Preference Elicitation in the Graph Model for Conflict Resolution

by
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Abstract

Flexible approaches for eliciting preferences of decision makers involved in a conflict are developed along with applications to real-world disputes. More specifically, two multiple criteria decision making approaches are proposed for capturing the relative preferences of a decision maker participating in a conflict situation. A case study in logistics concerned with the conflict arising over the expansion of port facilities on the west coast of North America as well as a transportation negotiation dispute are used to illustrate how these approaches can be integrated with the Graph Model for Conflict Resolution, a practical conflict analysis methodology.

Ascertaining the preferences of the decision makers taking part in a conflict constitutes a key element in the construction of a formal conflict model. In practice, the relative preferences, which reflect each decision maker's objectives or goals in a given situation, are rather difficult to obtain. The first method for preference elicitation is to integrate an Analytic Hierarchy Process (AHP) preference ranking method with the Graph Model for Conflict Resolution. The AHP approach is used to elicit relative preferences of decision makers, and this preference information is then fed into a graph model for further stability analyses. The case study of the Canadian west coast port congestion conflict is investigated using this integrated model.

Another approach is based on a fuzzy multiple criteria out-ranking technique called ELECTRE III. It is also employed for ranking states or possible scenarios in a conflict from most to least preferred, with ties allowed, by the decision maker according to his or her own value system. The model is applied to a transportation negotiation dispute between the two key parties consisting of shippers and carriers.

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Finally and most importantly, I am truly grateful to my family – my parents and my husband. They provided me with generous support during all of these long and special days.

Dedication

This thesis is dedicated to Enlong Ke and Xinqing Wang, my beloved parents.

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Introduction

A strategic conflict is a decision situation in which two or more decision makers (DMs) are in dispute over some issue. One can employ the Graph Model for Conflict Resolution (GMCR) (Fang et al., 1993) to investigate a real-world conflict situation by following the two main phases consisting of modeling and analysis. As a simple but flexible methodology, GMCR is designed to analyze conflicts arising from a wide range of areas, such as environmental management, labor-management negotiations, military strategies, and peace-keeping activities, to name a few (Kilgour and Hipel, 2005). The graph model facilitates interested parties to put complicated strategic decision problems into perspective and attain a better understanding about the current situation as well as envisioning potential resolutions (Fang et al., 1993). Of all the information required for GMCR, consisting of the DMs, each DM's options or courses of actions, and each DM's relative preferences over all feasible outcomes, preference information is the most important and sensitive input for calibrating a conflict model and subsequently carrying out a stability analysis. Each DM's relative preferences reflect his or her objectives or roles under a given conflict situation.

1.1. Motivation of the Research

In practice, quite often, DM's relative preferences are not easy to obtain. The objective of this research is to develop new approaches to elicit preference information reflecting diverse values or criteria of a given DM for ranking states, and thereby, expanding and enriching preference elicitation approaches for employment with GMCR. More specifically, two approaches are considered in this thesis: 1) an integrated Analytic Hierarchy Process (AHP) (Saaty, 1980, 1982, 2001) preference ranking method and 2) a three-layer hierarchical structure based on ELECTRE III (Roy, 1968, 1989, 2005) and fuzzy logic (Zadeh, 1965, 1973). The first method is to integrate a modified AHP preference ranking method with the Graph Model for Conflict Resolution. The AHP approach is used to elicit relative preferences for decision makers, and this preference information is then fed into a graph model for further stability analyses. First introduced by De et al. (2002) and Fu (2003), the second approach is based on a fuzzy multiple criteria out-ranking technique called ELECTRE III. It is also employed for ranking states or possible scenarios in the conflict from most to least preferred, with ties allowed, by the decision maker according to his or her own value system.

Another key motivation is to apply the proposed approaches to real-world disputes. The Canadian west coast port congestion problem is investigated in this thesis by employing the first approach. The strategic analyses carried out in this research suggest that Canada should expand port facilities at various locations, thereby, encouraging traders to continue choosing the Canadian west coast as one of their major trade gateways to North America. Additionally, a transportation negotiation problem between the two key parties, shippers and carriers, is used to illustrate how to implement the second approach. Detailed descriptions are furnished in Chapters 4 and 5.

1.2. Outline of the Thesis

As shown by Figure 1.1, this thesis consists of four main stages: problem descriptions, methodology overviews, proposed approaches and applications, as well as conclusions and future work. Remaining chapters are organized as follows.

Some basics of GMCR are presented in Chapter 2, including essential ideas, major components, stability definitions and related analyses, as well as the associated decision support system (DSS), GMCR II. In the Chapter 3, the basic ideas underlying multiple criteria decision making (MCDM) and some typical techniques are introduced, with an emphasis on AHP and ELECTRE. Chapter 4 adapts an AHP approach to elicit relative preferences for decision makers, and this preference information is then fed into a graph model for further stability analyses. The case study of the Canadian west coast congestion problem is used to illustrate how to implement this approach in practice. Chapter 5 addresses a three-layer hierarchical analysis model, based on the out-ranking method, ELECTRE III, for relative reference ranking in GMCR. The case study of a transportation negotiation conflict is employed to demonstrate its use. The thesis concludes with some remarks, as well as a summary of contributions and suggestions for future work.

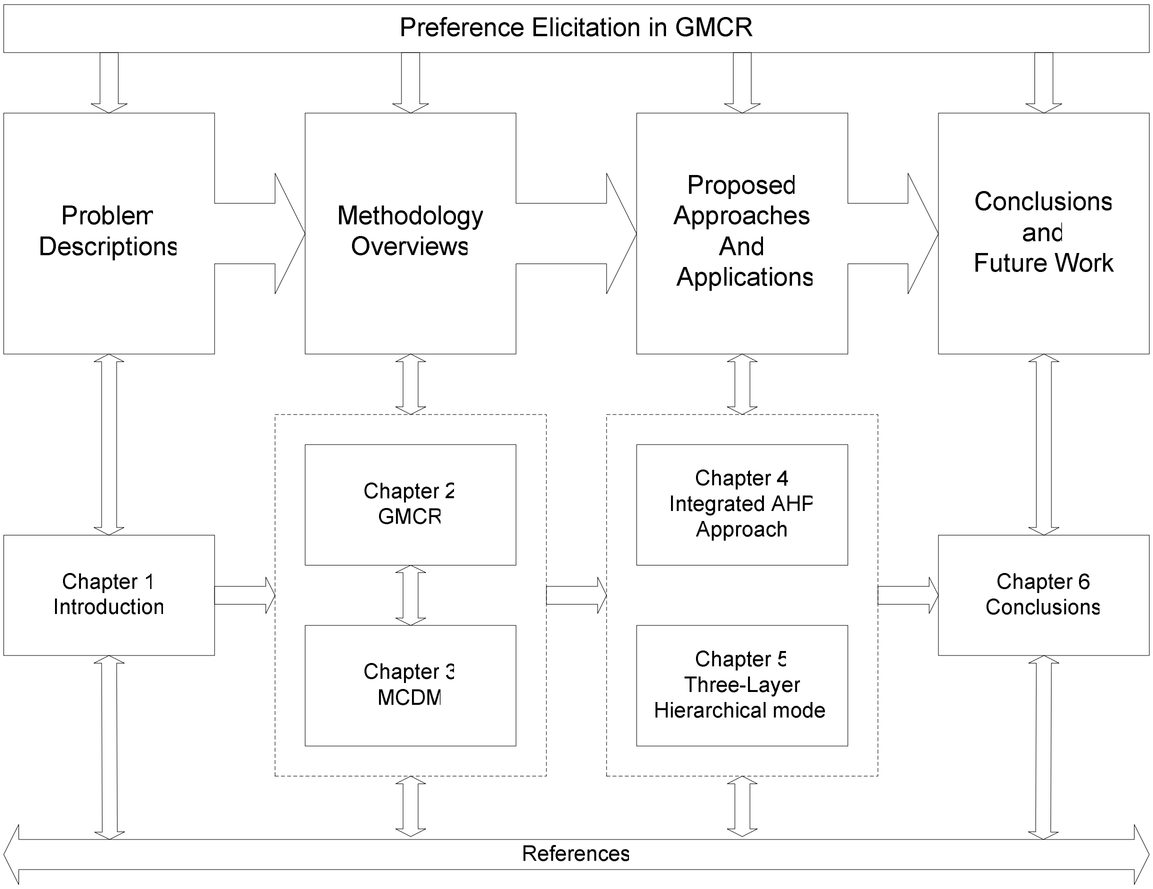


Figure 1.1 Organization of the thesis.

2

The Graph Model for Conflict Resolution

Conflicts could happen any time and anywhere in the real world. Conflict models are designed to approximate reality and systematically structure the essential components of a given dispute (Fang et al., 1993). The main motivation of GMCR is the demand for a comprehensive methodology to understand conflict decision-making and conflict resolution, since other competing methods fail to provide the required kind of analysis and advice (Kilgour and Hipel, 2005). The graph model is designed to be simple and flexible, as well as to have minimal requirements of information.

The original idea of GMCR is introduced by Kilgour, Hipel and Fang in 1987 while the first complete presentation is furnished by Fang, Hipel and Kilgour in 1993. GMCR has been applied to a wide range of application areas: from environmental management to labour management; from military and peace-keeping activities to economic issues; from local to international levels (Kilgour and Hipel, 2005).

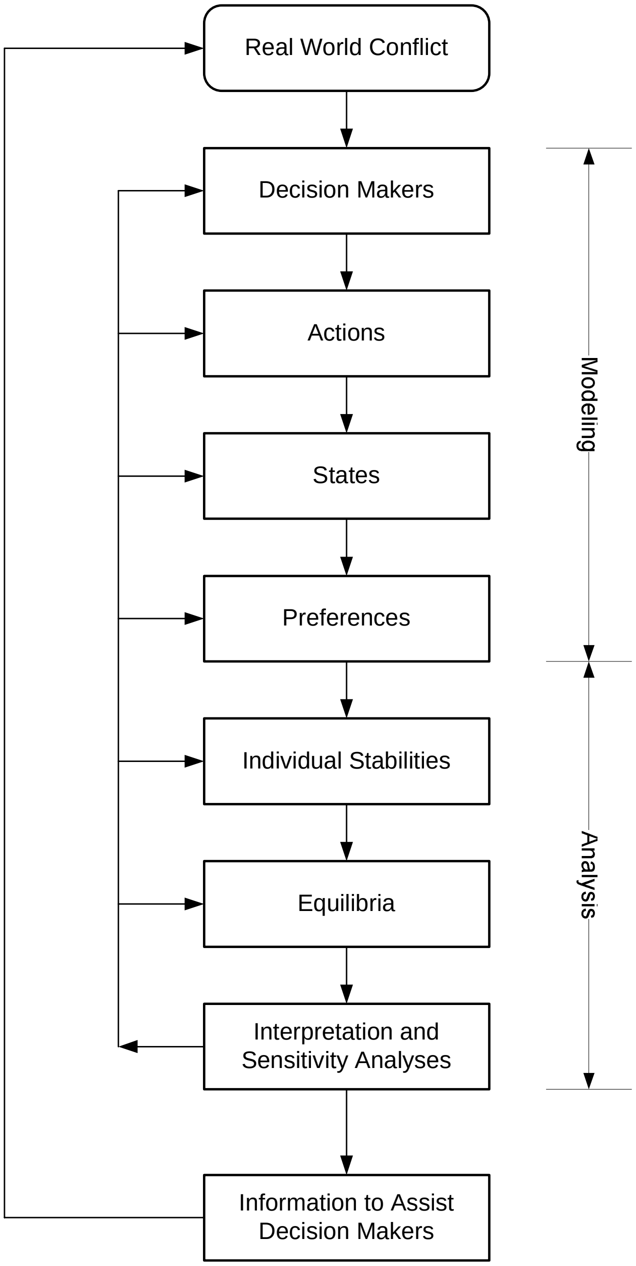


Figure 2.1 General Procedures for applying GMCR (adapted from Fang et al. (1993)).

Figure 2.1 illustrates the general procedure for applying the methodology of GMCR to a real-world conflict. Two main stages, modeling and analysis, are involved in this procedure. In the modeling stage, essential model elements, such as the decision makers (DMs), their options, and the relative preferences, are identified based on the understanding of the actual dispute. States are derived from the given options. Then this information is fed into the next stage: analysis. In this stage, the stability of every state is first calculated from each DM's viewpoint. Subsequently, the overall equilibria, which contain the states that are stable for all DMs, can be obtained. By interpretation and sensitivity analyses, DMs or other interested parties can understand the meaning of resolutions in terms of the real-world disputes. Note that feedback is allowed in the procedure. Feedback means that, at every step of the modeling or analysis stage, one may return to any previous point whenever new information is found. This characteristic makes GMCR more flexible and practical.

In the upcoming subsection, a famous conflict called Prisoner's Dilemma is used to explain some basic ideas about game theory. This same application is then employed to introduce modeling and analysis stages in the Graph Model for Conflict Resolution, followed by an overview of the associated decision support system, GMCR II.

2.1. Basic Concepts

2.1.1. Traditional representations of a game

Generally, DMs are referred to as players in game theory (GT). In this section, a classical simplified two-player game example, Prisoner's Dilemma, is employed to illustrate the basic ideas of a standard GT model. This game comes from a story about two suspects involved in a crime, who are held for questioning in two separate cells. There is enough evidence to convict each of them of a minor offense, but not the major crime unless one of them finks against the other (Osborne, 2003). In this case, players (DMs) are obviously the two suspects. Each of them has an action set of {Quiet (Q), Fink (F)}. Hence, four possible states can be formed on the basis of two suspects' conflict decisions:

1) (QQ) – Both suspects choose to keep quiet. Then both of them will be convicted of the minor offense and spend one year in prison.
2) (QF) – Suspect 1 keeps quiet and suspect 2 finks. Then suspect 2 will be freed and used as a witness against suspect 1; suspect 1 will spend four years in prison.
3) (FQ) – Suspect 2 keeps quiet and suspect 1 finks. Then suspect 1 will be freed and used as a witness against suspect 2; suspect 2 will spend four years in prison.
4) (FF) – Both suspects fink, then each will spend three years in prison.

Correspondingly, suspect 1's preference, from best to worst, is (FQ), (QQ), (FF), and (QF). Suspect 2's preference is (QF), (QQ), (FF), and (FQ). Let $P_1(\text{FQ}) = 4$, $P_1(\text{QQ}) = 3$, $P_1(\text{FF}) = 2$, and $P_1(\text{QF}) = 1$ denote the payoffs for suspect 1; as well as $P_2(\text{QF}) = 4$, $P_2(\text{QQ}) = 3$, $P_2(\text{FF}) = 2$, and $P_2(\text{FQ}) = 1$ denote the payoffs for suspect 2. Table 2.1 depicts Prisoner's Dilemma in normal form. The rows of the matrix represent the available strategies of suspect 1 and the columns the strategies of suspect 2. Each possible state is represented by a cell of the matrix, where the first entry represents the payoff for suspect 1 and the second for suspect 2.

Table 2.1 The Prisoner’s Dilemma in Normal Form

		Suspect 2	
		Quiet (Q)	Fink (F)
Suspect 1	Quiet (Q)	(3,3)	(1,4)
	Fink (F)	(4,1)	(2,2)

Intuitively, each suspect is willing to move unilaterally from a low preference to a higher one. Therefore, in Table 2.1, suspect 1 would only like to move from top to bottom and suspect 2 would only like to move form left to right. Based on these movements, the states will be finally stabilized at (FF), where both suspects will have a payoff of 2, because no suspect can unilaterally do better by choosing an action that differs from this state. This stable state is called a *Nash Equilibrium* (Osborne, 2003). In practice, other equilibria are also considered. Some of them will be discussed in the section describing the stability definitions for GMCR.

Table 2.2 illustrates Prisoner’s Dilemma in option form, where each player’s options or available courses of action are listed, as well as a rule for specifying the payoffs or preferences for each player. Note that a “Y” placed beside an option means the option is chosen whereas an “N” means not chosen.

Table 2.2. The Prisoner's Dilemma in the Option Form

	States			
1. *Suspect 1*				
(1) Quiet	N	N	Y	Y
2. *Suspect 2*				
(2) Quiet	N	Y	N	Y
Normal form notation	(FF)	(FQ)	(QF)	(QQ)

Preference Vectors

$$\textit{Suspect 1} \quad \begin{bmatrix} N & Y & N & Y \\ Y & Y & N & N \end{bmatrix}$$

$$\textit{Suspect 2} \quad \begin{bmatrix} Y & Y & N & N \\ N & Y & N & Y \end{bmatrix}$$

2.1.2. The Graph form

Although the normal and option forms can depict DMs' options and courses of actions easily, they both have some drawbacks, especially when considering the movements from one state to another (Fang et al., 1993). Therefore, a more flexible and understandable representation form, the graph form, is introduced. Firstly, some related definitions in graph theory are presented. Interested readers can find more details in research by Harary et al. (1965), Harary (1969), Berge (1973), Bondy and Murty (1975), and Fang et al., (1993).

A direct graph, G, is defined as a 2-tuple (S, A), where

1) S is a set $\{s_1, s_2, ..., s_n\}$ of elements called vertices, and

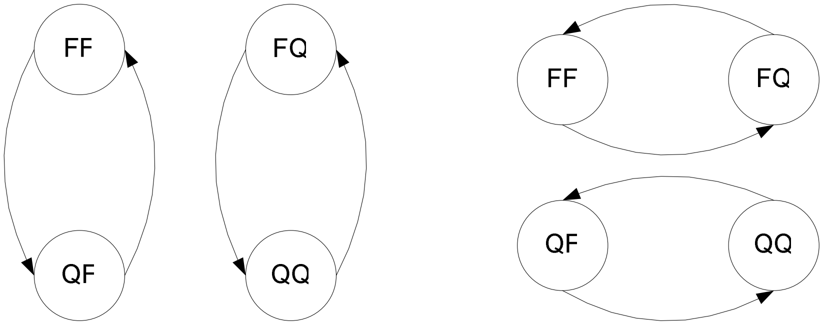
2) A is a set $\{a_1, a_2, ..., a_m\}$ of elements called arcs.

A is the Cartesian product $S \times S$. So if $a_{ij} \in A$ is an arc from vertex s_i to s_j such that $a_{ij} = \left(s_i, s_j\right)$, then a_{ij} is said to join s_i to s_j, where s_i is the tail of a_{ij}, and s_j is its head. Also, an arc with an identical head and tail is called a loop. A directed graph is finite if its vertex set is finite.

The reachability matrix *R* of a directed graph *G* is an $n \times n$ matrix, $\left[r_{ij}\right]$. When $\left(s_i, s_j\right)$ is an arc of *G*, $a_{ij} = 1$; otherwise, $a_{ij} = 0$. A directed graph is called transitive if there is an arc $\left(s_i, s_j\right)$ whenever arcs $\left(s_i, s_k\right)$ and $\left(s_k, s_j\right)$ are in *G*, for any *i* , *j*, and *k*.

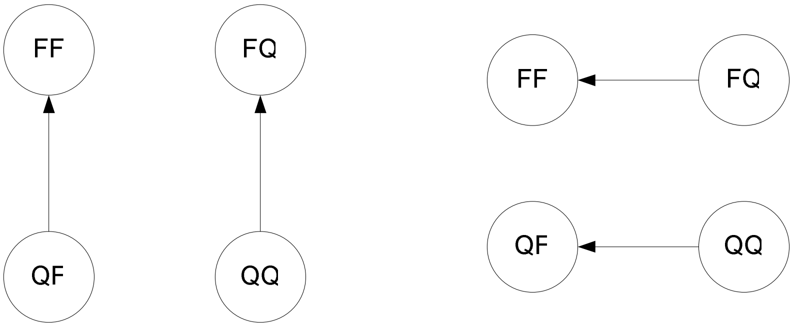
Based on these definitions, the graph form for a game can now be developed. Figure 2.2 shows the graph form of Prisoner's Dilemma. Vertices represent states, and arcs stand for possible movements. The direction of an arc in a player's graph indicates the direction of the movement that the suspect can make. Also, the preferences for each player are listed under the corresponding graph, where the *i*th entry is the payoff value of the *i*th state.

Moreover, this graph model can be further modified if a DM's decision to move from one state to another cannot be reversed. In the graph model, this type of irreversible move can be conveniently modeled as a unidirectional arc. For instance, if suspect 1 would only move from state (QQ) to (FQ) and from state (QF) to (FF), the arc from state (FQ) to (QQ) and from state (FF) to (QF) can be eliminated. The same situation also applies to suspect 2's graph. The modified graph form for this game is illustrated in Figure 2.3.



a) $P_1 = (2, 4, 1, 3)$ b) $P_2 = (2, 1, 4, 3)$

Figure 2.2 Prisoner's Dilemma in graph form: a) suspect 1; b) suspect 2.



a) $P_1 = (2, 4, 1, 3)$ b) $P_2 = (2, 1, 4, 3)$

Figure 2.3 Modified Prisoner's Dilemma in graph form: a) suspect 1; b) suspect 2.

2.1.3. The graph model for conflict resolution

GMCR is developed based on the definition of the graph form for a game. This methodology has the following four basic components (Fang et al., 1993; Kilgour et al., 1996; Hipel et al., 1997; Kilgour and Hipel, 2005):

1) A set of DMs, $N = \{1, 2, ..., n\}$;

2) A set of nodes, $S = \{s_1, s_2, ..., s_m\}$, where each node represents a feasible state

describing a distinguishable scenario of the conflict;

3) A collection of finite directed graphs $\{G_i = (S, A_i), i \in N\}$ to track unilateral moves for each DM *i*, where G_i is the directed graph for DM *i* and A_i is DM *i*'s set of directed arcs in G_i, for which each arc stands for the move DM *i* can make in one step between two states;

4) Each DM's relative preferences over *S*, $P_i(\cdot)$. For each state $s_j \in S$ and each DM $i \in N$, the numerical value of $P_i(k)$ measures the worth of state s_j to DM *i*.

Note that, although the set of states is identical for all DMs, each DM has a distinguishable preference ranking due to his/her different interests. Preference is discussed in detail in the last section of this chapter.

When DMs' moves and countermoves are assessed, it is reasonable to assume that each DM can only move from one state to another unilaterally, where the other DM's actions are fixed. When he/she prefers to stay at a state, or in other words, does not have the motivation to move away from this state unilaterally, this state is said to be stable for the given DM. An equilibrium is obtained when a state is stable for all DMs under a certain solution concept.

In GMCR, stability definitions are the most important concept related to determining and analyzing final resolutions. In the graph model, several distinct solution concepts are employed to define stability, thereby capturing DM's different behavioural and decision patterns in the face of conflict. The main stability definitions currently considered by GMCR include Nash Stability (R), General Metarationality (GMR), Symmetric

Metarationality (SMR), Sequential Stability (SEQ), Limited Move Stablity (L_h), and Non-Myopic Stability (NM).

Table 2.3 Stability Definitions and Human Behaviour (adapted from Fang et al. (1993))

Definition	Description	References	Foresight	Disimprovements
Nash stability (R)	A DM cannot unilaterally move to a more preferred state.	Nash (1950, 1951); von Neumann and Morgenstern (1953)	Low	Never
General metarationality (GMR)	All of a DM's unilateral improvements are sanctioned by its opponents' subsequent unilateral moves.	Howard, 1971	Medium	By opponents
Symmetric metarationality (SMR)	All of a DM's unilateral improvements are still sanctioned, even after a possible response by the original DM.	Howard, 1971		
Sequential stability (SEQ)	All of a DM's unilateral improvements are sanctioned by its opponents' subsequent unilateral improvements.	Fraser and Hipel (1979, 1984)		Never
Limited-move stability (L_h)	A fixed number (h) of state transitions are contemplated; all DMs are assumed to act optimally by backward induction.	Kilgour (1985); Kilgour et al. (1987); Zagare (1984)	Variable	Strategic
Non-myopic stability (NM)	The limiting case of the limited-move stability as the number of state transition approaches ∞.	Brams and Wittman (1981); Kilgour (1984,1985); Kilgour et al. (1987)	High	

Table 2.3 shows a list of these solution concepts with their descriptions, original references, and associated characteristics. As an important feature, foresight refers to a DM's capacity of foreseeing possible future moves under a particular stability definition. As shown in Table 2.3, Nash stability has the lowest foresight, while NM has the highest. The *strategic disimporvement* in the next column means a DM may move to a less preferred state temporarily in order to reach a more preferred one eventually. The

disimporvement by opponents means that other DMs may choose to move to a less preferred state in order to block the focal DM's unilateral improvements. For mathematical definitions, references, and other details, see Fang et al. (1993).

Additionally, for an *n*-player model, the relationships among these stabilities can be found in Table 2.4 and graphically illustrated by Figure 2.4. The detailed proof and explanations can be found in Fang et al. (1993). This knowledge of relationship is very informative in practice.

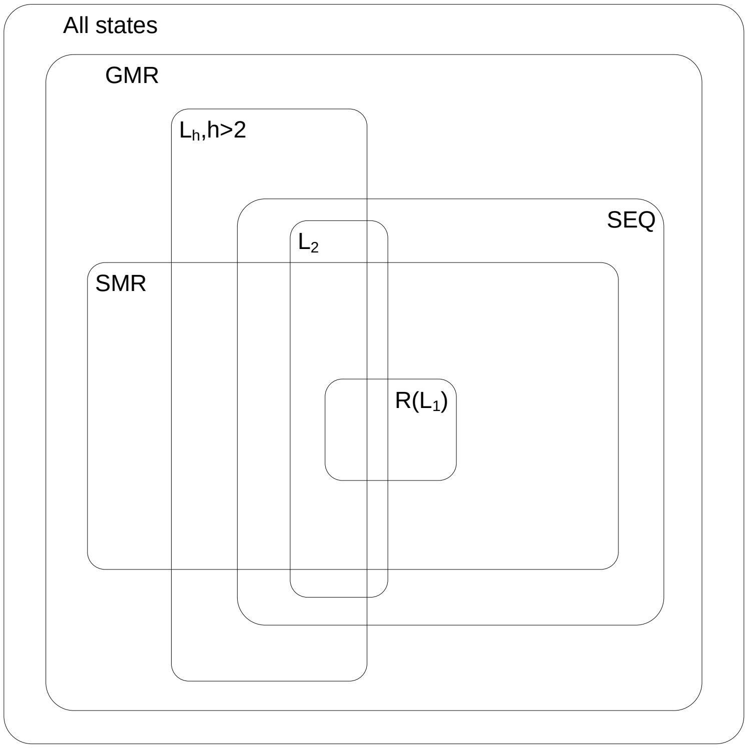


Figure 2.4 Relationships of n-player game stability concepts (Fang et al., 1993).

Table 2.4 Relationships of the solution concepts in n-player conflicts (Fang et al., 1993)

Individual (Stability) and Group (Equilibrium)
$R = L_1$
$R(L_1) \subseteq SMR \subseteq GMR$
$R(L_1) \subseteq SEQ \subseteq GMR$
$L_2 \subseteq SEQ \subseteq GMR$
$L_h(h > 2) \subseteq GMR$

2.2. Decision Support System GMCR II

As an efficient computer implementation of the graph model, GMCR II is a comprehensive decision support system (DSS), which is developed for the strategic analysis of real-world interactive decision problems. GMCR II furnishes a friendly user interface, requires minimal input, and completes calculations as well as analyses in an expeditious manner (Fang et al., 2003a, 2003b; Kilgour et al., 1996; Hipel et al., 1997; Peng, 1999).

The structure of GMCR II is depicted in Figure 2.5. As shown, the modeling subsystem receives user data, DMs and options, feasible state lists, reachable lists and preference rankings, through the user interface. GMCR then processes the input data and automatically converts them into a formal graph model that can be accepted by the analysis engine. The analysis engine applies each solution concept to each state for each DM. Stability results are then derived and stored in an efficient and easy-to-retrieve bit-wise structure, supported by the output presentation system. For details about GMCR II, readers are referred to Fang et al. (2003a, 2003b).

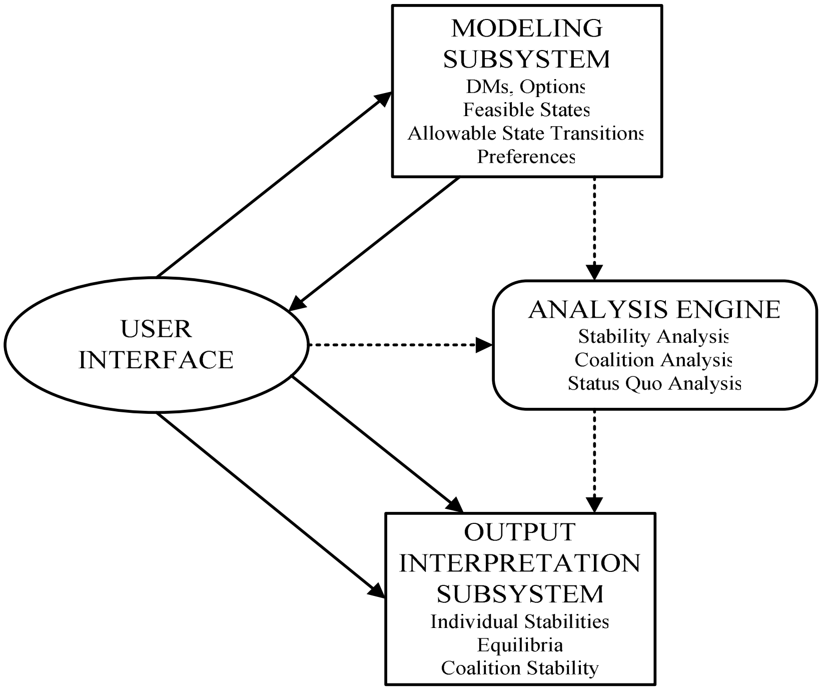


Figure 2.5 GMCR II structure (Fang et al., 2003a).

This decision support system can be beneficially applied to three main situations listed as follows (Kilgour and Hipel, 2005):

1) *Analysis and simulation tool for conflict participants:* GMCR II can be used in simulation or role-playing exercises that aim to achieve a better understanding or prediction of real world conflicts.

2) *Analysis and communication tool for mediators:* GMCR II can be used by mediators to reconcile opposite situations, creat a more disharmonious atmosphere in which to carry out negotiations, and assist in conducting and settling the disputes more effectively.

3) *Analysis tool for a third party or a regulator:* GMCR II can be used by other interested parties, such as representatives of a third party or a regulator, as a helpful mechanism to understand the conflict and perhaps seek fact-binding or legal-binding rules.

2.3. Preference Ranking

Preference ranking, or ordering of states from most to least preferred, with ties allowed, is a crucial element when a strategic dispute is analyzed by the graph model. In this section, some essential preference definitions for GMCR are introduced.

For a certain DM *i*, the relative preferences over the set of states, *S*, can be represented by binary relations $\{\succ_i, \sim_i\}$ on *S*, where $s \succ_i q$ indicates that DM *i* strictly prefers *s* over *q*; and $s \sim_i q$ indicates that DM *i* equally prefers *s* and *q*. This pair of binary relations constitutes a preference structure with the following properties:

1) $\succ_i$ is asymmetric, i.e., it cannot occur that both $s \succ_i q$ and $q \succ_i s$;

2) $\sim_i$ is reflexive an symmetric; and

3) $\{\succ_i, \sim_i\}$ is strongly complete.

GMCR II is equipped with three preference elicitation techniques: option weighting, option prioritizing, and direct ranking. These techniques assume that the preferences are transitive, and hence, states can be ordered. When employing option weighting, a user assigns option weights to reflect the relative importance of options from a given DM's viewpoint. In option prioritization, hierarchical preference statements are given in terms of one or more options and logical combinations thereof. Direct ranking permits a user to fine-tune the ranking of states that have first been obtained according to option weighting or option prioritization. For some small disputes, the user may wish to directly rank the states without any prior ordering.

However, in practice, sometimes the relative preferences are fairly hard to obtain, even with these three techniques. Therefore, two new approaches are proposed in this thesis in order to improve this procedure and serve users better. The details are presented in Chapters 4 and 5.

2.4. Summary

In this chapter, the basic concepts of the Graph Model for Conflict Resolution, as well as the associated decision support system, GMCR II, are introduced and explained. As the most critical and sensitive element of GMCR, preference issue is discussed in detail. In order to elicit the preference rankings in GMCR, the idea of multiple criteria decision making and two preference elicitation approaches based on practical MCDM techniques are presented in the following chapters.

3

Multiple Criteria Decision Making

Making decisions arise in everyday life. Most of the decisions are made based on different criteria. For example, when buying a car, people need to consider price, safety, reliability, brand reputation, size, oil consumption, repair costs, and so on. Even when facing the same problem, different people might have different preferences about these criteria, and hence, make different decisions.

In this chapter, key concepts of multiple criteria decision making (MCDM) are introduced, and two specific techniques, the Analytic Hierarchy Process (AHP) and ELECTRE, are discussed in greater detail in order to describe further research.

3.1. Introduction

Roy (1996) provides a definition on decision making that explains it in a theoretical manner. Decision making, also called decision aiding, "is the activity of the person who, through the use of explicit but not necessarily completely formalized models, helps obtain elements of responses to the questions posed by a stakeholder of a decision process. These elements work towards clarifying the decision and usually towards recommending, or simply favoring, a behavior that will increase the consistency between the evolution of the process and this stakeholder's objectives and value system". The term "stakeholder" mentioned in this definition may also be called a decision maker (DM).

Vincke (1992) defines an MCDM problem as a situation consisting of a set of actions (decision alternatives) and a family of criteria. A DM needs to determine: 1) a subset of actions that are the best ones considering the criteria; 2) the division of actions according to specific rules; or 3) the ranking of the actions from the best to the worst.

The purpose of MCDM is to provide a DM with some useful tools, which help him/her make decisions, especially when most of the times many contradictory points of view need to be taken into consideration (Vincke, 1992). Each point of view can be associated with a specific criterion, which shall be accounted for where the decision alternatives are evaluated (Figueira et al., 2005).

3.1.1. Basic concepts

There are three basic concepts for structuring and modeling an MCDM problem. From the definition of MCDM discussed earlier, two of them are rather obvious: actions and criteria. The third one is "problematic[1]" that "refers to the way in which decision making is

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[1] This term is translated by McCord from the original French word "problématique" in the book of Roy (1996). Translator noted the reason of this translation is that: "We considered translating this term as problem statements, problem types, or problem formulations, but felt that these could give the wrong impression. After discussion with several researchers in this field, we decided to remain close to the original French word 'problématique', even if it seems like jargon and sounds somewhat awkward, but which we feel will avoid misunderstanding."

envisaged”. Some brief descriptions of these concepts are presented as follows (Roy 1996).

1) Alternatives, or more generally, potential actions: possible resolutions for a given MCDM problem. These possible resolutions do not have to be one particular action but a combination of many actions.

2) Criteria: the tools or functions used to evaluate and compare the potential actions from different points of view. The performance of each action is evaluated by three types of scales: 1) purely ordinal scale, 2) quantitative scale, and 3) other types.

3) Problematic: the way in which MCDM problems are formulated. There are four main reference problematics usually used in practice: 1) description problematic, 2) choice problematic, 3) sorting problematic, and 4) ranking problematic.

3.1.2. MCDM techniques

Since the idea of MCDM was established, numerous techniques have been developed. These MCDM techniques can be divided into three categories with no clear-cut boundaries between them. Some explanation and typical examples for these categories are presented as follows (Vincke, 1992).

1) Multiple attributes utility theory, which aggregates different points of view into one function, and then, optimizes this function. The additive model and AHP (Saaty, 1980, 1982, 2001) are two typical techniques in this category.

2) Outranking methods, which aim to build an outranking relation based on the DM’s preferences. The ELECTRE (I, II, III, IV) method (Roy 1968, 1981, 1989, 1996, 2005) is one of the most famous MCDM outranking techniques.

3) Interactive methods, which tries to derive judgments by tracing, alternating, and dialoguing calculation steps. Through the interactions between the DM and MCDM problem formulations, solutions are iteratively adjusted and updated till satisfactory resolutions are finally obtained.

In the next two sections, two representative MCDM techniques, AHP and ELECTRE, are explained in detail. These two methods are then adapted later to elicit preferences for graph models in Chapters 4 and 5, respectively.

3.2. Analytical Hierarchy Process

Capable of handling not only quantitative but also qualitative criteria during a decision-making process, the Analytic Hierarchy Process (AHP) (Saaty, 1980, 1982, 2001) is a widely utilized multicriteria decision making technique that allows a DM to structure his or her decisions hierarchically and accommodates his or her personal experience, logical judgment, and even individual imaginations in the decision-making process. The major idea underlying AHP is to streamline complex decision problems by breaking them down into hierarchies with fundamental elements. Usually, a typical hierarchy includes four levels. 1) A focus level, specifying the overall objective of the decision problem. 2) A factor level, also called a criteria level, identifying all important criteria. 3) A sub-criteria level, used in some complicated situations in order to provide more detailed insights of certain criteria. For extremely complex cases, there may exist several sub-criteria levels. 4) An alternative level, listing possible alternatives. Figure 3.1 illustrates a typical hierarchy.

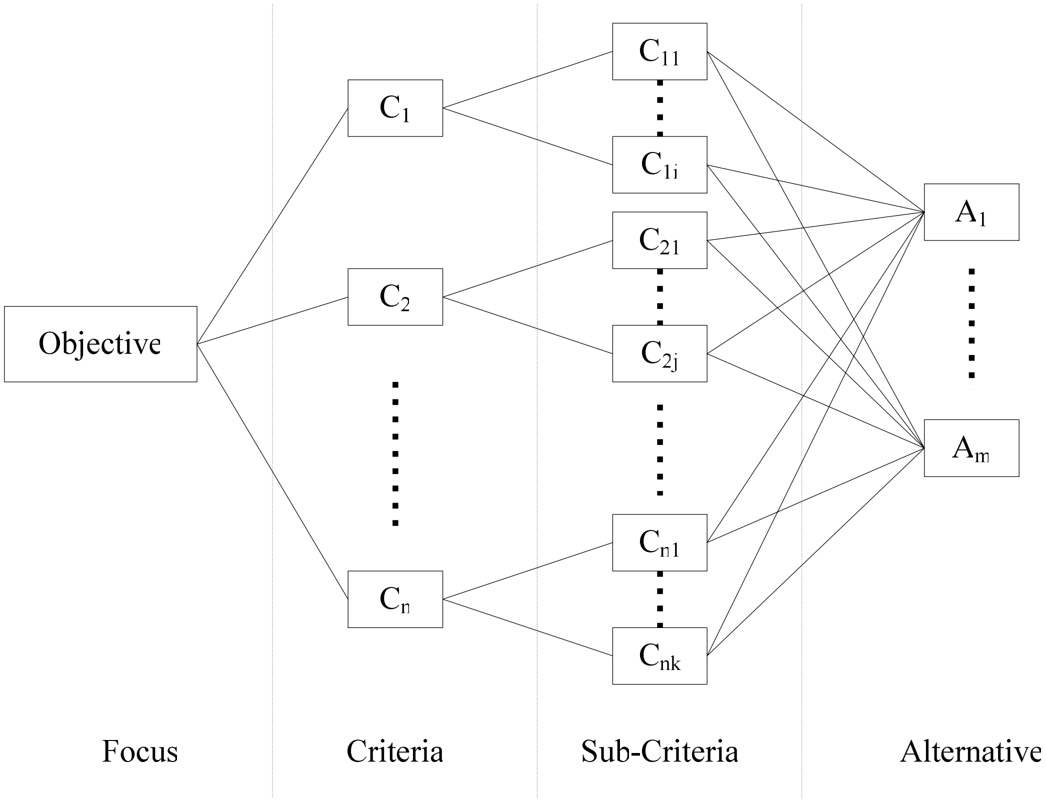


Figure 3.1 A typical AHP structure.

Next, pairwise comparison matrices are constructed for each element at the same level. The matrices contain the relative priorities of elements. Note that at different levels, these elements represent different objects: criteria, sub-criteria, or alternatives. For example, for a certain criterion (or sub-criterion) *X* with *n* elements below it: $Y_1, Y_2, ..., Y_n$, a pairwise comparison matrix can be made as illustrated in Table 3.1. In this matrix, $y_{ij} = w_i / w_j$ provides the pairwise comparison result of element Y_i over Y_j with respect to element *X*, where $w_i\left(i=1,2,...,n\right)$ are the derived scale values. Therefore, it is natural to have: 1) $y_{11}=y_{22}=...=y_{nn}=1$; and 2) $y_{ij}=1/y_{ji}$ ($i,j=1,2,...,n$).

Table 3.1. A sample matrix for pairwise comparison

X	Y_1	Y_2	$\cdots$	Y_n
Y_1	y_{11}	y_{12}	$\cdots$	y_{1n}
Y_2	y_{21}	y_{22}	$\cdots$	y_{2n}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	
Y_n	y_{n1}	y_{n2}	$\cdots$	y_{nn}

In AHP, a scale of “1” to “9” is adopted to conduct a non-quantitative pairwise comparison of two elements (Saaty, 1980, 1982, 2001). In this scale system, “1” indicates equal importance of two elements contributing to the upper level property, “9” means absolute importance of one element over another, and a value between “1” and “9” provides an in-between importance measurement of one element over another. Detailed descriptions of the 9-scale measurement system are shown in Table 3.2 (Saaty 1980, 1982, 2001). In the last decade, many concerns, such as weakness in the symmetry of negative and positive knowledge perception, have been raised about the 9-scale system. Therefore, alternative scale systems were developed (Ma and Zheng, 1991; Donegan et al., 1992). In this thesis, priority calculations are first carried out with the traditional 9-scale system, and then, verified with two popular alternative scales (Beynon, 2002). The results are discussed in the case study section of Chapter 4.

Table 3.2 The pairwise comparison scale

(Saaty, 1982, 2001; Saaty and Vargas, 2006)

Intensity of Importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally to the property
3	Weak importance of one element over another	Experience and judgment slightly favor one element over another
5	Essential or strong importance of one element over another	Experience and judgment strongly favor one element over another
7	Demonstrated importance of one element over another	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgments	Compromise is needed between two judgments
Reciprocals	If activity *i* has one of the preceding numbers assigned to it when compared with activity *j*, the *j* has the reciprocal value whe3n compared with *i*	A reasonable assumption
Rationales	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

After the establishment of the pairwise comparison matrices, a so-called eigenvalue technique is employed to calculate the weights of overall relative priorities for each element. According to the linear algebra, the largest or principal eigenvalue of the pairwise matrix, $\lambda_{\max}$, can be calculated by:

$$\begin{pmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & w_t/w_n \end{pmatrix} \cdot \begin{pmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{pmatrix} = \lambda_{\max} \cdot \begin{pmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{pmatrix}$$

where $w = \left(w_1, w_2, \dots, w_n\right)^T$ is the priority vector for the pairwise matrix.

The consistency of the comparison matrices is tracked by a Consistency Ratio (CR), which is obtained by comparing the consistency index CI and the random inconsistency index RI, i.e.,

$$CR = \frac{CI}{RI}$$

where

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

and RI is given by the values shown in Table 3.3.

Table 3.3 Random inconsistency for different sizes of matrices

(Saaty, 1982, 2001; Saaty and Vargas, 2006)

n	1	2	3	4	5	6	7	8	9	10
Random Inconsistency Index (RI)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Additionally, according to Saaty (1995), the consistency ratio should be less than 5%, 8%, and 10% for a 3×3 matrix, a 4×4 matrix, and matrices of higher orders, respectively. Within this interval, the judgmental consistency level is acceptable, and the corresponding matrices are said to be consistent. Finally, by a linear additive aggregation procedure, the global priority of each element relative to the overall objective is derived based on all the weights generated in the previous procedure.

However, when dealing with many decision problems in the real world, due to the involving interactions and dependence of elements from different levels, the problems can not be modeled simply by hierarchical structure (Saaty and Vargas, 2006). Therefore, a new approach, named Analytical Network Process (ANP), is developed by Saaty (1996, 2001, 2005). Figure 3.2 illustrates the differences between a linear hierarchy and a nonlinear network. In stead of a simple top-down hierarchy, a feedback network contains a more complicated structure, which involves all direction connections, cycles between clusters, and loops within the same cluster. For the detailed explanations and calculations for ANP approach, readers are referred to Saaty (1996, 2001, 2005) and Saaty and Vargas (2006).

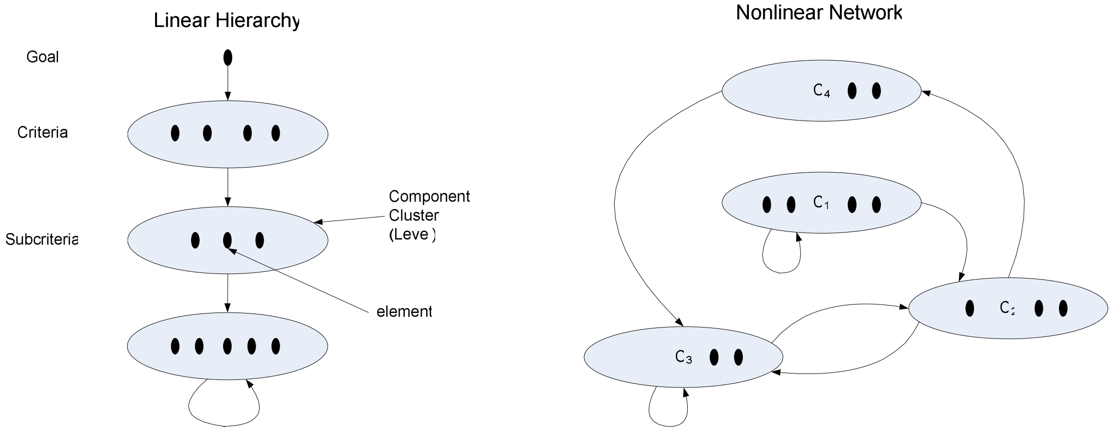


Figure 3.2 Structural differences between a linear hierarchy and a nonlinear Network (Saaty, 2006)

3.3. ELECTRE III

The term ELECTRE stands for *Elimination and Choice Expressing the Reality*. The methods were firstly introduced by Roy in the mid-60 (Roy, 1968). Subsequently, in the following decades, several versions of this method were established and improved. Since 1966, ELECTRE I, Iv, IS, II, III, IV, A, and TRI have been developed, and now, the methods are still being refined. Table 3.4 explains the main characteristics of ELECTRE methods. For more details of ELECTRE methods, readers are referred to Roy (1991, 2005) and Roy and Vanderpooten (1996). In this section, as the basis of the research presented in chapter 5, the method of ELECTRE III is discussed in detail.

By taking indifference and preference thresholds into account, ELECTRE III considers a fuzzy binary outranking relation. It defines a series of algorithms in order to obtain the outranking degree aRb or $R(a,b)$, representing the degree of outranking credibility of *a* over *b*. The pseudo-criterion g_i, a basic element involved in this method, shows the linear preference with indifference threshold q_i and preference threshold p_i.

A normalized weight w_i is assigned to each pseudo-criterion. Thus, the concordance index aCb or $C(a,b)$ can be calculated as:

$$C(a,b) = \frac{1}{W} \sum_{i=1}^{n} p_i c_i(a,b),$$

where

$$W = \sum_{i=1}^{n} w_i \quad \text{and}$$

Table 3.4. Main Characteristics of ELECTRE methods (Roy, 1991)

ELECTRE methods	I	IS	II	III	IV	A
Possibility for taking into account indifference and/or preference thresholds	no	yes	no	yes	yes	yes
Necessity of a quantification of the relative importance of criteria	yes	yes	yes	yes	no	yes
Number and nature of outranking relations[1]	1	1	2	1 fuzzy	5	1 fuzzy
Final results	a kernel	a kernel with consistency and connected indices	a partial preorder	a partial preorder	a partial preorder	An assignment to predefined categories

---

[1] All outranking relations are based on concordance and discordance concepts; except for boxes containing ‘fuzzy’, the figures refer to non-fuzzy relations.

$$c_i(a,b) = \begin{cases} 1 \quad \text{if} \quad g_i(a) + q_i(g_i(a)) \geq g_i(b); \\ 0 \quad \text{if} \quad g_i(a) + p_i(g_i(a)) \leq g_i(b); \\ \qquad \text{linear between the two.} \end{cases}$$

Next, a veto threshold v_i is introduced for each pseudo-criterion such that any credibility for the outranking of *b* by *a* is refused if

$$g_i(b) \geq g_i(a) + v_i(g_i(a)),$$

even when all the other criteria have the credibility for *b* outranking by *a*.

Now the discordance index ad_ib or $d_i(a,b)$, for each criterion *i*, is defined by:

$$d_i(a,b) = \begin{cases} 1 \quad \text{if} \quad g_i(b) \leq g_i(a) + p_i(g_i(a)); \\ 0 \quad \text{if} \quad g_i(b) \geq g_i(a) + v_i(g_i(a)); \\ \qquad \text{linear between the two.} \end{cases}$$

Finally, the degree of outranking can be computed by

$$R(a,b) = \begin{cases} C(a,b) \quad \text{if } d_i(a,b) \leq C(a,b), \forall i, \\ \qquad C(a,b) \cdot \prod_{i \in I(a,b)} \frac{1 - d_i(a,b)}{1 - C(a,b)}, \end{cases}$$

where $I(a,b)$ is the set of criteria that satisfies $d_i(a,b) > C(a,b)$ (Roy 1991, 2005; Vincke, 1992).

In Chapter 5, a fuzzy MCDM model based on ELECTRE III is implemented as a three-layer hierarchical model for eliciting relative preferences for conflict models in graph form. Some detailed explanation about ELECTRE III can also be found there.

3.4. Summary

The basic concepts of multiple criteria decision making, emphasizing on two specific techniques, AHP and ELECTRE, are introduced in this chapter. The following chapters propose two preference elicitation approaches based on different MCDM techniques: 1) an integrated AHP approach and 2) a three-layer hierarchical analysis model employing ELECTRE III.

4

Integrated AHP Approach for Preference Ranking in GMCR

The purpose of this research is to develop an integrated conflict analysis approach (Ke et al., 2007), which combines an Analytical Hierarchy Process (AHP) (Saaty, 1980, 1982, 2001) preference ranking method with GMCR (Fang et al., 1993). As introduced in Chapter 2, GMCR is a systematic procedure that handles complicated strategic decision problems involving two or more DMs with differing objectives as reflected by their diverse preferences over possible states or outcomes. Due to its simplicity and flexibility, the graph model enables interested parties or an analyst to analyze a conflict and obtain a better understanding about what is currently happening and what could eventually take place (Fang et al., 1993).

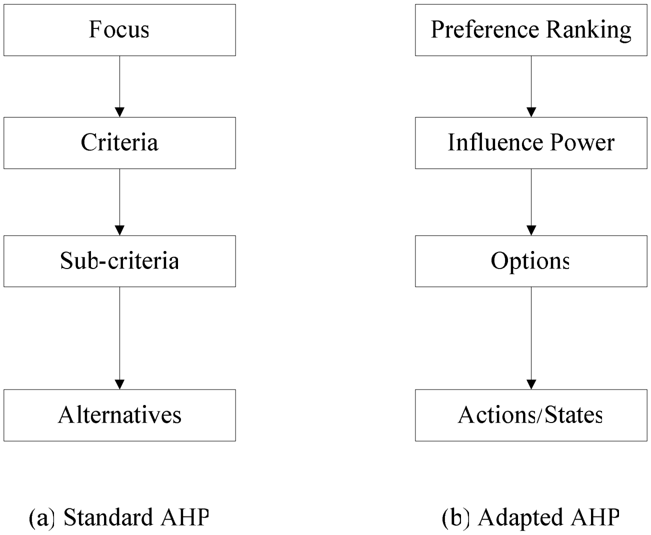
At the modeling stage of GMCR, the determination of relative preferences for each DM is one of the most important elements, as each involved party usually has different preferences over options, situations, and/or states. A compromise or consensus, if any, will be achieved according to these preferences. From each DM's standpoint, it is inevitably appealing to consider multiple criteria when preferences are ranked over feasible states. If each state is regarded as a decision alternative in the ranking process, preference elicitation can be naturally treated as a typical multiple criteria decision making (MCDA) problem.

As a useful MCDA technique, AHP (Saaty, 1980, 1993, 2001) provides a mathematical procedure to take both quantitative and qualitative criteria into consideration in ranking decision alternatives. An introduction for AHP can be found in Chapter 3. In this chapter, an integrated AHP approach is constructed to elicit preference rankings for each DM, which are then fed into a DSS, such as GMCR II (Fang et al., 2003a, 2003b), to carry out a standard graph model stability analysis.

This approach is then employed to investigate the Canadian west coast port congestion dispute. The Canadian west coast has historically been an important gateway connecting North America to Asia, thanks to its specific geographical and strategic location. Despite successful operations and maintenance of the port facilities to handle international trade during the past decades, the west coast is now facing increasing congestion problems, resulting in significant delays in transporting goods from the west coast to other parts of Canada and the USA. The strategic analyses carried out in this research suggest potential resolutions in which Canada would expand port facilities at various locations, encouraging traders to continue choosing the Canadian west coast as one of their trade gateways to North America.

4.1. Structure

This section proposes an AHP model for eliciting relative preferences over feasible states in a graph model. Figure 4.1 provides a simple comparison between the adapted version and the standard AHP approach. With a similar hierarchical structure, instead of the criteria level, the new approach introduces an influence power level. Through each DM's impact on his/her courses of action by different power strength, the DM's preferences thus influence the entire conflict situation. More specifically, the structure of the adapted AHP approach is depicted by Figure 4.2. Detailed explanations are given next for the four hierarchies in this adapted structure.



(a) Standard AHP (b) Adapted AHP

Figure 4.1 Comparison of standard and adapted AHP.

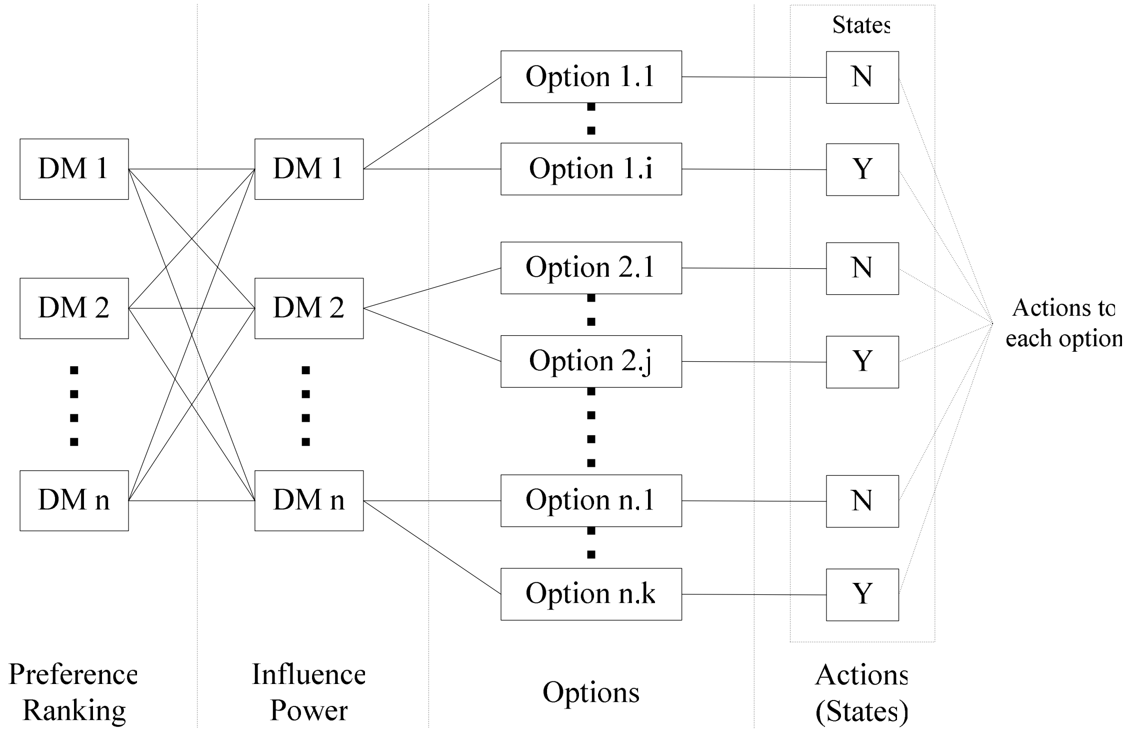


Figure 4.2 Structure of the adapted AHP approach.

1) The Preference Ranking level contains all DMs considered in the conflict model. Instead of only one objective as in the standard AHP approach, this level specifies that the objectives are to obtain preference rankings for all DMs. Then, the preference analysis contains in the following steps will be carried out from each DM's viewpoint separately.

2) As mentioned above, the influence power level furnishes different DMs' influence powers over the entire situation from each DM's standpoint. By the same pairwise matrix and eigenvalue technique as the traditional AHP, a weight list is obtained to illustrate the power strength for all DMs based on a certain DM's assessment.

3) The option level lists all options under each DM’s control. At this level, priority weights of all options will be obtained. Moreover, comparisons can be further decomposed into a sub-hierarchy model if the complexity of the problem warrants.

4) The action/state level displays a series of action profiles, characterized by combinations of “N” and “Y” against the options, where an “N” indicates a corresponding option is not chosen and a “Y” stands for the option being selected. The overall preference ranking is thus determined by multiplying option priority weights and action status. After all DMs’ relative preferences are elicited, they are then fed into GMCR II for further stability analyses.

4.2. Case study: Canadian West Coast Congestion Problem

Traffic congestions always have significant impact on the entire supply chain operations (Sankaran et al., 2005). Currently, the Canadian west coast is facing increasing congestion problems caused by the recent exploding increase in the trading volume with Asia, especially, China. This serious congestion results in significant delays either in receiving goods from other countries, or in transporting goods from the west coast to other parts of Canada and USA. For example, Canada’s largest west coast port, located in Vancouver, had increases in total tonnage and container volume of 21.2% and 21.8%, respectively, in 2005, when compared to 2002. These numbers are expected to keep growing even more rapidly in the foreseeable future. By 2020, the container cargo through British Columbian ports and the value of this trade are projected to expand to 5 to 7 million containers and $75 billion, increasing by about 300% and 114%, respectively (Government of Canada, 2005). The booming container traffic has strained the existing Canadian west coast port system. At the same time, the US west coast ports are also experiencing a similar bottleneck situation. Seattle, for instance, is the fastest-growing port in North America. From 2004 to 2005, its box volume has risen by 18% to more than 2 million TEUs (20-ft-equivalent units). In response to the volume growth, Seattle expects to increase its processing capacity by 10% after a new terminal project is completed by 2008 (Ryan, 2006a). Such expansions are taking place in other locations along the US west coast, such as Los Angeles and San Diego, as well as some east coast ports. Nevertheless, the expanded capacity still does not seem to be able to keep pace with the rapid growth of international trade.

4.2.1. Background

Generally, the west coast of Canada refers to British Columbia (BC), the westernmost Canadian province. As the key connection point in the Asia-Pacific Gateway, the BC port system has always been and will continue to be one of the most critical aspects of the economic future of Canada, and even the entire North American continent. Nevertheless, the recent booming trade between Asian countries and North America has brought serious concerns to all Canadian west coast ports. The Port of Vancouver, Canada’s largest and most diversified port, for example, is already handling a significantly large container business of 1,767,379 TEUs in 2005, which is forecasted to be tripled within 15 years (Ryan, 2006a). But the existing port capacity will never be able to handle such a massive amount. Some statistical data provide further description of this situation: the world gross domestic product in the past twenty years has increased 2.8% annually; global container trade has increased about 9% annually; more than 140 jumbo containerships of 8,000-10,000 capacity will be sailing on the world's oceans within five years. These capacity crises, due to exponentially increasing trading, are faced by all Canadian ports and generate immense pressure on Canadian transportation systems. Norman Stark, President and CEO of TSI Terminal Systems, put forward the following five issues in September 2005, when attending the annual Port Days Conference (Smyrlis, 2005): 1) congested terminals; 2) shortage of longshore labour; 3) strained road and rail infrastructure; 4) scarcity land for port expansions; and 5) increasing investment costs. Each issue poses a real challenge to Canada.

Meanwhile, the US ports are also experiencing a serious congestion situation. A supply chain directions report in 2005 (Eye for Transport, 2005) indicates that port congestion is a major concern of the supply chain industry. The huge amounts of international trading are "straining the supporting infrastructure" and significantly delaying all activities within supply chains (Sowinski, 2007). Pennsylvania State University recently studied 24 major US and Canadian ports and stated that west coast ports are underestimating expected future container volumes by as many as 11 million TEUs in 2015. "Delays due to congestion at west coast ports could then cause a domino effect" (Ryan, 2006a).

Facing all these challenges, Canadians have also come to realize some opportunities. As Stephen Poloz, Senior Vice-president, Corporate Affairs and Chief Economist of the Export Development Corporation (EDC) indicated (Ryan, 2006b), "Over the next five years, port capacity in Asia is slated to double. But in the United States, a lot of investments (since 9/11) are being funneled into security rather than capacity." Accordingly, it is possible for Canadian ports to act as "a facilitator of US trade". Therefore, a key purpose of this section is to facilitate Canada in seeking opportunities for maximizing its benefit from this role.

In the next section, a graph model, integrated with an integrated AHP preference ranking approach, is established regarding the conflict among different parties revolving around the west coast congestion problem. All major DMs, options, and relevant preferences will be discussed and investigated.

4.2.2. Model description

The point in time that was selected is the beginning of October 2006. Four DMs are considered in this model: Canadian government (CA), United States government (US), Chinese government (CN), and Traders. DMs and their corresponding options are listed in Table 4.1.

Table 4.1 DMs and corresponding options

DMs	Options
Canadian government (CA)	1. PPR: Expansion plan in the Port of Prince Rupert 2. PV: Expansion plan in the Port of Vancouver 3. OP: Other ports, either west or east coast ports
United States government (US)	4. EX: Expansion plan for its own ports 5. OS: Other solutions, such as shift cargo operations to off-peak hours
Chinese government (CN)	6. MS: Develop own superport in Mexico
Traders (TD)	7. US: US gateway 8. CA: Canadian gateway 9. ME: Mexican gateway

China is selected to be the representative for all fast-growing Asian trading partners, as China has now become one of the world's biggest economies due to its efficient labour costs. For instance, at the Port of Vancouver, China accounted for the highest trading tonnage of 16,310,000 metric tons and the highest container tonnage of 6,187,000 metric tons in 2005, increasing by 95.0% and 73.5% from the 2002 statistics, respectively (Port of Vancouver, 2002, 2005). As one of the DMs, Traders refer to all shippers involved in this problem, such as manufacturers, exporters, importers, carriers, and third-party logistics providers.

4.2.3. Feasible state generation

Except for China, each DM has to choose at least one option: Canada has to expand its port capacities in one location or another in response to the rising container volume; the US has to either expand its own port capacity or find other solutions to relieve the bottleneck situation; and Traders have to choose a gateway for their current and future trade.

As for the "Option dependence" method embedded in GMCR II, Traders would like to choose US as the gateway only if US expands its own ports, to choose CA as the gateway only if Canada addresses its expansion plan in one of its three options, and to choose Mexico as the gateway unless China builds its own superport there. By using the foregoing techniques in GMCR II to remove infeasible patterns, 105 feasible states are retained.

4.2.4. Preference ranking using the integrated AHP approach

Based on the list of DMs and options in Table 4.1, a hierarchy structure of this conflict model is given in Figure 4.3, which is employed to elicit relative preference rankings for each DM as explained below. Note that the consistency of all calculations are confirmed but omitted here for conciseness.

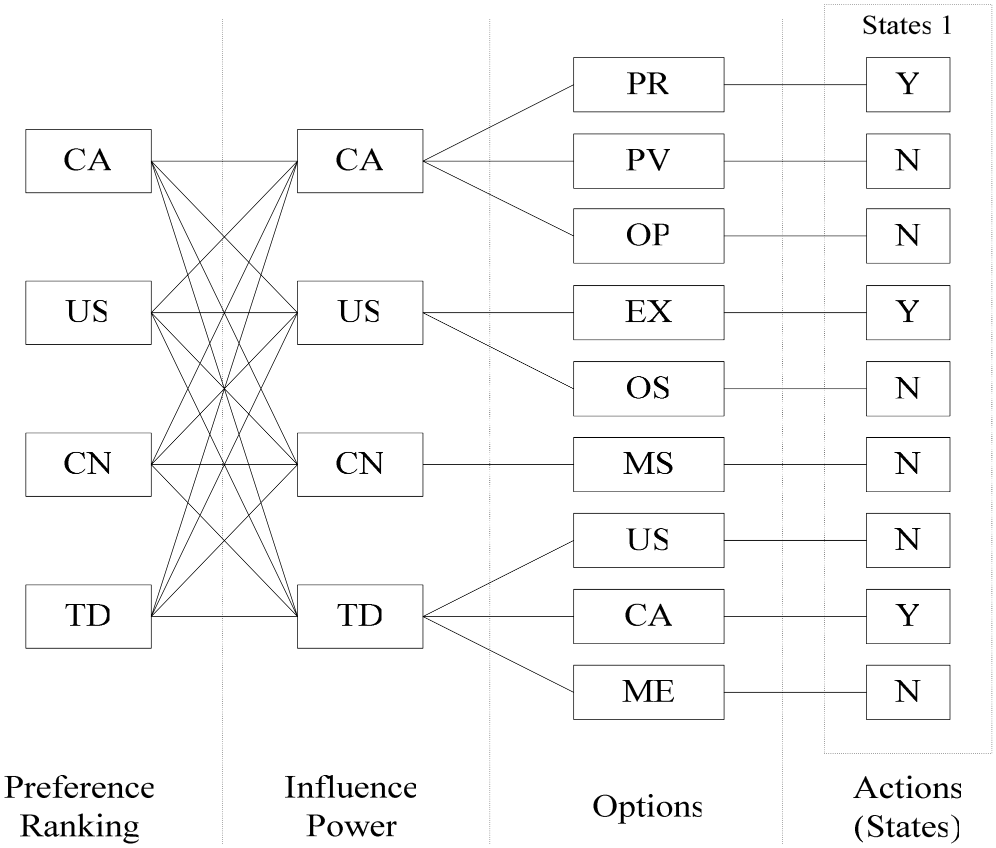


Figure 4.3 Adapted AHP model for the West Coast Congestion Problem.

4.2.4.1. Canada’s standpoint

From Canada’s standpoint, US is the most powerful DM, followed by Canada, then China, and with Traders exerting least control over the situation. Accordingly, the following pairwise comparison matrix is adopted and the ranking result (weights) for influence powers is shown in Table 4.2.

Table 4.2 Pairwise comparison matrix for influence powers from Canada’s standpoint

	CA	US	CN	TD	Weight
CA	1	1/5	3	5	0.204
US	5	1	7	9	0.661
CN	1/3	1/7	1	2	0.084
TD	1/5	1/9	1/2	1	0.050

At the option level, the expansion of the Port of Vancouver is definitely the first choice for Canada as Vancouver is Canada’s flagship port and the most diversified port on the continent (Pacific Gateway Portal, 2006). As a matter of fact, Vancouver had planned to construct a third berth at Deltaport at Roberts Back to increase its capacity by 400,000 TEUs to 1.3 million TEUs. But the federal government recently delayed this construction and requested more environmental impact studies (Ryan, 2006a).

Due to its strategic location and potential to offer efficient access to the North American market, the Port of Prince Rupert becomes another alternative. In fact, the Government of Canada already had the intent to build a container terminal there (Industry Canada, 2005). Some extra special features of the Port of Prince Rupert attract more attention from different parties. For example, its deep natural harbour provides the possibility of handling jumbo containerships; sailing times from Prince Rupert to China's main ports are about 24 to 60 hours shorter than from other west coast ports (Ryan, 2005); it has the safest west coast harbour with extensive capacity to expand (Prince Rupert Port Authority, 2006). However, this alternative also faces many obstacles. The main issues include: 1) Remoteness of the location. Prince Rupert is about 500 miles north to Vancouver; 2) Lack of infrastructure. The Canadian National Railway (CNR) provides the only land connection to the port; 3) Aboriginal issues. A tribal group has threatened to file lawsuits to stop the progress of the port expansion plan due to the violation of aboriginal land rights; 4) Some shipping lines are reluctant to add this port into their shipping routes because of additional piloting costs (Machalaba, 2006; Ryan, 2006a).

Besides these two west coast ports, other Canadian ports have also gained interests recently. It is known that the Ports of Montreal and Halifax have started to handle significant container businesses originating from the US Midwest (Ryan, 2006b). Furthermore, their geographic locations and existing surplus capacities provide them with competitive advantages over other alternatives. For example, the Port of Halifax has enough capacity to handle up to around 1.2M TEU containers a year, while it only took care of 550,000 TEU in 2005 (Asia Pacific Bulletin, 2006).

With respect to the US's options, it does not really matter for Canada if US chooses to expand its own ports or find some other solutions for the congestion problem. When it comes to Traders' options, the most important concern for Canada is that they choose Canada as one of their trading gateways. The other two choices, US and Mexico gateways, are much less preferred and do not make much difference for Canada. The pairwise comparison matrices for all these options for each DM are then constructed, and the ranking weights are also calculated as shown in Table 4.3.

Table 4.3 Pairwise comparison matrices for each DM's options from Canada's standpoint

CA	PR	PV	OP	Weights
PR	1	1/3	3	0.268
PV	3	1	4	0.614
OP	1/3	1/4	1	0.117

a) CA's options

US	EX	OS	Weights
EX	1	1	0.500
OS	1	1	0.500

b) US's options

TD	US	CA	ME	Weights
US	1	1/7	1	0.111
CA	7	1	7	0.778
ME	1	1/7	1	0.111

c) Traders' options

4.2.4.2. US's standpoint

Table 4.4 provides the pairwise comparison matrix and ranking results for influence power from US's viewpoint. US thinks itself as the most powerful DM, China slightly more powerful than Canada due to its rapid growth and its increasing impacts on the world trade, and Canada somewhat more powerful than the Traders.

Table 4.4 Pairwise comparison matrix for influence powers from US's standpoint

	CA	US	CN	TD	Weight
CA	1	1/3	1/2	2	0.159
US	3	1	3	4	0.510
CN	2	1/3	1	2	0.226
TD	1/2	1/4	1/2	1	0.104

At the option level, for the US, the Port of Prince Rupert is the most preferred, followed by the Port of Vancouver, and then other ports. Although the Port of Prince Rupert is remotely located in Northern BC, the railway system provides a direct link to Chicago with very few stops on the way. Therefore, the rail-transit time is likely about the same as the land route from Los Angeles to Chicago, even with a longer distance (Machalaba, 2006). By squeezing out unnecessary delays at other crowded ports, the entire transportation time from China to the US Midwest might possibly be reduced from 35-40 days to only about 20 days if the route via the Port of Prince Rupert is taken (Pitts, 2006).

In order to capture the booming Asian trade, US has to expand its own ports, especially its west coast ports, such as Los Angeles-Long Beach ports and Seattle-Tacoma ports, which handled more than 87 percent of the west coast's container volume in 2006 (Sowinski, 2007). However, due to the extremely expensive investment of expansion, some other approaches might be helpful. For instance, the Ports of Los Angeles and Long Beach were trying to shift cargo operations to off-peak hours in order to avoid serious congestions (Eye for Transport, 2005).

As for the options of Traders, US most prefers that they choose US as the gateway so it can capture more profits than Canada. Mexico would be the last choice due to the lack of supporting infrastructure, particularly transportation systems.

The pairwise comparison and ranking results for each DM's options from the US perspective are thus carried out and illustrated in Table 4.5.

Table 4.5 Pairwise comparison matrices for each DM's options from US's standpoint

CA	PR	PV	OP	Weights
PR	1	3	4	0.614
PV	1/3	1	3	0.268
OP	1/4	1/3	1	0.117

a) Canada's options

US	EX	OS	Weights
EX	1	2	0.667
OS	1/2	1	0.333

b) US's options

TD	US	CA	ME	Weights
US	1	2	4	0.558
CA	1/2	1	3	0.320
ME	1/4	1/3	1	0.122

c) Traders' options

4.2.4.3. China's standpoint

The Chinese government thinks the order of DMs' influence power from most to least is US, China, Canada, and Traders (Table 4.6).

Table 4.6 Pairwise comparison matrix for influence powers from China's standpoint

	CA	US	CN	TD	Weight
CA	1	1/4	1/2	2	0.143
US	4	1	2	6	0.526
CN	2	1/2	1	2	0.240
TD	1/2	1/6	1/2	1	0.092

From the point of view of the Chinese government, for Canadian ports, the Port of Prince Rupert, due to its shortest distance to Asia and future expansion potentials, naturally becomes the best alternative. Vancouver Port would be the second choice because of its existing container capacity and handling experience. In addition, some east coast ports, such as Halifax, also gain attention from China for the possibility of bypassing congestion on the west coast. For China, whatever US does, either expands ports or explores other methods, does not make any difference, as long as the serious bottleneck situation can be lessened so that their goods would be transported to their destinations instead of simply being piled up on the west coast. Building their own deep-water superport in Mexico is another potential resolution for China (Pitts, 2006). Therefore, the relative preference rankings for each DM's options from China's viewpoint are derived as shown in Table 4.7.

Table 4.7 Pairwise comparison matrices for each DM's options from China's standpoint

CA	PR	PV	OP	Weights
PR	1	2	4	0.571
PV	1/2	1	2	0.286
OP	1/4	1/2	1	0.143

a) Canada's options

US	EX	OS	Weights
EX	1	1	0.500
OS	1	1	0.500

b) US's options

TD	US	CA	ME	Weights
US	1	1/3	1/2	0.163
CA	3	1	2	0.540
ME	2	1/2	1	0.297

c) Traders' options

4.2.4.4. Traders' standpoint

From Traders' standpoint, US, again, is the most powerful party, then followed by Canada and themselves. China is the least powerful party (Table 4.8).

Table 4.8 Pairwise comparison matrix for influence powers from Traders' standpoint

	CA	US	CN	TD	Weight
CA	1	1/2	2	1	0.224
US	2	1	4	2	0.449
CN	1/2	1/4	1	1	0.136
TD	1	1/2	1	1	0.191

Table 4.9 Pairwise comparison matrices for each DM's options from Traders' standpoint

CA	PR	PV	OP	Weights
PR	1	3	2	0.550
PV	1/3	1	1	0.210
OP	1/2	1	1	0.240

a) Canada's options

US	EX	OS	Weights
EX	1	1	0.500
OS	1	1	0.500

b) US's options

TD	US	CA	ME	Weights
US	1	1/2	2	0.311
CA	2	1	2	0.493
ME	1/2	1/2	1	0.196

c) Traders' options

For Traders, any port that can handle their goods would be attractive. As their goods shipped to US west coast ports are being piled higher and higher, Canadian ports are definitely good choices, especially the Port of Prince Rupert. Furthermore, for the reason of capacity surplus, some Canadian east coast ports gain more attentions from different Traders than the Port of Vancouver. Again, to the extent that the west coast congestion problem is solved, the two options controlled by US are essentially the same to Traders too. Moreover, since US already has a much more developed infrastructure system than Mexico, it is a better gateway choice than Mexico, unless China develops its own deep-water superports in Mexico (Pitts, 2006). The pairwise comparison matrices and the corresponding weights for each DM's options from Traders' standpoint can hence be obtained as illustrated in Table 4.9.

4.2.4.5. Overall ranking

By aggregating results obtained from each individual DM's perspective, the overall ranking weights are listed in Table 4.10. As mentioned above, the weights for the Actions/States level are calculated by multiplying the related influence power with the option weight. For example, the Action/State weight for Canada choosing to expand the Port of Prince Rupert is $0.204 \times 0.268 = 0.054672 \approx 0.055$.

Table 4.10 Overall ranking weights

		CA			US			CN			TD		
		Influence Power	Options	Actions/ States	Influence Power	Options	Actions/ States	Influence Power	Options	Actions/ States	Influence Power	Options	Actions/ States
CA	PR	0.204	0.268	0.055	0.159	0.614	0.098	0.143	0.571	0.082	0.224	0.550	0.123
	PV		0.614	0.125		0.268	0.043		0.286	0.041		0.210	0.047
	OP		0.117	0.024		0.117	0.019		0.143	0.020		0.240	0.054
US	EX	0.661	0.500	0.331	0.510	0.667	0.340	0.526	0.500	0.263	0.449	0.500	0.225
	OS		0.500	0.331		0.333	0.170		0.500	0.263		0.500	0.225
CN	MS	0.084	1.000	0.084	0.226	1.000	0.226	0.240	1.000	0.240	0.136	1.000	0.136
TD	US	0.050	0.111	0.006	0.104	0.558	0.058	0.092	0.163	0.015	0.191	0.311	0.059
	CA		0.778	0.039		0.320	0.033		0.540	0.050		0.493	0.094
	ME		0.111	0.006		0.112	0.012		0.297	0.027		0.196	0.037

Now, all feasible states are treated as 105 alternatives and ranked accordingly in the integrated AHP framework from each DM's perspective. The preference rankings are then input into the GMCR II to conduct stability analyses, which provide a wide range of individual stability and equilibrium information for each state under different solution concepts.

4.2.5. Stability analysis

Table 4.11 displays the predicted equilibria from the GMCR II analysis, corresponding to possible resolutions, given the preference profiles generated in the last subsection. These two resolutions are stable for all solution concepts. For these two equilibria, there exist three distinct commonalities: 1) Canada performs expansion plans in all of its three options; 2) China builds its superport in Mexico; and 3) Traders continue choosing Canada as one of their trade gateways.

Table 4.11 Possible resolutions for the Canadian West Coast Congestion Problem

	84	98
CA:		
1. PPR	Y	Y
2. PV	Y	Y
3. OP	Y	Y
US		
4. EX	N	Y
5. OS	Y	N
CN		
6. MS	Y	Y
TD		
7. US	N	Y
8. CA	Y	Y
9. ME	Y	Y

As far as Canada’s concerns, this is exactly what happened after the point in time that this model was built. According to CBC Canada, on October 11, 2006, Canadian Prime Minister Stephen Harper announced a $591 million investment over the next eight years on ports, roads, rails and other infrastructure to improve trading access to Asia-Pacific markets (Theodore, 2006). Particularly, the expansion plan includes a $28 million investment over four years to improve cargo screening at the Prince Rupert Port Authority (Prince Rupert Port Authority, 2006) and a high-tech system that will cost up to $152 million to promote more efficient and seamless transportation at the Port of Vancouver (Port Vancouver Authority, 2006). In the meantime, China has been working actively to open and develop NAFTA shipping ports in Mexico (Corsi, 2006). In order to further smooth the flow of international trade through Canada’s west coast, an additional $233.5 million “Asia-Pacific Gateway and Corridor Transportation Infrastructure Fund” is promised to improve the road and rail connections (Prince Rupert Port Authority, 2006; Brooks, 2007). On June 1, 2007, in a speech to the 70th annual conference on the Federation of Canadian Municipalities, Prime Minister announced a $33-billion infrastructure funding plan, among which one of the most critical projects is “the Asia-Pacific gateway and Corridor Initiative to Canada into the booming Far East through the West Coast ports” (Office of the Prime Minister, 2007). In October 2007, the Speech from the Throne further confirmed an infrastructure program, the Building Canada Plan, to support Canada’s long-term growth by investing in the transport and trade hubs (Government of Canada, 2007).

In the meantime, China has been working actively to open and develop NAFTA shipping ports in Mexico (Corsi, 2006). A China-Mexico trade route highlighted on the North American Inland Ports Network (NAIPN) website (2007) shows a route crossing the Pacific Ocean from China to Mexico at the ports of Manzanillo and Lazaro Cardenas, and then entering the US through San Antonio.

4.2.6. Status quo analysis

Table 4.12 State transition from the status quo to state 98

	Status Quo	Transitional States		Equilibrium
	44	49	63	98
CA:				
1. PPR	N →	Y	Y	Y
2. PV	Y	Y	Y	Y
3. OP	N →	Y	Y	Y
US				
4. EX	Y	Y	Y	Y
5. OS	N	N	N	N
CN				
6. MS	N	N →	Y	Y
TD				
7. US	Y	Y	Y	Y
8. CA	Y	Y	Y	Y
9. ME	N	N	N →	Y

As one of the most important research topics in GMCR, status quo analysis is used to track the moves and countermoves of conflict problems starting from the status quo, passing through transitional states, and finally, reaching the outcomes or equilibria (Li, 2003; Li et al., 2004). The status quo of this case is state 44. At this state, 1) Canada only carries out the expansion plan in the Port of Vancouver; 2) US expands its own ports; 3) China does not build the superport in Mexico; and 4) Traders choose US and Canada as their trade gateways. Consider one of the possible resolutions, state 98, Table 4.12 illustrates the conflict evolves from the status quo to this state. As shown in the table, one can see that from the status quo, Canada takes the first move from state 44 to 49 by carrying out the expansion plans in all ports. Then, China decides to build the superport in Mexico in order to facilitate the increasing international trade. Finally, Traders extend their choices of gateway to all three options.

4.2.7. Further Discussion

As outlined by Saaty (1995), consistency ratios should be less than 5%, 8%, and 10% for 3×3, 4×4, and higher-order matrices, respectively. For all of the pairwise matrices presented earlier (Tables 4.2 - 4.9), Saaty's original 1-9 scale system is employed. Analytical results confirm that most of the consistency ratios satisfy these requirements except for two 3×3 matrices (Tables 4.3.a and 4.5.a), which yield a consistency ratio of 0.07.

Accordingly, two alternative scales discussed by Beynon (2002) were employed to execute sensitivity analyses. Beynon (2002) indicates that the original 1-9 scale may exhibit its weakness in the presence of the symmetry of negative and positive knowledge perceptions, whereas alternative scales offer some certain benefits in this case. Therefore, preference priorities are re-calculated with the following two suggested alternative scales:

1) ‘9/9-9/1’ scales (Ma and Zheng, 1991), namely $9/(10-k)$, with $k=1,...,9$;

2) ϕ mapping (Donegan et al., 1992), where the relevant scales satisfy $\phi : k \to \exp\left(\tanh^{-1}\left(\frac{k-1}{9}\right)\right)$, with $k=1,...,9$.

With these two new scales, all consistency ratios are effectively controlled within the threshold of 0.05. Recalculations with these alternative scale systems result in nearly identical state rankings (preferences), and the final equilibria remain the same as the original analysis. This sensitivity analysis confirms the consistency of our calculations and the robustness of this integrated approach.

4.3. Summary

In this chapter, the Canadian west coast congestion problem is analyzed from a conflict-analysis perspective. An integrated AHP approach is proposed to elicit preferences for each DM, and preference rankings are then fed into the conflict model within the framework of the DSS, GMCR II, for further stability analysis. This research sheds strategic insights into the conflict under consideration. Practically, the analysis suggests potential resolutions where Canada would expand its port facilities on the west coast, and traders would then continue to select Canadian west coast ports for trading purposes.

5

Three-Layer Hierarchical Analysis Model for Relative Preference Ranking in the Graph Model

In this chapter, a three-layer hierarchical analysis approach, which utilizes a fuzzy multicriteria model of a specific MCDM technique called ELECTRE III (Roy, 1996), is presented to elicit relative preference information for ranking states. An extra action layer, embedded between the criterion and option layers, is introduced and serves as a bridge between the criterion and option layers in a conflict model. Thus, it clarifies the relationships between actions and options. By using criteria instead of only options, this hierarchical analysis model can assist users to reflect more precisely on a DM's preferences or values and fully attain his or her standards of reasonableness in ranking states. Therefore, the result is more consistent and predictable. Moreover, by using the ELECTRE algorithm (Roy, 1968, 1989), it can handle quantitative as well as qualitative information. Hence, it improves the acquisition of relative preferences for each DM when employing the graph model. The original idea of this three-layer hierarchical structure was put forward by De et al. (2002) and Fu (2003), but the procedure has been extensively revised and reprogrammed.

The remainder of this chapter is organized as follows. The three-layer hierarchical analysis model and relative preference calculation procedure are presented in detail within the next section. By applying this approach to a transportation negotiation problem between shipper and carrier, the practicality and effectiveness of this approach are illustrated. Conclusions and insights are provided in the final section.

5.1. A Three-Layer Hierarchical Analysis Model

As mentioned previously, the hierarchical structure introduced in this section constitutes an additional complementary approach for the graph model, which is used to generate the relative preferences for each DM. This preference information is required before a stability analysis of the calibrated model can be carried out to find the potential equilibria and obtain other strategic insights. Figure 5.1 presents the framework of this model. The criteria in this MCDM model reflect the value system or objectives of a specified DM while the states in the model are analogous to alternatives in a usual MCDM study. The following sub-sections explain details about this procedure.

According to De et al. (2002) and Fu (2003), some concepts and definitions for this model are defined as follows:

- A *criterion* is a standard, upon which a decision or judgment is based (Merriam-Webster’s Collegiate Dictionary, 1998).

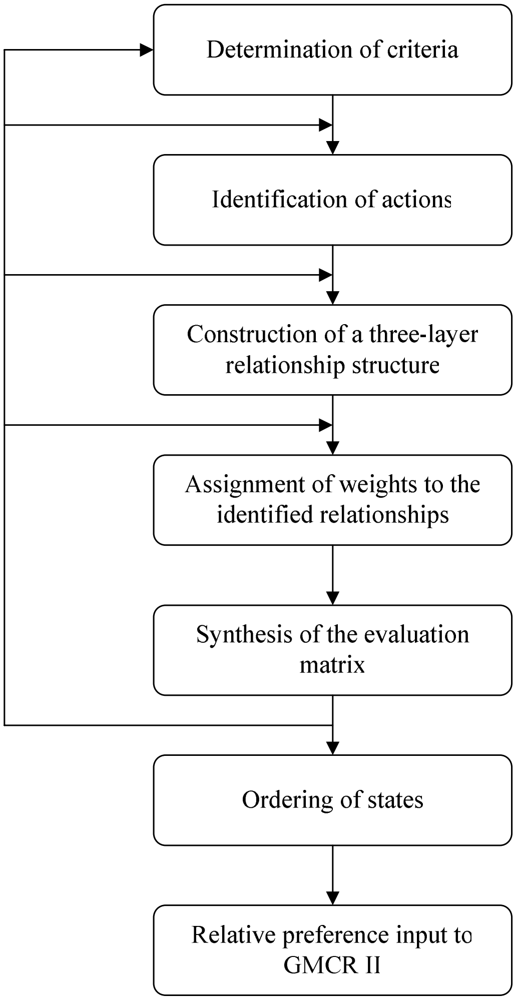


Figure 5.1 The framework of a three-layer hierarchical analysis model for relative preferences

(adapted from Fu (2003))

- An *action* is an operation that satisfies or does not satisfy with one of the criteria.
- An *option* is a combination of actions.
- A *state* is a combination of options, also called an alternative, for which a ranking of all states reflects the relative preferences of a given DM in the graph model for conflict resolution.

5.1.1. Determination of criteria

First, the objectives of a given DM should be obtained. In conflict situations, different DMs usually consider different, often contradictory, criteria to evaluate the alternatives. A set of criteria is determined according to the DM's primary interest. Let $C = \{c_1, c_2, ..., c_m\}$ denote the set of criteria, where *m* is the number of criteria.

The overall objective for a DM is usually conceptual and immeasurable. Hence, a hierarchical analysis of criteria may be employed to break down the objectives into different levels or degrees in order to reach clearly measurable criteria (Levy et al., 2000). To simplify the explanation for the preference elicitation model developed in this chapter, all of the criteria are assumed to be at the lowest level.

5.1.2. Identification of actions

The main distinction between an action and an option in this model is that the former is directly or closely related with each criterion and can be identified as a sub-object that satisfies a specific criterion or a set of criteria, while the latter is more compressed and formed by different combinations of actions. Therefore, the set of actions is generated based on each criterion and the background information of the modeled conflict. Since additional actions will not affect the final ranking result, all those actions that are unrelated with the options will automatically be eliminated during the evaluation stage. Let $A=\{a_1,a_2,...,a_k\}$ and $O=\{o_1,o_2,...,o_n\}$ represent the set of actions and options, respectively, where k is the number of actions and n is the number of options.

5.1.3. Construction of the three-layer structure

Figure 5.2 graphically portrays how the three-layer relationship structure connecting preference criteria via actions to options is constructed. Three sets of variables are put together to build a three-layer structure where each node stands for an element in the corresponding set and the arcs represent the relationships among them. From left to right, the order of the layers is criterion layer, action layer and option layer.

The construction of the relationships between criteria and actions is not difficult, because an action is a sub-criterion from the criteria's point of view. The identification of each action is based on its relationship with criteria. On the other hand, from the option layer's viewpoint, an action can be treated as a "sub-option". An action may not exist independently in the real world, but it is a direct solution to its corresponding criterion or criteria. Let $\mathrm{CA}=\left\{c_1a_1,c_1a_2,...,c_ma_k\right\}$ denote the set of relationships between the criterion and action layers, and $\mathrm{AO}=\left\{a_1o_1,a_1o_2,...,a_ko_n\right\}$ stand for the set of relationships between the action and option layers, where m is the number of criteria, k is the number of actions, and n is the number of options.

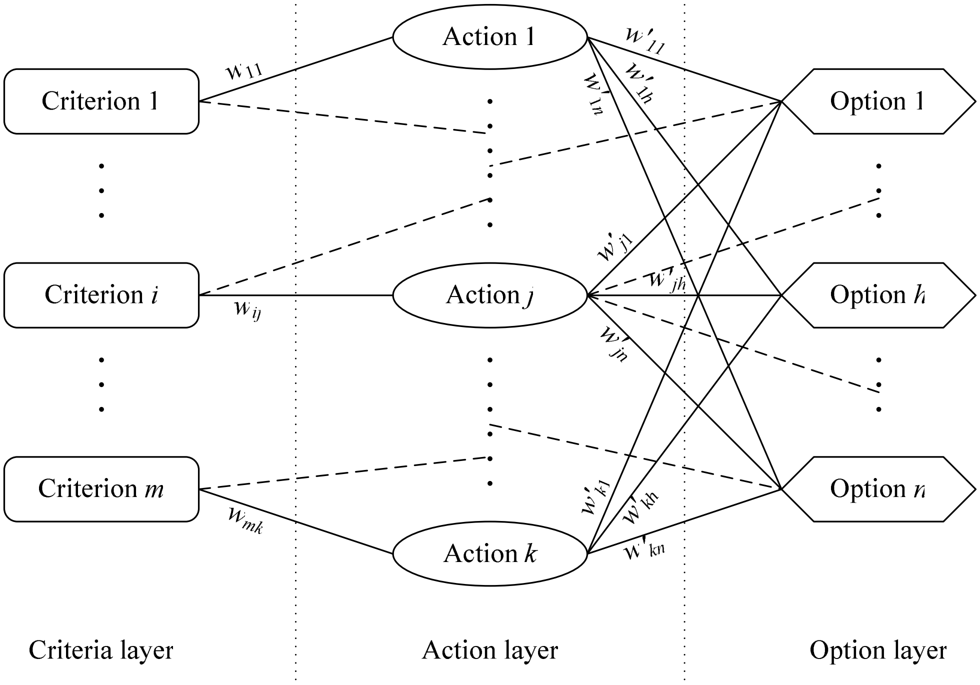


Figure 5.2 Construction of the Three-layer Relationship Structure

(adapted from Fu (2003))

The importance of the various relationships is reflected by the weights determined from a specific DM's viewpoint. In particular, for each $c_i a_j \in \mathrm{CA}$, a normalized weight denoted by w_{ij} is assigned such that:

$$\sum_{j=1}^{k} w_{ij} = 1$$

Similarly, normalized weights are also assigned to the relationships between actions and options. For each $a_j o_h \in \mathrm{AO}$, a weight w'_{jh} is assigned such that:

$$\sum_{h=1}^{n} w'_{jh} = 1$$

5.1.4. Synthesis of the evaluation matrix

For each criterion, the evaluation of each alternative value in the evaluation matrix is calculated using a linear relationship. States are the combinations of options which are either selected or not selected, as is done in GMCR. Let $S = \{s_1, s_2, ..., s_g\}$ represent the set of states, where g is the number of states. Thus, the corresponding evaluation of a certain state s_t corresponding to criterion c_i is calculated as follows:

$$W_{it} = \sum_{j=1}^{k} \sum_{h=1}^{n} w_{ij} w'_{jh} o_h$$

where:

o_h: option h ($o_h = 1$ means option h is selected in a state; otherwise, $o_h = 0$);

w_{ij}: the weight between criterion c_i and action a_j;

w'_{jh}: the weight between action a_j and option o_h;

$1 \le i \le m$ and $1 \le t \le g$.

The calculated value, W_{it}, represents the value of each state corresponding to every criterion, which constitutes each entry of an $m \times g$ matrix. This specific matrix, denoted by W^{EM}, is called the evaluation matrix. A general format of this matrix is depicted as:

$$W^{EM} = \begin{array}{c} \\ c_1 \\ \cdots \\ c_i \\ \cdots \\ c_m \end{array} \begin{array}{c} \begin{array}{ccccc} s_1 & \cdots & s_t & \cdots & s_g \end{array} \\ \begin{pmatrix} W_{11} & \cdots & W_{1t} & \cdots & W_{1g} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ W_{i1} & \cdots & W_{it} & \cdots & W_{ig} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ W_{m1} & \cdots & W_{mt} & \cdots & W_{mg} \end{pmatrix} \end{array}$$

5.1.5. Calculation of the relative ranking of states

After obtaining the evaluation matrix, a fuzzy MCDM methodology (De and Hipel, 1987) based on ELECTRE III (Roy, 1989) is used to calculate the preference ranking, whereby states are ranked from most to least preferred for each DM and ties are allowed. Fuzzy set theory was first introduced by Zadeh (1965, 1973) and has subsequently become a highly popular technique for modeling uncertainty in many disciplines. Integrating a fuzzy approach into ELECTRE permits this methodology to handle both quantitative and non-quantitative criteria in the presence of uncertainty.

As shown in Figure 5.3, the basic element of this methodology is a pseudo-criterion, which is identified based on the definitions of the indifference, *q*, and preference threshold, *p*.

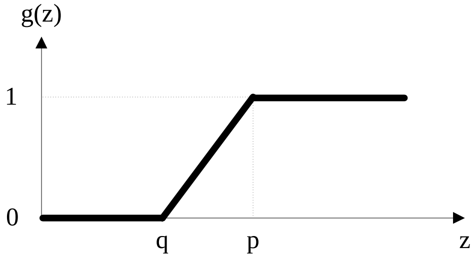


Figure 5.3 Pseudo-criterion

Let $f_i(a) = W_{ia}$ and $f_i(b) = W_{ib}$ denote the corresponding evaluation of states s_a and s_b, respectively, for a certain criterion *i*. Then, the fuzzy preference relation aP_ib is represented by:

$$aP_ib = \begin{cases} 0, & if \quad f_i(a) \le f_i(b) \\ g(z), & if \quad f_i(a) > f_i(b) \end{cases}$$

where $g(z) = g\left[f_i(a) - f_i(b) \right]$ and $\left[f_i(a) - f_i(b) \right]$ corresponds to the evaluation of states *a* and *b,* respectively, for a particular evaluation criterion *i*.

Then, a pseudo-criterion is defined as:

$$g(z) = \begin{cases} 0, & 0 \le z \le q \\ (z-q)/p, & q < z \le (q+p) \\ 1, & z > (q+p) \end{cases}$$

where *p* and *q* represent the preference threshold and indifference threshold, respectively.

Alternatives a and b are indifferent when $\left[f_i\left(a\right) - f_i\left(b\right) \right]$ is smaller than q. The preference then increases gradually until $\left[f_i\left(a\right) - f_i\left(b\right) \right]$ equals $(q+p)$ and the preference becomes absolute if $\left[f_i\left(a\right) - f_i\left(b\right) \right] \geq (q+p)$.

By employing this pseudo-criterion definition, the preference matrix for all states and criteria can then be constructed. The preference matrix contains the pairwise fuzzy preference relationship information, which is derived from the evaluation matrix mentioned earlier. For a certain criterion i, the preference matrix, denoted by P_i^M, can be depicted as:

$$P_i^M = \begin{array}{cc} & \begin{array}{ccccccc} s_1 & \ldots & s_a & \ldots & s_b & \ldots & s_g \end{array} \\ \begin{array}{c} s_1 \\ \ldots \\ s_a \\ \ldots \\ s_b \\ \ldots \\ s_g \end{array} & \begin{pmatrix} 1P_i1 & \ldots & 1P_ia & \ldots & 1P_ib & \ldots & 1P_ig \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ aP_i1 & \ldots & aP_ia & \ldots & aP_ib & \ldots & aP_ig \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ bP_i1 & \ldots & bP_ia & \ldots & bP_ib & \ldots & bP_ig \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ gP_i1 & \ldots & gP_ia & \ldots & gP_ib & \ldots & gP_ig \end{pmatrix} \end{array}$$

The next step, called aggregation of the preferences, is to measure the degree of preference allotted to one alternative over another considering the integrated view of all criteria. In order to reflect the weights or the importance of each criterion from a DM's points of view, a normalized weight, $\overline{w_i}$, is assigned to each criterion such that:

$$\sum_{i=1}^{m} \overline{w_i} = 1, \quad 0 \leq \overline{w_i} \leq 1$$

Then, for every criterion $c_i \in C$, the concordance-discordance index can be determined by calculating two fuzzy relationships: fuzzy preference, aP_ib, and fuzzy doubt, aDb.

The concordance relation, aCb, represents the aggregated preference relation over all criteria. It can be calculated as the weighted sum of the preference degree aP_ib.

$$aCb = \sum_{i=1}^{m} \overline{w_i} \, . aP_ib$$

When all criteria have the same importance, i.e., $\overline{w_1} = \overline{w_2} = ... = \overline{w_m} = \frac{1}{m}$, the concordance relation is:

$$aCb = \frac{1}{m} \sum_{i=1}^{m} aP_ib$$

Now, a veto threshold is introduced for each pseudo-criterion such that any credibility for the outranking of *b* by *a* is refused if

$$f_i(b) \geq f_i(a) + v_i\left[f_i(a)\right].$$

Then, the discordance index is calculated as:

(a) $ad_ib = \left\langle \text{Min}\left[1, \left\{ \text{Max}(0, \frac{f_i(b) - f_i(a) - p_i[f_i(a)]}{v_i[f_i(a)] - p_i[f_i(a)]}) \right\} \right] \right\rangle$, when $v_i[f_i(a)] - p_i[f_i(a)] \neq 0$;

(b) $ad_ib = 1$, when $v_i[f_i(a)] - p_i[f_i(a)] = 0$;

where p_i is the preference threshold and v_i is the veto threshold. When all the preference and veto thresholds are equal, the discordance index can be rewritten as:

(a) $ad_ib = \left\langle \mathrm{Min}\left[1, \left\{\mathrm{Max}(0, \frac{f_i(b) - f_i(a) - p[f_i(a)]}{v[f_i(a)] - p[f_i(a)]})\right\}\right]\right\rangle$, when $v[f_i(a)] - p[f_i(a)] \neq 0$;

(b) $ad_ib = 1$, when $v[f_i(a)] - p[f_i(a)] = 0$.

Then, the aggregation of the discordance index forms a global index via a fuzzy logical operation given as:

$$aDb = 1 - \prod_{i=1}^{m} (1 - ad_ib)$$

A final outranking relationships, aRb, obtained from the conjugation of both concordance and discordance relation, can be used to represent that alternative *a* is at least as good as alternative *b*, and does not cause any serious doubt towards the preference of *a* over *b*, with respect to every criterion.

(a) $aRb = aCb$, when $ad_ib \leq aCb$ for $i = 1, 2, ..., m$;

(b) $aRb = aCb \cdot \left\{\prod_{i^*} \frac{1 - ad_ib}{1 - aCb}\right\}$, when $ad_ib > aCb$ for $i = 1, 2, ..., m$; for i^* = set of all i where $ad_ib > aCb$.

Finally, the equation $\Phi(a) = \sum_{k \in S} aRk - \sum_{k \in S} kRa$ is used to obtain the evaluation value over all states or alternatives considered in the preference ranking. The alternative with the highest $\Phi(a)$ value will rank first.

5.1.6. Output of Preference Information

Decision aid processes are never sequential, and hence, different phases in a model can be revised and recalculated. Therefore, the ranking results should be interpreted for meaning and compared to the actual situation in the real world. One can carry out a sensitivity analysis by changing the weights and the assignment of relationships between different layers or parameters in the ELECTRE algorithm (for example: indifference threshold and preference threshold). The new input information is then used to re-calculate the preference ranking. Several iterations may be needed in order to achieve a stable or satisfactory ranking result. Then, the preference information for DMs is ready for being input into GMCR II.

5.2. Case study: A Transportation Negotiation Problem

As one of the four drivers of supply chain management, transportation cost is a significant portion of the costs that incur in most supply chains (Chopra and Meindl, 2003). Recently, modern transportation logistics have been experiencing several important transforming trends, such as increasing competition, and growing complexity and variability. Challenges raised from these trends require systematic and sophisticated optimization solutions involving each organization within supply chains (Putten et al., 2006).

Shippers and carriers are two key players in any transportation problem. To build and maintain a practical relationship between them has turned out to be critical and prudent. Virtually, every facet of such a relationship must be negotiated and stated in a contract (Stank and Thomas, 2000). Hence, negotiations between different parties in the transportation domain become ineluctable and crucial, especially in the newly-developed and widely-employed just-in-time (JIT) systems. Within JIT systems, organizations necessitate very stable and reliable transportation services in order to maintain a low level of inventory, and at the same time, guarantee the demand to be completely met.

In this case study, a hypothetical two-player transportation negotiation problem (Bookbinder and Fraser, 1990) is investigated. There are two participants (DMs), a *Shipper* and a *Carrier*, involved in this negotiation problem. The relationship between shippers and carriers is similar to the one between buyers and sellers, but distinguishable due to the transportation environment. A *Shipper* represents the consumer of transportation services, while a *Carrier* is the provider. Manufacturers are a typical example for the shippers. Suppose that the two DMs have been maintaining an ongoing cooperative relationship over a very long time horizon. However, at a particular situation, some changes might exist. For instance, the *Carrier* might raise the transportation charge in order to obtain higher revenues or lower the service level in order to reduce overall costs. The other party in this case, the *Shipper*, would have various responses accordingly. Table 5.1 depicts the negotiation model of this situation.

Table 5.1 DMs and Options in the transportation negotiation problem

DMs	Options
Carrier	1) Raise price: In order to obtain more revenue. 2) Keep or lower price: In order to keep Shipper as its customer. 3) Lower services: In order to reduce overall costs. 4) Keep or improve services: In order to keep Shipper as its customer.
Shipper	5) Accept: Accept Carrier’s price and services 6) Abandon: Abandon this Carrier and choose a private fleet or another carrier. 7) Require service: Require a higher level of service than the current one.

In this negotiation model, each of the options can be chosen by DMs, denoted by ‘Y’, or not chosen, denoted by ‘N’. Thus, mathematically, a total of 7 options would represent 2^7 possible combinations. Nevertheless, many of them are impossible in the real situation. For example, it is impractical for the *Shipper* to choose to *Accept* and *Abandon* at the same time. Similarly, the *Carrier* cannot simultaneously choose to *Raise price* and *Keep or lower price*, as well as *Lower services* and *Keep or improve services*. The reason is that these options are mutually exclusive. Moreover, the *Shipper* has to react to the *Carrier* by choosing at least one of these two options. After considering all these circumstances, GMCR II automatically generates a list of feasible states for this model, which contains the 16 feasible states shown by Table 5.2.

Table 5.2 Feasible states

DMs and Options	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Carrier																
1) Raise price	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
2) Keep or lower price	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
3) Lower services	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N
4) Keep or improve services	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y
Shipper																
5) Accept	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N	N	N
6) Abandon	N	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y
7) Require service	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y

5.2.1. Construction of the three-layer structure

From the viewpoint of the *Carrier,* its major concern is to achieve more profits based on the relationship with the current customer, the *Shipper*. Therefore, two criteria are identified for the *Carrier*: 1) *Increase profits* (C1); 2) *Maintain a long-term relationship with the Shipper* (C2). In order to satisfy the first criterion, *Increase profits*, two actions are quite obvious: *Increase revenue* (A1) and *Decrease costs* (A2). Also, for the second criterion, the *Carrier* needs to *Fulfill Shipper's requirements* (A3) and *Improve its performance* (A4).

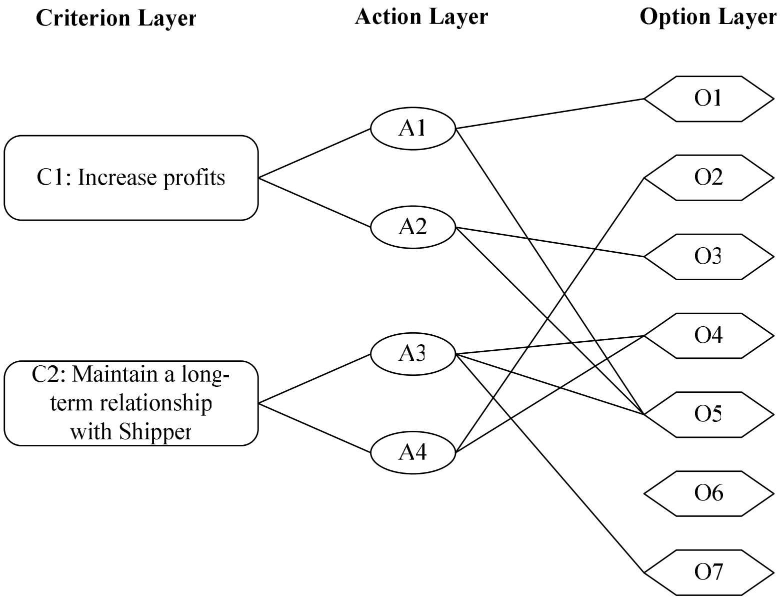


Figure 5.4 Overall Relationships in the Hierarchical Analytical Model for the *Carrier*

In the three-layer model, the relationships between the criterion and action layers naturally exist because each action corresponds to a specific criterion in the action definition procedure. Then, these relationships are extended to the option level. For instance, as to the *Carrier*, two options, the *Carrier Raise price* (O1) and the *Shipper Accept* (O5), result in the action of *Increase revenue* (A1). Thus, the connections from A1 to O1 and A1 to O5 are established. The overall relationships for the *Carrier* are shown in Figure 5.4.

After the construction of these relationships, a normalized weight is assigned to each relationship to represent the importance or the interests of the DM under study. For example, from the viewpoint of the *Carrier*, both actions *Increase revenue* (A1) and *Decrease costs* (A2) are equally attributable to the criterion *Increase profits* (C1). So a weight of 0.5 is assigned to either relationship. All the assigned weights for criterion-action and action-option layers are shown in Tables 5.3 and 5.4, respectively.

Table 5.3 Weights for the Criterion-Action Layer

Criteria	Actions	Weights
C1: Increase profits	A1: Increase revenue	0.5
	A2: Decrease costs	0.5
C2: Maintain a long-term relationship with Shipper	A3: Fulfill Shipper’s requirements	0.5
	A4: Improve its performance	0.5

Table 5.4 Weights for the Action-Option Layer

Actions	Options	Weights
A1: Increase revenue	O1: Raise price	0.6
	O5: Accept	0.4
A2: Decrease costs	O3: Lower services	0.6
	O5: Accept	0.4
A3: Fulfill Shipper’s requirements	O4: Keep or raise services	0.4
	O5: Accept	0.4
	O7: Require services	0.2
A4: Improve its performance	O2: Keep or lower price	0.5
	O4: Keep or raise services	0.5

5.2.2. Synthesis of the evaluation matrix

Figure 5.5 depicts the procedure for constructing the evaluation matrix for the first criterion, *Increase profits*, and its hierarchical relationships with states via the action and option levels, as well as the relevant weights. For a criterion, each entry in the evaluation matrix can be determined by a linear aggregation method, as explained previously. Consider state 2 for the *Carrier*, for example, the entry for this state under the criterion, *Increase profits*, is calculated as follows:

$$0.5\times\left(0.6\times0+0.4\times1\right)+0.5\times\left(0.6\times1+0.4\times1\right)=0.7$$

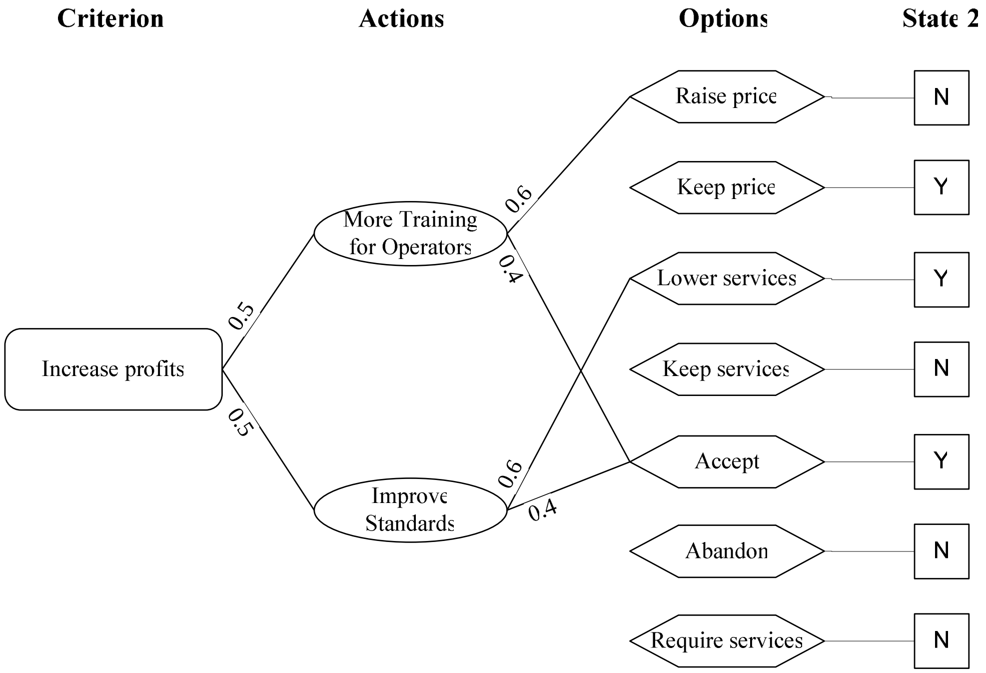


Figure 5.5 Assigned weights associated with Criterion 1 for the *Carrier.*

5.2.3. Calculation of the relative ranking of states

Based on this evaluation matrix, the calculation of the relative ranking of states is ready to be carried out using the fuzzy MCDM approach as detailed in Section 5.1.5. In this case study, indifference, preference and veto thresholds are set to be 0.03, 0.25 and 0.5, respectively.

As explained in Section 5.1, the fuzzy preference relation, aP_ib, is firstly calculated by the pairwise comparison of two states' evaluation values. Then, the weighted sum of the preference degree, the concordance relation, aCb, is accordingly obtained. Additionally, the discordance index, ad_ib, and corresponding aggregation are also computed by comparing the evaluations of two states and employing a fuzzy operation. Through the computation of aCb and ad_ib, the outranking relation, aRb, is attained, and, thus, the overall preference evaluation value, Φ, is finalized. Table 5.5 provides the final preference values of states for the *Carrier*, as well as the preference values for the *Shipper*, where the larger a preference value is, the more preferred the corresponding state is. Therefore, the preference rankings for two DMs are elicited and listed in Table 5.6. The states within a square bracket are equally preferred by the given DM.

The relative preferences may be fine-tuned to reconcile the ranking results with the situation in the real world. Sensitivity analyses may be carried out by changing weights and assignments of relationships between different layers or parameters for ELECTRE, such as, indifference, preference, and/or veto thresholds.

Table 5.5 Relative Preference Information

States	Carrier	Shipper
1	0.76	-3.34
2	3.09	2.00
3	7.13	2.00
4	2.94	9.02
5	-5.04	-5.84
6	-7.50	-3.68
7	-4.28	-3.68
8	-3.88	-1.84
9	2.13	-0.16
10	4.61	6.86
11	8.11	6.86
12	3.56	10.84
13	-4.40	-5.18
14	-5.96	-2.00
15	-2.46	-2.00
16	-2.84	-0.50

Table 5.6 Preference rankings

DMs	Preference Rankings Most preferred < ---> Least preferred															
Carrier	11	3	10	12	2	4	9	1	15	16	8	7	13	5	14	6
Shipper	12	4	[10	11]	[2	3]	9	16	8	[14	15]	1	[6	7]	13	5

5.2.4. Stability analysis

After the hierarchical analysis approach is utilized to obtain preference rankings for each DM in the conflict model, the ranking results serve as input into GMCR II. Then, the stability of every state for each DM can be calculated by running GMCR II.

When a state is stable according to a specific solution concept for all DMs in a conflict, the state constitutes an equilibrium under the solution concept. This implies that no DM has the incentive to move away from that state unilaterally. Table 5.7 lists the unique strongest equilibrium, state 11, which is stable for all solution concepts. This resolution indicates that: 1) the *Carrier* will raise price and keep or improve the service level; and 2) the *Shipper* will require higher service level and accept the price and services offered by the *Carrier*.

Table 5.7 Equilibrium for the transportation negotiation problem

DMs and Options	11
Carrier	
1) Raise price	Y
2) Keep or lower price	N
3) Lower services	N
4) Keep or improve services	Y
Shipper	
5) Accept	Y
6) Abandon	N
7) Require service	Y

5.2.5. Status quo analysis

As stated in the modeling procedure, at the status quo, described by state 4, the *Carrier* and the *Shipper* are maintaining an ongoing cooperative relationship, which indicates that these two parties agree with a certain level of price and services. At a particular time point, the *Carrier* tries to increase their profits by raising the service price. So the situation moves from state 4 to state 3. Subsequently, the *Shipper* still wants to keep a long-term relationship with the *Carrier* and, therefore, decides to discuss a higher rate for a premium service. Thus, the equilibrium is achieved. This state transition from the status quo to state 11 is depicted in Table 5.8.

Table 5.8 State transition from the status quo to state 11

	Status Quo		Transitional State		Equilibrium
DMs and Options	4		3		11
Carrier					
1) Raise price	N	→	Y		Y
2) Keep or lower price	Y	→	N		N
3) Lower services	N		N		N
4) Keep or improve services	Y		Y		Y
Shipper					
5) Accept	Y		Y		Y
6) Abandon	N		N		N
7) Require service	N		N	→	Y

5.3. Summary

Relative preferences constitute the most important information required for modeling a strategic conflict using the Graph Model for Conflict Resolution. A hierarchical preference analysis procedure is presented in this chapter to enrich preference elicitation approaches implemented in GMCR II. An extra action layer is introduced into the hierarchical analysis methodology and serves as a bridge for a user to disclose the relationships between criteria and alternatives or states. Thus, the three-layer structure provides a solid platform for aggregating option weighting with fuzzy MCDM and ELECTRE-based methodologies and forming a criterion-oriented preference ranking technique, which can readily handle both quantitative and qualitative information.

6

Conclusions

Two multiple criteria decision making approaches are developed for eliciting relative preferences for decision makers included in a graph model. The first preference ranking approach, presented in Chapter 4, is a modified Analytical Hierarchy Procedure that considers not only each decision maker's individual preferences, but also his or her power of influence over the entire situation. The other effort given in Chapter 5 refines a three-layer hierarchical multiple criteria decision analysis (Fu, 2003), which utilizes a fuzzy multiple criteria technique called ELECTRE III and aims to obtain required preferences based on the values or criteria of a given decision maker.

In order to demonstrate the integration of these methods with the graph model for conflict resolution, two case studies are carried out. In the first case study, the Canadian west coast port congestion problem is examined within the graph model framework. The strategic analyses carried out in this research suggest potential resolutions in which Canada would expand port facilities at various locations, encouraging traders to continue choosing the Canadian west coast as one of their trade gateways to North America. Another case study involving transportation negotiations between the shipper and the carrier is conducted for illustrating the three-layer hierarchical multiple criteria decision analysis for preference elicitation.

6.1. Comparison of the Two Proposed Approaches

In addition to utilizing MCDM techniques to generate preference rankings, both approaches proposed in this thesis involve a hierarchical structure with weights, based on which the preference elicitation procedure is carried out. However, several differences also exist. For example, the two hierarchies have distinct contents, MCDM techniques are used in dissimilar ways, and ELECTRE III is essentially a fuzzy approach while the other one is not. Table 6.1 lists the commonalities and differences between the two approaches.

Essentially, each approach deals with the negative preference issue in its own manner. Opposite to positive preference information, a negative preference indicates that the DM prefers not to choose a particular option. In a regular case, the option with a negative preference can be assigned a negative weight. As stated in Chapter 4, the adapted AHP approach calculates the weight for each option by pairwise comparison. Thus, the negative preference problem is avoided by assigning a comparatively lower weight to the option that has a negative preference.

Alternatively, in the other approach, modifications of options within the modeling stage are very helpful. More specifically, for each option with a negative preference, an additional opposite option is added to the given analytical model. Subsequently, because the additional options are opposite, they have positive preferences and are considered in a similar fashion to the original options.

Table 6.1 The commonalities and differences between the two proposed approaches

		Adapted AHP approach	Three-layer hierarchical approach
Commonalities		1) Both are approaches based on MCDM techniques, and integrated with the methodology of GMCR in order to capture the relative preference information.	
		2) Both methods employ a hierarchical structure to carry out the calculations. Different layers within the structure are connected by relationships and weights.	
Differences	1) Contents of Hierarchy	DMs' influence powers and individual preferences.	DMs' criteria and corresponding actions.
	2) MCDM is used for?	AHP is used to construct the hierarchical structure and obtain weights.	ELECTRE III is used to calculate the preference values of the states.
	3) Fuzzy?	No.	Yes.
	4) Negative preferences?	Avoid the problem through pairwise comparison.	Solve the problem through modifications of options.

6.2. Summary of Contributions

(1) Two multiple criteria decision making methods are presented to elicit a preference ranking of states for each decision maker involved in a conflict within the paradigm of the graph model for conflict resolution. In addition to the regular techniques used to generate preference information in GMCR II, these two methods enhance this function by

considering each decision maker’s power of influence over the entire situation and his/her criteria or objectives, respectively. The derived information is then reentered into the GMCR II system for further stability analyses.

(2) As an ongoing real-world conflict, the case study of the Canadian west coast congestion dispute furnishes a unique visual angle to fast-growing international trade, especially for the Canadian government. Moreover, this case may reflect many similar situations throughout the world. Interested parties may gain useful information and better understanding of different situations, which could facilitate their decision-making processes.

(3) Transportation is one of the most important dimensions in the modern logistics environment. The relationships between shippers and carriers, two key parties involved in transportation, are always critical and sophisticated. The graph model analysis enables various parties, not only shippers and carriers themselves, but also other interested parties, such as supply chain organizers or researchers, a diverse aspect to systematically study and provides strategic advice for transportation negotiations.

6.3. Future Research Opportunities

The two approaches introduced in this thesis are based on two MCDM techniques, AHP and ELECTRE III. In fact, many other MCDM or outranking techniques, such as ANP (Saaty, 1996, 2001, 2005), MELCHIOR (Leclercq, 1984), TRICHOTOMIC (Moscarola and Roy, 1977; Roy, 1981), PROMETHEE (Brans and Vincke, 1985), are also available and may be applied to the procedure of eliciting preference information.

Next, because of their sensitivity, preferences may be affected by many different matters. Emotional issues are a specific example. Also, as the situation moves from one stage to another, the preferences may change accordingly. In addition, interactions between different parties might affect the preferences. Therefore, one possible line of research is to take these issues into consideration when preferences are elicited.

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