of Table 4.4, where Y means yes, the option of cooperate is taken, and N indicates no, i.e., is not selected by the DM controlling the option. For instance, for the situation shown in Figure 4.7, DM 1 can cause the conflict to move from state 1 CC to state 3 (DC) by deciding not to cooperate with DM 2 and thereby tell the police what happened. In turn, DM 2 can make the conflict evolve from state 3 (DC) to state 4 (DD) by also choosing not to cooperate.

The movement between states 1 and 3 is unilateral on the part of DM 1 since DM 1 decides whether or not to choose strategy C, given that DM 2 remains at strategy C in both states 1 and 3. Likewise, DM 1 can also unilaterally cause the conflict to progress from state 2 to 4 and back. DM 2, on the other hand, is in command of the movement between states 1 and 2 as well as states 3 and 4, as depicted in the integrated graph model shown in the center of Figure 4.7 in which the orientation of the arc in a DM's graph indicates the direction of the movement that the DM can make.

The preferences of each DM are indicated by the ranking of states from the most preferred on the left to the least preferred on the right, as shown at the bottom of Figure 4.7. Hence, DM 1 most prefers state 3, or DC, in which he does not cooperate with DM 2 while DM 2 cooperates

with him. The least preferred scenario for DM 1 is state 2, which is the reverse of state 3 since at state 2, DM 1 is cooperating while DM 2 is not. It should be noticed that the second most preferred state for each DM is state 1, or CC, in which they both cooperate with one another. Additionally, the cooperative state 1 is more preferred to the non-cooperative state 4, in which both DMs do not cooperate. Hence, compared to state 4, state 1 is a win/win situation for both DMs. The dilemma for each prisoner is which strategy each DM should select independently of the other DM's choice.

An equivalent way of representing a ranking of states is to assign a payoff for each state in which a higher number means more preferred. Hence, as shown at the bottom of Table 4.4 the payoffs for DM 1 for states 1, 2, 3, and 4 are 75, 0, 100, and 50, respectively. The payoff function for DM 2 is also shown here as $P_2 = (75, 100, 0, 50)$.

In general, the Prisoner's Dilemma constitutes a generic conflict which can be used to explain how cooperation can or cannot be brought about in a dispute. For the construction industry and infrastructure management, this dispute has widespread implications for dealings between various decision makers or stakeholders. In reality, real-world conflict is more complicated than the Prisoner's Dilemma as illustrated by the real-life conflicts examined in Chapter 5.

Step 4: Calculate stable states for each decision maker

Once the model is graphically represented, the conflict analysis continues by analyzing, for each DM, the stability of the decision states with respect to the solution concepts noted earlier in Table 2.4, which represent different types of strategic thinking by DMs in conflict situations. The different solution concepts imply different levels of foresight, or a DM's ability

to consider possible moves that can take place in the future. A DM with a high level of foresight thinks further ahead. Nash stability (R) has a low level of foresight, and the level of the foresight increases from low at the top of Table 2.4 to high at the bottom. A DM with Non-myopic stability (NM) has the highest level of foresight.

Some solution concepts, such as limited move (L_h) and nonmyopic (NM), allow strategic disimprovements, which occur when a DM temporarily moves to a worse state in order to reach a more preferred state eventually. Other solution concepts, such as Nash (R) and sequential stability (SEQ), never allow disimprovements. Still others, such as general metarationality (GMR) and symmetric metarationality (SMR), permit strategic disimprovements by opponents only.

Different solution concepts also imply different levels of preference knowledge. Under R, GMR, and SMR, for example, a DM needs to know only his own preferences. On the other hand, under the solution concepts SEQ, L_h , and NM, a DM must know the preference information for all of the DMs. Finally, the top four solution concepts in Table 2.4 are used more commonly in practice and are easier to implement.

In a stability analysis, if a particular decision state is found to be stable for all the DMs with respect to one solution concept (e.g., Nash stability), then this decision state is an “equilibrium” for that concept (e.g., Nash equilibrium). The final solution to the conflict may be the decision state that achieves equilibrium status for most of the solution concepts, since it constitutes a strong equilibrium. The mathematical formulations for the top four solution

concepts in Table 2.4 together with their manual calculations for the Prisoner's Dilemma are given below. The notation used is as follows:

The set of DMs, N , consists of $i, j \in N$,

S is the set of feasible states,

$R_i^+(s)$ is the set of unilateral improvements by DM i from state s ,

$R_j^+(s_j)$ is the set of unilateral improvements by DM j from state s_j .

1. Nash stability

Definition: Nash Stability (Nash, 1951): Let $i \in N$. A state $s \in S$ is Nash stable for DM i , denoted by $s \in S_i^{Nash}$, if and only if $R_i^+(s) = \emptyset$.

Each prisoner or DM will expect that the other prisoner will stay at any state the focal DM will move to, and that state will be the final state.

Examples of Nash stability calculations are as follows:

- DM 2 has unilateral improvement from state 1 to state 2 \Rightarrow state 1 is unstable (u) for DM 2.
- Similarly, DM 1 has unilateral improvement from state 1 to state 3 \Rightarrow state 1 is unstable.
- For state 4: DM 2 has no unilateral improvement to state 3 \Rightarrow state 4 is stable (s) for DM 2.
- Similarly, for state 4, DM 1 has no unilateral improvement to state 2 \Rightarrow state 4 is stable for DM 1.

The overall Nash stable states for each DM are shown in Table 4.5, where s and u mean stable and unstable, respectively. A state which is stable for both DMs is an equilibrium and is indicated by an E in Table 4.5.

Table 4.5: Nash Stability Analysis results

State	Stability		Equilibrium
	DM 1	DM 2	
1	u	u	
2	u	s	
3	s	u	
4	s	s	E

As shown in Table 4.5, since state 4 is stable for both DMs, it represents an equilibrium (E).

2. General Metarationality

Definition: General Metarationality (GMR) (Howard, 1971): For $i \in N$, a state $s \in S$ is general metarational for DM i , denoted by $s \in S_i^{GMR}$, if and only if for every $s_1 \in R_i^+(s)$, there exists at least one $s_2 \in R_j(s_1)$ such that $s \succ_i s_2$.

Each DM will judge his possible moves very conservatively by considering all possible moves by his opponent. The focal DM will ignore his own possible counteractions.

Examples of GMR stability calculations are as follows:

- DM 1 has unilateral improvement from state 1 to state 3, but DM 2 can move from state 3 to state 4. A comparison of state 4 with state 1 reveals that the preference (payoff) for DM 1 at state 4 is less than the preference (payoff) at state 1: \Rightarrow state 1 is GMR stable for DM 1.

- DM 2 has unilateral improvement from state 1 to state 2, but DM 1 moves from state 2 to state 4. A comparison of state 4 with state 1 reveals that the preference for DM 2 at state 4 is less than the preference at state 1: \Rightarrow state 1 is GMR stable for DM 2.

- State 4 is Nash stable for both DMs \Rightarrow GMR stable.

Using the same procedure for examining states 2 and 3 results in the finding shown in Table 4.6.

Table 4.6: GMR Stability Analysis Results

State	Stability		Equilibrium
	DM 1	DM 2	
1	s	s	E
2	u	s	
3	s	u	
4	s	s	E

As shown in Table 4.6, since states 1 and 4 are stable for both DMs, both states represent an equilibrium (E).

3. Symmetric Metarationality (SMR)

Definition: *Symmetric Metarationality (SMR)* (Howard, 1971): For $i \in N$, a state is symmetric metarational for DM i , denoted by $s \in S_i^{SMR}$, if and only if for every $s_1 \in R_i^+(s)$, there exists $s_2 \in R_j(s_1)$ such that $s \succ_i s_2$ and $s \succ_i s_3$ for all $s_3 \in R_i(s_2)$.

A DM who is symmetrically metarational considers not only his own possible moves and the reaction of his opponent to each move, but also his own counter-reactions.

Examples of an SMR stability analysis are as follows:

- DM 1 has a unilateral improvement from state 1 to state 3, from which DM 2 can react by moving from state 3 to state 4, and in a counter-reaction, DM 1 can move from state 4 to state 2. A comparison of state 1 with final state 2 shows that the preference for DM 1 at state 1 is more than the preference at state 2 \Rightarrow state 1 is SMR stable for DM 2.

- Similarly, DM 2 has a unilateral improvement from state 1 to state 2. DM 1 can react by moving from state 2 to state 4, and DM 2 can counter-react by moving from state 4 to state 3.

A comparison of the initial state 1 with the last state 3 reveals that the preference for DM 2 at state 1 is more than the preference at state 3: \Rightarrow state 1 is SMR stable for DM 2.

- State 4 is Nash stable for both DMs \Rightarrow SMR stable for each DM.

Using the same procedure for states 2 and 3 yields the results shown in Table 4.7. As shown in Table 4.6, states 1 and 4 are in equilibrium (E) for both DMs.

Table 4.7: SMR Stability Analysis Results

State	Stability		Equilibrium
	DM 1	DM 2	
1	s	s	E
2	u	s	
3	s	u	
4	s	s	E

4. Sequential stability

Definition: Sequential Stability (SEQ) (Fraser and Hipel, 1984): For $i \in N$, a state is sequentially stable for DM i , denoted by $s \in S_i^{SEQ}$, if and only if for every $s_1 \in R_i^+(s)$, there exists at least one $s_2 \in R_j^{+,U}(s_1)$ such that $s \succ_i s_2$.

A state is sequentially stable for a DM if and only if he is deterred from acquiring any unilateral improvement from this state because of a credible sanction by the opponent that

could result in a state less preferred (for the original DM) than the initial state. A rational state is actually a subset of the sequential stability definition for the special situation in which the set $S_i^+(k)$ is empty. In other words, this stability concept is similar to the GMR concept with the exception that any move by the second DM should be credible and hence be a unilateral improvement (UI) in his preference (payoff).

Examples of SEQ stability calculations are as follows:

- DM 1 has a UI from state 1 to state 3, but DM 2 has a credible action (UI) from state 3 to state 4. An examination of the preference for DM 1 reveals that the preference at state 4 is less than the preference at state 1: \Rightarrow state 1 is SEQ stable for DM 1.

- DM 2 has UI from state 1 to state 2, but DM 1 has credible action (UI) from state 2 to state 4. An examination of the preference for DM 2 reveals that the preference for state 4 is less than the preference for state 1: \Rightarrow state 1 is SEQ stable for DM 2.

Using the same procedure for states 2, 3 and 4 will result the finding given in Table 4.8. The table shows that states 1 and 4 are sequentially stable for both DMs, which means that both states 1 and 4 are in equilibrium.

Table 4.8: SEQ Stability Analysis Results

State	Stability		Equilibrium
	DM 1	DM 2	
1	s	s	E
2	u	s	
3	s	u	
4	s	s	E

From Tables 4.5 to 4.8, it can be seen that only states 1 and 4 are possible equilibria, or compromise resolutions. Hence, each of these states represents a compromise resolution if the state can be reached. To achieve state 1 (CC), the cooperative equilibrium, both DMs must cooperate with one another to jointly cause the conflict to move from state 4 (DD) to state 1 (CC), which is more preferred by both of them

To confirm the manual calculations, the results were compared with those of the software GMCR II (Hipel et al., 1997; Fang et al., 2003a, b) that produced the exact same results for the Prisoner's Dilemma, as shown in Figure 4.8. While GMCR II is useful software, it is not transparent and cannot be easily integrated with external models. Therefore, in this research, a Graph Model is implemented on Excel as a more flexible environment, as explained in the next section.

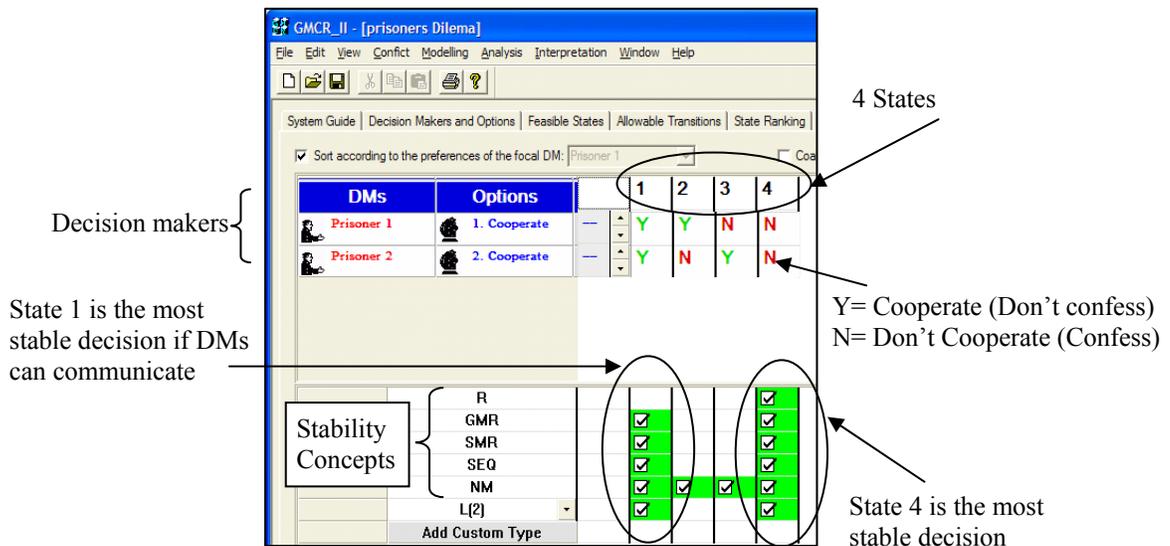


Figure 4.8: GMCR II Stability Analysis and Equilibrium

4.4.4 Experimenting with Decision Optimization Using Genetic Algorithms

The privatization problem is now structured as a graph model in which decisions are optimized using Genetic Algorithms (GAs) (Figure 4.9). The key challenge is to model a decision-analysis problem on a transparent spreadsheet program that will incorporate all graph model formulations.

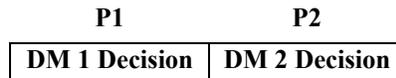


Figure 4.9: Chromosome Structure of the Prisoner’s Dilemma

For the Prisoner’s Dilemma, as noted earlier and shown in Figure 4.10, P_1 and P_2 are the payoffs for DMs 1 and 2, respectively. In a payoff function, the location, (reading from left to right), denotes the state being considered. The number written at that location gives the ordinal preference (or payoff), where a higher number means more preferred. For example, the most preferred state for DM 2 is the second state (CD), since number 100 is written at the second position. Likewise, the least preferred state is the third state (DC), because a number 0 is shown at the third entry in the P_2 payoff function.

<div style="display: flex; justify-content: space-around; margin-bottom: 5px;"> 1 2 3 4 States (Table 4.4) </div> <div style="display: flex; justify-content: space-between; padding: 5px;"> <div style="width: 60%;"> <p>[Payoff function for DM 1, $P_1 = (75, 0, 100, 50)$]</p> <p>[Payoff function for DM 2, $P_2 = (75, 100, 0, 50)$]</p> </div> </div> <hr style="border: 0.5px solid black;"/> <div style="display: flex; justify-content: space-between; padding: 5px;"> <div style="width: 60%;"> <p>States ranking for DM 1, $P_1 = (3, 1, 4, 2)$</p> <p>States ranking for DM 2, $P_2 = (2, 1, 4, 3)$</p> </div> </div>

Figure 4.10: Preferences (Payoffs) for Decision Makers in Prisoner’s Dilemma

Using this information, the Prisoner’s Dilemma was modeled on Excel as shown in Figure 4.11. The two parties, DMs 1 and 2, are listed with their alternative decisions, [P1-01, P1-02] and [P2-01, P2-02], respectively. Spreadsheet equations were written to model all aspects,

Variable with possible values:
 1 Cooperate (Don't Confess)
 2 Don't Cooperate (Confess)

Sum of all decision payoffs

Variable with possible values:
 1 Cooperate (Don't Confess)
 2 Don't Cooperate (Confess)

Equations are set up for all stability calculations based on the Graph Model

	A	B	C	D	E	F	G	H	I	J
1	Conflict Resolution									
2						Objective:	400	maximize		
3										
4										
5	Two participated in a crime. During interrogation, if one cooperates and the other does not, he is free and the other receives ten years.									
6	If both cooperate, each receives five years. If no one cooperates, each receives one year.									
7										
8	Party 1: Prisoner1					Party 2: Prisoner2				
9		P1-O1	P1-O2	P1-Decision	Payoff		P2-O1	P2-O2	P2-Decision	Payoff
10	Option:	Cooperate	Don't-Cooperate	2	100	Option:	Cooperate	Don't-Cooperate	1	0
11	Preference:	75	100	Don't-Cooperate		Preference:	0	50	Cooperate	
12		P1-O1	P1-O2	P1-Decision	Payoff		P2-O1	P2-O2	P2-Decision	Payoff
13		Cooperate	Don't-Cooperate	1	0		Cooperate	Don't-Cooperate	2	100
14		0	50	Cooperate			75	100	Don't-Cooperate	
15										
16										
17	Methods	Position			Player 1	Payoff	Player 2	Payoff	Equilibrium	Bonus
18	Nash	Don't-Cooperate , Cooperate (2 , 1)			Stable	100	Unstable	0	No Equilibrium	0
19	GMR	Don't-Cooperate , Cooperate (2 , 1)			Stable	100	Unstable	0	No Equilibrium	0
20	SMR	Don't-Cooperate , Cooperate (2 , 1)			Stable	100	Unstable	0	No Equilibrium	0
21	SEQ	Don't-Cooperate , Cooperate (2 , 1)			Stable	100	Unstable	0	No Equilibrium	0
22										
23										
24	Nash Stable (R)	a state is Nash stable for a player P1 if there is no unilateral improvement to that player to move away from it.								
25	GMR Stable	a state is GMR stable for a player P1 if there is at least one move from player P2 to a new state that will result in lower preference to player P1								
26	SMR Stable	a state is SMR stable for player P1 in which he or she considers not only his own possible moves and the reaction of his opponent to each move,								
27		but also his own counter-reactions								
28	Sequential Stability	a state is SEQ stable for a player P1 if there is at least one improve movement from player P2 to a new state that will result in lower preference to player P1								

Figure 4.11: DSS Model for the Prisoner's Dilemma Conflict

Equation to determine payoff as a function of the decision

including the calculation of the payoff values and the calculation of the stability condition (following the solution concepts).

The preferences for every decision were modeled in the spreadsheet equations as follows:

The payoff or preferences for DM 1 = (75, 0, 100, 50), and for DM 2, the preference (payoff) = (75, 100, 0, 50), as shown in Table 4.4. For example, in Figure 4.11, cells D-10 and I-10 show a current state of decision in which prisoner 2 cooperates (does not confess) while prisoner 1 does not cooperate (confesses), which is represented by state DC (state 3 in Table 4.4). Accordingly, the shaded cells next to these decisions show the preference values.

As an improvement to the graph model implementation on Excel, the decision-analysis problem is considered here for the first time as an optimization problem. The objective function, variables, and constraints are as shown in Table 4.9.

Table 4.9: Optimization Parameters for the Prisoner’s Dilemma

Parameter	Description	Formulation
Objective Function	Maximize the total payoff for a DM	Cell F-2 to be maximized
Variables	The values representing the decision to [1]: Cooperate (do not confess), or [2]: Do not cooperate (confess).	Cells [D-10 and I-10]
Constraints	1) Variables are integers 2) Variable values are $1 \geq$ and ≤ 2	[INT] $1 \leq$ Cells [D-10 and I-10] ≥ 2

Mathematically, the Prisoner’s Dilemma can be formulated as follows:

Variables:

Decision of DM 1 (P1): choose either (1: Cooperate or 2: Do not cooperate)

Decision of DM 2 (P2): choose either (1: Cooperate or 2: Do not cooperate)

Objective Function:

The objective function is to maximize the overall payoffs for all decision makers, which is formulated mathematically as follows:

$$(\text{Objective Function}) = \text{Max} \sum_{n=1}^n (P_1 + P_2) + P_{\text{Nash}} + P_{\text{GMR}} + P_{\text{SMR}} + P_{\text{SEQ}}, \text{ Where}$$

n is the number of feasible states.

P_1 is the payoff for decision maker 1,

P_2 is the payoff for decision maker 2,

P_{Nash} is the bounce payoff for a decision satisfying Nash stability = 1000 points,

P_{GMR} is the bounce payoff for a decision satisfying GMR stability = 1000 points,

P_{SMR} is the bounce payoff for a decision satisfying SMR stability = 1000 points, and

P_{SEQ} is the bounce payoff for a decision satisfying SEQ stability = 1000 points.

The objective function is linked to the variables X1 and X2 as follows:

If $X_1 = 1$ and $X_2 = 1$, then the payoff is $P_i = 75$ for P1 and $P_j = 75$ for P2;

$X_1 = 1$ and $X_2 = 2$, then the payoff is $P_i = 0$ for P1 and $P_j = 100$ for P2;

$X_1 = 2$ and $X_2 = 1$, then the payoff is $P_i = 100$ for P1 and $P_j = 0$ for P2;

$X_1 = 2$ and $X_2 = 2$, then the payoff is $P_i = 50$ for P1 and $P_j = 50$ for P2.

Constraints:

The optimization constraints are included in the formulation as follows:

X_1 is an integer and takes values $1 \geq X_1 \leq 2$.

X_1 is an integer and takes values between $1 \leq X_2 \leq 2$.

For the non-linearity of the Prisoner's Dilemma problem, the Genetic Algorithms (Gas) technique is used since many types of mathematical optimizations are suitable. To simplify the genetic optimization, a commercial genetic-based optimization software "Evolver v.4.02" is used. Evolver is a spreadsheet add-in program and works from inside Microsoft Excel software. Evolver has a simple interface (Figure 4.12) to allow the user to easily specify the objective functions, variables, and constraints by highlighting the corresponding spreadsheet cells. During the optimization process, Evolver tries first to find a feasible solution (a solution that satisfies all the constraints) and then to improve this solution until an optimum one is achieved.

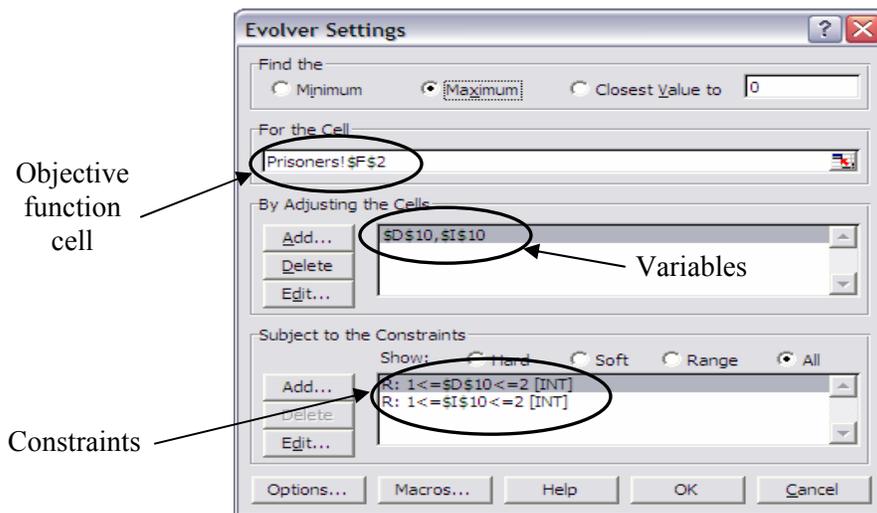


Figure 4.12: Evolver Optimization Screen

For this study, once the optimization parameters are specified, all variables are initialized by the setting of the initial values that represent any conflict state, and the optimization experiments are carried out for each example. Each experiment is run until a cancellation

criterion is met. This criterion is set to a population size of 50 with 1000 trials or with a running time of 5 minutes, as shown in Figure 4.13.

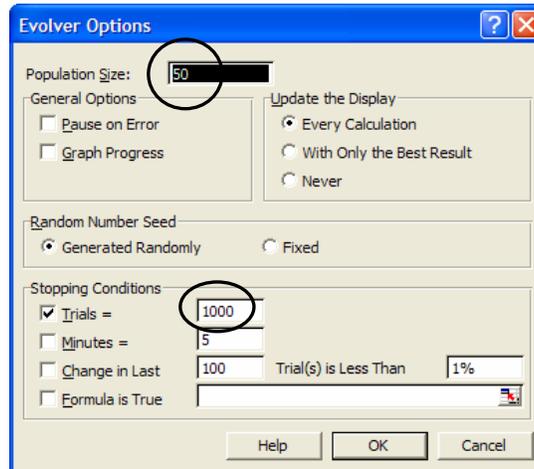


Figure 4.13: Evolver Parameters

The Genetic Algorithm optimization tool (Evolver) will change the values representing the options for each simulation run within the predefined constraints and without violating other constraints until it finds an option with a combination of values that yields the best value for the selected objective function. This best decision is the result of calculations based on the stability concepts of Nash, GMR, SMR, and SEQ stability. The final best decision will be a decision that satisfies the maximum payoffs for both prisoners (DMs) without any bias. In the privatization problem, a criteria weight will adjust this bias to reflect variations in its importance. By the end of the optimization process, an output screen presents the final decision, as shown in Figure 4.14. It should be noted that the proposed model interacts with the preference payoff vectors based on the ordinal ranking of its values, and not on cardinal values.

Objective Function

	A	B	C	D	E	F	G	H	I	J	
1	Conflict Resolution										
2					Objective:	4400	maximize				
3											
4											
5	Two participated in a crime. During interrogation, if one cooperates and the other does not, he is free and the other receives ten years.										
6	If both cooperate, each receives five years. If no one cooperates, each receives one year.										
7											
8		Party 1: Prisoner1						Party 2: Prisoner2			
9		P1-O1	P1-O2	P1-Decision	Payoff			P2-O1	P2-O2	P2-Decision	Payoff
10	Option:	Cooperate	Don't-Cooperate	2	50			Cooperate	Don't-Cooperate	2	50
11	Preference:	0	50	Don't-Cooperate				0	50	Don't-Cooperate	
12											
13		P1-O1	P1-O2	P1-Decision	Payoff			P2-O1	P2-O2	P2-Decision	Payoff
14		Cooperate	Don't-Cooperate	1	75			Cooperate	Don't-Cooperate	1	75
15		75	100	Cooperate				75	100	Cooperate	
16											
17	Methods	Position			Player 1	Payoff	Player 2	Payoff	Equilibrium		Bonus
18	Nash	Don't-Cooperate , Don't-Cooperate (2 , 2)			Stable	50	Stable	50	Equilibrium		1000
19	GMR	Don't-Cooperate , Don't-Cooperate (2 , 2)			Stable	50	Stable	50	Equilibrium		1000
20	SMR	Don't-Cooperate , Don't-Cooperate (2 , 2)			Stable	50	Stable	50	Equilibrium		1000
21	SEQ	Don't-Cooperate , Don't-Cooperate (2 , 2)			Stable	50	Stable	50	Equilibrium		1000
22											
23											
24	Nash Stable (R)	a state is Nash stable for a player P1 if there is no unilateral improvement to that player to move away from it.									
25	GMR Stable	a state is GMR stable for a player P1 if there is at least one move from player P2 to a new state that will result in lower preference to player P1									
26	SMR Stable	a state is SMR stable for player P1 in which he or she considers not only his own possible moves and the reaction of his opponent to each move,									
27		but also his own counter-reactions									
28	Sequential Stability	a state is SEQ stable for a player P1 if there is at least one improve movement from player P2 to a new state that will result in lower preference to player P1.									

Using the GA optimization model, the best option combination is found to be (2, 2), which corresponds to the decision of not cooperating by the two DMs. The resulting decision matches exactly the results obtained by the manual calculation and by GMCR II, as shown previously in Tables 4.5 to 4.8 and in Figure 4.8.

The experimental results for the Prisoner's Dilemma example show that GAs, when applied to a Graph Model of the privatization problem, are very promising. In addition, the number of DMs and alternatives can be increased to cover all stakeholders and criteria, each with its relative strength represented by its weight. The GA also considers the concept of Info-gap theory. It is important to note that while the Prisoner's Dilemma problem is simple, and it requires careful effort for it to be modeled on Excel. The privatization problem is more complex and requires a more extensive modeling effort. The model created for this study offers much-needed decision support that uses optimization to arrive at the best decision.

4.4.5 Uncertainty: Information Gap Theory

Due to the complex nature of the privatization decision and the difficulties associated with covering all related circumstances, the concept of Information Gap Theory or Info-gap theory, as described in Chapter 2, is utilized to solve the problems of missing or insufficient information about stakeholders' preferences in the decision-making process.

- ***Experimenting with Prisoner's Dilemma***

In this section, an experiment is performed using the Prisoner's Dilemma, which is explained in previous sections. The purpose of the experiment is to demonstrate the advantages of extending the concepts of Info-gap theory to the proposed DSS model. Such enhancement will allow the DMs in the construction conflict and infrastructure privatization decision-making process to analyze uncertainty in the preferences of the various DMs involved. The experiment illustrates how the concepts from info-gap modeling and robustness can be utilized a privatization decision and how strategic insights can be gained through a careful examination of the robustness of equilibrium solutions to uncertainty.

1. The Info-gap uncertainty model

The information gap uncertainty model was built as follows:

Let:

$P_1^0 = (0, 0, 100, 0)$ is the nominal payoff function of DM 1;

$P_2 = (75, 100, 0, 50)$ is the payoff function for DM 2;

α is the uncertainty parameter which represents the "distance" from the nominal payoff function;

$P_1^0(\alpha_0^\alpha)$ is the payoff function of DM 1, which differs from the nominal vector by not more than a single preference change;

Q is the the set of equilibrium states for the conflict;

Q1 is the constrained subset of equilibrium states which are conditioned by the option "Yes" or "No";

then the information-gap uncertainty model can be defined as

$$Q(\alpha, P_1^0) = \bigcup_0^\alpha P_1^0(\alpha) \quad \alpha = 0, 1, 2, \dots \quad (4.1)$$

where $Q(\alpha, P_1^0)$ is the set of all payoff functions of DM 1, which differ from the known nominal payoff function by no more than a change in rank.

The collection of sets $Q(\alpha, P_1^0)$, $\alpha = 0, 1, 2, \dots$, is a family of nested sets

$$\alpha < \beta \text{ implies that } Q(\alpha, P_1^0) \subset Q(\beta, P_1^0) \quad (4.2)$$

It can be seen that $Q(\alpha, P_1^0)$ is the set of payoff functions whose distance from the nominal payoff function P_1^0 is no more than α :

$$Q(\alpha, P_1^0) = \{P_1^0(\alpha) : \text{dis}(P_1^0(\alpha), P_1^0) \leq \alpha\} \quad \alpha = 0, 1, 2, \dots \quad (4.3)$$

$Q(\alpha, P_1^0)$ is defined for any non-negative integer α , indicating that it is a family of nested sets. It is this nesting, together with the distance measure, which gives the uncertainty parameter α its meaning as an information gap.

2. The robustness of strategy in the conflict

In the next step, the robustness measure illustrates the powerful approach of information gap theory in helping DMs who might be reluctant to choose the best satisficing decision. This approach is utilized in the proposed DSS to overcome the situation of scarce information that is crucial to finding the most satisficing decision.

The established uncertainty model is used to measure the robustness of the strategy of DM 2 in the presence of missing or insufficient information regarding his or her opponent's preferences and strategy. This measurement can be achieved by performing a stability analysis to determine all stable and equilibrium states which are contained in the equilibrium set Q . Next, a segregation procedure is used to classify $\{Q\}$ sets based on the focal DM's strategy of his available options of "Yes" or "No". Accordingly, a new equilibrium subset $\{Q_1\}$ is constrained by elements entailed in the implementation of option or strategy $\sigma = \text{"Yes"}$ or "No".

The robustness γ of strategy $\sigma = \text{"Yes"}$ or "No" is the greatest number of occurrences of the constrained equilibrium subsets $\{Q_1\}$ which are associated with that strategy. The robustness is represented by the following equations:

$$\gamma (\sigma) = \max \{Q_1 (P_2) \mid \sigma = \text{Yes}\} \quad \text{for the Yes option} \quad (4.4)$$

$$\gamma (\sigma) = \max \{Q_1 (P_2) \mid \sigma = \text{No}\} \quad \text{for the No Option} \quad (4.5)$$

The best strategy or decision is the one that has the maximum number for robustness.

3. Experiments

As can be seen in Figure 4.7, when the first DM remains fixed on choosing C for his strategy, the second DM can unilaterally cause the game to move from state 1 to 2 by changing his selected option from C to D. If DM 2 is allowed to change his decision from D back to C, he or she also controls the movement from state 2 to 1. In addition, when the first DM has fixed his or her strategy on D, the second DM can also control the movement between states 3 and 4. Following the same arguments, DM 1 controls the unilateral movements between States 1

and 3 and between states 2 and 4, if the second DM has fixed his or her strategy on C and on D, respectively.

As Figure 4.7 shows, the payoff function for the second DM is $P_2 = (75, 100, 0, 50)$, which indicates that the greatest preference for him or her is for state 2 (DC), in which he or she receives the freedom sentence for not cooperating, and the first prisoner cooperates by not confessing). The next preference is for state 1 (CC), in which both DMs cooperate (by not confessing, and hence, both receive a one-year jail sentence. The third preference is for state 4 (DD) in which both receive a five-year jail sentence, and the least preferred state is state 3 (DC), in which he or she cooperates (does not confess) and DM 1 does not. This state represents the worst scenario for DM 2, in which a ten-year jail sentence will be imposed on him and the other DM will be set free. Using the same reasonable preference thinking, the payoff function for the second DM is $P_1 = (75, 0, 100, 50)$.

In choosing his best option, let us assume that the only state DM 2 is completely certain about with respect to his opponent is that his opponent's highest preferred state is state 3, in which he or she will receive the ultimate payoff by gaining his or her freedom and letting the first DM stay for 10 years in prison. In other words, the first DM's payoff function is $P_1^0 = (0, 0, 100, 0)$, in which DM 1 is indifferent to any other outcome.

As noted previously, there are many definitions of stability and equilibria in games. With respect to Nash stability as defined before, a state is Nash stable for a given DM if he or she has no incentive for moving from that state. That is, state m is Nash stable for DM i if i 's preference for state m is no less than his preference for any other accessible state for the fixed

strategy choices of the other DMs. State m is stable for DM i if $P_{m,i} \geq P_{k,i}$ for all states k in which the strategy choices of the other DMs are the same as in state m . It should be recalled that a state is in equilibrium if it is stable for both DMs. Table 4.10 shows the stable and equilibrium states for the Prisoner's Dilemma problem, with the payoff functions that have been adopted. It can be seen that the two states 2 and 4 are in equilibrium, since according to the specified payoff functions and the Nash stability definition, neither DM has an incentive to move from either of these states.

Table 4.10: Nash Stability Analysis and Equilibria with a Payoffs Function of $P_2 = (75, 100, 0, 50)$. $P_1^0 = (0, 0, 100, 0)$

State	Stability		Equilibrium
	DM 2	DM 1	
1	u	u	
2	s	s	E
3	u	s	
4	s	s	E

State 4, for example, is Nash stable for prisoner 2 because he or she prefers state 4 more than state 3, and from state 4 he or she can move only to state 3. It should be noted that for both states 3 and 4, the first prisoner has a fixed strategy of D to not cooperate (by confessing). From prisoner 1's point of view, state 4 is Nash stable for him because he prefers state 4 over state 2, whereas prisoner 2 has a fixed strategy of D for do not confess. Since state 4 is Nash stable for both DMs, it constitutes a Nash equilibrium.

The analysis of uncertainty can now be considered by employing the robustness of Equation (4.1) and adopting the perspective of prisoner 2. The payoff function for prisoner 2 is $P_2 = (75, 100, 0, 50)$. His knowledge of prisoner 1's preferences is uncertain. However, he is certain about the nominal payoff function of his opponent, prisoner 1, of $P_1^0 = (0, 0, 100, 0)$. Based

on the nominal payoff function of prisoner 2, it is found that the set (Q) of equilibrium states contains states 2 and 4 as shown in Table 4.11.

$$Q(P_2, P_1^0) = \{2, 4\} \tag{4.6}$$

Accordingly, the set of equilibrium solutions constrained to entail option “No” by prisoner 2 is the subset of $Q_1(P_2, P_1^0)$ that contains states 2 and 4:

$$Q_1(P_2, P_1^0) \mid \sigma = \text{No} = \{2, 4\} \tag{4.7}$$

Likewise, the set of equilibrium solutions constrained to entail option “Yes” by prisoner 2 is the subset of $Q_1(P_2, P_1^0)$, which is an empty set ϕ :

$$Q_1(P_2, P_1^0) \mid \sigma = \text{Yes} = \{\phi\} \tag{4.8}$$

In a similar fashion, the collection of all equilibrium sets can be constructed for all the payoff functions of prisoner 1, as the level of uncertainty increases. These results are shown in Table 4.11.

Table 4.11: Equilibrium Sets with Increasing Uncertainty with the Payoff Functions of $P_2 = (75, 100, 0, 50)$ and $P_1^0 = (0, 0, 100, 0)$

Level of Uncertainty (σ) $P_1^0 = (\text{Payoff functions})^1$	Equilibrium Sets $Q(P_2, P_1^0)$	Constrained Equilibrium with Yes Option for DM 1 $Q_1(P_2, P_1^0) \mid \sigma = \text{No}$	Constrained Equilibrium with No Option for DM 1 $Q_1(P_2, P_1^0) \mid \sigma = \text{Yes}$
(0) $P_1^0 = (0, 0, 100, 0)$	{2, 4}	{2, 4}	ϕ
(1) $P_1^0 = (50, 0, 100, 0)$	{2, 4}, {2}, {4}	{2, 4}	ϕ
(2) $P_1^0 = (50, 0, 100, 50)$	{2, 4}, {2}, {4}	{2, 4}	ϕ
(3) $P_1^0 = (50, 50, 100, 50)$	{2, 4}, {2}, {4}	{2, 4}	ϕ

1. Ben-Haim and Hipel (2002) explain the procedure for obtaining payoff functions of various levels P_1^0 .

Table 4.11 shows that, when $\sigma = 1$, implying uncertainty of no more than one step away from P_1^0 , more than a single equilibrium solution set exists: the previous set as well as the new singular sets of states $\{2\}$ and $\{4\}$.

Next, and in order to determine the robustness of prisoner 2's decision, a classification for the equilibrium states is performed based on the possible options available for him or her. These constrained subsets are used to measure the robustness of his or her decision. Thus, the constrained solution set for option $\sigma = \text{"No"}$ contains states 2 and 4. However, for the option $\sigma = \text{"Yes"}$, the constrained set is empty, implying that the desired option does not lead to an equilibrium with a payoff function for prisoner 1 at an uncertainty level of $\sigma = 1$. This situation also recurs at uncertainty levels $\sigma = 2$ and $\sigma = 3$, as shown in Table 4.11.

From Table 4.11, it can be seen that if prisoner 2 chooses option $\sigma = \text{"No"}$ (not cooperating) by choosing to confess, then he will always reach an equilibrium for any payoff function of his opponent, prisoner 1 (up to and including an uncertainty level of $\sigma = 3$). Additional experiments for uncertainty levels beyond $\sigma = 3$ may lead to an equilibrium set if the first prisoner chooses the option "Yes" (cooperate) and does not confess. In short, the conclusion that can be made from the results shown in Table 4.11 is that the conditional robustness γ for the two options available to Prisoner 2 is

$$\gamma = Q1 (P_2) \mid \sigma = \text{No} = 3 \quad (4.9)$$

$$\gamma = Q1 (P_2) \mid \sigma = \text{Yes} = 0 \quad (4.10)$$

these values show that, option “No” is much more robust than option “Yes”, with respect to prisoner 2’s uncertainty about his opponent’s preferences. In other words, it is better for prisoner 2 not to cooperate with his partner, and hence, choose to confess.

In this research, the proposed DSS model is extended to incorporate the concepts of Info-gap theory, in order to allow consideration of the strategic consequences of uncertainty that may be present in the preferences of one or more DMs involved in a conflict. As illustrated by the Prisoners’ Dilemma problem, the uncertainty analysis concept of the Info-gap model possesses a rigorous axiomatic basis and can be readily applied in infrastructure privatization decisions; it furnishes a systematic procedure for investigating concepts of robustness under the uncertainty of DMs’ preferences. Although from one point of view, Info-gap modeling could be interpreted as a comprehensive approach to executing sensitivity analyses, it does, in fact, go beyond traditional sensitivity analysis and constitutes a mathematical procedure for formally modeling and analyzing large levels of strategic uncertainty. In addition to its use for the uncertainty related to preferences, Info-gap models could be designed for tackling other kinds of uncertainties arising in conflict conditions, such as option and strategy selection as well as coalition formation (Ben-Haim and Hipel, 2002).

4.5 Summary

Infrastructure systems are typically complex systems interconnected with many technical, economic, social, environmental and political factors. Decision-making in such complex systems is not an easy task; it requires thorough analysis and study. Combining the MCDA methodology with the advantages of the advancement in computer technology yields a

comprehensive decision support system that provides a powerful tool for decision makers and project managers.

Making the decision to privatize and later selecting the optimum proposal are especially complex and difficult tasks. They involve analyzing all stakeholders' perspectives in conjunction with socio-economical and political factors. Hence, they are conflict analysis problems characterized by the necessity to reconcile technical, socio-economic, environmental, and political value judgments, which explains the difficulties associated with the solution process and the absence of straightforward decisions. Rather, the final decisions are acceptable, compromise solutions that represent common ground for all the parties and stakeholders concerned. In most cases, the decisions lack a precise evaluation methodology, and that explains why most privatization processes and contracts result in serious disputes. Multi-criteria evaluation and selection techniques aim to provide such a missing set of tools through a comprehensive analysis methodology, with a flexible approach capable of dealing with qualitative as well as quantitative multi-dimensional parameters.

CHAPTER 5

MODEL IMPLEMENTATION AND CASE STUDY

5.1 Introduction

This chapter presents the implementation of the decision support system (DSS) model described in Chapter 4 into a working prototype. The prototype integrates the Elimination Method for shortening the number of solutions, the Graph Model for Conflict Resolution to determine the best solution that satisfies all stockholders' preferences, and Information Gap Theory for considering uncertainty in the decision preferences. The prototype DSS is implemented on a spreadsheet program. To demonstrate the decision support capabilities of the prototype, details of its implementation are presented using a case study of an actual construction conflict.

5.2 Implementation Media

The proposed decision support methodology described in Chapter 4 lends itself well to spreadsheet modeling, in which each module can be represented on a different sheet.

Furthermore, spreadsheets have many advantages and powerful features that enable rapid prototyping of the proposed methodology, which facilitates validation and testing.

Spreadsheets were among the earliest software innovations that had a profound effect on the widespread use of personal computers. Among their strong features are their intuitive cell-based structure and their simple interface that is easy to use even for a first-time user. Underneath the structure and the interface are a host of powerful and versatile features, from data entry and manipulation to a large number of functions, charts, and word processing capabilities. To increase productivity, newer spreadsheet versions have also added programmability options, a number of add-in programs, and features that allow Internet connectivity and workgroup sharing. Because of their wide use, spreadsheets have proven suitable as a tool for developing computer models that require ease of use, versatility, and productivity, such as those for decision support methodologies. Spreadsheets have already been applied successfully in many infrastructure applications such as planning and cost estimation for highway projects (Hegazy and Ayed, 1998), Critical Path Method (CPM) and time-cost trade-off (TCT) analysis (Hegazy and Ayed 1999), construction delay analysis (Mbabazi et al., 2005), and infrastructure asset management (Hegazy et al., 2004). In this study, Microsoft Excel software was selected for the implementation of the proposed model because of its ease of use and powerful programmability features.

5.3 Prototype Decision Support System

Using the macro language of Microsoft Excel, a DSS (ConGres) was developed. The development of the prototype involved substantial programming effort in order to code and test the different modules in order to develop a unified user-friendly interface, and to experiment with several case studies. Basically, the decision support system was developed as a workbook that contains several worksheets, including a main screen with a simple interface and buttons to activate the step-by-step options, as shown in Figure. 5.1. A schematic diagram of all the prototype components is shown in Figure. 5.2

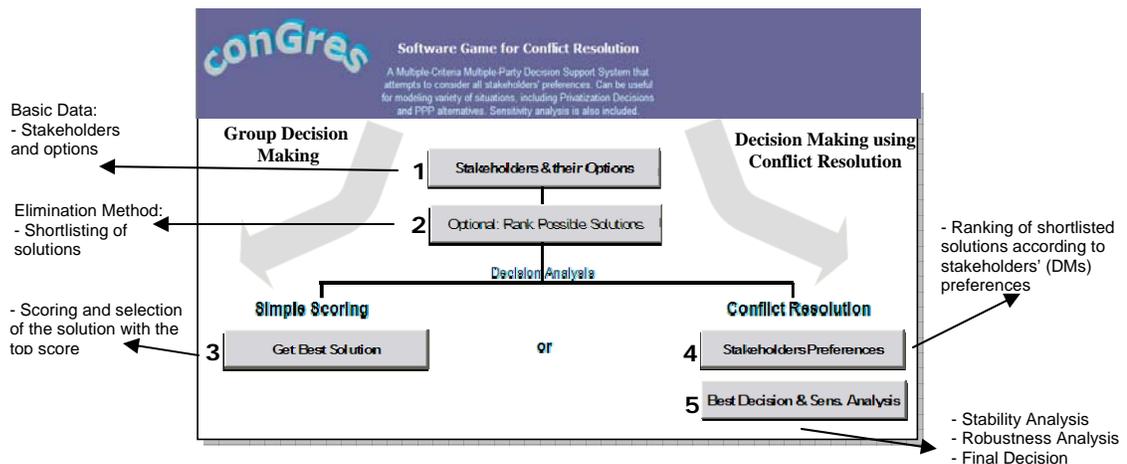


Figure 5.1: Main Menu Screen

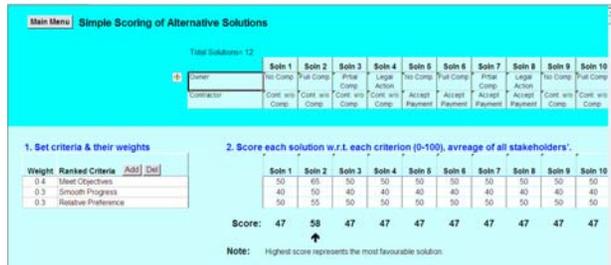
The interface automates all of the computations involved and allows the user or decision maker to interact with the system to obtain decision support.

The prototype provides decision support in two ways, as shown in the two branches in Figure 5.1 and 5.2:

Group Decision Making

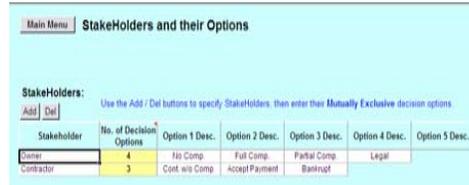
(Steps 1, 2, and 3)

Step 3



Details: Figures 5.9 and 5.10

Step 1



Details: Figure 5.4

Step 2



Details: Figures 5.5, 5.6, 5.7, and 5.8

Main Screen



Details: Figures 5.1 and 5.3

Decision Making Using Conflict Resolution

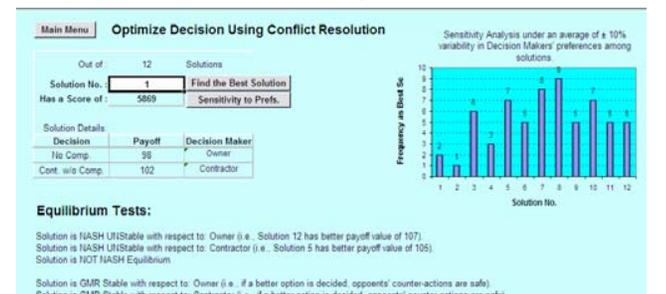
(Steps 1, 2, 4 and 5)

Step 4



Details: Figure 5.15

Step 5



Details: Figures 5.16, 5.17, and 5.18

Figure 5.2: Components of the Proposed Prototype

- a) Using a simple static scoring approach to have a group decision making and to prioritize possible solutions (left-hand side branch, i.e., Steps 1, 2, and then 3).
- b) Using a conflict-resolution approach to simulate negotiation tactics and arrive at the most stable solution for all decision makers (right-hand side branch, i.e., steps 1, 2, 4, and then 5).

In the next section, a case study of a construction conflict decision is used to describe the two approaches in detail.

5.3.1 Case Study: Construction Conflict

In this conflict, a dispute arose in a building project in Meaford, Ontario, Canada, between an Owner and a mid-sized Contractor; names have been omitted for confidentiality. The total value of the project was \$6 million Canadian, and the Contractor was awarded the job, as being the lowest bidder. The project was under restrictive time constraints, so the process of designing, bidding, and awarding the job was done in a speedy manner. The Contractor started mobilizing resources and construction immediately after signing the contract. Later, when the job was almost 12% complete, a memo from the consulting office was sent to the Contractor questioning the delay in the submission of a shop drawing for a particular item. At that time, the Contractor discovered that he had omitted a \$450,000 item in his bid (almost 7.5% of the total contract value). Because of the tight market and tense competition, the Contractor did not include a profit margin, depending solely on discounts from subcontractors and suppliers for obtaining profit. The maximum discount he obtained, however, was only about 3%, and almost all the subcontractors

refused to renegotiate their prices. The Contractor realized that his company would go bankrupt unless the Owner agreed to cover the missing item. His main arguments were that the bid documents were not clear, the bidding time was short, and many addenda were issued during the bidding period.

Although he officially rejected the Contractor's request, the Owner needed a speedy completion of the construction, which put some constraints on his negotiation options. The Owner did not want to extend the negotiation time, take legal action, or assign a new contractor. The Contractor, on the other hand, threatened to declare bankruptcy but preferred to find a way to complete the work. The construction conflict was formally modeled using ConGres, following the general steps depicted in Figure 5.1, which are explained in detail in the following subsections.

5.3.2 Decision Support Using Simple Weighting for Group Decision Making

Using a simple weighting approach, the prototype reached an optimum decision through the following steps.

Step 1. Identify the stakeholders and their options. Clicking on the “Stakeholders and their options” button (number 1 in Figure. 5.3), transfers the user to the Stakeholders’ sheet to add or delete stakeholders and/or their options, as shown in Figure 5.4.

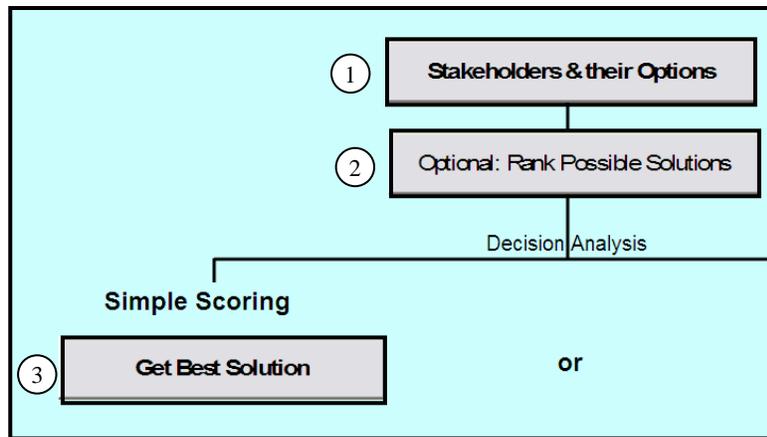


Figure 5.3: Main Menu Screen with the Simple Scoring Option

In this case, as shown in Figure 5.4, two DMs are specified for the construction conflict: the Owner and the Contractor. The DMs and their options are described in the specified spreadsheet cells. The Owner is specified to have four decision options: No Comp.: the owner will not pay the contractor any compensation; Full Comp.: the Owner will compensate the Contractor in full for the missing item; Partial Comp.: the Owner will pay the Contractor only partial compensation; and Legal: the Owner will sue the Contractor if the latter does not complete the job. On the other hand, the Contractor has three decision options: Conti. w/o Comp.: Continue without compensation; Accept Payment: accept payment (either partial or full) from the Owner; or Bankrupt: declare his bankruptcy, given that the Owner will not agree to compensate. It is noted that the specified options represent each DM's mutually exclusive choices. The DMs' preferences among these options, however, are not specified at this stage. It should also be noted that for future study, the system can be expanded to handle situations where not all options are mutually exclusive.

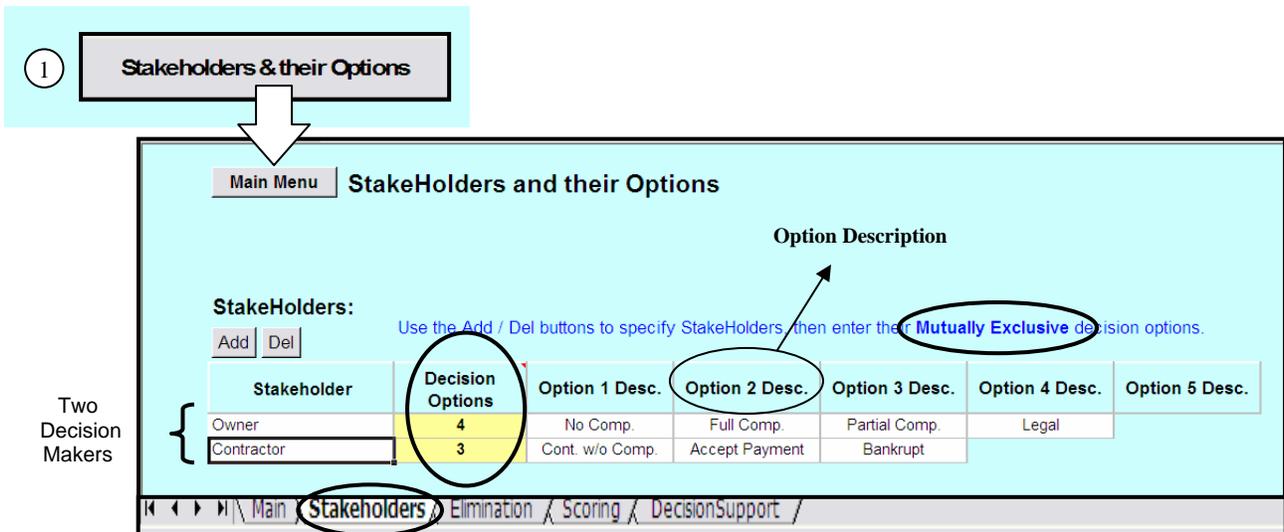


Figure 5.4: Stakeholders Screen

Once all the DMs are specified with their options, the user can return to the main screen (Figure 5.3) to continue with other steps in the decision-support process. It should be noted that the step of specifying the decision makers and their options is the most crucial step in the process. It needs to be carried out carefully so that no important party is omitted. The options also need to represent realistic courses of actions that each party can take based on extensive consultation with its associated group and that may involve surveys, expert opinion, and/or brainstorming. Once the decision makers or stakeholders and their options are specified, the program then lists all possible solutions (decision states). The total number of decision possibilities is the multiplication of the number of Decision Options listed in column 2, in this case $4 \times 3 = 12$. These 12 decision states represent all possible decision states. For example, State 6 (Soln 6) in Figure 5.5 represents a solution in which the owner will agree to pay full compensation to the contractor and the contractor will accept that payment and will continue with construction.

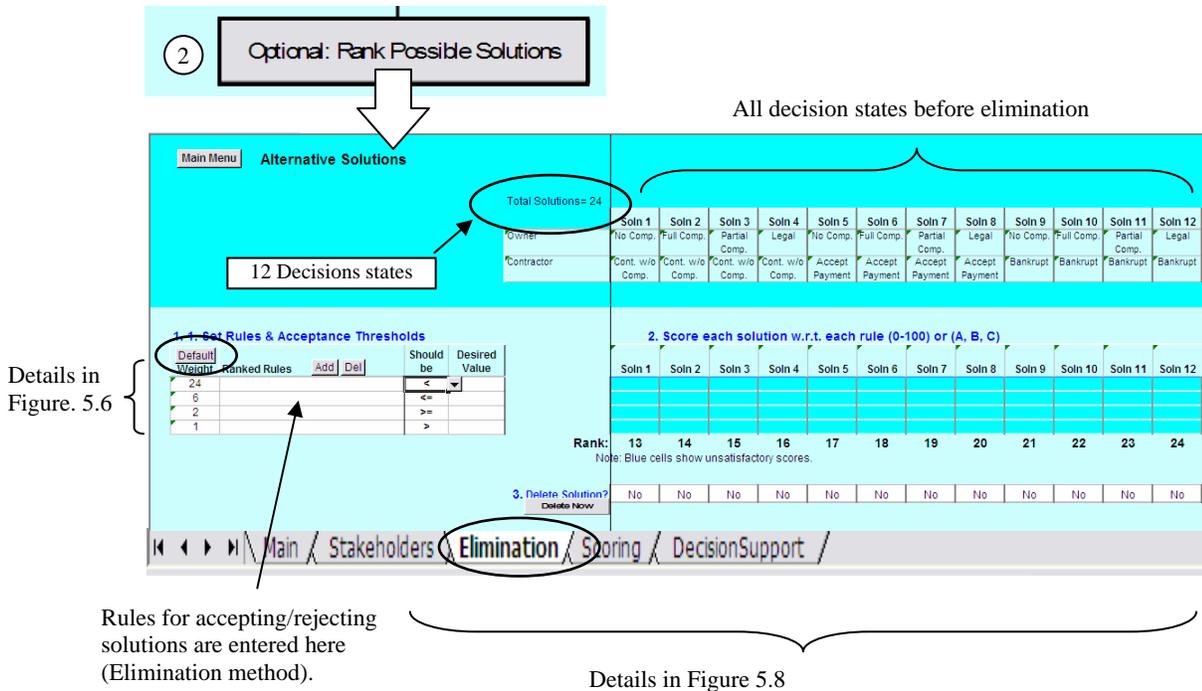


Figure 5.5: List of Possible Decision States before Elimination

Step 2. Rank possible solutions. Since there are a large number of decision states that represent possible solutions, it is important to identify and exclude any infeasible solutions so that the most promising ones can be shortlisted. Therefore, this step activates a new sheet, which applies the Elimination Method (described in Section 4.4.1), as shown in Figures 5.5 and 5.6.

The elimination process requires the user of the program to analyze the decision makers' important rules that affect their desire to reject or accept 12 possible solutions. This process may include common knowledge, surveys, and interviews with the decision makers. The purpose is to define the decision makers' minimum acceptable threshold value (range). Once this information becomes available to the user, the elimination process can be carried out.

First, the acceptance rules are entered into the program in a ranked order, starting from the most important at the top and finishing with the least important at the bottom (Figure 5.6). As shown in the figure, four rules were specified as a screening filter to consider a solution acceptable if

- 1) the consequent project delay (days) ≤ 15 days
- 2) the project cost increase (%) $\leq 10\%$
- 3) the Contractor's reputation remains good (b or better)
- 4) the continuity of the existing projects remains good (b or better)

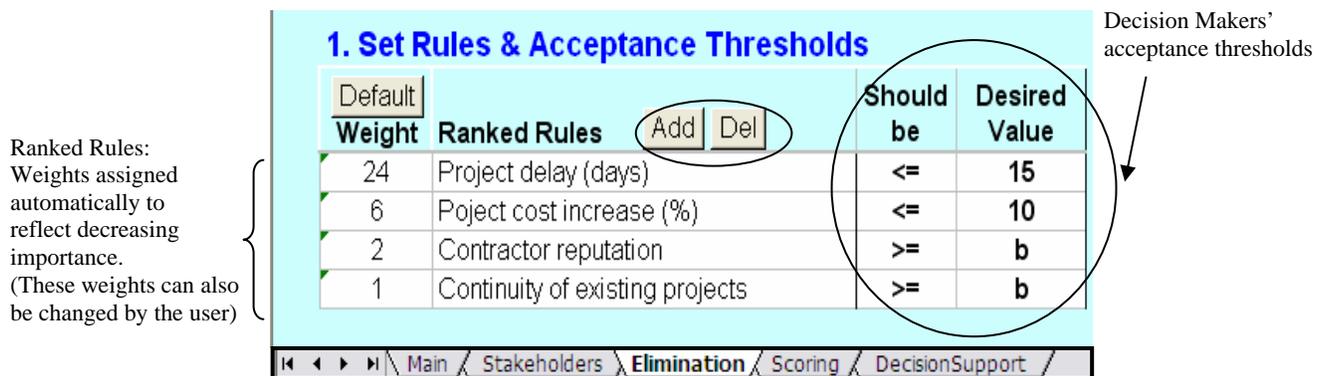


Figure 5.6: Specifying Acceptance Rules and Threshold Values

As shown in Figure 5.6, the program automatically assigns numerical values to the rules to reflect their decreasing importance. The weight for any rule of a rank i is calculated as the factorial of $(N-i+1)$, where N is the number of rules. For example, the most important rule (project delay) is ranked first (i.e., $i=1$) and is assigned the highest score of $(4-1+1)! = 4! = 4 \times 3 \times 2 \times 1 = 24$. In this manner, the rules exhibit exponential decay in their importance. Accordingly, the four listed rules are assigned the numerical ranks of 24, 6, 2, and 1, respectively.

It should be noted here that the acceptance rules are selected in a manner that considers the points of view of both decision makers. In addition, one of the strengths of the Elimination Method is the ability to deal with alphabetical and numerical values for the threshold values since in real life, evaluation scales can be set alphabetically as A, B, C, etc. or with real values that reflect physical quantities (e.g., cost). In the present case study, the top two rules are assigned numerical values. Alternatively, the third and fourth rules are assigned alphabetical values.

Once the acceptance rules are specified, the user evaluates each of the possible solutions and assigns a score for each rule as shown in Figure. 5.7, using the specified scales for each rule. For example, in Figure. 5.7, the user specifies that the consequences of solution 1 (Soln 1): “Contractor to continue without compensation” are 5 days of delay, 10% additional cost, Contractor reputation of b, and continuity of projects of c. Accordingly, since only the last rule is below the threshold, the associated cell is highlighted.

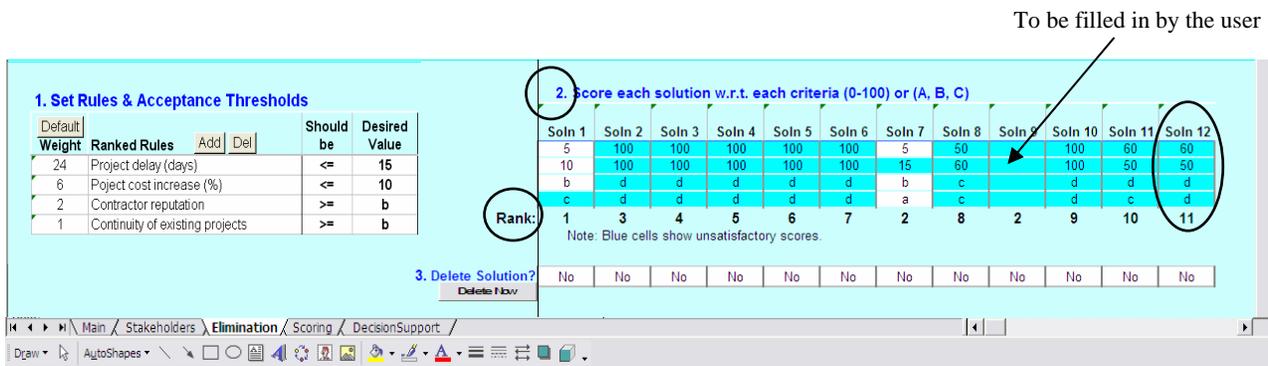


Figure 5.7: Shortlisting Solutions Using the Elimination Method

Similarly, values are entered for the rest of the possible solutions. For example, solution 12 (Soln 12) failed with respect to the first rule since its project delay (60 days) exceeds

the threshold of 15 days. Because the first rule is top-ranked, failure to meet this rule means that solution 12 is ranked very low. Thus, based on the weights of the rules and the user's evaluation, the system ranks solutions depending on how many rules have been satisfied. The rank is shown below each solution. Based on this ranking, the user can manually specify any undesirable solution for deletion, by selecting the (Yes) button, as shown at the bottom of Figure 5.8.

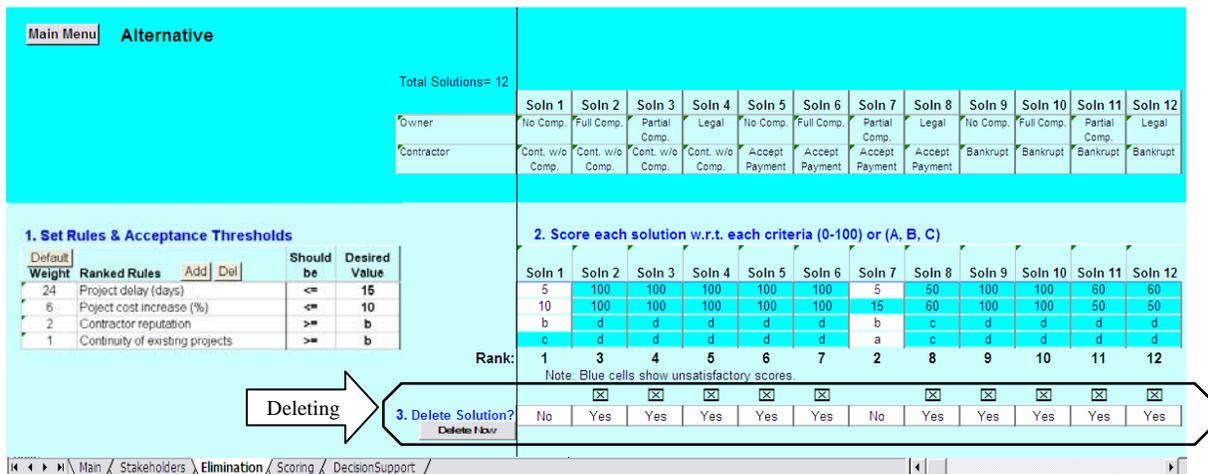


Figure 5.8: Eliminating Infeasible Solutions

Once a solution is deleted (eliminated), the system rearranges the remaining solutions based on the acceptable rules. At the end of this process, the user has a short list of decision solutions for the next step in the decision support process. In this case, the shortlisted solutions are 1 and then 2, as shown in Figure. 5.9. This example demonstrates that the strength of the Elimination method is its simplicity in identifying and eliminating less desirable solutions in order to provide a feasible short list of the potential solutions to the problem.

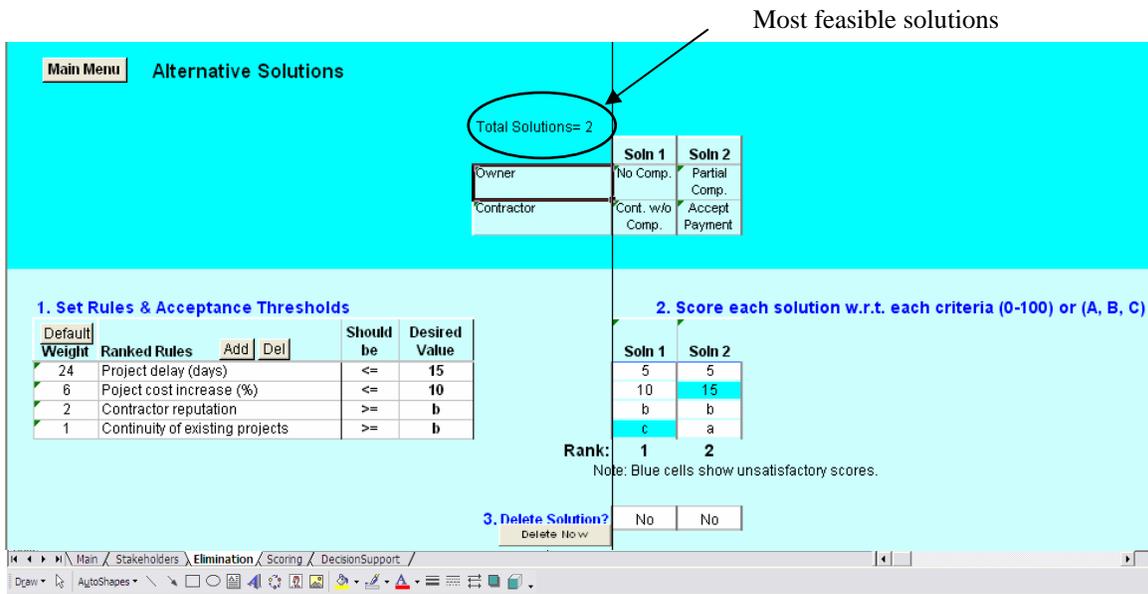


Figure 5.9: Final Results of the Elimination Method

Step 3. Get best solution. After shortlisting using the Elimination Method, the shortlisted solutions are ready for a more detailed multiple criteria analysis through a simple scoring method to determine the best solution. This step can be activated by the third button shown in Figure 5.3, which transfers the user to a new spreadsheet that displays only the shortlisted solutions. The process involves defining the important evaluation criteria (v_j^i) and soliciting their relative weights (w_i) from the decision makers, as shown in Figure 5.10. For example, a weight of $w_1 = 0.4$ is assigned to the first criterion of “Satisfying Both Parties”, while a weight of 0.3 is assigned to each of the second and third criteria, “Smooth Progress” and “Avoid Litigation”. In reality, a panel of experts or representatives of the various decision makers can be assembled to define the criteria and assign their weights with respect to the type of project being considered. The weights represent relative importance and indicate the relative preference of all parties for the final decision.

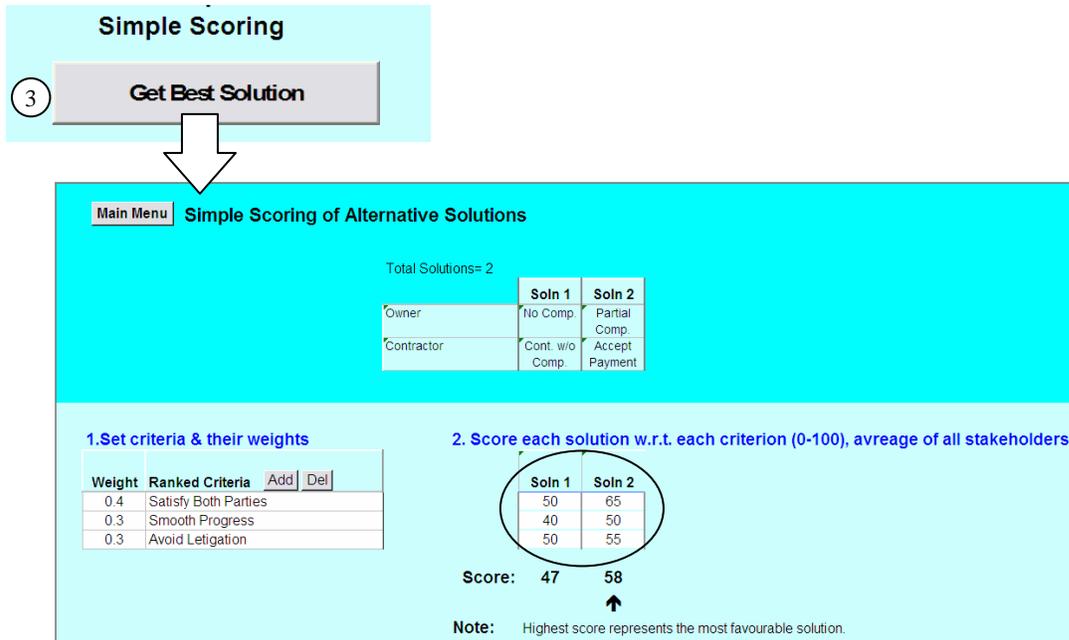


Figure 5.10: Criteria, Weights, and the Solutions' Scores

Once the criteria and their relative weights, which sum to a total of 1.0, are determined, the evaluation process proceeds. In this process, decision makers' scores (v_j^i) are averaged for each shortlisted solution, with respect to each criterion. As shown in Figure 5.10, scores are assigned on a scale of 1 to 100. For example, a score of $v_1^2 = 65$ for solution 2 with respect to "Satisfy Both Parties" is the average of the scores given by the various decision makers. Similarly, scores of $v_2^2 = 50$ and $v_3^2 = 55$ are achieved for the second and third criteria, respectively. Accordingly, an aggregate for each solution is calculated as

$$\text{Overall score of each solution} = v^i = w_1 v_1^i + w_2 v_2^i + w_3 v_3^i + \dots + w_q v_q^i = \sum_{j=1}^q w_j v_j^i$$

Where q is the total number of criteria. Substituting the values for solution 2 yields

$$\text{Overall score for solution \# 2} = \sum (0.4 * 65 + 0.3 * 50 + 0.3 * 55) = 58$$

Thus, the total score for each solution is automatically calculated, and the solution with the highest total score is highlighted by an upward arrow underneath (solution 2 in Figure 5.10), the solution requiring the Owner to offer the Contractor partial compensation. He will satisfy his constraint of meeting the project deadline. On the other hand, the Contractor's agreement to complete the job will keep his company from bankruptcy and his reputation intact. It should be noted that the scores (v_j^i) can be determined through interviews with the decision makers/stakeholder groups or through surveys.

5.3.3 Decision Support Employing Conflict Resolution

While the Group decision support using scoring is simple and highly consistent with the current processes utilized by private and government sectors in construction and infrastructure decision making; however, it is static and does not reflect interactive negotiation tactics. Conflict resolution, therefore, is employed as a more powerful and dynamic decision support tool. Through the second option (Figure 5.1), the process examines the stability of solutions with respect to decision makers' (stakeholders') preferences and has powerful features that can consider the uncertainty in the process using Info-gap theory, as described in Chapter 4.

The decision support process starts with the same two Steps 1 and 2 described earlier: defining the stakeholders and their options as well as shortlist possible solutions. In this example, the process results in the two feasible solutions shown in Figure 5.9. The process then proceeds to Steps 4 and 5, as indicated in Figure. 5.11.

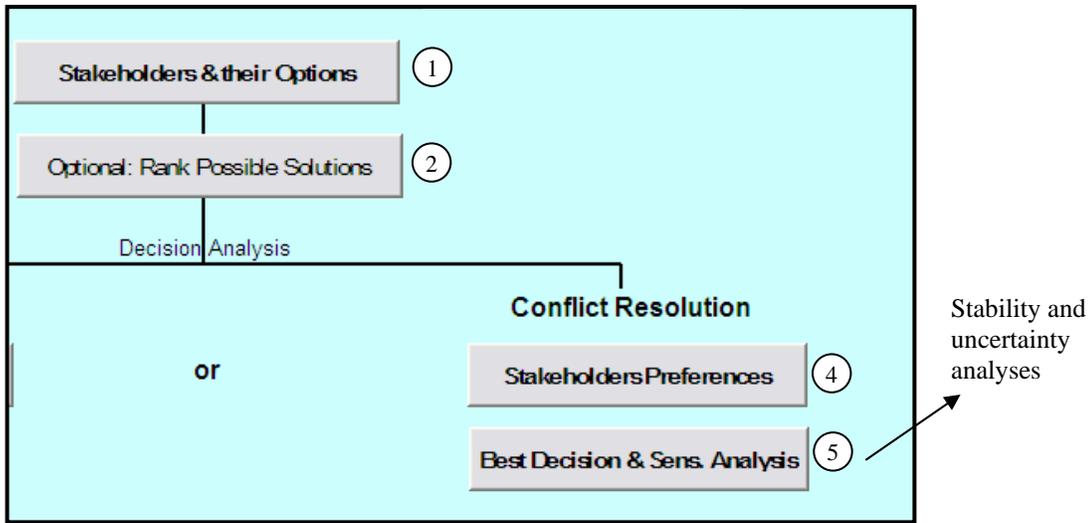


Figure 5.11: Main Screen with the Conflict Resolution Option

It should be noted that conflict resolution was applied to this case study in a previous effort by Kassab et al., (2006), utilizing the GMCR II program. Table 5.1 (left side) shows GMCR II’s screen after information related to the decision makers and their options was entered. In this representation, each decision state is represented by a combination of yes (Y) and/or no (N) symbols to form a state as shown in each column.

Table 5.1: Feasible States using GMCR II

DMs/Options *	Decision States													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Owner														
1. Full	N	Y	N	N	N	N	N	N	N	N	N	N	N	N
2. Partial	N	N	Y	N	N	N	N	N	Y	N	N	Y	N	N
3. New	N	N	N	Y	N	N	N	N	N	N	N	N	Y	N
4. Legal	N	N	N	N	Y	N	Y	N	N	Y	N	N	N	Y
Contractor														
5. Continue	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N
6. Accept	N	N	N	N	N	N	N	Y	Y	Y	N	N	N	N
7. Bankruptcy	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y

* Same as defined in Figure 5.4

As such, the conflict has ($2^7 = 128$) possible decision states. Subsequently, GMCR II has four approaches to identify infeasible states, as shown in the upper part of Figure 5.12. For example, selecting the “Mutually Exclusive Options” approach enables the user to specify the states that must be eliminated because they involve options that could not exist together (i.e., are mutually exclusive), as shown in the lower part of Figure 5.12. Following the elimination process, 114 of the 128 decision states were removed, leaving only the 14 feasible states shown as columns in Table 5.1.

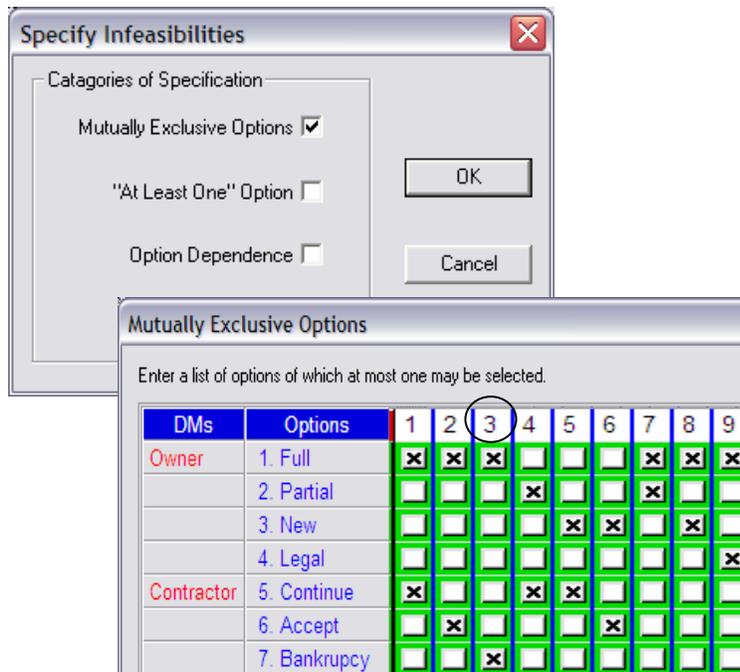


Figure 5.12 Removing Infeasible States

Once the feasible states are defined, the program allows the DMs to define their relative preference statements as shown in Figure 5.13, which can be interpreted as set out in Tables 5.2 and 5.3, where the numbers refer to the option numbers and a negative sign means the option is not taken.

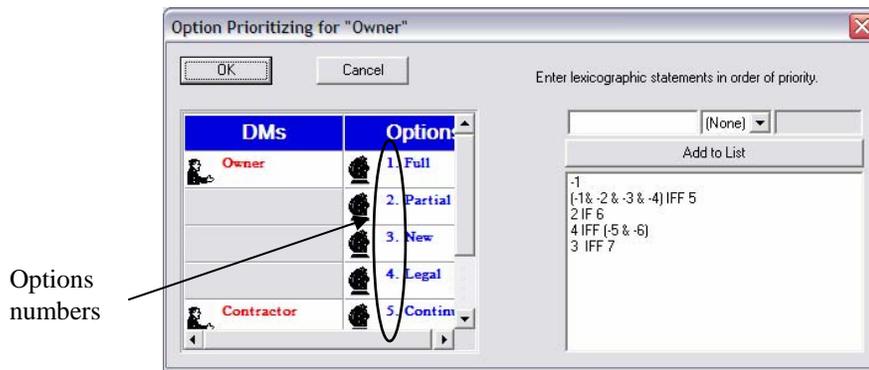


Figure 5.13: Owner's Preference Statements in GMCR II

Table 5.2: Owner's Preference Statements

Preference Statement	Explanation
-1	Owner most prefers not to give full payment to the Contractor.
(-1, -2, -3, -4) IFF 5	Owner prefers not to take any action if and only if (IFF) the Contractor continues without extra payment.
2 IF 6	Owner would like to provide partial payment if the Contractor agrees to continue without extra payment.
4 IFF (-5, -6)	Owner would take court action if and only if the Contractor refuses to continue the job.
3 IFF 7	Owner prefers to acquire a new contractor if and only if the Contractor declare bankruptcy.

Table 5.3: Contractor's Preference Statements

Preference Statement	Explanation
- 5	Contractor most prefers not to continue the job without compensation from the Owner.
(5 & -7) IF 1	Contractor prefers to continue the Job if the Owner agrees to pay full compensation.
6 IFF 2	Contractor would complete the job if and only if the Owner agrees to pay him partial compensation.
-4	Contractor does not prefer legal action.
7 IFF 4	Contractor would declare bankruptcy if and only if the Owner takes legal action.

Once the preferences were entered, the stability analysis was conducted. GMCR II calculates the stability of each feasible state for every DM with respect to all the solution concepts previously mentioned in Chapter 4. In general, a state is stable for any DM when he or she cannot move away from it without suffering negative consequences. When a given state is stable for all DMs according to a given stability concept, it is deemed to be an equilibrium or compromise resolution since no DM has an incentive to move away from it (Hipel et al., 1997).

Based on the stability analysis, Figure 5.14 shows the states that are in equilibrium (equilibria). The results showed that the two most stable states are States 9 and 14, since they are stable according to all of the solution concepts. This result means that if the conflict were to arrive at one of these states, it would stay there since it would be in equilibrium. This means that

- in State 9, the Owner will pay part of the requested expenses, and the Contractor agrees to complete the job;
- in State 14, the Owner will refuse to pay the Contractor any compensation, and will take legal action, which will trigger a bankruptcy decision by the Contactor.

DMs	Options	3	4	5	9	14
Owner	1. Full	N	N	N	N	N
	2. Partial	Y	N	N	Y	N
	3. New	N	Y	N	N	N
	4. Legal	N	N	Y	N	Y
Contractor	5. Continue	N	N	N	N	N
	6. Accept	N	N	N	Y	N
	7. Bankruptcy	N	N	N	N	Y
	R			Y	Y	
	GMR	Y	Y	Y	Y	Y
	SMR	Y	Y	Y	Y	Y
	SEQ	Y	Y	Y	Y	Y
	NM	Y	Y	Y	Y	Y
	L[2]	Y	Y	Y	Y	Y

Figure 5.14: The Final Equilibrium Results

While GMCR II is useful and applies the Graph Model concepts, it was not used in the development of this thesis due to some drawbacks, including the following:

- It uses “yes” and “no” representations for the DM options, thus resulting in a very large number of decision states (128 as opposed to the 12 with the present DSS).

- It is not flexible enough to be integrated with the Elimination Method, the Info-gap Theory, and Genetic Algorithms.

Applying conflict resolution using the DSS of this thesis is detailed as follow in Steps 4 and 5 below:

Step 4. Specify stakeholders' preferences. The shortlisted solutions are transferred to a new spreadsheet as shown in Figure 5.15. Rather than asking the decision makers to define evaluation criteria and collectively score the solutions through averaging, the conflict resolution option requires DMs to enter their preferences for each solution using a numerical scale of 0 to 100 to reflect each DM's point of view. The use of a 0-to-100 range is reasonable for this application. The values represent each DM's payoff from each solution. For example, the first preference row in Figure 5.15 shows the point of view of the Owner, who indicates a high preference (100) for solution 1 "No Compensation", and a lower preference (75) for solution 2 "Making Partial Compensation to the Contractor". From the Contractor's point of view, on the other hand, a preference value of zero is assigned to the first solution since the Contractor does not accept any solution with "No Compensation". The Contractor also assigns a preference value of 50 for the second solution "Partial Compensation". It should be noted that the system could be expanded in future work to include an option prioritization method of listing stakeholders' preferences using ordinal preferences rather than cardinal.

Main Menu		Alternative Solutions	
Total Solutions= 2			
	Soln 1	Soln 2	
Owner	No Comp.	Partial Comp.	
Contractor	Cont. w/o Comp.	Accept Payment	
Preferences		Enter the stakeholders' preferences in the above solutions (0-100 scale).	
Owner	100	75	
Contractor	0	50	

Figure 5.15: Specifying Decision Makers' Preferences

Step 5: Conduct stability analysis. The program now analyzes each specified solution using the Nash, GMR, SMR, and SEQ stability analyses. As shown in Figure 5.16, solution 2 is analysed and given a total score of 9250; equilibrium was achieved in all four stability tests. The Nash stability result indicates that no other decisions bring a better payoff. The GMR stability analysis also indicates that the opponents' counter-actions are safe. The SMR stability result shows that the opponents' counter-actions are safe and not harmful to the opponent. Lastly, the SEQ stability result indicates that the opponents' beneficial counter-actions are safe. Once these analyses are completed, the program presents the report shown at the bottom of Figure 5.16.

To calculate the score for any solution, the following formulation is used:

$$\begin{aligned} \text{Score} = & (\text{Sum of payoffs assigned by the DMs}) \times 10 \\ & + \text{Bonuses for solution stability with respect to Owner (B1 + B2 + B3 + B4)} \\ & + \text{Bonuses for solution stability with respect to Contractor (B5+ B6 + B7 + B8)} \end{aligned}$$

where,

- the payoff represents the values of the preferences assigned by the DMs;
- B1 to B8 are bonus values assigned by the program if the examined solution passes the Nash, GMR, SMR, and SEQ analyses (with respect to each of the DMs).

For example, in Figure 5.16, solution 2 has total payoff values of 50 (Owner) plus 75 (Contractor). In addition, the solution successfully passed the Nash, GMR, SMR, and SEQ stability analyses for both the Owner and the Contractor. Each stability result adds a bonus

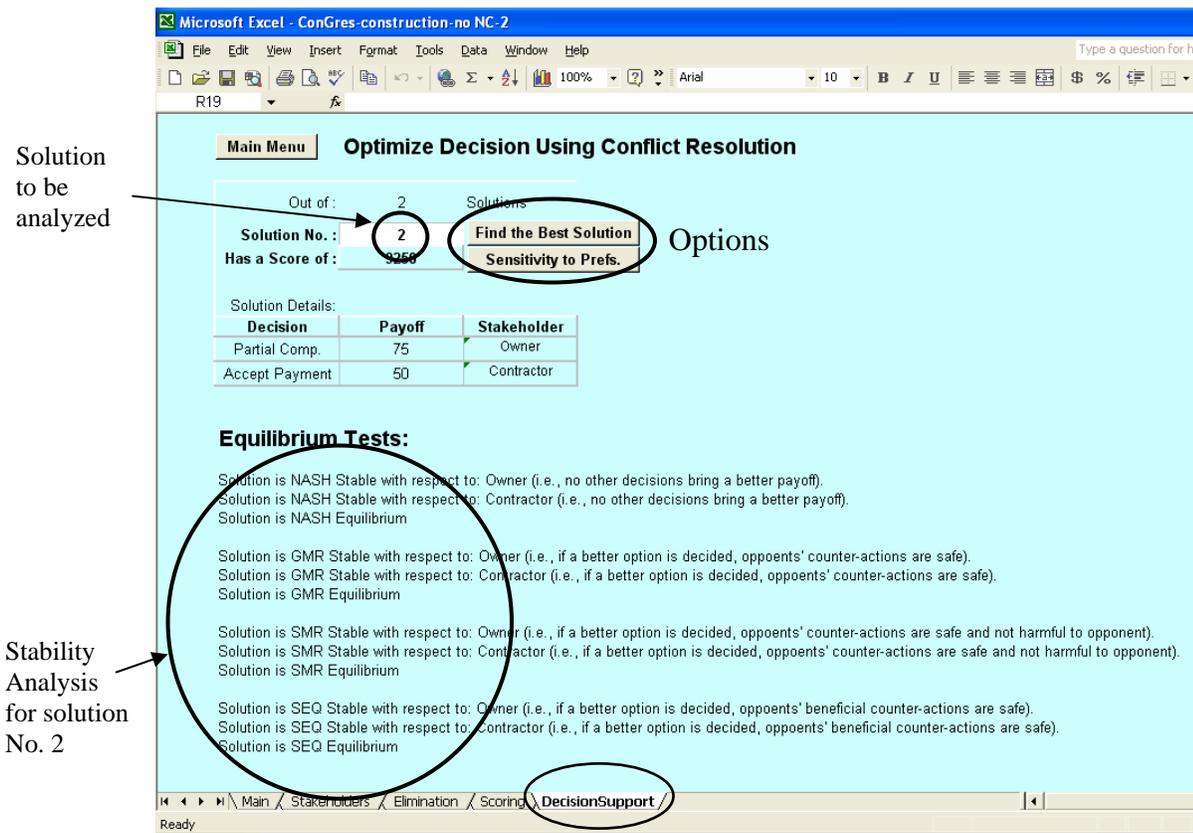


Figure 5.16: Decision Optimization Using the Conflict Resolution Approach

value of 1000 to the final score, and hence, the total score becomes

$$\begin{aligned} \text{Score} &= \text{Total payoff } (75+50) \times 10 + \text{Owner stability } (1000+1000+1000+1000) \\ &+ \text{Contractor stability } (1000+1000+1000+1000) = 9250. \end{aligned}$$

In the present example, testing solution 1 results in a total score of only 9000, and therefore, with the highest total score, solution 2 is the better solution.

In Step 5, while the system allows the user to enter and test a solution manually, it also contains two processes – process automation and uncertainty analysis – which are explained in the following sections.

- **Process Automation:** the prototype has an interesting option for automating an exhaustive search for the best solution. The “Find the best solution” button in Figure 5.16 activates a macro program that tests all the shortlisted solutions, automatically calculates and compares their total scores, and presents the best result to the user (Figure 5.17). In the case of an extremely large number of shortlisted solutions, it is possible to use GAs to search for the optimum one.
- **Uncertainty Analysis:** Some decision makers may be certain about their preferences; however, in real life, many are not. The model can handle cases in which the DMs’ preferences are ambiguous by using information gap theory to calculate the robustness of each solution.

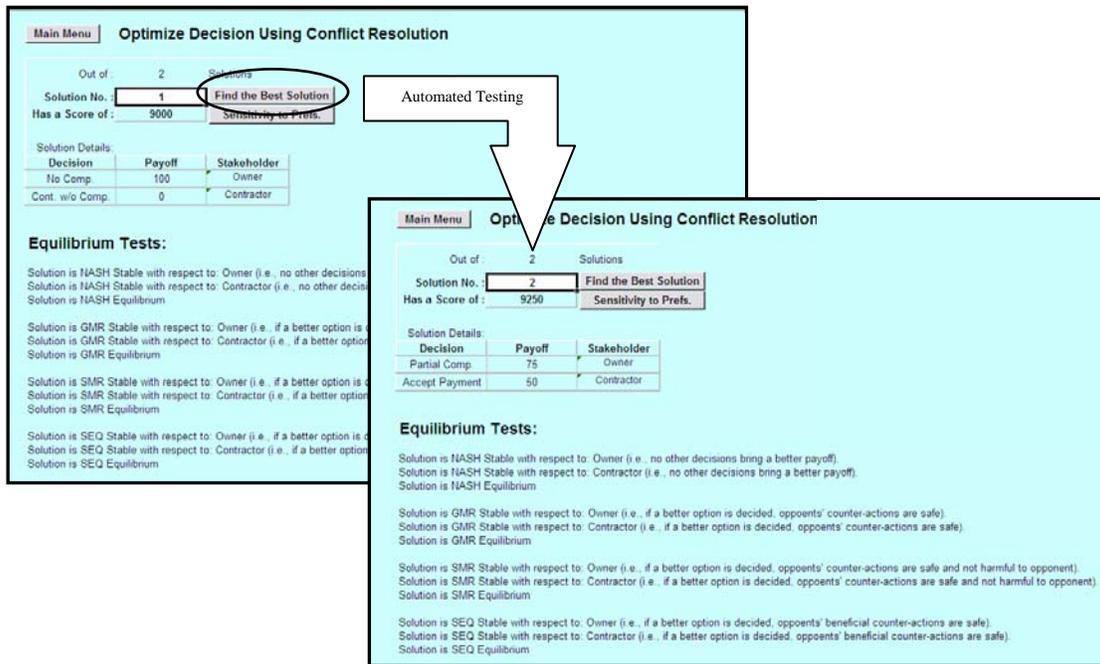


Figure 5.17: Finding the Best Solution Using the Automated Feature

Using the “Sensitivity to Prefs” button shown in Figure 5.16, the prototype asks the user to express the level of uncertainty associated with the preferences as a \pm percentage (Figure 5.15). In the present example, for demonstration, it is assumed that the users specify the following uncertainty levels:

DM	Uncertainties
Owner	Original preference value \pm 10%
Contractor	Original preference value \pm 15%

Next, the system presents the user with a dialogue box where he can enter the number of random experiments to be considered for the uncertainty analysis, as shown in Figure 5.18. Figure 5.19 is a flowchart for uncertainty analyses for 100 experiments carried out by the system for this case study. In this process, 100 random scenarios are generated with random preference values within the uncertainty level specified. Accordingly, each

scenario has a best solution, and the model counts the occurrence of each solution being the best as an indication of the robustness of the solution. Accordingly, the final decision in the construction example is solution 2, which shows high robustness because it was selected almost 100 times during the 100 experiments.

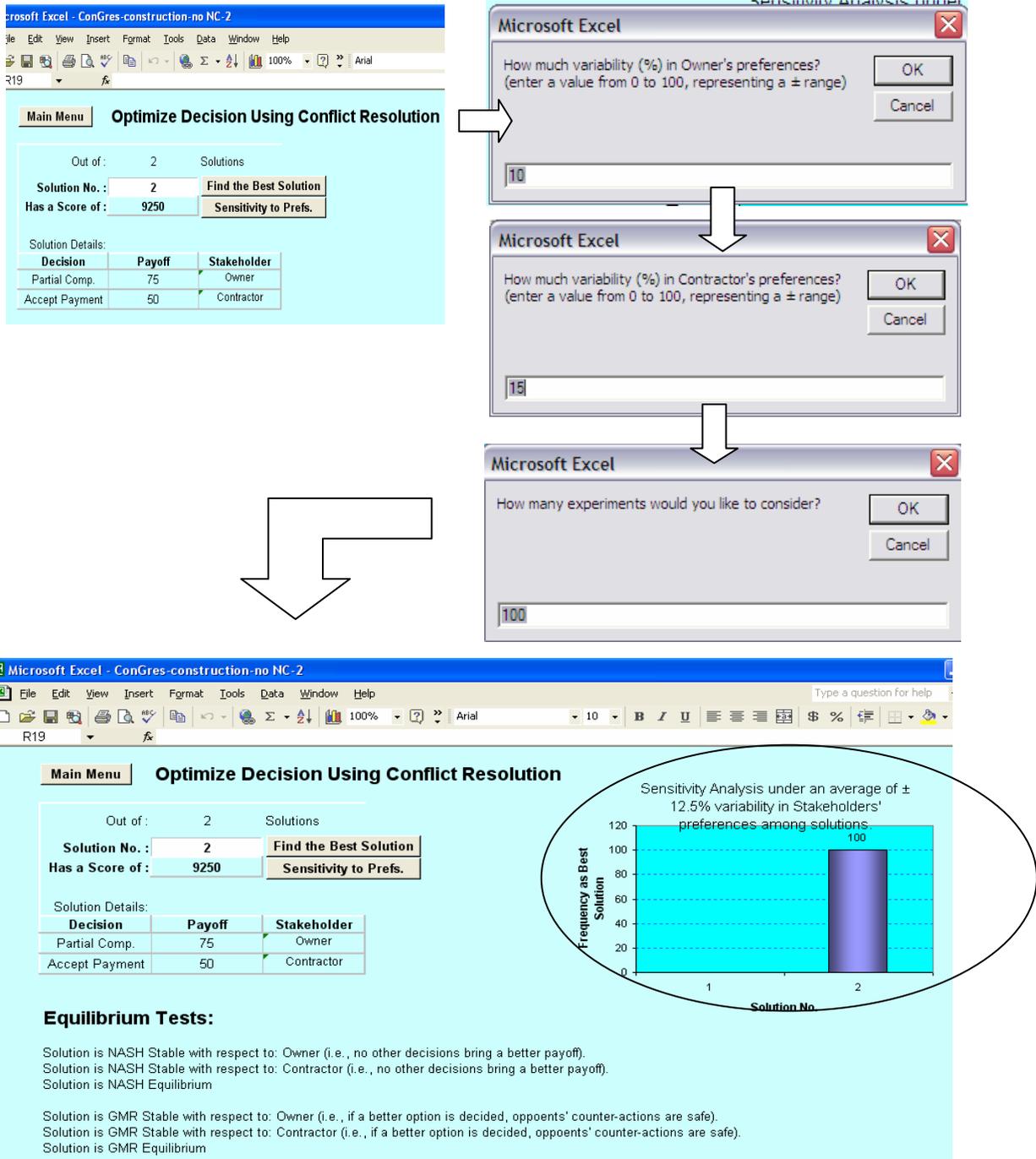
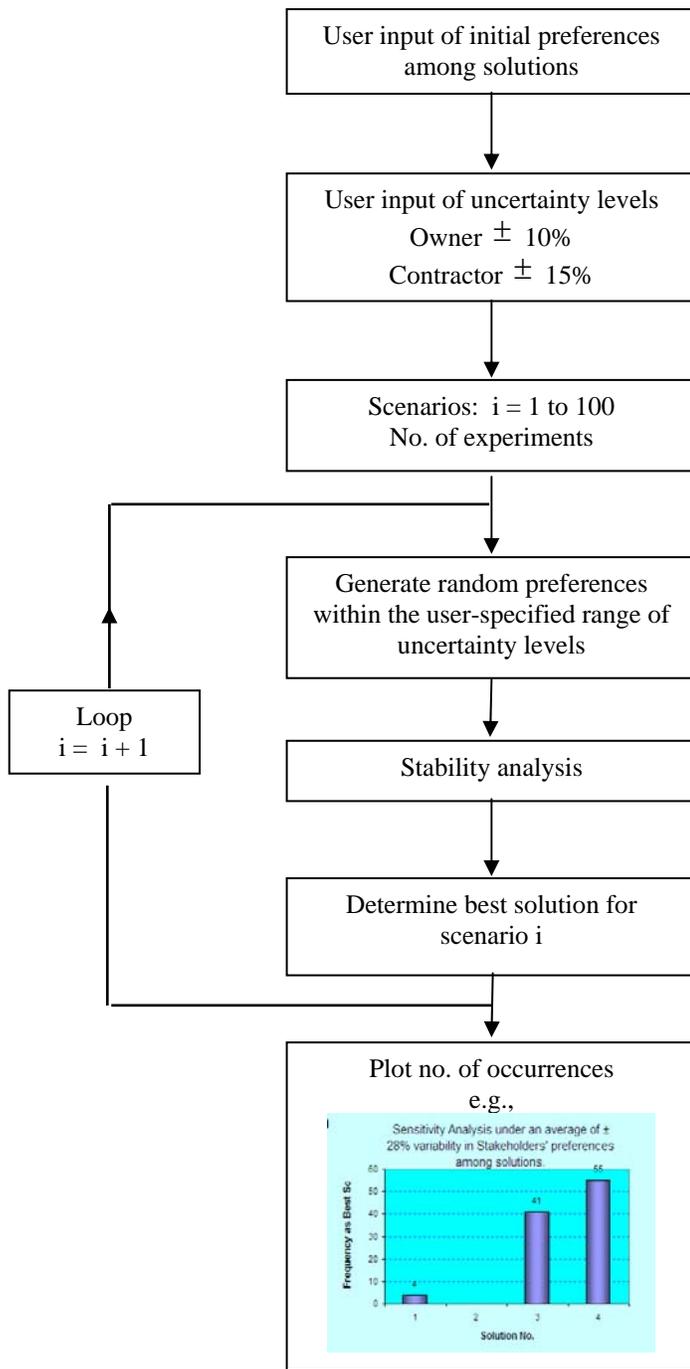


Figure 5.18: Decision Optimization Considering Information Gap Theory



Example showing solution 3 with 41% robustness

Figure 5.19: Flowchart for the Uncertainty Analyses Process

Interpretation of Results

The results provided by the developed DSS show that solution 2 is the wisest decision that the two DMs could reach with the minimum possible loss for both parties. In this state, the Owner admits some responsibility for the uncertainty caused by the bidding procedure and the very restricted time constraints. On the other hand, the Contractor, who had already completed 12% of the project, would lose any chance to recover his expenditures if he declared bankruptcy and pulled out of the job.

In reality, what happened in this conflict matches this result. After several meetings between the representatives of both parties and intense negotiations, the Contractor agreed to continue and complete the project in exchange for a cost compensation for the missing item, which matches solution 2. This state represents the best equilibrium state, since no DM has an incentive to move away from it. Notice that this type of cooperation reflects the kind of cooperation that can take place in the generic game of the Prisoner's Dilemma previously explained in Chapter 4.

The main benefit of solution 2 is that both parties met halfway to resolve the conflict, and a win/win situation was reached. The Owner won by

- not paying the full compensation that the Contractor initially requested,
- having the Contractor guarantee that the project would finish on time, and
- avoiding the messy situation of hiring a new Contractor if the current Contractor pulls out.

The Contractor also gained by

- gaining payment for the cost of the missing item; and
- not having to declare bankruptcy, which saved him significant financial loss and preserved his reputation in the market place.

The final resolution was possible because the Owner was under time constraint in this project. The Contractor was fully aware of this fact. As a result of this conflict, the Owner expressed sensitivity in future dealings with this Contractor, and a memo was issued by the Owner's head office, modifying the bidding procedure to avoid automatic awarding of construction work to the lowest bidder or to unreasonable bid.

5.4 Summary

This chapter presented the implementation and the prototype development of a decision support system for conflict resolution. The presented system was implemented on a spreadsheet program because of its ease of use and powerful operating features. The prototype was developed using macro programs written in Excel's Visual Basic for Application language. The development of the system involved a substantial programming effort in testing and coding the different modules and in developing a friendly, unified user interface.

An example application of an actual construction conflict was presented to demonstrate the capabilities of the developed system and to validate the usability of the different modules of the DSS. The ability to measure the decision robustness in the presence of the

uncertainty associated with stakeholders' preferences is a powerful feature of the developed system. While the presented example is small, it served as a useful test for the prototype, which performed well. The next chapter describes its use for privatization problems.

CHAPTER 6

PRIVATIZATION CASE STUDY: HAMILTON WASTEWATER TREATMENT PLANT

6.1 Introduction

To demonstrate the applicability and practicality of the developed decision support system (DSS). This chapter is devoted to the application of the model for a real-life infrastructure privatization project, the Hamilton Wastewater Treatment Plant. A description of the case study project is presented along with the information required in order for the project to be analyzed using the proposed DSS. The use of the developed prototype suggesting the best privatization option for the case study is then explained, taking into consideration stakeholder preferences and the level of expected uncertainty.

6.2 Case Study Overview

In December 1994, the Regional Municipality of Hamilton-Wentworth, (Ontario, Canada) signed a ten-year, \$180 million contract, with a new, one-year-old company, Philip Utilities Management Corporation (PUMC). The contract between the two entities

transferred the region's water and sewage system operation, management, and maintenance responsibilities to PUMC. When the deal was signed, it was the largest Private-Public Partnership (PPP) agreement of this type in North America.

The details of the decision-making process that resulted in the use of an Operation & Maintenance (O&M) type of PPP option in Hamilton are not available. However, Loxley (1999) published a detailed report that highlighted the flaws in this PPP agreement and its failure to meet the actual needs of the citizens. The data from that report are included in this study. Loxley took a broad approach by analyzing the Hamilton privatization experience of the wastewater treatment plant with respect to six aspects: 1) efficiency and cost savings, 2) financial risk transfer, 3) environmental risk and quality of service, 4) the issue of accountability and transparency, 5) the impact of the project on workers and the community, and 6) the economic development benefits. These six thus represent key rules and thresholds that can be used to accept or reject any PPP option for the case study. They can be used directly by the proposed DSS for eliminating infeasible PPP options.

The background related to the privatization project and the history of the project that resulted in the failure of the privatization are useful for an understanding of the parameters involved in such a project and are described below.

The 18.6 million annual contract between the Regional Authority (RA) and the Philip Utility and Maintenance Company (PUMC) transferred the operation, management, and maintenance of the water and sewage plants to PUMC for a 10-year period. Hence, PUMC possessed total control of the municipally owned water treatment plant and three other

water treatment plants (Woodward, Dundas, and Watertown) as well as 129 pumping stations and outstations.

PUMC agreed to keep all existing employees and contracts for the first 18 months, in addition to respecting successor rights legislation. In addition, Philip Services (PS), PUMC's parent company, made an additional commitment to create 100 new jobs over the next five years and to guarantee overall contract performance. However, according to Section 3:04 of the contract, Philip was exempt from any liability if the system failed due to such factors as

- the quality or quantity of the influent;
- the limits of the capacity of the facilities;
- the RA's failure to make capital, regulatory, or emergency expenditures;
- the operating parameters of the outstations.

PUMC had an asset base of about \$125 million according to Leo Gohier, Acting Commissioner Regional Environmental Department. However, at the time PUMC won the Hamilton contract, it had absolutely no record of running any equivalently sized water facility.

In addition, while the parent company (PS) was Hamilton-based, (a major criterion for winning the contract) it later sold about 70% of PUMC to company based in the United States (USA). Thus, the ownership of PUMC was transferred to a foreign company after the contract was signed.

Both the Government and PUMC argued that the form of privatization (O & M) would provide the following benefits:

- 1) increase an economical, cost-effective means of providing treatment services
- 2) be the most cost-effective means of providing capital improvements to facilities
- 3) allow access to financial resources
- 4) allow access to emerging technologies
- 5) create a higher level of operating efficiency
- 6) transfer risk/responsibility from the city to the contractor
- 7) enhance water quality and protect the environment
- 8) fill the gap created by the downsizing of government operations

In reality, however, Loxley's (1999) report revealed the actual performance of the privatization, as shown in Table 6.1:

Table. 6.1: Perceived Benefits Versus Actual Performance of the Contract

Perceived Benefits	Actual Performance
Efficiency and Cost Saving	
<ul style="list-style-type: none"> • The private sector will share in maintenance costs • PUMC will be responsible for any maintenance costs less than \$ 10, 000. • The RA will be responsible for any maintenance costs more than \$ 10,000 	<ul style="list-style-type: none"> • Because the entire wastewater treatment plant needs major renewal, the RA has to make all capital expenditures. • While PUMC made no renewal investment, it will gain from operating the renewed system. • Taxpayers, not the private sector, will ultimately provide the funding for the renewal.
Risk Transfer	
<ul style="list-style-type: none"> • A major reason for privatization is that risk is transferred to the private sector. 	<ul style="list-style-type: none"> • Design: the RA bears the full burden of the design. • Construction and Maintenance: the RA bears the risk of any maintenance exceeding \$ 10,000/ year. • Financial risks: the RA is responsible for arranging financing for any upgrades. • The RA faced financial and operating risks from the instability of its private partner (PUMC).

Table 6.1: Perceived Benefits versus Actual Performance of the Contract (Cont'd)

Perceived Benefits	Actual Performance
Environmental Risk and Quality of Service	
<ul style="list-style-type: none"> • Private sector will keep maintaining the sewage treatment plant Certificates of Approval (C of A); rates are set by the province. • Private sector will maintain the baseline performance criteria (BPC) for effluent quality after treatment as set by the RA and as contained in its contract with PUMC. 	<p>PUMC did not fulfill their environmental duties. Some indications include:</p> <ul style="list-style-type: none"> • In January 1996, a major spill occurred at the main pumping station at the sewage plant under Philip's control. In this accident, the worst disaster ever to affect the system, 180 million litres of raw sewage were spilled into Hamilton Harbour and surrounding areas. • More than 115 houses and businesses were flooded in the Stoney Creek area. • In September 1996, a report by Rand Rosell of the RA's legal department said PUMC was responsible for the spill. Filer Consultants (an independent company) put the blame on mechanical and operational failure caused by PUMC. • RA ultimately had to pay for all damage. • PUMC has often failed to meet governmental or Remedial Action Plan (RAP) standards for the discharge of effluents. • It is estimated that 4.33 billion litres of untreated sewage flows into the harbour each year. • The treated effluent from PUMC plants often falls below government standards. • Hamilton Bay water contains high levels of phosphorous and ammonia which contribute to poor water quality. • For total phosphorus content, the average exceeded the BPC over almost four years. • In at least eight months, standards were surpassed considerably. • Some observers feel that PUMC is choosing to operate at a much higher level of risk of environmental problems in order to reduce costs and increase its profits.
Accountability and Transparency	
<ul style="list-style-type: none"> • While the contract contains a requirement for an annual performance review (Article 17), there is no stipulation that this review be made public. 	<ul style="list-style-type: none"> • The reporting criteria to the RA and the Ministry of Environment are very vague. • No quarterly or monthly reports are required. • Public reporting criteria are non-existent. • The contract itself was awarded to PUMC without being tendered publicly. • PUMC's performance in the first year, on a scale of 1 to 4, is a 1. • PUMC has not even bothered to file its taxes or report its financial position to the RA.

Table 6.1: Perceived Benefits versus Actual Performance of the Contract (Cont'd)

Perceived Benefits	Actual Performance
Impact on Workers and the Community	
<ul style="list-style-type: none"> ● Philip Services would guarantee employment opportunities by creating 100 new jobs somewhere in the RA over five years. ● PUMC promised to pay \$1 million, or \$10,000 for each job Philip did not create. ● Workers were offered an equal 10% share in any expenditure reductions. 	<ul style="list-style-type: none"> ● In April 1996 layoffs began. Philip cut about 60 of the 120 or so workers, leaving 58 staff, including management, by the end of 1999. ● No CUPE members remained beyond the end of 1999. ● There were also 19 vacant positions at the operations when PUMC took over. These positions were never filled. ● No decent lay-off compensation was provided. ● PUMC is paying laid-off workers the strict minimum of one week's pay for one year's work. ● No job guarantees or decent severance packages were included in the agreement. ● PUMC is attempting to multitask and multi-skill most jobs. The CUPE jobs in administration and cleaning were eliminated.
Economic Development Benefits	
<ul style="list-style-type: none"> ● One of the main reasons there was no tendering for this contract was to bring economic development benefits to the Hamilton-Wentworth region, and Philip was a local company. ● Philip promised to <ol style="list-style-type: none"> a. develop an environmental enterprise centre, b. establish an international training centre with Mohawk College and spend \$15 million on new capital projects over five years, c. build a new head office building and even collaborate with McMaster University. 	<ul style="list-style-type: none"> ● The only one of these initiatives undertaken was the moving of Philip's head office to Hamilton. ● Later the company was sold to U.S.A. based company.

Based on the Loxley's (1999) report and the analysis in Table 6.1, the following changes should take place:

- The RA should have the ability to terminate the contract in case of defaults such as not paying to creditors, or in case of processes related to bankruptcy or insolvency.
- The RA should appoint an independent regulatory body composed of independent observers to monitor and examine contract compliance in a public and transparent fashion.

- No more privatizations should be implemented without a full public discussion and an election on the issue. Then, if the proposal is approved, there must be a full public tendering process.
- Immediate publication is required of all financial items related to the PUMC contract, including the audited PUMC annual statements.
- Companies which are the subject of RA or City contracts should not be permitted to contribute financially to the campaigns of municipal candidates.
- All laid-off workers at PUMC should be given a fair severance package paid for out of Philip profits from the cuts.
- Annual reports on contract compliance should be available.
- The contract and all subsequent changes should be published.
- All information regarding the quality of drinking water, effluent, and spills should be made public on a monthly basis.
- The quality of Hamilton's water and wastewater should be benchmarked against other large Ontario regions and published on a regular basis.

6.3 Case Study Implementation

The proposed decision support system (DSS) is to be used for the Hamilton Treatment Plants (HTP) privatization project. It should be noted that this case study was analyzed after the fact: the decision had already been made, and many data were not available due to ongoing litigations. Accordingly, some missing information was assumed.

The DSS process begins with the identification of the stakeholders and their options. Next, the elimination method is used to shortlist the privatization alternatives. Then, two decision support techniques are used: Group Decision Making using simple scoring, and the Graph Model for Conflict Resolution. Finally, Info-gap Theory is used to help select the best decision in view of the uncertainty that may be associated with stakeholders' preferences. The step-by-step analysis is described as follows:

6.3.1 Group Decision Making Using Simple Scoring

The group decision-making process consists of the following three steps:

Step 1: Identify stakeholders and their options. Five stakeholders are specified in this case study, as shown in Figure 6.1.

Main Menu StakeHolders and their Options

StakeHolders: Use the Add / Del buttons to specify StakeHolders, then enter their **Mutually Exclusive** decision options.

Stakeholder	No. of Decision Options	Option 1 Desc.	Option 2 Desc.	Option 3 Desc.	Option 4 Desc.	Option 5 Desc.
Private sector	4	R&O	R&O&M	O&M	Purchase	
Employees	2	No Firing	Unionize			
Public users	2	<2% Increase	Open compet.			
Environmentals	2	Filtration	Regular Tests			
Government	2	No Share	51%			

Figure 6.1: Stakeholders and their Options

The first stakeholder is the Private Sector, representing PUMC, which has four options: rebuild and operate (R&O), renovate-operate-manage (R&O&M), operate and manage (O & M), and finally Purchase the whole facility (purchase).

The second stakeholder in the case study is the Employees, represented by their union. It is assumed that they have two conditions for approving any proposal: a guarantee that no employee be fired and a guarantee that the facility will remain unionized.

The third stakeholder represents Public Users. This group is assumed to have two options for approving proposals: fee increases must be less than 2%, annually and open competition must be allowed in order to prevent a monopoly.

The fourth stakeholder is the Environmental group (Environmentals), which has two conditions: installation of a filtration system to screen out any hazardous materials, and regular quality control and tests by an independent party.

Finally, the fifth stakeholder group is the Government, which has 2 conditions: the private sector should be a Canadian company, or at least 51% of the private-sector contractors should be owned by Canadian shareholders.

Specifying the stakeholders and their options resulted in a total of 64 “decision states” ($4 \times 2 \times 2 \times 2 \times 2$), as shown in Figure 6.2. These decision states represent all possible decisions that could be made as a result of the combination of all possible stakeholders and their desired options. For example, decision state 4 (Soln 4) represents a privatization solution in which the local (no foreign shareholders) private sector buys the facility with a guarantee that no employee will lose his or her job, that a maximum increase of 2% in the

users' fees will be implemented annually to overcome inflation, and that an effective filtration system will be placed at the disposal outlet to appease the environmental groups.

The screenshot shows a software interface with a menu bar at the top containing 'Main Menu' and 'Alternative Solutions'. Below the menu, a text box indicates 'Total Solutions= 121'. A table lists 11 solutions (Soln 1 to Soln 11) across five stakeholder categories: Private sector, Employees, Public users, StakeHolder 4, and StakeHolder 5. The 'Elimination' tab is highlighted in the bottom navigation bar.

	Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7	Soln 8	Soln 9	Soln 10	Soln 11
Private sector	B&O	B&O&M	M	Purchase	Lease	B&O	B&O&M	M	Purchase	Lease	B&O
Employees	No Firing	Unionize	Unionize	Unionize	Unionize	Unionize	No Firing				
Public users	<2% Increase	Open compet									
StakeHolder 4	Filteration	Filteration									
StakeHolder 5	No Share	No Share									

Figure 6.2: List of Possible Decision States before Eliminations

Step 2: Shortlist feasible solutions. Given 64 decision states, it is important to identify and exclude any solutions with infeasible options, and then shortlist and focus on the most promising ones. Hence, activating the elimination spreadsheet allows the user to enter thresholds rules for shortlisting solutions.

In the present case study, based on comprehensive brainstorming results, the following nine acceptance rules are assumed (Table 6.2).

Table 6.2 Accepted Rules

Public and Social Impact should be less than C
Technology Transfer should be more than 5% of the yearly budget
Operational Efficiency should be more than B
Economic Cost Reduction should be less than \$ 3 million
Degree of Risk Transfer to Gov. should be less than 10%
Environmental Protection should be more than B
Political (Foreign Shareholders) should be less than 51%
Accountability and Transparency should be more than 90%
Economic Development Benefits should be more than 5%

These acceptance rules are explained as follows:

1. Public and Social Impact should be less than C:

It is important that any decision taken by the government not be harmful to the public, either socially or environmentally. However, in real life it is very hard to find an ideal project without an undesirable cost, but this anticipated cost should not be more than a level D on a scale of A, B, C, D, and F.

2. Technology Transfer should be more than 5% of the yearly budget:

The new company should invest at least 5% of its yearly profit in updating and improving the existing facility.

3. Operational Efficiency should be more than B:

PUMC should utilize the latest technology in the wastewater treatment market by implementing its related software and hardware to improve the efficiency of the plan so that it reaches level B.

4. Economic Cost Reduction should be less than \$ 3 million:

PUMC should work at saving operating costs, which will be allocated on a 60/40 basis between PUMC and the Government.

5. Degree of Risk Transfer to Gov. should be less than 10%:

PUMC should be responsible for any risk resulting from managing, operating the facility, and arranging for financing. The Government is committed to helping up to a maximum of 10 % toward these duties.

6. Environmental Protection should be more than B:

PUMC should be very sensitive and give extra attention to avoiding pollution of the environment. In addition, it should meet the national standards for treated-sewage outlets.

7. Political (Foreign Shareholders) should be less than 51%:

PUMC has the option of being owned by a single Canadian company or by shareholders; however, the percentage of Canadian shareholders should always be more than 51% to protect the interest of local citizens and businesses.

8. Accountability and Transparency should be more than 90%:

PUMC should have its records open for inspection despite being owned by shareholders, except for special cases that do not affect public interest.

9. Economic Development Benefits should be more than 5%:

PUMC should invest at least 5% of its profits in the City of Hamilton.

Once the rules and thresholds values are entered, the DSS assigns a relative weight to each rule as shown in Figure 6.3.

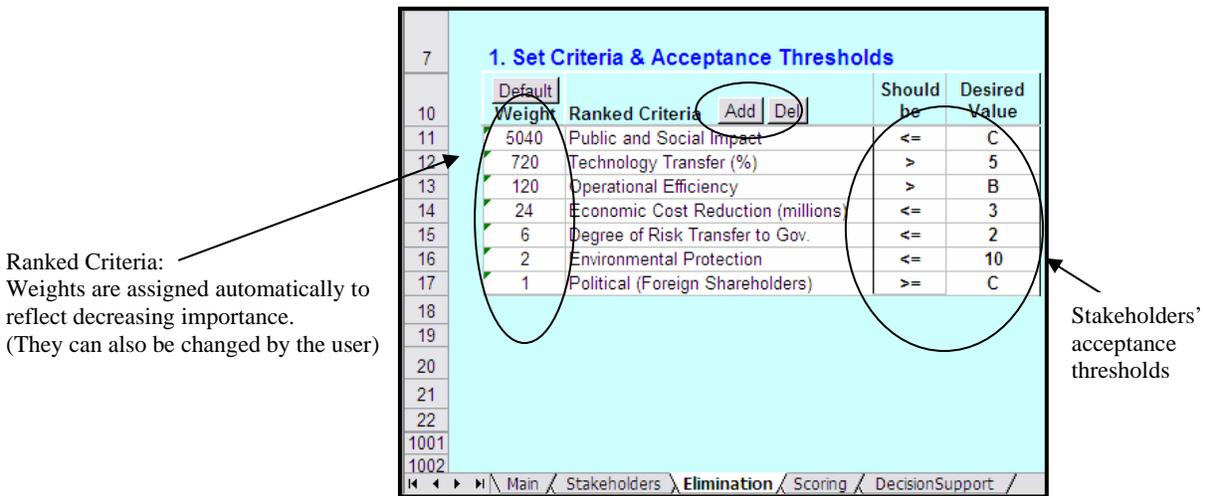


Figure 6.3: Elimination Rules and Threshold Values

Next, the Elimination Method is applied to shortlist the feasible alternatives. Once the acceptance rules are specified, each of the possible solutions is entered with respect to the rules, as shown in Figure 6.4. The values shown in Figure 6.4 are entered for demonstration purposes.

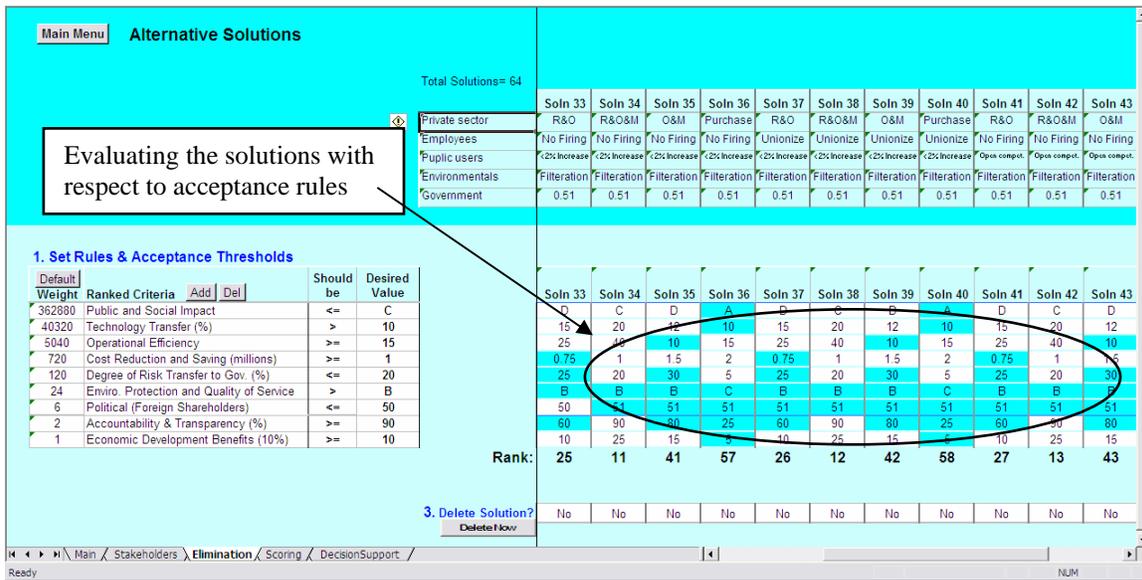


Figure 6.4: Shortlisting Solutions using the Elimination Method

Once the assigned values are entered as shown in Figure 6.4, the program identifies and highlights the failures for each solution. For example, solution 38 (Soln 38) fails with respect to the Sixth and Seventh rules since its level of environmental protection and concern is less than level B, and its foreign ownership of the facility exceeds the threshold rule limits of 49%. Thus, based on the weights of the rules and the evaluation values, the system ranks solutions depending on how many rules are satisfied. For example, solution 40 is almost last in ranking since it violates six rules, and hence it is ranked 63 in the ranking row below.

The next step is for the infeasible solutions to be eliminated (Figure 6.5), thus producing a short list of feasible alternatives. In this example, after elimination, ten solutions are shortlisted, as shown in Figure 6.6.

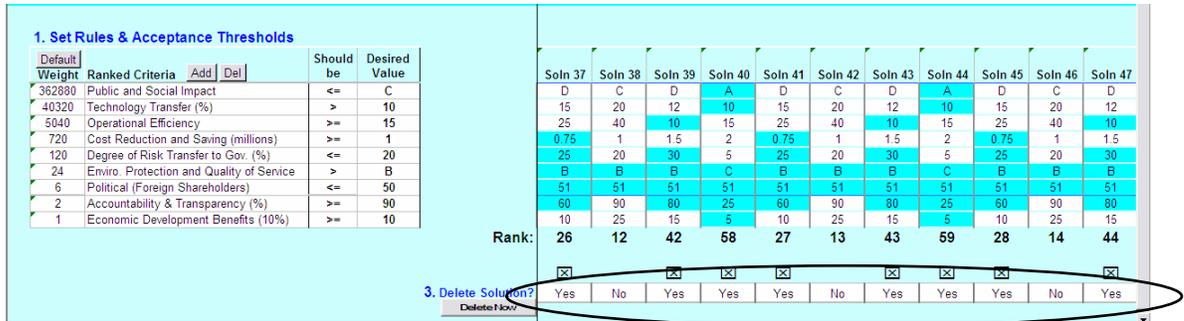


Figure 6.5: Identifying Infeasible Alternatives for Deletion

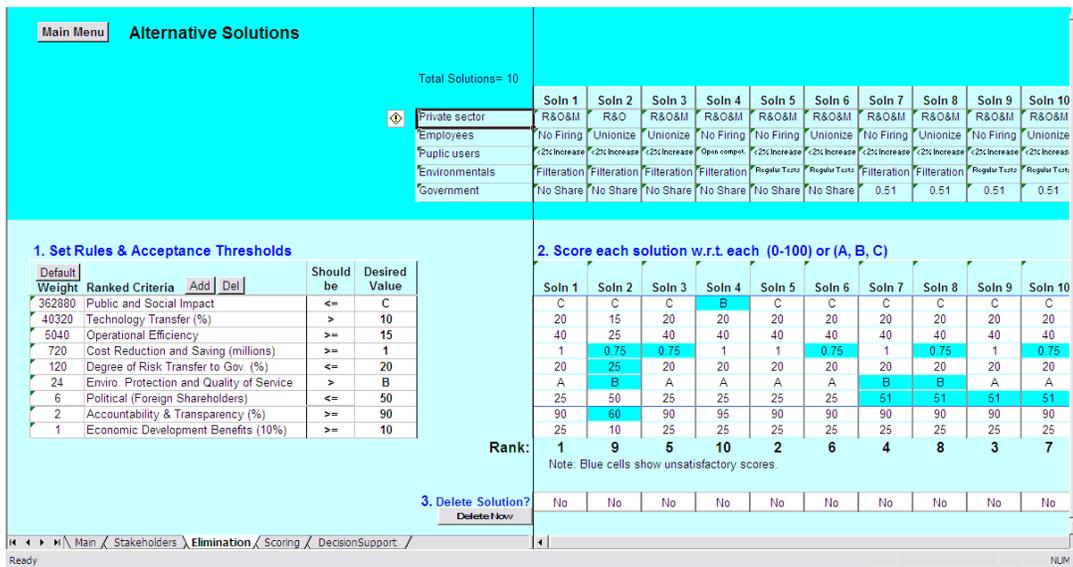


Figure 6.6: Ten Shortlisted Solutions

Step 3: Produce final group decision. After shortlisting the solutions using the Elimination Method, the shortlisted solutions are ready for more detailed analysis, using the simple scoring method of Multi-Criteria Decision Analysis (MCDA) to determine the best solution. This process involves defining the important evaluation criteria and soliciting their relative weights from the stakeholders, as shown in Figure 6.7. The weighting numbers on the left in Figure 6.7 are obtained from a panel of experts (representatives of the various stakeholders) who can be assembled to define the criteria

and assign their weights. The weights represent the relative importance and indicate the relative preference of all parties with respect to the final decision.

1. Set criteria & their weights

Weight	Ranked Criteria	Add	Del
0.2	Efficiency and cost savings		
0.25	Financial risk transfer		
0.1	Operational Efficiency		
0.15	Environmental risk & quality of service		
0.1	Issues of accountability & transparency		
0.05	Impact on worker and the community		
0.15	Economic development benefits.		

Figure 6.7: Specifying Criteria and Their Weights

Once the criteria and their relative weights, which sum to total of 1, are determined, the evaluation process proceeds. In this process, the stakeholders' scores are averaged for each shortlisted solution, with respect to each criterion. As shown in Figure 6.8, scores are assigned on a scale of 1 to 100. For example, in solution 6, the stockholder's options are assigned as follows:

Main Menu Simple Scoring of Alternative Solutions

Total Solutions= 10

	Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7	Soln 8	Soln 9	Soln 10
Private sector	R&O&M	R&O	R&O&M	R&O&M	R&O&M	R&O&M	R&O&M	R&O&M	R&O&M	R&O&M
Employees	No Firing	Unionize	Unionize	No Firing	No Firing	Unionize	No Firing	Unionize	No Firing	Unionize
Public users	<2% Increase	<2% Increase	<2% Increase	Open compet	<2% Increase	<2% Increase	<2% Increase	<2% Increase	<2% Increase	<2% Increase
Environmentals	Filteration	Filteration	Filteration	Filteration	Regular Tests	Regular Tests	Filteration	Filteration	Regular Tests	Regular Tests
Government	No Share	No Share	No Share	No Share	No Share	No Share	0.51	0.51	0.51	0.51

1. Set criteria & their weights

Weight	Ranked Criteria	Add	Del
0.2	Efficiency and cost savings		
0.25	Financial risk transfer		
0.1	Operational Efficiency		
0.15	Environmental risk & quality of service		
0.1	Issues of accountability & transparency		
0.05	Impact on worker and the community		
0.15	Economic development benefits.		

2. Score each solution w.r.t. each criterion (0-100), average of all stakeholders'

	Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7	Soln 8	Soln 9	Soln 10
Private sector	90	50	90	60	90	90	90	90	90	90
Employees	70	60	70	70	70	70	70	70	70	70
Public users	70	90	70	70	70	70	70	70	70	65
Environmentals	65	65	65	55	50	50	40	40	30	40
Government	20	20	20	50	20	20	20	20	10	20
	20	70	20	50	20	20	20	20	20	20
	25	90	35	35	80	90	35	35	30	35

Score: 59 63 61 58 65 67 57 57 54 56

Note: Highest score represents the most favourable solution.

Figure 6.8: Simple Scoring Method

- PUMC will choose the option of R&O&M, as it will be a government investment project with a budget larger than that of R&O alone. Hence PUMC will make a larger profit from renovating the old facility, updating its machinery, and increasing efficiency.
- The Employees will agree to privatization if they have a union representing them, which will eliminate their fear of unemployment due to privatization.
- The Public users appreciate this type of privatization as it guarantees a maximum rate increase of 2% with government approval. Although an open competition may reduce users' future utility bills, there may also be an accompanying sacrifice in quality.
- The Environmental group prefers this privatization alternative since it addresses their concerns. Regular quality tests mean that PUMC will always be scrutinized, and that a red flag will be raised for any violation of the approved environmental standards.
- The Government (RA) likes this option since it will be relieved of this responsibility. As well, it will answer public demands to keep the ownership of the facility in public hands

Table 6.3 The Best Solution and its Options Using Simple Scoring

Stakeholders	Solution 6
Private sector	R&O&M
Employees	Unionize
Public users	<2% Increase
Environmentals	Regular Tests
Government	No Share

As shown in Figure 6.8, the criteria are ranked from most important at the top to least important at the bottom. This ranking can be assumed to have been set by the Government and represents its preferences. In solution 6 for example, the most important issue for the Government is the “efficiency and cost saving” criterion which corresponds to PUMC being able to perform the job and save the Government money. Efficiency and cost saving

are the main problems facing public infrastructure management. Hence, the Government assigned it a score of 90. The second criterion is “Financial risk transfer” because it represents other serious problems facing the local government and indeed most governments around the world, which are budget cuts and emergency financing. The Government assigned a score of 70 to reflect its importance to them. The third criterion is “Operational efficiency”, which scored 70 due to the importance of saving money and providing adequate service. Next, the “Environmental risk & quality of service” criterion scored a value of 50, and the “Issues of accountability and transparency” scored a low value of 20 because the union and the environmental groups will be monitoring PUMC’s performance. Next, the “Impact on workers and community” criterion also scored a low value of 20 due to the existing union, and the absence of foreign ownership and the inclusions of environmental monitoring. The final criterion, “Economic development benefits” has been assigned a high score of 90 as one of the main reasons for outsourcing these facilities is to help the local economy.

As a result of this input, the total score for each solution is automatically calculated using the embedded formulas of simple scoring, and the solution with the highest total score is highlighted as shown in Figure 6.8. Based on these scores, the shortlisted solutions are then ranked as shown in Table 6.4.

Table 6.4 Scores and Ranks of the Shortlisted Solution

Solution	6	5	2	3	1	4	7	8	10	11	9
Score	67	65	63	61	59	58	57	57	56	55	54
Rank	1	2	3	4	5	6	7	7	8	9	10

Solution 6 achieved the highest score of 67, followed by solution 5 and solution 2, etc. The best solution (Figure 6.8) represents the case of R&O&M which is Renovate-Operate-Manage with the stakeholders' preference options as shown in Table 6.5

Table 6.5 Best Decision (Solution) Scores

Weight (w_i)	Criteria	Scores (s_i)
0.2	Efficiency and cost savings	90
0.25	Financial risk transfer	70
0.1	Operational efficiency	70
0.15	Environmental risk & quality of service	50
0.1	Issues of accountability & transparency	20
0.05	Impact on worker and the community	20
0.15	Economic development benefits.	90
		67

The next best solution listed in Figure 6.8 is solution 5 of ROM. It is ranked second due to the employees' stakeholders assigning a lower score for the option of "no firing", thus giving a total score of 65 for this solution. This value is very close to that of the first solution. This narrow gap in score difference explains the need for a different decision selection tool that performs further tests to rank and select the best decisions. Steps 4 and 5 in the next section explain this process.

6.3.2 Decision Making Using Conflict Resolution

In this process, the mechanism of the Graph Mode for Conflict Resolution is used, and the process examines the stability of the solutions with respect to the stakeholders' preferences. The decision support process starts by following the same two steps 1 and 2 described earlier: identifying the stakeholders and their options and shortlisting possible solutions. The process then proceeds to steps 4 and 5.

Step 4: Assigning stakeholders' preferences to Alternative Solutions. In this step, the shortlisted solutions obtained in step 2 using the Elimination Method are transferred to a new spreadsheet as shown in Figure 6.9.

Conflict resolution requires stakeholders' preferences for each solution. These preferences are entered using a numerical scale of 0 to 100 to reflect each stakeholder's point of view.

In the short list, the preference values for the stakeholders were assigned as follows:

Main Menu		Alternative Solutions									
Total Solutions= 10											
	Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7	Soln 8	Soln 9	Soln 10	
Private sector	R&O&M	R&O	R&O&M	R&O&M	R&O&M	R&O&M	R&O&M	R&O&M	R&O&M	R&O&M	
Employees	No Firing	Unionize	Unionize	No Firing	No Firing	Unionize	No Firing	Unionize	No Firing	Unionize	
Public users	<2% Increase	<2% Increase	<2% Increase	Open compet.	<2% Increase	<2% Increase	<2% Increase	<2% Increase	<2% Increase	<2% Increase	
Environmentals	Filteration	Filteration	Filteration	Filteration	Regular Tests	Regular Tests	Filteration	Filteration	Regular Tests	Regular Tests	
Government	No Share	No Share	No Share	No Share	No Share	No Share	0.51	0.51	0.51	0.51	
Preferences		Enter the stakeholders' preferences in the above solutions (0-100 scale).									
Private sector	80	90	80	80	80	80	80	80	80	80	
Employees	65	85	85	65	65	85	65	85	65	85	
Public users	60	60	60	55	60	60	60	60	60	60	
Environmentals	55	55	55	55	80	80	55	55	80	80	
Government	70	70	70	70	70	70	50	50	50	50	

Figure 6.9: Stakeholders' Preferences for Shortlisted Solutions

- **Private Sector:**

- RO: for this option, PUMC assigned a value of 90, since renovating the facility will increase the contract volume, and hence increase the company's profit.

- ROM: for this option, PUMC assigned a value of 80. Despite receiving a high score, this option falls below the RO score because PUMC wishes to avoid any future complaint from the public or the government about mismanagements.

- **Employees:**

- No Firing: despite the security associated with the promise of “no firing”, which has convinced the employees to assign 65 points for this option, other employees’ rights are not guaranteed. The company may force the employees to multitask rather than hire new employees. On the other hand, a union may guarantee these and other future benefits for its members.

- Unionization: the employees prefer this option even if no permanent employment is guaranteed. Furthermore, the local population will increase in the future, and hence the plant capacity must increase, which will lead to greater job security. The union will also protect employee’s rights, so they have assigned 85 points for this solution.

- **Public Users:**

- 2% increase: The public users have two preferred options. The first is a maximum increase in fees of 2% per year. Public users assigned this option a score of 60, which reflects the fact that any increase is not appreciated; however, it is better than the second option of “Open competition” which may drastically lower the service quality.

- **Environmental Groups:**

- This group has two options, “Filtration” and “Regular Testing”. They assigned a score of 55 to filtration, since they believe that the new filtration system will yield a well-defined outlet quality. However, due to past experience with large corporations, not to mention the Ontario Walkerton Tragedy, the Environmental group would prefer to have regular test

reports by independent parties. PUMC will then automatically be forced to have reliable filtration systems. Accordingly, they assigned a score of 80 to “Regular Testing” .

- **Government (Hamilton Municipality, RA)**

- The government has two preferred options in these shortlisted alternatives. The first option is “No Share” for foreigner investors. In this case, PUMC must remain purely Canadian, since it manages a vital facility serving a Canadian population. The second is “51%”; that is, no foreign shareholder has the right to have more than 49% of the PUMC, thus, retaining an effective influence over operation and decisions. Therefore, the RA has assigned a higher score of 70 to the option of a Canadian-controlled PUMC and assigned a lower score of 50 to the option involving foreign shareholders. Yet the two scores are not as disparate as one may readily expect, so it is plausible that the government is taking a neutral but decided stance.

Based on the entered preference information, the alternatives and their option scores are listed as shown in Figure 6.9. For example, the column for solution (Soln 2) in Figure 6.9 shows the point of view of the employees as a preference value of 85, indicating their full support for project unionization to protect their jobs and interests. However, the Government are in a neutral position regarding the percentage of foreigner stakeholders having 51% of the ownership of the project The reason for this position is probably that the Government does not want to discourage foreign investors from contributing to the

local economy, but they also do not want to upset the local voting public by selling a national asset to foreign entities.

Once the preferences are specified, the program examines and compares the shortlisted solutions using the stakeholders' payoff (preferences) values. Utilizing the conflict resolution analysis that involves the stability analyses of Nash, GMR, SMR, and SEQ, it determines the best solutions. The best decision is the one that achieves the highest number of equilibria as shown in Figure 6.10. In this case study, solution 6 (ROM) is chosen as the best decision because its total score is 24166 and stability equilibrium was accomplished in the Nash, GMR, SMR, and SEQ stability tests.

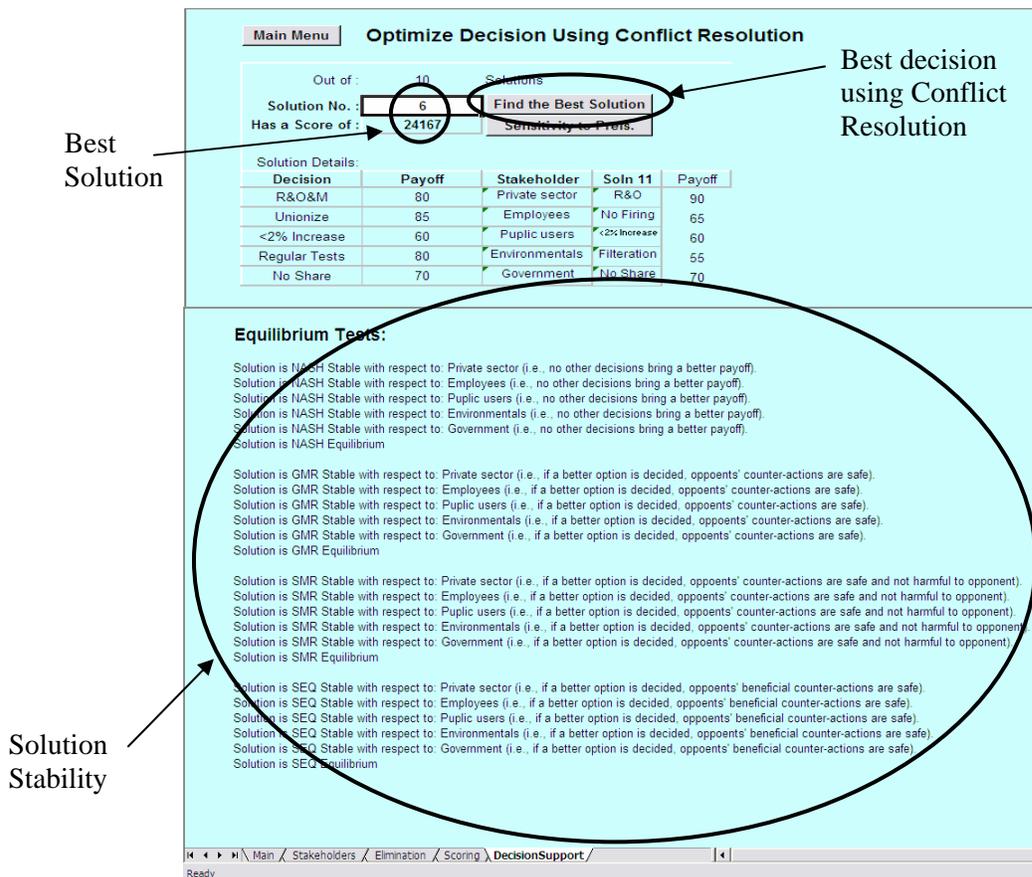


Figure 6.10: Decision Optimization Using the Conflict Resolution Approach

Step 5: Accounting for uncertain information: In this step, uncertainties are assumed about the stakeholders' preferences due to the associated ambiguity. These uncertainties could have resulted from unexpected future results of the projects, previous experience, or public hesitation about the private sector in fulfilling its promises. The program uses Info-gap Theory to furnish the user with the ability to optimize the results to produce decisions. The robustness of the best decisions is then calculated according to the stakeholders' preferences in calculating the solution stability in the Graph Model for Conflict Resolution.

For this case study, the stakeholders are certain about their goals and preferences. For example, the private sector is certain about their preferences and expected benefits, and the government is certain about its own budget preferences and the final privatization decision. Other DMs or stakeholders, on the other hand, may not be certain about their preferences. For example, the public users may not trust the private sector to run an important facility. In this case, the DSS is capable of using the info-gap Theory to test the solution's robustness in the presence of the uncertainty associated with each stakeholder's preferences.

For the Hamilton case study, Table 6.6 lists the percentage of the assumed uncertainty for each stakeholder.

Table 6.6 Uncertainty for the Stakeholders

DM	Uncertainty %
Private Sector	5
Employees	40
Public Users	30
Environmental Group	20
Government	5

The Private Sector (PUMC) had 5% uncertainty in their preferences. The Government also assigned a value of 5% uncertainty to their preferences. Hence PUMC and the government are both very certain about their own budgets and final goals. However, the Employees assigned a high value of 40% uncertainty to their preferences, showing that they do not trust the privatization. In contrast, the Public Sector assigned a 30% uncertainty to their preferences. The Public Sector is happy about any decision leading to a reduction in the government deficit; however, they still have doubts about PUMC's goals in taking over a facility from the government. Environmental group assigned a 20% uncertainty to their preferences, since they believe that the private sector is always capable of finding a way to accumulate profit and escape strict regulations. It should be noted that the uncertainty values for the preferences would be collected from a panel of selected experts as well as from a questionnaire distributed to the stakeholders and their representatives.

As shown in Figure 6.11, these values are entered, and 100 are requested in the dialogue box. The DSS is then committed to performing 100 experiments. In each experiment, new values for the uncertainties of the preferences are randomly selected from within a specified uncertainty range (\pm a value). For example, the DSS carries out 100 experiments that consider uncertainty values within the range of \pm (20) for the Environmental group, and so on. The DSS then runs the required experiments to test and identify the most robust decisions and presents the results in the form of a histogram graph. In this case study, two histogram graphs are presented, one with a value of 71 and the other with a value of 29, as shown at the top of each histogram. The results show that 71% of the experiments

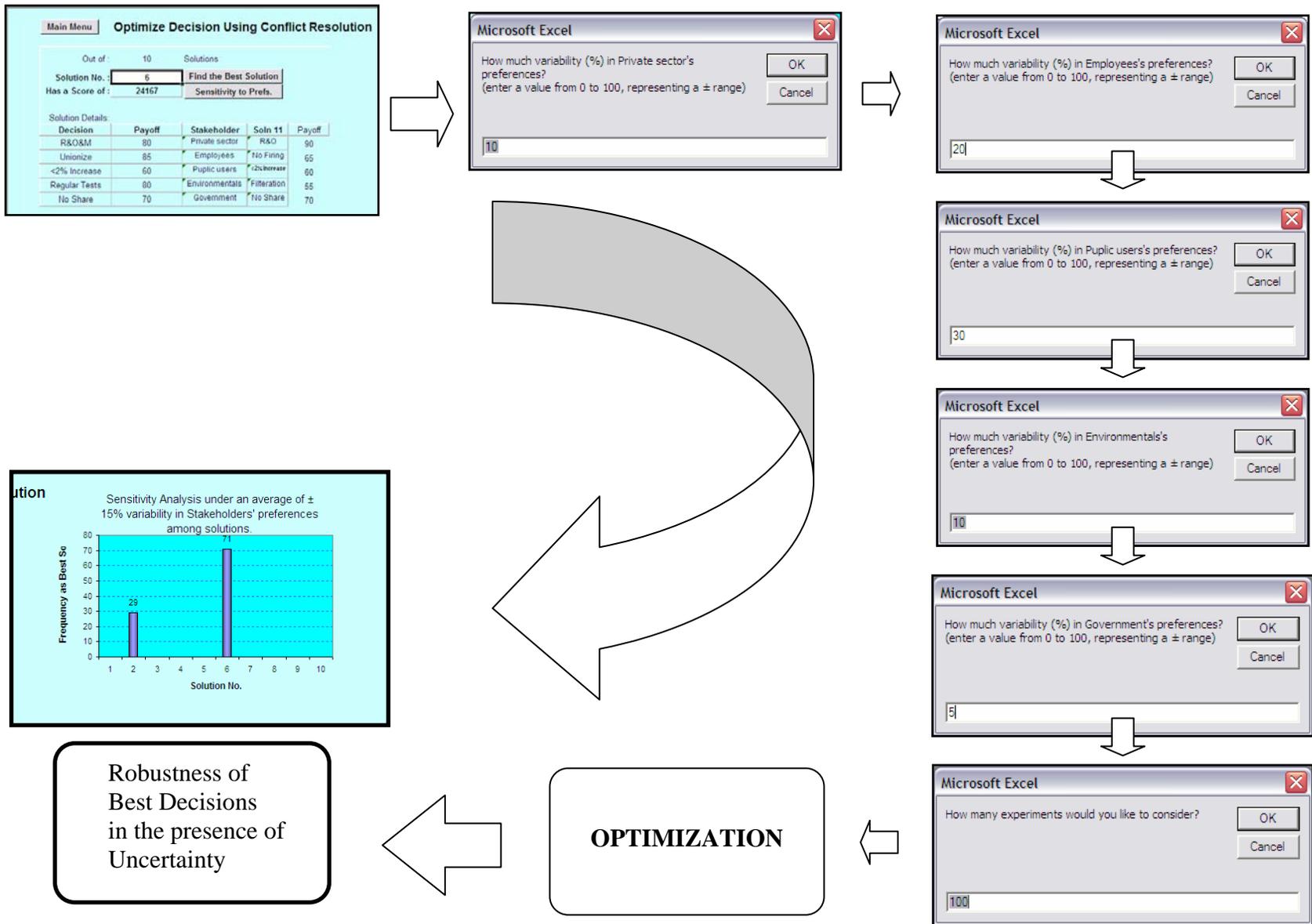


Figure 6.11: Testing the Robustness of the Best Decisions in the Presence of Uncertainty

identified solution 6 as the best solution, followed by solution 2, which was selected as the best solution in 29% of the experiments.

The technique of conflict resolution analysis, together with Info-gap Theory has again identified decision solution 6 (ROM) as the best solution with the best robustness. It clearly reflects its stability and the satisfaction of all stakeholders, as shown in Fig 6.12.

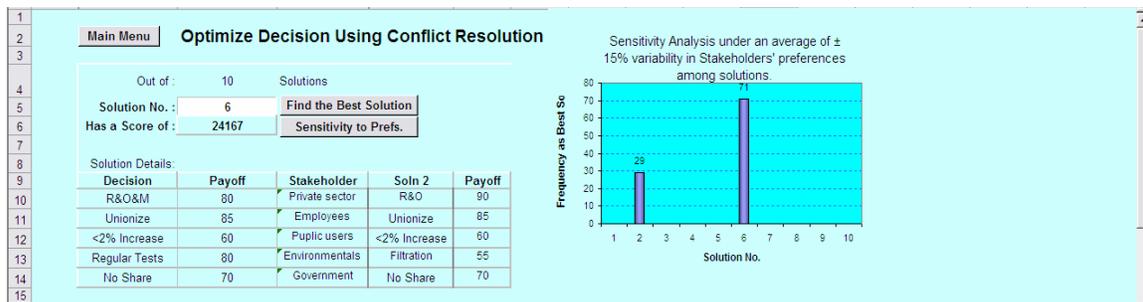


Figure 6.12: Robustness of the Optimum Decisions

Once the best PPP option is selected, the next step in the decision process starts by inviting well-known companies or consortiums to submit their proposals and experience. The best-qualified company based on the threshold rules specified earlier can then be selected to draft a full comprehensive contract as shown in the process depicted in Figure 6.13

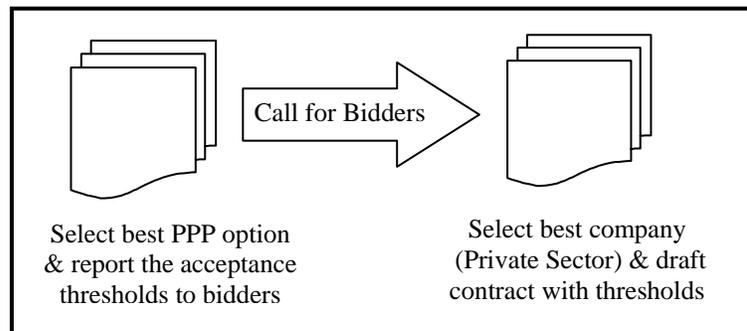


Figure 6.13 Privatization Decision Process

6.4 Discussion of Results

The developed prototype DSS makes possible a comparison and evaluation of various privatization alternatives. A large problem such as the Hamilton Wastewater Treatment Plant project could be analyzed and its 64 alternatives reduced to only ten feasible solutions, from which the best solution was chosen.

The results of using two different decision-making approaches, simple scoring and conflict resolution, show that both approaches are useful to the decision maker. Figure 6.12 shows that once the shortlisted privatization alternatives are available, both approaches determine solution 6 “Renovate-Operate-Manage (ROM)” to be the best decision, better than the failed decision of “Operate and Manage (OM)” actually made by the Government. However, despite its success in selecting the best decision, the simple-scoring method has drawbacks. It listed other solutions with close-to-best solution scores, which may easily mislead the DM(s), particularly if slight changes are made in the weight values. These slight changes can easily push up the second or third best solutions in the ranking list and hence move the genuine best decision down.

Using the conflict resolution approach together with Info-gap Theory also led to solution 6 as the best decision. This solution is “Renovate–Operate–Mange (ROM)”, which is characterized by unionization, less than 2% annual rate increase, regular quality testing of facilities and product, and no share for foreign investors. The solution score of 24167 was successful in meeting the four stability concepts of Nash, GMR, SMR, and SEQ. In addition, the solution achieved a high robustness value of 71% in uncertainty testing,

compared with 29% achieved by the second best score (solution 2). The robustness test was useful in indicating the stability of the solutions, which is not easily possible using the simple scoring method.

The advantages of using the elimination method of an MCDA tool in the prototype system were clearly noticeable. In this case study, with 5 stakeholders, 7 criteria, and 9 acceptance rules, the number of possible alternatives was quite large (64 decision alternatives). However, that number was dramatically reduced to ten feasible alternatives by using the elimination method of MCDA for screening.

Figure 6.12 shows the two solution alternatives for the privatization of the Hamilton wastewater Treatment Plant that were suggested by the developed DSS. Figure 6.8 shows the best decision available through the use of a simple scoring method. The results shown in both figures (ROM) differ from the real-life decision of OM, taken by the RA. The differences may be due to the following factors:

- The developed system uses a systematic approach to analyze and specify all the stakeholders' preferences and their rules, while apparently the decision made by the RA did not involve an organized procedure.
- There are no specific threshold rules or guidelines to show how the RA selected a short list of potential alternatives.
- There are no standard guidelines or methods for the project staff to use in choosing and evaluating a private sector company to take over the facility.
- Accurately defining the possible scores of the acceptance rules, criteria and

- preferences (using a 0-to-100 scale among various options) greatly affected the rankings of the prospects and hence solidified an effective final decision.
- The optimum final decision of ROM (Figure 6.12) is very different from the actual decision of OM, because of the addition of the task of renovating the old facility. In addition, it considered the preferences of all stakeholders and not just those of two of them: the RA and PUMC.
 - All the possible alternative decisions selected by the DSS share the option of renovating, showing that the OM decision taken by the RA was not optimal.
 - Part of the actual failure of the real-life project was due to the exclusion of renovation regardless of the skills and capability of the private sector.
 - Accordingly, consideration of the current condition of the utility must be part of any decision related to infrastructure outsourcing and should be included in any future research.

6.5 Summary

In this chapter, a case study for the real-life project of the Hamilton Wastewater Treatment Plant was used to demonstrate the capabilities of the developed prototype decision support system (DSS) in choosing the best privatization alternative. The case study showed the ability of the DSS to generate optimum privatization alternatives that suit different stakeholders' preferences and values, while considering the robustness of the solution and the uncertainties involved. Two decision-making processes were utilized in the DSS procedure: First, the Group decision making using the simple scoring method. Second, the

decision-making process using conflict resolution. Both processes were successful in identifying the optimum decision.

The main limitation on the case study is that the test data are relatively limited, and although Loxely's (1999) report about the Hamilton Wastewater Treatment Plant did provide historical information that was beneficial for validation testing, more case study details would enable a more comprehensive analysis. This limitation resulted from three main factors: 1. The field of PPP projects is relatively new in many countries, so there are limited implemented cases; 2. Within this field, data from the public sector is considered sensitive and confidential; and 3. For the case study of Hamilton, in particular, is subject to extra confidentiality because of the outstanding litigation regarding this case.

CHAPTER 7

CONCLUSIONS

7.1 Overview

This chapter presents a review of the contents of this study as well as a summary of its conclusions. It also highlights recommendations and suggestion for future studies regarding the construction conflict and infrastructure privatization decisions.

The research developed a practical and efficient methodology for infrastructure privatization decisions and conflict resolution in construction projects. The developed decision support system (DSS) methodology can be used to consider all stakeholders' preferences and to support decisions related to construction conflicts and infrastructure privatization.

A thorough analysis of the characteristics of the problem and the procedures that decision makers use in the field of infrastructure privatization and construction conflict resolution was performed along with a study of the diverse tools that can be used to support decisions. A new decision support methodology was then developed by integrating the Elimination Method for MCDA, the Graph Model for Conflict Resolution, Genetic Algorithms for large-scale optimization, and the Info-gap Theory for uncertainty analysis.

The integrated decision-making process methodology has been demonstrated to work effectively on the example applications of two case studies: a construction conflict resolution and an infrastructure privatization decision. The developments made with respect to both of these decisions demonstrate the benefits of combining different intelligent concepts to utilize their individual capabilities of producing good solutions. The result is a DSS with a prototype capable of handling and solving large-scale, practical, complicated infrastructure and construction problems. Two decision-making processes were utilized in the system: Group decision making using simple scoring and decision making using conflict resolution. The methodology may contribute to current automation efforts in infrastructure and construction management decision-making by linking the developed system to a comprehensive decision making system capable of handling all construction and infrastructure management issues such as planning, scheduling, dispute resolutions, and asset management. The main characteristics of the developed methodology that make it an efficient tool for decision making in construction and infrastructure management include the following:

- It applies to any user-defined Multiple Criteria Decision Making (MCDM) problem and is not limited to a privatization decision or construction conflict resolution decision.
- The Elimination Method proved to be efficient in screening feasible alternative solutions with little subjectivity, which adds to the clarity and strength of the final decisions.
- It permits the use of a wide range of numerical and alphabetical scales that can describe precisely the quality of a solution.
- It works for either consequences or values of the criteria.

- It incorporates a powerful Graph Model for Conflict Resolution to study the actions and counter-reactions that take place in disputes.
- It examines the stability of solutions by using the stability concepts of Nash, GMR, SMR, and SEQ tests to reach a final decision equilibrium.
- It uses Info-gap Theory to provide direct help in testing and choosing the best decisions in the case of uncertainty in the stakeholders' preferences, thus automatically evaluating the strength and robustness of the decisions.
- The decision process accommodates input from various decision-making groups, thus helping the decision makers to accommodate diverse judgments.
- It has been implemented on a spreadsheet program that practitioners in infrastructure and construction management are accustomed to using.
- It enables the user to run a what-if analysis at different stages of the decision process.

A study of the results of the two case studies shows that the proposed DSS can satisfactorily be used to support decisions with respect to both construction conflicts and infrastructure privatization. The developed system is simple to apply and can therefore save time and avoid the costs associated with wrong decisions.

7.2 Contributions

The developed framework is expected to help in re-engineering the traditional conflict resolution process, particularly for construction conflict resolution and infrastructure privatization decisions. The framework provides decision support at the management level through four successive decision support processes related to: 1. Screening of feasible

solutions using MCDA, 2. Group decision making using the simple scoring method, 3. Decision making using conflict resolution, and 4. Considering of uncertainty in preferences using Info-gap Theory.

The model developed in this research is expected to provide the following important contributions:

1. It acts as a proposal-selection guide that helps the public and private sectors to select various criteria for evaluating and selecting the best privatization alternatives.
2. It is a DSS tool that can provide decision advice in two systematic ways of group decision and conflict resolution.
3. It can save decision makers in the public sector a great deal of time and effort.
4. It encourages the private sector to bid on projects by providing a clear and fair selection process in a competitive fashion.
5. It introduces a powerful yet simple tool that can deal with both quantitative and qualitative criteria.

In addition, this study introduces knowledge and experience related to infrastructure privatization decisions and construction conflicts. The field practice regarding decision-making methods normally used by governments has been reviewed and compiled, and information related to construction conflict resolution has been included as well. Despite confidentiality and the difficulties associated with obtaining the required information and data, the author was able to build a practical case study to mimic real-life case scenarios.

This research has also made a number of specific contributions within the individual modules of the system:

1. Screening of Alternatives: The proposed methodology of listing and screening all possible alternatives for various stakeholders' strategies to shortlist feasible alternatives is very useful, due to the powerful and practical nature of the Elimination Method in dealing with cardinal and ordinal values as well as consequences and values. These results are possible because the acceptance rules used by the Elimination Method screen out all defective alternatives, remove any subjectivity, and improve the accuracy of assessing the shortlisted alternatives. This process also results in speeding up the decision-making process and makes the system suitable for less-experienced individuals to use. In addition, a new approach for using the preference tree decision in MCDA based on the option prioritization idea is presented.

2. Conflict Resolution Technique for actions and counter-actions: A new decision-making system is presented not only to support a simple ranking decision, but also to choose the best decision based on the solution stability concepts of game theory. The technique utilized the main stability concepts used in the Graph Model for Conflict Resolution to test the best solution stability and determine the maximum equilibrium using the Nash, GMR, SMR, and SEQ stability tests based on the stakeholders' preference payoffs. This technique will further eliminate subjectivity from future decisions analyzed by this DSS. In addition, when a large number of feasible solutions exist, a GA-based optimizing methodology can be used to optimize decisions, as demonstrated in Chapter 4.

3. Uncertainty and Risk Management: The presented model for infrastructure privatization and conflict resolution in construction is capable of determining the best overall

decisions given the presence of uncertainty that may associated with the stakeholders' preferences and values. This feature will help decision makers to avoid future risk and to deal realistically with the problem at hand. The formulation of the Info-gap Theory technique is simplified for the average user, so all the mathematical procedures are hidden. A simple histogram graph is used to illustrate the final best decisions and their robustness. Real life contains many uncertainties, especially with respect to a unique case study. For example, differences could result from the facility functions and conditions, from the type of stakeholders and their preferred options, and from government agendas and policies. These and others factors will produce enormous hesitation for stakeholders when they are listing their preferences. Hence, no one will assign 100% support for any decision. Therefore, using this technique to deal with these uncertainties is useful and practical.

In addition to the above contributions, this thesis has successfully structured a comprehensive DSS for resolving construction conflicts and supporting infrastructure management systems. Although the focus has been on a wastewater treatment plant privatization decision, the proposed system can easily be adapted to other types of infrastructure privatization decisions such as those related to highways, power plants, airports, and hospitals. The proposed research is expected to aid engineers, project managers, and decision makers both in the private sector and in public sector, municipalities and government agencies to make appropriate decisions that will ensure the sustainable operation of the infrastructure assets with the least cost and optimum operational conditions.

7.3 Recommendations for Future Work

Despite the capabilities and benefits of the developed DSS for infrastructure privatization decisions and construction conflicts, it has limitations, and a number of improvements would be beneficial:

- Add a fourth module to assess the current condition of the facility to be privatized. Such a module will help the government and the private sector make better estimates and better PPP decisions.
- Add a fifth module for costing and budgeting as a main step for the government when it is deciding whether to privatize.
- Add a sixth module for the private-sector selection procedure using available tools, such as the Analytical Hierarchy Process (AHP) for selecting a qualified contractor.
- Examine the applicability of the DSS for other types of infrastructure assets and determine improvements that would allow more generalized use.
- Build a privatization library that contains information about previous privatization experiences, history, criteria, successes, and failures. In addition, compile another historical library about private-sector participation in the business domain, which would contain information about the company's reputation.
- Incorporate other factors in conflict resolution that reflect human behaviour in conflicts, such as emotion and attitudes. For example, some people are calm and simple to deal with in conflict, while others are hard negotiators and easily become angry and make harsh decisions.
- Introduce changes to the uncertainty test algorithm formulation to speed up the procedure.

- Create an Internet application from the current system to enable multiple users to benefit from the system.
- Consider the cost of delays due to disputes in construction projects or due to wrong decisions in infrastructure privatization processes.
- Conduct an extensive investigation of the construction industry to cover all types of conflicts raised in construction projects and their method of solution based on site practicality.
- Expand the DSS to handle situations in which not all options are mutually exclusive.
- Besides weighting, expand the system to include option prioritization for both Group decision and Conflict Resolution process.

It is believed that the developed model will make the decision process clear, transparent, and easy to track for all parties. These advantages will likely help decision makers in both the public and private sectors make better decisions about selecting Public-Private-Partnership alternatives and will encourage the private sector to bid with competitive prices. Furthermore, the model will help project managers find the best resolution of conflicts in the construction industry.

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