Decision Support Tools for Strategic Policy Analysis

by

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A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Applied Science
in
Systems Design Engineering

Waterloo, Ontario, Canada, 2006

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

New or improved decision analysis tools are developed in this thesis to address strategic policy analysis with specific focus on two topics: strategic conflict analysis and region-performance comparisons.

A strategic conflict refers to a situation in which two or more decision makers (DMs) are to make a decision that affects issues over which they have different preferences. Various forms of strategic conflict exist all around us, in areas such as environmental management, international relations, economic competition, and relationships among individuals. The graph model for conflict resolution (GMCR) is an advanced and comprehensive tool to systematically study strategic conflicts. A well-known decision tool, the analytic network process (ANP) is adapted for use in strategic conflict analysis and a comparison of the performance of ANP with GMCR is carried out. Both methods are applied to an international trading conflict between the United States and China over the importation of television sets into the US in order to gain strategic insights about this dispute using the two different but complementary approaches.

A country's overall performance comparison with respect to different kinds of indices such as economic, environmental and political indices constitutes another interesting topic for strategic policy analysis. An index aggregation approach is proposed to compare BRICSAM countries, a populous rapidly-growing economic group of nations consisting of Brazil, Russia, India, China, South Africa, ASEAN (Association of South-East Asian Nations), and Mexico with G7 (Group of Seven), the most developed country club including Canada, France, Italy, Japan, Germany, United Kingdom and the United States. A data-envelopment-analysis (DEA) based approach is proposed to aggregate different ranking indices for BRICSAM and the G7 countries. The proposed method can provide a fair overall assessment of a country's standing by maximizing its possibility of obtaining the best evaluation score.

Finally, a framework to carry out generic strategic analysis for regions' competence analysis is designed based upon the theory of generic strategic analysis proposed by Porter (1980). This is a well-known approach for use in business competence analysis. The basic idea is to carry out generic strategic analysis in policy studies and two decision tools, DEA and the analytic hierarchy process, are employed to quantify the analysis of competence efficiency and potentiality, respectively. A case study of the competence analysis of provinces in China is used to demonstrate the analysis procedure.

Acknowledgments

I would like to express my sincere appreciation to my thesis supervisor, Dr. Keith W. Hipel, for his valuable guidance. Without his confidence in me, his continuous support, constructive guidance, kind patience, and helpful comments, I would not have been able to accomplish this work. It is my great honour to work under his supervision and have my self-confidence strengthened through this experience.

Special thanks are due to Professor John English, Director of the Centre for International Governance Innovation (CIGI) located in Waterloo, Ontario, Canada, for providing me with a scholarship to support my Master's study. I am also grateful for my committee members, Drs. Kumaraswamy Ponnambalam and Jonathan Kofman for their constructive comments in the final stages of the work. They have been abundantly helpful and have assisted me in numerous ways.

I cannot end without thanking my parents and my husband for their constant encouragement and love, on which I have relied upon throughout the period of this work.

Dedication

This is dedicated to Dr. Ye Chen, my beloved husband.

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Chapter 1

Motivation and Objectives

1.1 An Overview of Decision Making

Decision making is considered to be one of the fundamental activities of human beings. People make decisions every day. Human decisions range in difficulty from very simple to very complex and in scope from very narrow to very broad. Figure 1.1 demonstrates the general procedure for decision making which includes four components: real world problem, modeling, analysis and implementation. For a real world problem, decision tools are utilized to model and analyze the problem to find a suitable solution to solve the problem.

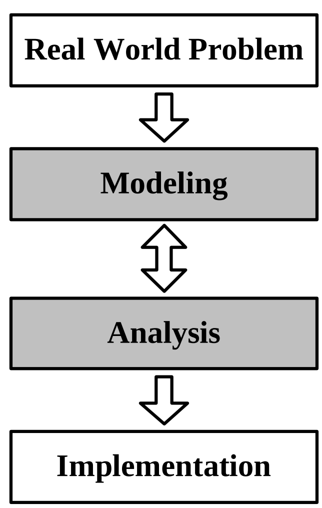


Figure 1.1: The decision making procedure

Every decision situation exists within a context. This environment consists of a set of circumstances and conditions that affect the manner in which the decision making problem can be resolved. Hipel et al. (1993); Radford (1989) suggested four major factors that determine the context, namely:

1. Whether or not uncertainty exists in the decision situation being studied,

2. Whether or not the benefits and costs resulting from the implementation of courses of actions can be completely assessed in quantitative terms,

3. Whether a single criterion is involved or if multiple criteria must be taken into account,

4. Whether the power to make the decision lies in the hands of one organization, individual or group or whether two or more of the participants have power to influence the result.

Figure 1.2 shows the relationships among different decision making scenarios. The simplest type of decision making is one with a single decision maker who has a single objective. Beyond this problem comes the single decision maker, multiple objective situation and then the multiple decision maker, single objective problem. Finally, there is the multiple decision maker-multiple objective problem. Operations research techniques such as traditional mathematical programming (linear and nonlinear) usually deal with single decision maker - single objective problems, while game theory is concerned with multiple decision makers having multiple objectives.

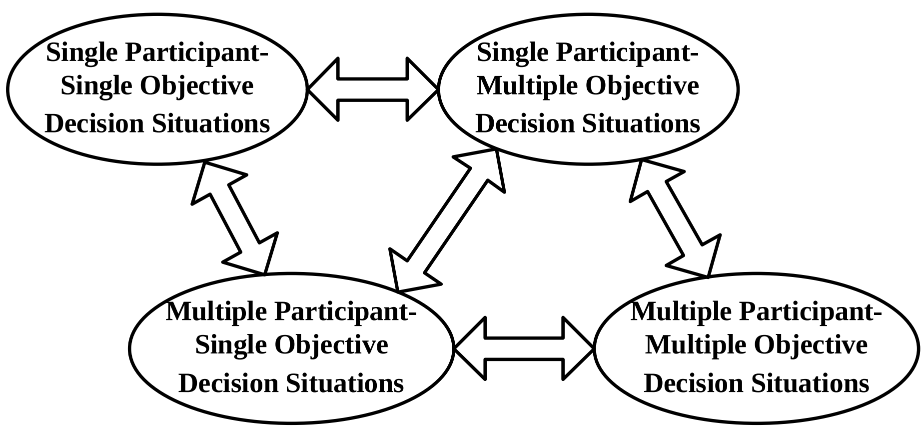


Figure 1.2: Relationships among different decision making scenarios, adapted from Hipel et al. (1993)

1.2 Decision Making for Strategic Policy Analysis

The main purpose of this thesis is to develop decision support tools for strategic policy analysis with specific focuses on the following two topics:

1.2.1 Strategic Conflict Analysis

A strategic conflict is a situation in which two or more decision makers (DMs) are to make a decision that affects issues over which they have different preferences (Fang et al., 1993). Conflicts are one of the most characteristic attributes of human societies. Various forms of strategic conflict exist all around us, in areas such as environmental management, international relations, economic competition, and relationships among individuals.

Conflicts are studied in a wide range of disciplines including social science, game theory, systems engineering, and information and decision sciences, in which researchers conceptualize and analyze conflicts from different perspectives. Social scientists focus mainly on the qualitative study of conflicts, describing how to improve relationships among individuals, groups, organizations, and nations (Daniel, 2000). Other fields, including operations research, systems engineering, game theory, economics, information science and decision science concentrate on quantitative studies, explaining conflicts using mathematical models. Myerson (1991), for example, provides a thorough examination of the models, solution concepts, and methodological principles of game theory approaches for conflict analysis; Pawlak (1998, 2005) uses rough set theory for the same purpose.

Howard (1971) developed metagame analysis with option form for structuring and modelling a conflict problem; Fraser and Hipel (1984) extended metagame analysis to conflict analysis; and Fang et al. (1993) proposed the graph model for conflict resolution, which is an expansion and reformulation of conflict analysis. Meanwhile, Saaty (1980) developed the analytic hierarchy process (AHP) for decision analysis, Alexander (1993) and Saaty and Alexander (1989) employed AHP for conflict analysis, and Saaty (2001) created the analytic network process (ANP) as a generalization of AHP. Vargas (1985) reviewed the conflict analysis approach of Fraser and Hipel (1984) and compared it with the AHP method, summarizing the different features of the two methods.

In this thesis, ANP is designed for use in conflict analysis and a comparison study of ANP and the graph model for conflict resolution for conflict analysis is carried out. ANP and the graph model are based on different principles: ANP is a decision-theory-based technique, while the graph model is a game-theory-related technique. The objective of this part of the research is to highlight the distinctive features and to compare different information requirements of these two methods for better understanding of a conflict.

1.2.2 Performance Comparisons of Regions

Strategic policy analysis is also studied under the umbrella of multiple criteria decision analysis (MCDA). MCDA is a procedure aimed at supporting DMs whose problem involves multiple criteria which are usually conflicting. MCDA aims at highlighting these conflicts and deriving a way to come to a compromise in a transparent process. For example, the European Parliament may apply MCDA to arrive at a number of conclusions on whether introducing software patents in Europe would help or destroy the European software industry (Wikipedia, 2006). Specifically, the study of overall evaluation of the performances of regions from various points of view is discussed in this thesis.

An index aggregation approach is proposed to carry out comparisons of BRICSAM countries, a populous rapidly-growing economic group consisting of Brazil, Russia, India, China, South Africa, ASEAN (Association of South-East Asian Nations), and Mexico with the G7 (Group of Seven), the most developed country club including Canada, France, Italy, Japan, Germany, United Kingdom and the United States (US). It is estimated that by 2050, the accelerated economic activity of BRICSAM could significantly impact investment flows, legal and regulatory frameworks, the stability of political institutions, human capital and migration flows, competition policy, intellectual property rights, and social and environmental policies.

The comparison analyses of BRICSAM and the G7 countries could assist people to better understand the status quo of these countries in the global economy and international system, particularly in the areas of economics and responsible activities such as sustainable development, global commitments and transparent practices. Many country-ranking indices, such as the indices given in the global competitiveness report by the World Economic Forum, and the environmental sustainability index by Yale University, constitute evaluations of countries from different perspectives. In this research topic, a data-envelopment-analysis based approach is proposed to aggregate different ranking indices for BRICSAM and the G7 countries. The approach can provide a fair overall assessment of a country's standing by maximizing its possibility of obtaining the best possible evaluation score.

Finally, a framework to carry out generic strategic analysis for regions' competence analysis is designed based upon the theory of generic strategic analysis proposed by Porter (1980). The theory of generic strategic analysis is used for competence analysis in business. This idea is adapted to carry out the performance comparison of regions, and two decision tools, the data envelopment analysis and the analytic hierarchy analysis, are designed to quantify the analysis of competence efficiency and potentiality, respectively. A case study of the competence analysis of provinces in China is used to demonstrate the analysis procedure.

1.3 Organization of Thesis

Figure 1.3 summarizes the organization of this thesis.

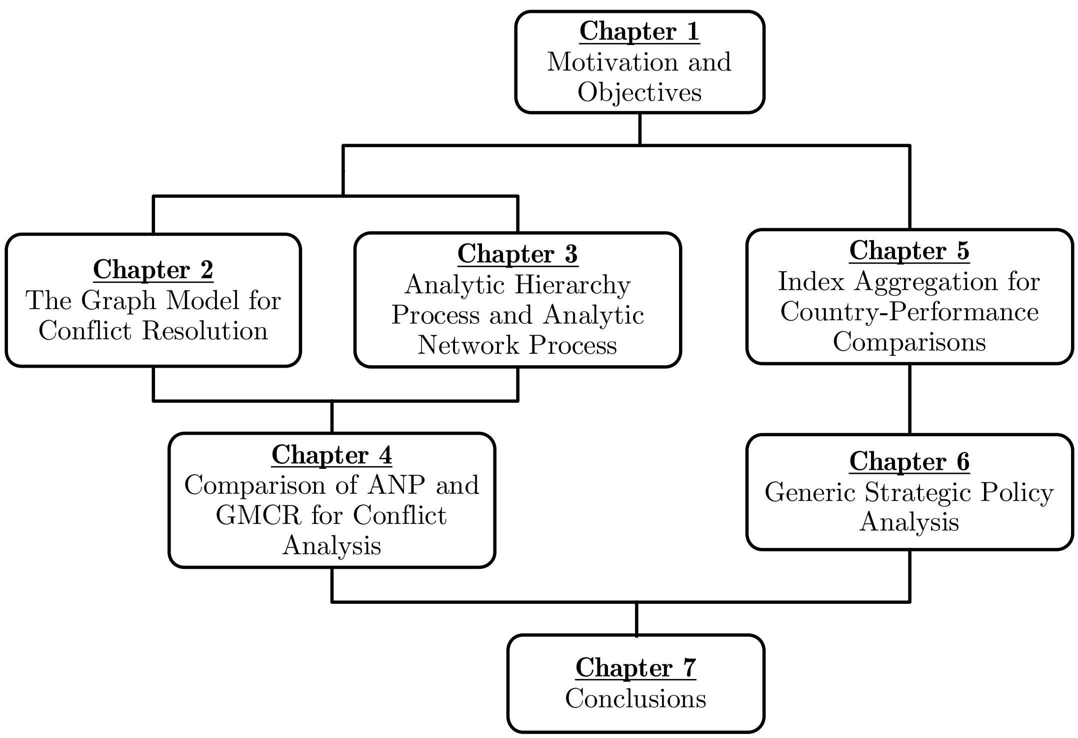


Figure 1.3: Contents of this thesis

The contents of each chapter are as follows:

- **Chapter 1** describes the motivation and objectives of this thesis, including an overview of decision making, decision making for strategic policy analysis and the organization of the thesis.

- **Chapter 2** constitutes a background and literature review of the graph model for conflict resolution (GMCR), including strategic conflict analysis, modeling conflicts using the Graph Model and the decision support system GMCR II.

- **Chapter 3** introduces the analytic hierarchy process (AHP) and analytic network process (ANP), including general descriptions of the theories and some applications of AHP and ANP for strategic decision analysis.

- **Chapter 4** focuses on the comparison of ANP and GMCR for conflict analysis. ANP is designed to analyze strategic conflict problems and is compared with GMCR in a case study of a television (TV) conflict between China and US.

- **Chapter 5** contains a new index aggregation approach to handle country-performance comparisons. A data-envelopment-analysis based approach is proposed to aggregate some famous country-ranking indices and is demonstrated in a case study of a comparison study of some developed and developing countries.

- **Chapter 6** proposes a framework to carry out generic strategic analysis for regions-competence analysis based upon the theory of generic strategic business analysis. A case study of the competence analysis of provinces in China is used to demonstrate the analysis procedure.

- **Chapter 7** summarizes of the main contributions of the research and suggestions for future research.

Chapter 2

The Graph Model for Conflict Resolution

2.1 Introduction

In this chapter, a background and literature review of the graph model for conflict resolution (GMCR) are presented. Firstly strategic conflict analysis is discussed, and then how to model a conflict using the graph model is explained. Finally, the decision support system, GMCR II is described briefly. This chapter is based upon the research of Kilgour and Hipel (2005).

2.2 Strategic Conflict Analysis

A strategic conflict is an interaction of two or more independent DMs, each of whom makes choices that together determine how the state of the conflict evolves, and each of whom has preferences over these possible states (as eventual resolutions). Thus, a strategic conflict is a joint, or interactive, decision problem; there are two or more DMs, each DM has a choice (i.e. two or more alternatives), and every DM is in principle concerned about the others' choices (Kilgour and Hipel, 2005). More specifically, each DM must benefit, or be harmed, according to the choices of at least one other DM, in the sense that that other DM's choices make the eventual resolution more, or less, preferable. It is clear that strategic conflicts are very common in interactions at all levels including personal, family, business, national, and international (Fang et al., 1993).

One way to model and analyze a strategic conflict is to use *non-cooperative game theory* (von Neumann and Morgenstern, 1953). A game structure permits the analyst to capitalize on a large and well-developed body of theory which has connections with economics and Bayesian decision analysis. But to use a non-cooperative game model to analyze a strategic conflict and provide strategic advice imposes constraints which may limit the verisimilitude of the model and the usefulness of analysis suggestions (Kilgour and Hipel, 2005). For example, in a game, the order of actions of the DMs (players) must be specified, but in many situations, the order of actions is not known in advance—deciding when to act is part of the problem. Another requirement is that in a game, DMs' preferences must be represented by real-valued utilities, which allow the possibility of mixed strategies (probabilistic mixtures of actions, as opposed to specific actions). But this requirement is a serious drawback for two reasons: utilities are notoriously difficult to measure; and mixed strategies are often hard to interpret as "suggestion".

The *Graph Model for Conflict Resolution* (GMCR) provides a methodology for modeling and analyzing strategic conflicts that does not suffer from these problems. The GMCR is quite different from "classical game" (von Neumann and Morgenstern, 1953), although there are some connections; Fang et al. (1993) explain the relationship between the graph model and extensive-form games. The GMCR focuses on analyzing a strategic conflict in terms of its components: DMs, states, transitions, options, and preferences. It searches for possible resolutions based on certain stability definitions, which mathematically describe how DMs interact with one another in terms of moves and countermoves. It is easy-to-use, flexible, and provides a good understanding of how DMs should choose what do to. Of course, there are alternative systems to model and analyze strategic conflicts that are distinct from non-cooperative game theory; they include metagame analysis (Howard, 1971), conflict analysis (Fraser and Hipel, 1984) and theory of moves (Brams, 1994). For a broader view of related approaches and results, see the Encyclopedia section introduced by Hipel (2002).

The original formulation of the GMCR appeared in Kilgour et al. (1987); the first complete presentation is the text of Fang et al. (1993). It has been applied across a wide range of application areas; examples include environmental management at the national level (Hamouda et al., 2004; Noakes et al., 2003) and the international level (Noakes et al., 2005); military and peacekeeping activities (Kilgour et al., 1998); and international negotiations on economic issues (Hipel et al., 2001) and arms control (Obeidi et al., 2005).

2.3 Modeling Conflicts using the Graph Model

2.3.1 The Overall Analysis Procedure

Figure 2.1 shows the steps involved in applying the GMCR. A graph model study consists of two main stages: modeling and analysis. During the modeling stage, one must first identify the DMs involved in the conflict, as well as the options controlled by each DM. Ascertaining the relative preferences for each DM over all feasible states is another important component of the modeling process. During the stability analysis, each DM's willingness to accept various possible states as resolutions is assessed in detail; when a state is stable for every DM it represents a possible resolution or equilibrium. In a sensitivity analysis, the robustness of the stability results is examined with respect to changes in model parameters, such as DMs' preferences. The stability and sensitivity analyses can be interpreted, by analysts, actual DMs, or interested parties, in order to gain guidance for enhanced decision making.

2.3.2 Graph Model Definitions

A Graph Model has four components, as follows:

- $\mathbf{N}$, the set of decision-makers (DMs), where $2 \leq |\mathbf{N}| < \infty$. We write $\mathbf{N} = \{1, 2, ..., n\}$.
- $\mathbf{S}$, the set of (distinguishable) states, satisfying $2 \leq |\mathbf{S}| < \infty$. One particular state, s_0, is designated as the *status quo* state.
- For each $i \in \mathbf{N}$, DM i's directed graph $G_i = (\mathbf{S}, A_i)$. The arc set $A_i \subseteq \mathbf{S} \times \mathbf{S}$ has the property that if $(s, t) \in A_i$, then $s \neq t$; in other words, G_i contains no loops. The entries of A_i are the *state transitions* controlled by DM i.
- For each $i \in \mathbf{N}$, a complete binary relation $\succeq_i$ on $\mathbf{S}$ that specifies DM i's *preference over* $\mathbf{S}$. If $s, t \in \mathbf{S}$, then $s \succeq_i t$ means that DM i prefers s to t, or is indifferent between s and t. Following well-established conventions, we say that i *strictly prefers* s to t, written $s \succ_i t$, if and only if $s \succeq_i t$ but $\neg[t \succeq_i s]$ (i.e. it is not the case that $t \succeq_i s$). Also, we say that i is *indifferent* between s and t, written $s \sim_i t$, if and only if $s \succeq_i t$ and $t \succeq_i s$.

The arcs in a DM's graph represent state transitions controlled by the DM; specifically, if $s, t \in \mathbf{S}$ and $s \neq t$, then there is an arc from s to t in DM i's

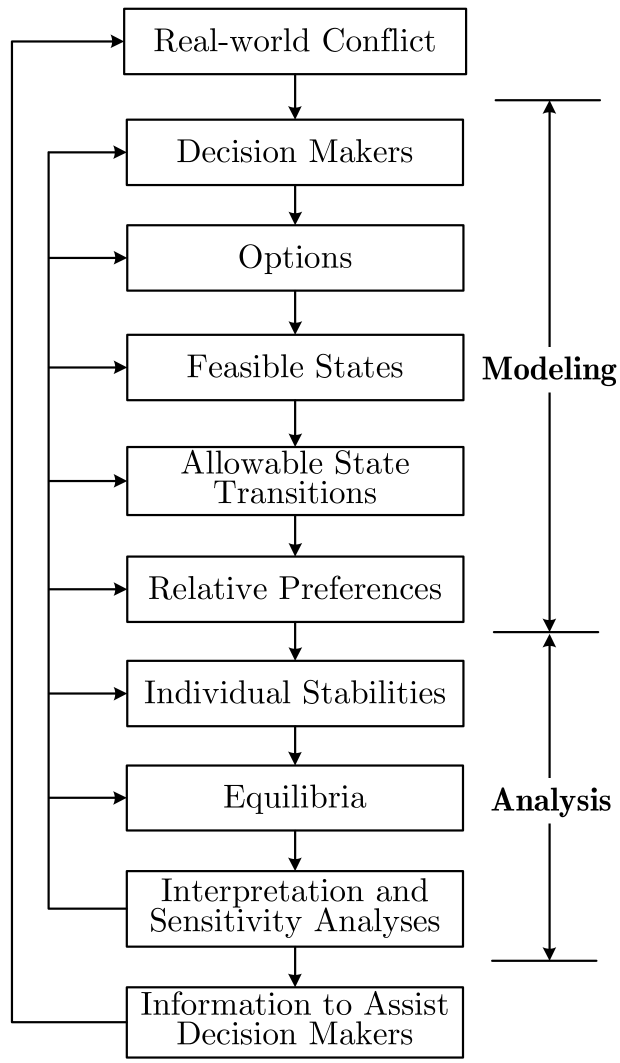


Figure 2.1: The analysis procedure of the graph model, adapted from Fang et al. (1993).

graph, i.e. $(s,t) \in A_i$, if and only if DM i can (unilaterally) force the conflict to change from state s to state t. In this case, we say that t is *reachable* for i from s. Note that all DMs' graphs have the same vertex set, $\mathbf{S}$. A consequence is that relatively small Graph Models can be conveniently described using the *integrated graph* $G = (\mathbf{S}, (A_1, A_2, ..., A_n))$. Note that the integrated graph is a directed graph, in which each arc is labelled with the name of the DM who controls it.

In principle, the Graph Model methodology does not require preference relations to be transitive. (For example, $\succeq_i$ is *transitive* if, whenever $s_1 \succeq_i s_2$ and $s_2 \succeq_i s_3$, then $s_1 \succeq_i s_3$ also.) Typically when participants begin to think about a dispute, confusion and lack of information may produce intransitive preferences. But intransitive preferences usually disappear over time. If preferences are transitive, then each DM's preference can be used to order the state set $\mathbf{S}$. In other words, each DM can rank all states from most preferred to least preferred, possibly including ties as groups of equally preferred states. The assumption of ordinal preferences makes the presentation of a graph model using the integrated graph particularly compact. The decision support system GMCR II assumes that all preferences are transitive. Figure 2.2 shows a case study using the Graph Model.

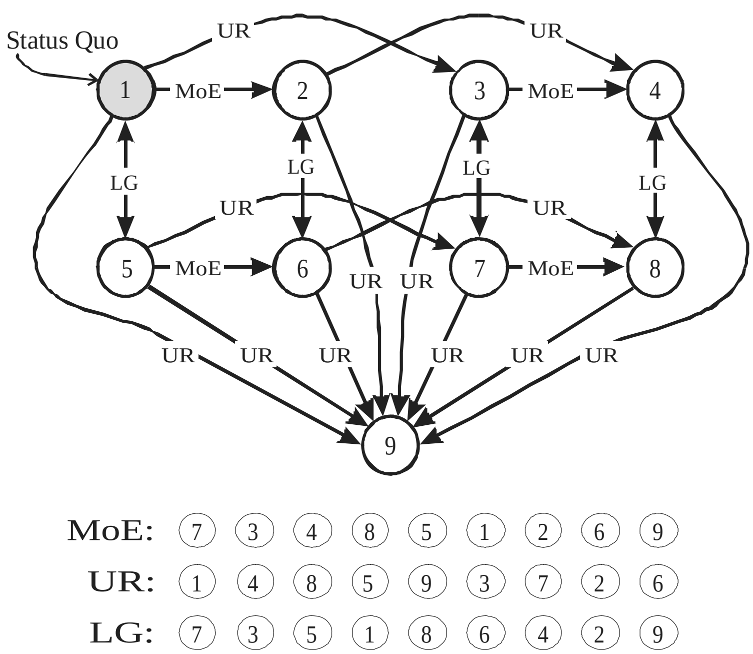


Figure 2.2: Elmiral Graph Model, adapted from Kilgour et al. (2001)

Figure 2.2 is a graph model of a conflict situation that arose in 1991 when a carcinogen was discovered in the underground aquifer from which the town of

Elmira, Ontario drew all of its water (Kilgour et al., 2001). The three DMs are the Ontario Ministry of the Environment (MoE), Uniroyal Chemical Limited (UR), and the Local Governments (LG). The strategic conflict centers on responsibility for clean-up of the pollution; at the time point of the model, the Ministry has just issued a control order requiring Uniroyal to clean up the pollution, but Uniroyal has the right to appeal. In the Elmira1 model, MoE is considering modifying the control order to make it more acceptable to UR (an option called *Modify*); UR is deciding whether to delay the process by appealing (*Delay*), accept the current version of the control order (*Accept*), or abandon its Elmira facility (*Abandon*); and Local Governments have not yet decided whether to support the Ministry's control order (*Support*).

It is a reflection of the simplicity of the Graph Model that the states form the basis for all the definitions and all of the analysis. States are depicted as circles in Figure 2.2. The current state of a Graph Model is assumed to be known to all DMs at all times, beginning with the status quo state. At the status quo state (shown as state 1) in the model of Figure 2.2, MoE is refusing to modify its control order, UR is delaying, and LG has not yet taken a position. If the current state of a Graph Model is s, then DM i may choose to change the state to any $t \in \mathbf{S}$ that is reachable for i from s (i.e., such that $(s,t) \in A_i$) if any such t exists; but DM i may also choose not to change the state. In Figure 2.2, for example, all three DMs can move away from the status quo, while no DM can move away from state 9 (which represents the consequences of UR's choice to Abandon).

DM i's preference over $\mathbf{S}$ represents i's preferences among the states of $\mathbf{S}$ considered as final outcomes, or resolutions, of the conflict. Thus, in the Elmiral model (Figure 2.2), Uniroyal most prefers the status quo, state 1, whereas both MoE and LG most prefer state 7, where LG supports MoE's control order and UR accepts it. Note also that state 9, at which UR abandons its Elmira facility, is the least preferred outcome for both MoE and LG.

2.3.3 Stability Analysis of a Graph Model

From any state, $s \in \mathbf{S}$, a state that is reachable by DM i from s and that DM i prefers to s is called a *(unilateral) improvement* for i from s, and a state that is reachable by i from s but is less preferred by i than s is called a *(unilateral) disimprovement*. For example, in Figure 2.2, a move by LG from the status quo, state 1, to state 5 is a unilateral improvement, whereas a move by UR from state 1 to state 3 is a unilateral disimprovement.

In the GMCR, a *stability definition* (*solution concept*) is a set of rules for calculating whether a decision-maker would prefer to stay at a state or move away from it unilaterally. A stability definition is therefore a model of a DM's strategic approach, or more generally of human behavior in strategic conflict. Of course, different stability definitions may be appropriate for different DMs.

A general principle for stability definitions in a Graph Model with two DMs is that specifying a state, s, a DM, i, and a particular stability definition is equivalent to specifying a two-person finite extensive-form game of perfect information with a particular structure. In this game, the first move must be a choice by DM i to stay at s or to move to any of the states reachable for i from s. If i chooses to stay at s, the game is over and the outcome is s. If i does not stay on the initial move, then there may be additional choices by other DMs (and possibly by i again), but at all subsequent decision nodes one alternative is always to stay at the current state, and selecting this alternative always ends the game at that state. For the GMCR, stability definitions are generalized in a natural way from the $n = 2$ to $n > 2$ DMs case.

An *equilibrium* is a state that is stable, according to an appropriate definition, for every DM in a Graph Model. The equilibria are the *predicted resolutions* of the strategic conflict. The main stability definitions currently used in the GMCR include Nash Stability (Nash), General Metarationality (GMR), Symmetric Metarationality (SMR), Sequential Stability (SEQ), Limited Move Stability (L_h), and Non-Myopic Stability (NM). Table 2.1 describes some features of these definitions that relate them to behavior in conflicts. For complete definitions and original references, see Fang et al. (1993).

2.4 Decision Support System GMCR II

The decision support system GMCR II implements the Graph Model for Conflict Resolution within a Windows environment (Fang et al., 2003a,b). The structure of GMCR II is shown in Figure 2.3.

A user inputs the DMs, their options, patterns of infeasible states, allowable state transitions, and preference information. Then GMCR II generates the states and transitions, and carried out a stability analysis. Based on the information generated at the modelling stage, the analysis engine performs a thorough stability analysis on the conflict model. The analysis engine determine the stability of every state, for each DM, under the range of solution concepts listed in Table 2.1. The output interpretation subsystem presents the stability results in a user-friendly

Table 2.1: Solution concepts and human behaviour, adapted from Fang et al. (1993).

Solution Concepts	**Stability Descriptions**
Nash stability (R)	Focal DM cannot unilaterally move to a more preferred state.
General metarationality (GMR)	All of the focal DM's unilateral improvements are sanctioned by subsequent unilateral moves by others.
Symmetric metarationality (SMR)	All focal DM's unilateral improvements are still sanctioned even after possible responses by the focal DM.
Sequential stability (SEQ)	All of the focal DM's unilateral improvements are sanctioned by subsequent unilateral improvements by others.
Limited-move stability (L_h)	All DMs are assumed to act optimally and a maximum number of state transitions (h) is specified.
Non-myopic (NM)	Limiting case of limited move stability as the maximum number of state transitions increases to infinity.

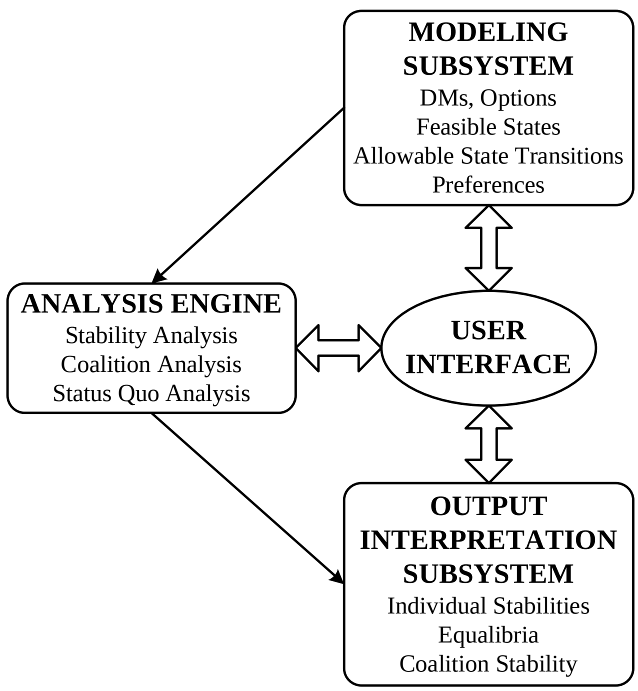


Figure 2.3: The analysis components in GMCR II, adapted from Fang et al. (1993)

manner. Information about individual stability, equilibria, and coalition stability is easily identified and interpreted.

2.5 Conclusions

GMCR is a methodology designed for the modeling and analysis of strategic conflicts. In this chapter, the basic context of GMCR is explained as follows:

- Strategic conflict analysis: different methods for strategic conflict analysis are reviewed and an historical overview of the graph model is presented.
- Modeling conflict using the graph model: the basic modeling and analysis components of GMCR are discussed in detail with a demonstration of a practical application.
- Decision support system GMCR II: the framework and different functions of GMCR II are introduced.

Chapter 3

The Analytic Hierarchy Process and Analytic Network Process

3.1 Introduction

The basic modeling and analysis components of the analytic hierarchy process (AHP) and analytic network process (ANP) are explained in this chapter. AHP is discussed first including pair-wise comparison for local priority and global priority. Then, ANP is addressed including structural features and synthesizing priorities. Finally, the applications of AHP and ANP for strategic policy analysis are presented. The description of AHP is based upon Saaty (2001) and the explanation of ANP is based on Su et al. (2005).

3.2 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a mathematical decision making technique that allows consideration of both qualitative and quantitative aspects of decisions. It reduces complex decisions to a series of one-on-one comparisons, then synthesizes the results. Compared to other techniques like ranking or rating techniques, the AHP uses the human ability to compare single properties of alternatives. It not only helps decision makers choose the best alternative, but also provides a clear rationale for the choice. The process was developed in the 1980s by Thomas Saaty (Saaty, 1980). The details are explained below.

3.2.1 Pair-wise Comparisons for Local Priority

AHP uses subjective assessment followed by simple matrix algebra to establish the optimal rank (and weighted average score) for alternatives based on predetermined criteria. Given a set of criteria, $\mathbf{c} = c_1, c_2, ..., c_n$, where n is the number of criteria, the analyst repeatedly compares one criterion to another until all possible pair-wise comparisons are completed. If the criteria are quantitative, then deterministic mathematical relationships of each pair-wise comparison may be used. If the criteria are non-quantitative, the subjective scale shown in Table 3.1 is used. An even numbered response is acceptable if the analyst is wavering between the interpretation associated with odd numbers.

Table 3.1: Comparison scale of relative importance

Numerical rating	Verbal judgement of preferences
1	Equally preferred
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred

All n possible pairwise column vectors can be combined into a matrix $\mathbf{A}$ shown as follows:

$$\mathbf{A} = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix}, \tag{3.1}$$

where a_{ij} represents the pairwise comparison of criterion c_i with criterion c_j, and $a_{ij} = a_{ij}^{-1}$. Thus the following equation can be used to estimate the weight vector $\mathbf{w} = \{w_1, w_2, ..., w_n\}$ for the criteria set $\mathbf{c}$.

$$\mathbf{Aw} = \lambda_{\max}\mathbf{w}, \tag{3.2}$$

where $\lambda_{\max}$ is the maximal eigenvalue of $\mathbf{A}$.

A comparison matrix, $\mathbf{A}$, is said to be consistent if $a_{ij}a_{jk} = a_{ik}$ $\forall i, j$, and $k = 1, 2, ..., n$. However, too strict consistency may not be realistic when dealing with human judgments. To evaluate the consistency of pair-wise comparisons in AHP, the consistency index CI is defined as

$$CI = \frac{\lambda_{\max} - n}{n - 1}. \tag{3.3}$$

Next, a random consistency index RI is calculated by generating a reciprocal matrix using the scale $\frac{1}{9}$, $\frac{1}{8}$, ..., 1, ..., 8, 9 and checking if it is about 10% or less. The average random consistency index of sample size 500 matrices is shown in Table 3.2 below:

Table 3.2: Random consistency index, RI

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.1	1.24	1.32	1.41	1.45	1.49

Then, the consistency ratio, CR, is defined as

$$CR = \frac{CI}{RI}. \tag{3.4}$$

If CR is smaller or equal to 10%, the inconsistency is acceptable. Otherwise, $\mathbf{A}$ needs to be revised.

3.2.2 Global Priority

In a more general case, the AHP considers a hierarchy structure of criteria-subcriteria-alternatives, or even with more intermediate levels. The main goal consists of comparing all the alternatives. The AHP estimates global priorities of the alternatives by synthesizing their local priorities with preference weights of the sub-criteria and criteria based on the following procedures:

1. The overall objective of the decision problem is decomposed into sub-criteria levels in a hierarchy. Elements of approximately equal importance are arranged at the same level. For example, in a decision problem the overall objective is represented by a few criteria at the criteria level. Then for each criterion, sub-criteria that represent it are located at the sub-criteria level.

2. Once a hierarchical structure is established, pairwise comparisons of the elements at each level of the hierarchy must be carried out. Local priorities can then be generated by an eigenvalue technique.

3. Based on linear additive aggregation, the global priority of each element to the overall objective is determined.

3.3 Analytic Network Process

The ANP generalizes AHP, by replacing hierarchies with networks. ANP allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such feedback can capture complex interplay, and is especially appropriate when risk and uncertainty are involved. ANP has been applied to a wide variety of decision situations, including marketing, medical, political, societal, forecasting and many others. Its accuracy of prediction has been impressive in applications to economic trends, sports and other events (Saaty, 2001).

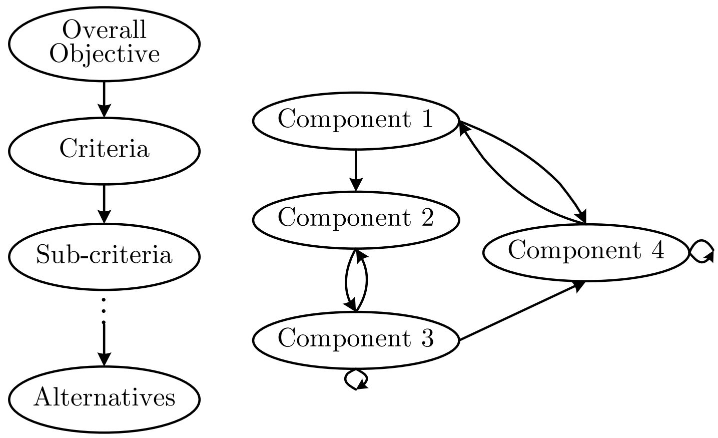
3.3.1 Structural Features in ANP

ANP permits interrelationships among different decision levels to be taken into consideration in a general form. Figure 3.1 shows the structural differences between AHP and ANP. In an ANP network, nodes represent components of the system that are composed of homogeneous elements, and arcs represent the interactions between them. The directions of the arcs represent dependence, whereas loops signify dependence of the elements within a component. Obviously, the hierarchical structure of AHP is a special case of the network structure of ANP.

The two main stages involved in applying ANP are:

1. Construction of the network: to structure the problem, all of interactions among the elements should be considered. Let $\mathbf{C} = \{C_1, C_2, ..., C_m\}$ denote the component set in an ANP system. Assume that component $C_p = \{e_p^1, e_p^2, ..., e_p^j, ..., e_p^{n_p}\}$ and note that C_p has n_p elements. Three different impact relationships can be identified: (a) when the elements in a component C_p depend on another component C_q, it is represented as this relationship with an arrow, $C_q \rightarrow C_p$; (b) when the elements of two components mutually impact each other, it is denoted as $C_q \leftrightarrows C_p$; (c) when the elements in component C_h have inner impacts, we represent it as $C_h^{\circlearrowleft}$;

2. Calculation of the priorities of elements: first pairwise comparisons are carried out for each kind of impact relationship defined above. Local priorities are



(a) AHP **(b) ANP**

Figure 3.1: Structural differences between AHP and ANP

next generated using the eigenvalue method. Then using this local priority information, a supermatrix is set up to describe interactions among all elements. Next, a weighted supermatrix is designed so that its powers converge to a limit. Thus a global priority vector, that takes account of the cumulative influence of each element on every other element in the network, is obtained.

The procedure for synthesizing priorities is explained next.

3.3.2 Synthesizing Priorities in ANP

Suppose an ANP network has components $\mathbf{C} = \{C_1, C_2, ..., C_p, ..., C_m\}$. For components $C_p = \{e_p^1, e_p^2, ..., e_p^j, ..., e_p^{n_p}\}$ and $C_q = \{e_q^1, e_q^2, ..., e_q^j, ..., e_q^{n_q}\}$, let $\mathbf{W}_{pq}$ $(n_p \times n_q)$ denote component C_p's priority (impact) matrix on C_q and let $\mathbf{w}_{pq}^j = (w_{pq}^{1j}, w_{pq}^{2j}, ..., w_{pq}^{ij}, ..., w_{pq}^{n_pj})^T$ $(n_p \times 1)$ denote the priority vector of C_p on element e_q^j in C_q, where $w_{pq}^{ij} \in \mathbb{R}$ and $w_{pq}^{ij} \geq 0$, $\sum_{i=1}^{n_p} w_{pq}^{ij} = 1$, and T denotes the transpose of a vector or matrix. The priority vectors are derived from pair-wise comparisons; an element with no influence on another element has impact priority zero. When a component has no impact on another, the priority matrix is the *zero matrix*. Figure 3.2 shows the priority matrix $\mathbf{W}_{pq}$.

Similarly, for component C_p, the inner priority matrix $\mathbf{W}_{pp}$ $(n_p \times n_p)$ can be constructed. The priority of an element on itself is set of zero. Figure 3.3 shows the priority matrix $\mathbf{W}_{pp}$.

$$
\mathbf{W}_{pq} = \begin{array}{cc}
 & \begin{array}{cccc} e_q^1 & e_q^2 & \cdots & e_q^{n_q} \end{array} \\
\begin{array}{c} e_p^1 \\ e_p^2 \\ \vdots \\ e_p^{n_p} \end{array} &
\left[\begin{array}{c|c|c|c}
w_{pq}^{11} & w_{pq}^{12} & & w_{pq}^{1n_q} \\ \hline
w_{pq}^{21} & w_{pq}^{22} & \cdots & w_{pq}^{2n_q} \\ \hline
\vdots & \vdots & \vdots & \vdots \\ \hline
w_{pq}^{n_p1} & w_{pq}^{n_p2} & \cdots & w_{pq}^{n_pn_q}
\end{array}\right]
\end{array}
$$

Figure 3.2: The priority matrix $\mathbf{W}_{pq}$

$$
\mathbf{W}_{pp} = \begin{array}{cc}
 & \begin{array}{cccc} e_p^1 & e_p^2 & \cdots & e_p^{n_p} \end{array} \\
\begin{array}{c} e_p^1 \\ e_p^2 \\ \vdots \\ e_p^{n_p} \end{array} &
\left[\begin{array}{c|c|c|c}
0 & w_{pp}^{12} & & w_{pp}^{1n_p} \\ \hline
w_{pp}^{21} & 0 & \cdots & w_{pp}^{2n_p} \\ \hline
\vdots & \vdots & 0 & \vdots \\ \hline
w_{pp}^{n_p1} & w_{pp}^{n_p2} & \cdots & 0
\end{array}\right]
\end{array}
$$

Figure 3.3: The priority matrix $\mathbf{W}_{pp}$

The number of elements in an ANP network is $n = \sum_{p=1}^{m} n_p$. All priority matrices in the network can be combined into a "supermatrix", in which each entry indicates the influence of the row element on the column element. We denote this supermatrix $\mathbf{W}$ $(n \times n)$ as shown in Figure 3.4. The vector of priority matrices on C_q, $\mathbf{V}_q$, is defined as $\mathbf{V}_q = (\mathbf{W}_{1q}, \mathbf{W}_{2q}, ..., \mathbf{W}_{pq}, ..., \mathbf{W}_{mq})^T$; it represents all components' influences on C_q. Therefore, $\mathbf{W} = (\mathbf{V}_1, \mathbf{V}_2, ..., \mathbf{V}_m)$.

To make the powers of $\mathbf{W}$ converge to the limit, for $q = 1, 2, ..., m$, a weight vector $\alpha_q = (\alpha_q^1, \alpha_q^2, ..., \alpha_q^p, ..., \alpha_q^m)^T$ is assigned to $\mathbf{V}_q = (\mathbf{W}_{1q}, \mathbf{W}_{2q}, ..., \mathbf{W}_{pq}, ..., \mathbf{W}_{mq})^T$ to represent the ratio of impacts from different components on C_q, where $\alpha_q^p \in \mathbb{R}$

$$
\mathbf{W} =
\begin{array}{cc}
 & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \\ e_1{}^1\ e_1{}^2 \ldots e_1{}^{n_1} & e_2{}^1\ e_2{}^2 \ldots e_2{}^{n_2} & & e_m{}^1\ e_m{}^2 \ldots e_m{}^{n_m} \end{array} \\
\begin{array}{cc} & e_1{}^1 \\ & e_1{}^2 \\ C_1 & \cdots \\ & e_1{}^{n_1} \\ & e_2{}^1 \\ & e_2{}^2 \\ C_2 & \cdots \\ & e_2{}^{n_2} \\ & \vdots \\ & e_m{}^1 \\ & e_m{}^2 \\ C_m & \cdots \\ & e_m{}^{n_m} \end{array}
&
\left[\begin{array}{c:c:c:c}
\mathbf{W}_{11} & \mathbf{W}_{12} & \cdots & \mathbf{W}_{1m} \\ \hdashline
\mathbf{W}_{21} & \mathbf{W}_{22} & \cdots & \mathbf{W}_{2m} \\ \hdashline
\vdots & \vdots & \vdots & \vdots \\ \hdashline
\mathbf{W}_{m1} & \mathbf{W}_{m2} & \cdots & \mathbf{W}_{mm}
\end{array}\right]
\end{array}
$$

Figure 3.4: Supermatrix in ANP

and $\alpha_q^p \geq 0$, and $\sum\limits_{p=1}^{m} \alpha_q^p = 1$. When $\mathbf{W}_{pq}$ is a zero matrix, the weight α_q^p equals zero. The weighted priority matrix vector for C_q, $\overline{\mathbf{V}}_q$ is defined as $\overline{\mathbf{V}}_q = (\alpha_q^1 \cdot \mathbf{W}_{1q}, \alpha_q^2 \cdot \mathbf{W}_{2q}, ..., \alpha_q^p \cdot \mathbf{W}_{pq}, ..., \alpha_q^m \cdot \mathbf{W}_{mq})^T$, where "$\cdot$" is the scalar product. The *weighted supermatrix*, $\overline{\mathbf{W}}$ is defined as $\overline{\mathbf{W}} = (\overline{\mathbf{V}}_1, \overline{\mathbf{V}}_2, ..., \overline{\mathbf{V}}_m)$. The limiting supermatrix is denoted as $\overline{\mathbf{W}}_\infty = \lim\limits_{k\to\infty} (\overline{\mathbf{W}})^k$. Since $\overline{\mathbf{W}}$ is irreducible and primitive, it has limiting values (Saaty, 2001). Then, $\overline{\mathbf{W}}_\infty = (\mathbf{v}_\infty^1, \mathbf{v}_\infty^2, ..., \mathbf{v}_\infty^i, ..., \mathbf{v}_\infty^n)$, where $\mathbf{v}_\infty^1 = \mathbf{v}_\infty^2 = ... = \mathbf{v}_\infty^i = ... = \mathbf{v}_\infty^n = \mathbf{v}_\infty = (v_1, v_2, ..., v_j, ..., v_n)^T$, is the global priority vector representing the overall priorities of each element considering all interactions in the network. Note that n is the number of elements, $v_j \in \mathbb{R}^+$ and $\sum_{i=1}^{n} v_j = 1$. The global priority vector, $\mathbf{v}_\infty$, is intended to provide information to assist the DM in making decisions.

3.4 Applications for Strategic Policy Analysis

There are many practical applications of AHP and ANP. Vaidya and Kumar (2006) presented a literature review of the applications of AHP and ANP including personal, social, manufacturing sector, political, engineering, education, industry, government, and sports areas. The following examples show how AHP and ANP can be applied to strategic policy analysis.

3.4.1 Comparisons of Countries' Overall Economies

As early as 1973, Drs. Saaty and Khouja did the following exercise on an airplane (Saaty, 1980). They simply used their common knowledge about the relative influence and standing of several countries in the world and without referring to any specific economic data related to gross national product (GNP). Results of the estimation from AHP and the actual GNP data are close. This demonstrates that the general understanding an interested person has about a problem can be used to advantage to make fairly good estimates through paired comparisons. The following matrix gives the judgments using the AHP 1-9 scale and Table 3.3 provides the derived priorities, the actual and relative GNP values.

$$
\begin{array}{l}
\\
\text{US} \\
\text{USSR} \\
\text{China} \\
\text{France} \\
\text{UK} \\
\text{Japan} \\
\text{W. German}
\end{array}
\begin{array}{c}
\begin{array}{ccccccc}
\text{US} & \text{USSR} & \text{China} & \text{France} & \text{UK} & \text{Japan} & \text{W. German}
\end{array} \\
\begin{pmatrix}
1 & 4 & 9 & 6 & 6 & 5 & 5 \\
1/4 & 1 & 7 & 5 & 5 & 3 & 4 \\
1/9 & 1/7 & 1 & 1/5 & 1/5 & 1/7 & 1/5 \\
1/6 & 1/5 & 5 & 1 & 1 & 1/3 & 1/3 \\
1/6 & 1/5 & 5 & 1 & 1 & 1/3 & 1/3 \\
1/5 & 1/5 & 5 & 1 & 1 & 1 & 1/3 \\
1/5 & 1/4 & 5 & 3 & 3 & 1/2 & 1
\end{pmatrix}
\end{array}
$$

Pairwise comparisons of seven nations

Table 3.3: Comparisons of the estimated and the actual values

Countries	Normalized Eigenvector	Actual GNP (1972, Billion US$)	Normalized GNP Values
US	0.427	1,167	0.413
USSR	0.23	635	0.225
China	0.021	120	0.043
France	0.052	196	0.069
UK	0.052	154	0.055
Japan	0.123	294	0.104
W. German	0.094	257	0.091

3.4.2 Monetary Exchange Rate-US Dollar versus the Japanese Yen

In 1987 three economists at the University of Pittsburgh, Dr. Blair, Nachtmann, and Olson, worked with Dr. Saaty on the application of AHP to predict the exchange rate between the Japanese yen and US dollar (Saaty, 2001). They claimed the predicted value was fairly close to the average value for a considerable number of months after that. Applications of ANP in strategic decision making including forecasting the date of a turnaround in the US economy and market shares for fast-food restaurants. The detailed explanation can be found in Saaty (2001).

3.5 Conclusions

AHP and ANP are flexible methodologies for use in complex decision making using pairwise comparison techniques. In this chapter, the basic context of AHP and ANP was explained as follows:

- Analytic hierarchy process: the procedures of pair-wise comparisons for local priority and global priority were explained.
- Analytic network process: the structural features of ANP were explained and the procedure of synthesizing priorities was discussed.
- Applications for strategic policy analysis: the applications of AHP and ANP for strategic policy analysis were presented, including the comparison of countries's overall economics and monetary exchange-rate forecasting.

Chapter 4

Comparison of ANP and GMCR for Conflict Analysis

4.1 Introduction

In this chapter, AHP is designed for strategic conflict analysis and a comparison of ANP and GMCR is carried out with an application of a conflict over TV exports between China and the US. First, the framework of comparison of ANP and GMCR for strategic conflict analysis is introduced. Then, GMCR and ANP are used to carry out the TV conflict analyses. Finally, comparisons and interpretations are presented. This chapter is based upon the research of Su et al. (2005).

4.2 Comparison of the Design of ANP and GMCR

Recall that in a graph model, there is a set $\mathbf{N} = \{1, 2, ..., r\}$ of DMs and a set of $\mathbf{S} = \{s_1, s_2, ..., s_t\}$ of feasible states. To employ ANP in conflict analysis and to carry out a combination study of ANP and the graph model, a network is designed to represent a conflict problem as shown in Figure 4.1.

Two components constitute the network for a graph model: the decision makers ($\mathbf{N}$) and the feasible states ($\mathbf{S}$). There are three arcs in the system representing three interactions: (1) $\mathbf{W_{SN}}$, the priority matrix of $\mathbf{S}$ on $\mathbf{N}$, which represents the relative importance (state ranking) of feasible states for a given DM. (2) $\mathbf{W_{NS}}$, the priority matrix of $\mathbf{N}$ on $\mathbf{S}$, which estimates the possibilities that DMs are satisfied

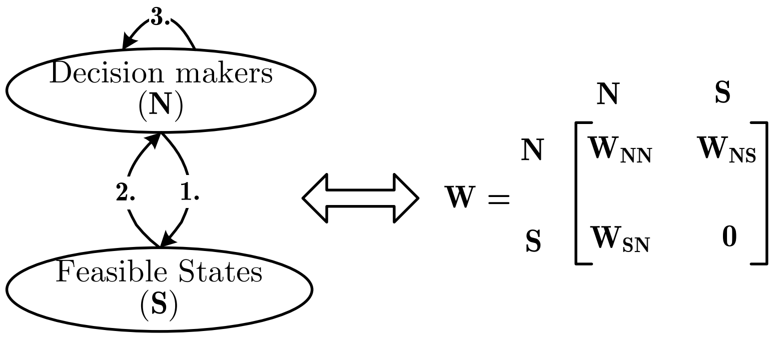


Figure 4.1: ANP structure for a graph model

with given feasible states. (3) $\mathbf{W_{NN}}$, which represents the inner impacts among DMs.

The weighted supermatrix is thus

$$\overline{\mathbf{W}} = \begin{bmatrix} \alpha_1 \mathbf{W_{NN}} & \mathbf{W_{NS}} \\ \alpha_2 \mathbf{W_{SN}} & 0 \end{bmatrix}, \tag{4.1}$$

where α_1 and α_2 represent the relative importances of $\mathbf{W_{NN}}$ and $\mathbf{W_{SN}}$, and $\alpha_1 + \alpha_2 = 1$. The ratio $\frac{\alpha_1}{\alpha_2}$ represents how strongly DMs influence themselves, as compared with their influences on the feasible states contained in the set $\mathbf{S}$.

The limiting supermatrix is calculated using $\overline{\mathbf{W}}_\infty = \lim_{k\to\infty}(\overline{\mathbf{W}})^k$, and $\mathbf{v}_\infty$ is obtained from $\overline{\mathbf{W}}_\infty$. Let $\mathbf{v}_\infty = (\mathbf{v_N}, \mathbf{v_S})^T$, where $\mathbf{v_N} = (v^1_{\mathbf{N}}, v^2_{\mathbf{N}}, ..., v^i_{\mathbf{N}}, ..., v^r_{\mathbf{N}})$ represents the global priority vector of DMs and $\mathbf{v_S} = (v^1_{\mathbf{S}}, v^2_{\mathbf{S}}, ..., v^i_{\mathbf{S}}, ..., v^t_{\mathbf{S}})$ denotes the overall priority vector of feasible states. $\mathbf{v_N}$ provides information about the relative impact of DMs in the conflict: a greater value of $v^i_{\mathbf{N}}$ indicates that DM_i has greater influence on other DMs. $\mathbf{v_S}$ provides information about the overall preferences for the feasible states: a greater value of $v^i_{\mathbf{S}}$ indicates that state s_i has higher preference among all DMs. Let $s^*_i = \{s_i \in \mathbf{S} : \max v^i_{\mathbf{S}}, i = 1, 2, ..., t\}$ stand for the most stable state, s^*_i which can be regarded as the equilibrium in a conflict considering all impact factors. By changing the ratio $\frac{\alpha_1}{\alpha_2}$, sensitivity analysis can be carried out to check the stability of s^*_i. Figure 4.2 summarizes the procedure for comparison study of the graph model and ANP.

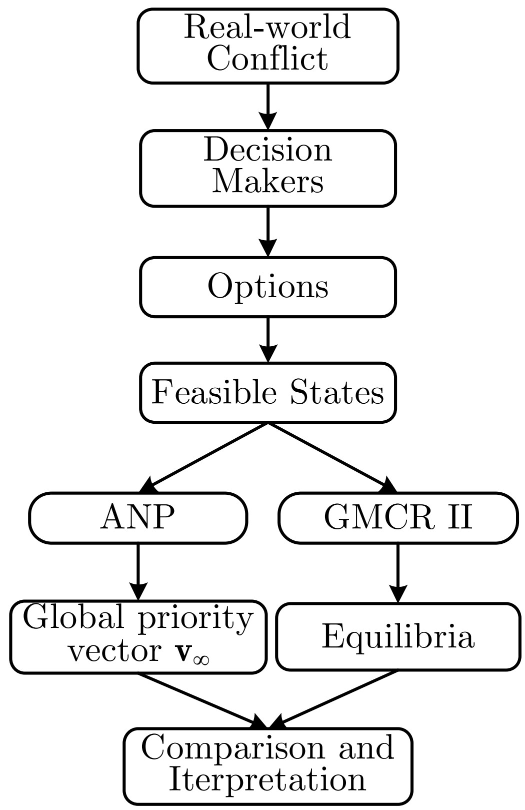


Figure 4.2: Comparison study of GMCR II and ANP

4.3 GMCR Approach to Conflict Analysis

The comparison of the graph model and ANP is based on a case study of the China-US TV dumping conflict. Some historical background is given first.

4.3.1 Background information

Over the past ten years, China has become the world's largest producer of TV sets. Chinese color TV exports have increased dramatically since the year 2000. In its heyday, 2002, the number of exported color TV sets reached 18.82 million units, with a total value of US $2.14 billion. The US receives more Chinese TVs than any other countries. US retailers, such as Wal-Mart and SEARS, as well as dealers like APEX Digital, gain great benefits from Chinese TV sales and accelerated Chinese TV exports in US. American, Japanese, Korean and European TV makers have lost American market share, and are gradually withdrawing from the US market.

On May 2, 2003, the US TV manufacturer, Five Rivers Electronic Innovations, and two labor unions, the International Brotherhood of Electrical Workers and the International Union of Electrical, Electronic, Furniture and Salaried Workers, formally accused TV manufacturers in China of unfair trade practices and argued for the imposition of duties of up to 84% on Chinese-produced TV sets. The accusation covered all Chinese TV manufacturers exporting products to the US. Most of China's major TV manufacturers were affected, including Changhong, Haier, Konka and TCL.

The US Department of Commerce (DOC) must decide whether to accept the case. If it were accepted, DOC would make an anti-dumping ruling. Chinese TV manufacturers, who were united and prepared to fight the charge, negotiated with DOC and US TV manufacturers about increasing prices or constraining the TV exports under a quota that would appease US TV manufacturers and smooth the dispute. Because Chinese TV sales in the US were very profitable, some retailers such as Wal-Mart strongly supported the Chinese TV manufacturers, and expected that China could win the dispute.

On June 16, 2003, DOC ruled, with three votes to zero that sales of Chinese color TV sets constituted substantial damage to the US color TV industry. Although it was under pressure from China, DOC decided to investigate four representative Chinese firms and differentiate anti-dumping duties among Chinese TV manufacturers (US Department of Commerce, 2003). On November 24, 2003, after the first round of investigations, DOC released its initial ruling that China was dumping its color TV sets into the US market and applied anti-dumping duties ranging from 27.94% to 78.45% to various Chinese TV manufacturers (Labor Research Association, 2003).

Fearing that the preliminary anti-dumping ruling would lead to a sharp decline in TV exports to the US, Chinese TV manufacturers filed suit against the initial ruling. The Chinese government also become involved, expressing deep concern over the dispute, and declaring that it would consider levying retaliatory duties on US products if DOC retained the initial import duty in its final conclusion (Chinese Embassy in US, 2004). DOC began a second round of field surveys in China from December 8 to 26, 2003. On April 13, 2004, DOC released its final ruling, confirming that Chinese manufacturers were dumping TVs in US market, but DOC dropped the anti-dumping duties significantly.

4.3.2 Modeling the Conflict as of April, 2004

The stage of the China-US TV dumping conflict between DOC's initial ruling (Novmber 24, 2003) and the scheduled time for its final ruling (April 13, 2004) was selected for study. The date of April 12, 2004 was chosen as the time of the analysis.

Select Decision Makers and Their Options

There are three DMs involved at this stage: the Chinese TV manufacturers (CNTVs), US Department of Commerce (DOC), and Chinese Government (CNG). The only option for CNTVs is **file** - file a suit against the initial anti-dumping ruling. The options for DOC are: **retain** - retain the import duty; **drop** - drop the import duty; and **cancel** - cancel the initial ruling. The options for CNG are: **support** - support CNTVs against DOC's initial ruling; and **levy** - levy retaliative duties on US products.

Infeasible State Removal

GMCR II provides a range of techniques to remove infeasible states. In this conflict, *mutually exclusive option* and *at least one option* are chosen to remove the infeasible states, as shown in Figure 4.4.

DOC's three options are mutually exclusive, since DOC would only choose one of its options. The means to input this information into GMCR II is indicated by the X's in the two columns on the right in Figure 4.5.

DOC's and CNG's options also are subjected to the constraint of selecting at least one option. This means that DOC and CNG must choose one option; neither DM can do nothing. Figure 4.6 illustrates how this information is input into GMCR II using two columns of Xs.

Coalesce Indistinguishable Specification

When CNTVs reject their option of filing against the initial ruling, then no matter what the other DMs' strategies are, the conflict is over. Therefore, all option combinations satisfying this condition are indistinguishable, and should be treated as a single state. The coalescing indistinguishable specification is shown in Figure 4.7.

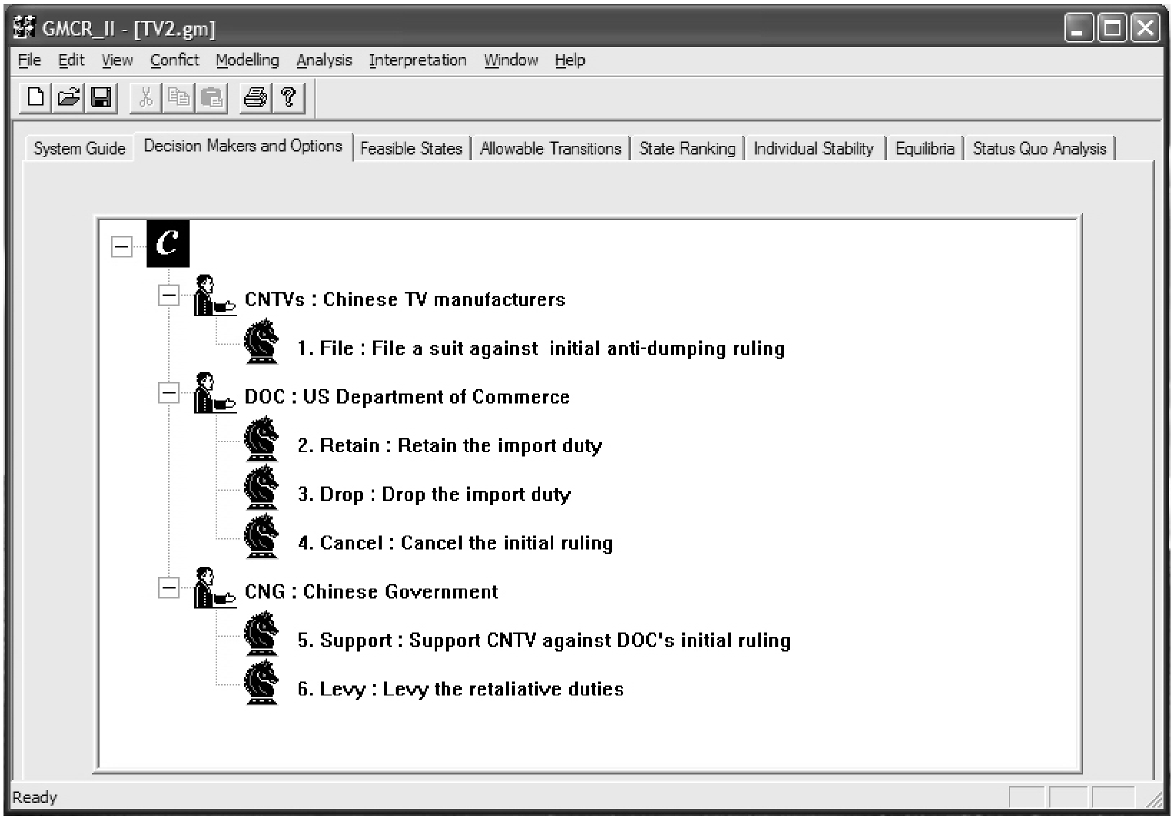


Figure 4.3: DMs and their options

Feasible State Generation

After the infeasible states are removed and indistinguishable states are combined using GMCR II, the system generates all feasible states. There are ten feasible states in the TV dumping conflict model, as shown in Figure 4.8.

4.3.3 GMCR II Approach to Conflict Analysis

State Ranking

GMCR II incorporates a flexible and convenient methodology to elicit a user's assessment of each DMs relative preferences: option weighting, in which weights are assigned to each option, and total weights of states used to determine an ordering; option prioritizing, based upon a set of lexicographic statements about options; and

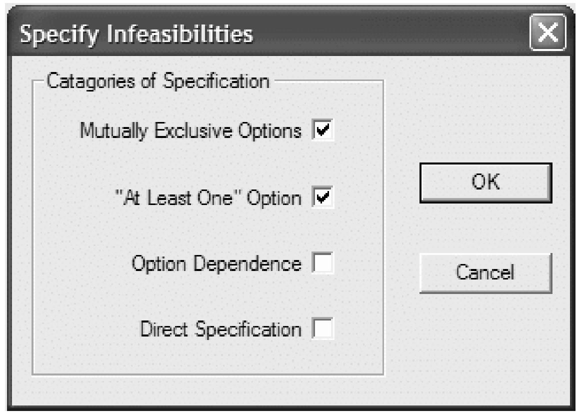


Figure 4.4: Removing infeasible states

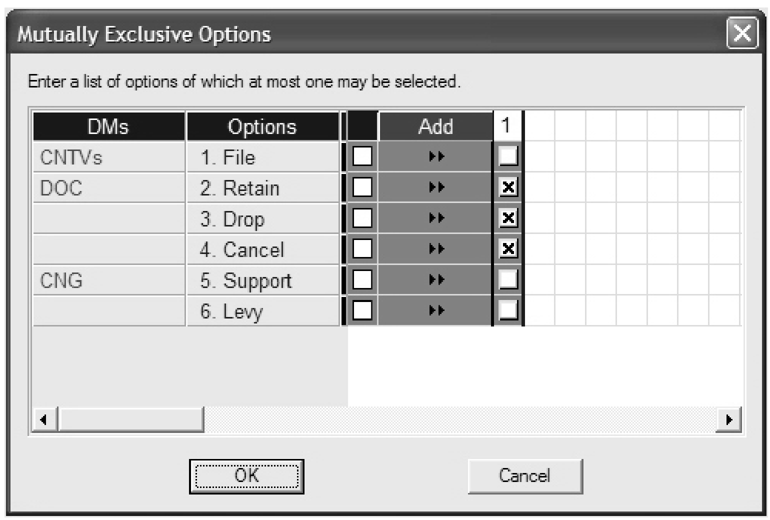


Figure 4.5: Mutually exclusive options

manual ranking, using a process called fine tuning or direct ranking (Fang et al., 2003a). Here, we combine option prioritizing and direct ranking to estimate the state ranking for each DM.

CNTVs most prefers DOC to cancel the initial ruling; secondly they would like DOC to decrease the anti-dumping tariff. Based on this information, three groups of states are identified: $\mathbf{G}_1 = \{s_3, s_6, s_9\}, \mathbf{G}_2 = \{s_2, s_5, s_8\}$, and $\mathbf{G}_3 = \{s_1, s_4, s_7, s_{10}\}$, with $\mathbf{G}_1 \succ \mathbf{G}_2 \succ \mathbf{G}_3$. Then, direct ranking is carried out within $\mathbf{G}_1$, $\mathbf{G}_2$, and $\mathbf{G}_3$. In $\mathbf{G}_1$, the ranking is $s_3 \succ s_9 \succ s_6$. In $\mathbf{G}_2$, the ranking is $s_2 \succ s_8 \succ s_5$. In G_3, the ranking is $s_1 \succ s_7 \succ s_4 \succ s_{10}$. Therefore, the ranking of all ten states is

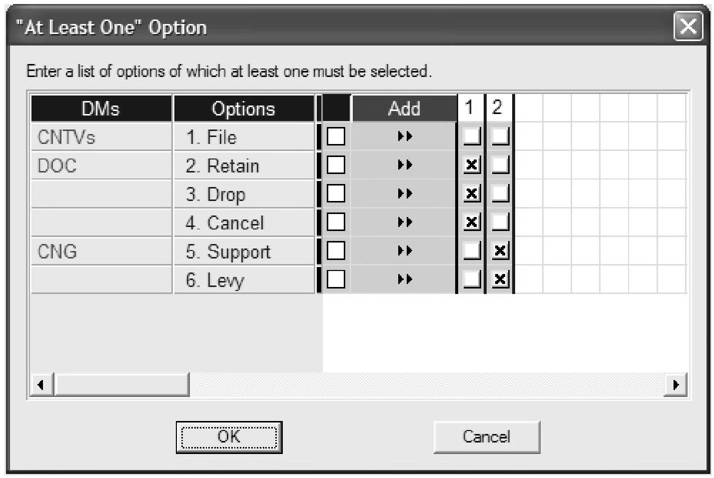


Figure 4.6: At least one option

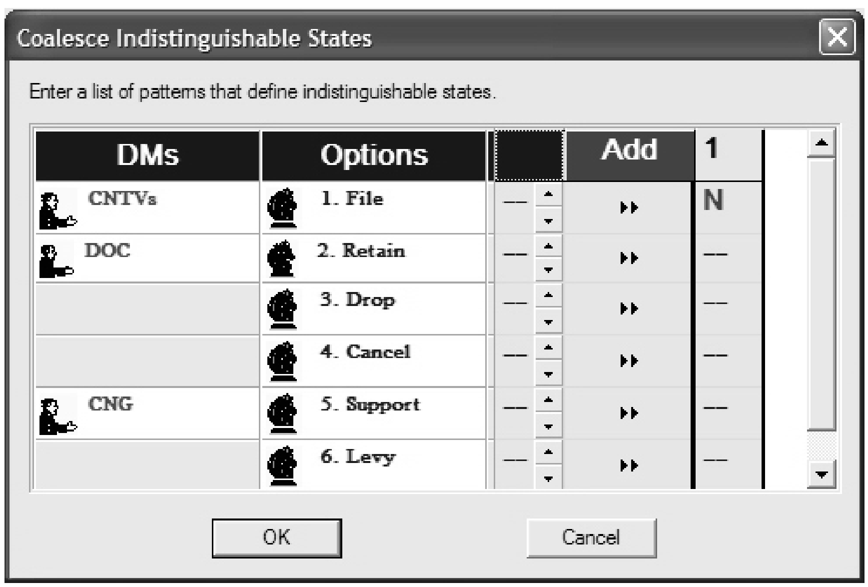


Figure 4.7: Indistinguishable state specification

$s_3 \succ s_9 \succ s_6 \succ s_2 \succ s_8 \succ s_5 \succ s_1 \succ s_7 \succ s_4 \succ s_{10}$.

CNG did not want to levy retaliatory duties and exacerbate the conflict. Based on this information, two groups are identified: $\mathbf{G}_1 = \{s_1, s_2, s_3\}, \mathbf{G}_2 = \{s_4, s_5, s_6, s_7, s_8, s_9, s_{10}\}$. Direct rankings within $\mathbf{G}_1$ and $\mathbf{G}_2$ were carried out, resulting in the overall ranking is $s_3 \succ s_2 \succ s_1 \succ s_9 \succ s_6 \succ s_8 \succ s_5 \succ s_7 \succ s_4 \succ s_{10}$.

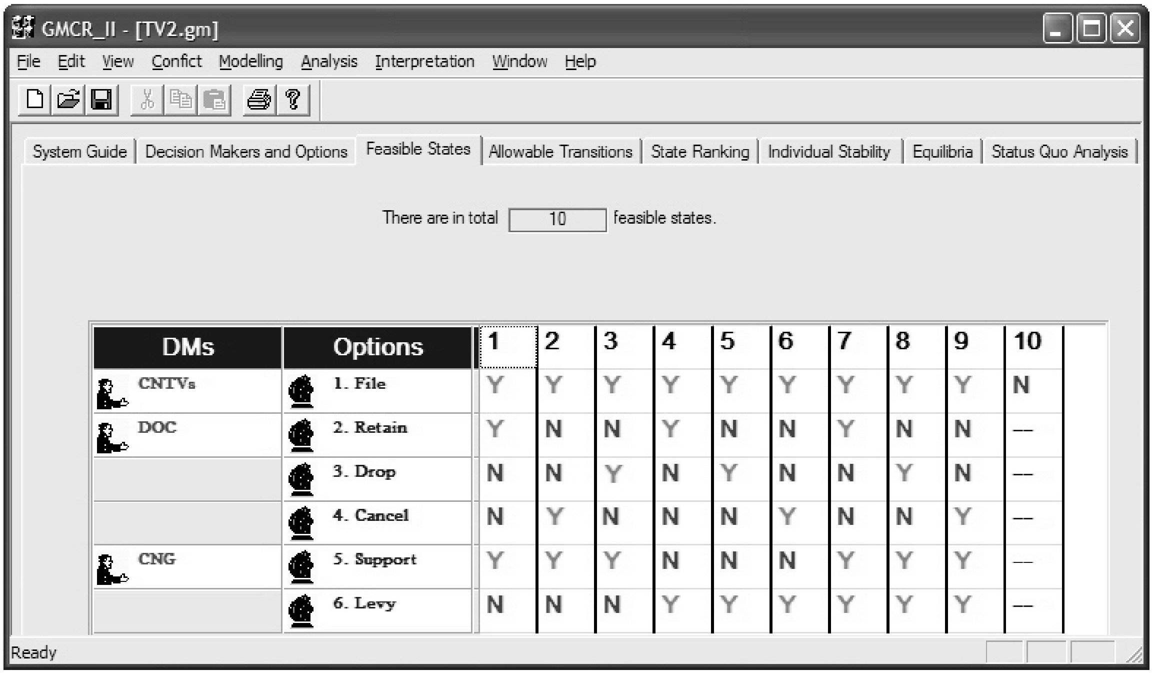


Figure 4.8: Feasible states in TV dumping conflict as of April, 2004

DOC most prefers that CNTVs withdraw from the dispute. Secondly it would like to drop the anti-dumping duties to appease China. Based on this information, three groups are identified: $\mathbf{G}_1 = \{s_{10}\}, \mathbf{G}_2 = \{s_1, s_2, s_4, s_5, s_8\}$, and $\mathbf{G}_3 = \{s_3, s_6, s_7, s_9\}$, with $\mathbf{G}_1 \succ \mathbf{G}_2 \succ \mathbf{G}_3$. The inner group rankings for $\mathbf{G}_2$ and $\mathbf{G}_3$ are $s_2 \succ s_5 \succ s_8 \succ s_1 \succ s_4$ and $s_3 \succ s_6 \succ s_9 \succ s_7$, respectively. Therefore, the overall ranking is $s_{10} \succ s_2 \succ s_5 \succ s_8 \succ s_1 \succ s_4 \succ s_3 \succ s_6 \succ s_9 \succ s_7$.

Equilibria and Evolution of the Conflict

Figure 4.9 shows all equilibria calculated according to different solution concepts. But state 10 is not an attainable equilibrium since no decision maker can move to it. CNTVs and CNG prefer the equilibrium at State 3 over State 10 because CNTVs and CNG want to fight the initial DOC ruling. Otherwise, there is no benefit from the TV export trade, and CNTVs must withdraw from the US market. Furthermore, no other strong equilibrium can be threatened to force CNTVs to move to State 10. Even though DOC most prefers the equilibrium at State 10, there is no hope to achieve it. Therefore, State 3 is a compromise for all sides; with the support of CNG, CNTVs formally files against the DOC's initial ruling and DOC revises the initial ruling and drops the anti-dumping duties. This is what actually happened on April 13, 2004, so far as we know; no further action has been taken by any DM to change the situation.

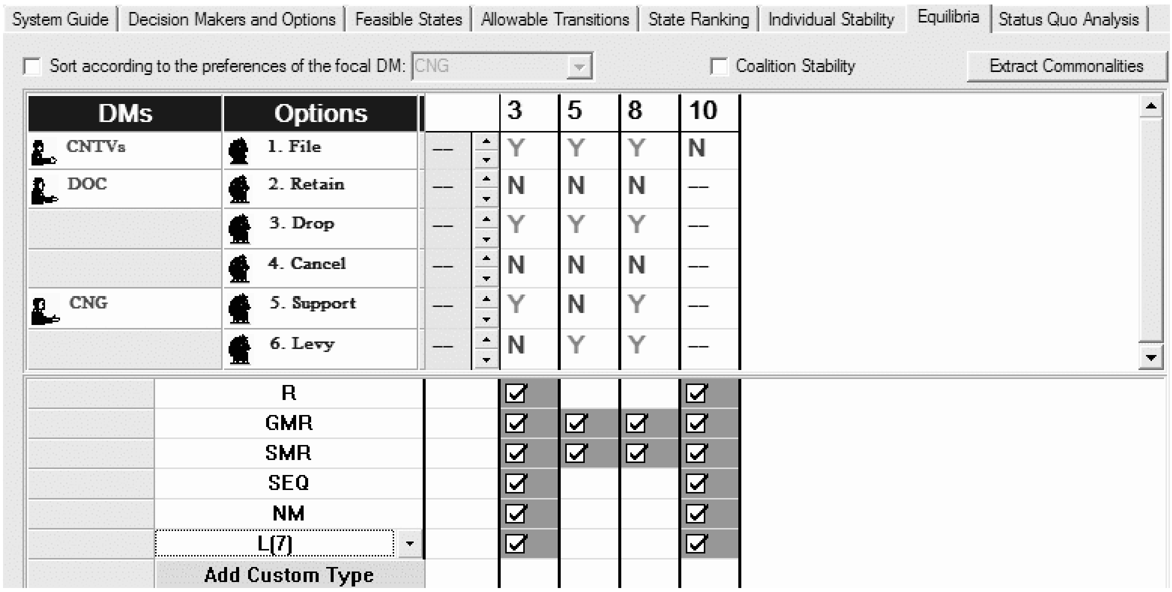


Figure 4.9: Equilibria of TV dumping conflict as of April, 2004

Figure 4.10 traces the evolution of the model from the status quo (State 1) to the final equilibrium (State 3). Starting at State 1 on the left, CNG supported CNTVs to file a suit against DOC, and warned of possible retaliatory duties on TV exports to the US. Then the conflict moved from State 1 to State 7. DOC dropped the anti-dumping duties in the final ruling, which moved the model from State 7 to 8. Finally, CNTVs accepted this ruling and CNG cancelled the possible levy, causing the transition from State 8 to State 3, which is stable for all DMs and is therefore an equilibrium.

4.4 ANP Approach to Conflict Analysis

4.4.1 The Network Setting

Based on information provided in Section 4.3.2, there are ten feasible states and three DMs in the conflict. Figure 4.11 shows the network setting of this conflict.

Decision Makers and Options	Status Quo State		Intermediate State				Equilibrium State
1. **CNTVs**							
(1) File	Y		Y		Y		Y
2. **DOC**							
(2) Retain	Y		Y		N		N
(3) Drop	N		N	$\longrightarrow$	Y		Y
(4) Cancel	N		N		N		N
3. **CNG**							
(5) Support	Y		Y		Y		Y
(6) Levy	N	$\longrightarrow$	Y		Y	$\longrightarrow$	N
State Number	1		7		8		3

Figure 4.10: Moving from the status quo to equilibrium

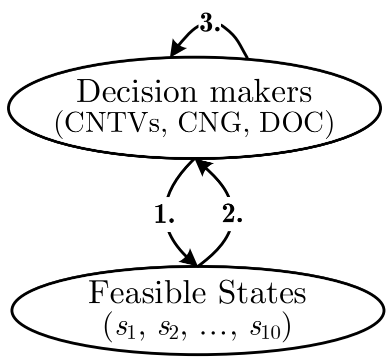


Figure 4.11: The ANP network for TV dumping conflict

4.4.2 Construction of the Supermatrix

First we estimate the inner priority matrix $\mathbf{W_{NN}}$. We obtain the entries by answering the question: *For the other two DMs, which DM has more influences on DM i, and how much more influence has it ?* (1-9 ratio data are used to represent the degree of influence) Table 4.1 shows the results. Based on this information, $\mathbf{W_{NN}}$ is shown in Table 4.2.

The priority matrix $\mathbf{W_{SN}}$ is obtained by answering the question: *For two feasible states, which is more preferred by DM i, and how much more preferred is it?*. The pairwise comparisons given CNTVs are listed in Table 4.3. Similarly, the pairwise comparisons of feasible states given CNG and DOC can be carried out to generate relative priorities. Then $\mathbf{W_{SN}}$ is set up and the results are shown in Table 4.4.

Table 4.1: The inner pairwise comparisons

(CNTVs)	CNG	DOC	Weights
CNG	1	5	0.833
DOC	$\frac{1}{5}$	1	0.167
(CNG)	CNTVs	DOC	Weights
CNTVs	1	3	0.75
DOC	$\frac{1}{3}$	1	0.25
(DOC)	CNTVs	CNG	Weights
CNTVs	1	$\frac{1}{5}$	0.167
CNG	5	1	0.833

Table 4.2: Inner impact matrix $\mathbf{W_{NN}}$

	CNTVs	CNG	DOC
CNTVs	0	0.75	0.167
CNG	0.833	0	0.833
DOC	0.167	0.25	0

The priority matrix $\mathbf{W_{NS}}$ is obtained by answering the question: *Given a feasible state s_j, which of two DMs prefers it more, and how much more preferred is it?*. Carrying out similar pairwise comparisons, the result of $\mathbf{W_{NS}}$ is listed in Table 4.5. Based on this information the supermatrix $\mathbf{W}$ is constructed and the results are given in Table 4.6.

Table 4.3: The pairwise comparisons of feasible states

(CNTVs)	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	Weights
s_1	1	$\frac{1}{4}$	$\frac{1}{7}$	3	$\frac{1}{2}$	$\frac{1}{5}$	2	$\frac{1}{3}$	$\frac{1}{6}$	5	0.04
s_2	4	1	$\frac{1}{4}$	7	3	$\frac{1}{2}$	5	2	$\frac{1}{3}$	8	0.114
s_3	7	4	1	8	5	3	6	4	2	9	0.278
s_4	$\frac{1}{3}$	$\frac{1}{7}$	$\frac{1}{8}$	1	$\frac{1}{4}$	$\frac{1}{7}$	$\frac{1}{2}$	$\frac{1}{6}$	$\frac{1}{8}$	2	0.019
s_5	2	$\frac{1}{3}$	$\frac{1}{5}$	4	1	$\frac{1}{4}$	3	$\frac{1}{2}$	$\frac{1}{6}$	4	0.053
s_6	5	2	$\frac{1}{3}$	7	4	1	5	3	$\frac{1}{2}$	8	0.154
s_7	$\frac{1}{2}$	$\frac{1}{5}$	$\frac{1}{6}$	2	$\frac{1}{3}$	$\frac{1}{5}$	1	$\frac{1}{4}$	$\frac{1}{6}$	3	0.029
s_8	3	$\frac{1}{2}$	$\frac{1}{4}$	6	2	$\frac{1}{3}$	4	1	$\frac{1}{4}$	5	0.080
s_9	6	3	$\frac{1}{2}$	8	6	2	6	4	1	7	0.218
s_{10}	$\frac{1}{5}$	$\frac{1}{8}$	$\frac{1}{9}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{3}$	$\frac{1}{5}$	$\frac{1}{7}$	1	0.016

Table 4.4: Impact matrix $\mathbf{W_{SN}}$

	CNTVs	CNG	DOC
s_1	0.04	0.167	0.079
s_2	0.114	0.016	0.211
s_3	0.278	0.192	0.034
s_4	0.019	0.274	0.059
s_5	0.053	0.021	0.152
s_6	0.154	0.038	0.030
s_7	0.029	0.083	0.016
s_8	0.080	0.029	0.106
s_9	0.218	0.058	0.029
s_{10}	0.016	0.122	0.283

Table 4.5: Impact matrix $\mathbf{W_{NS}}$

	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}
CNTVs	0.143	0.258	0.637	0.136	0.122	0.655	0.238	0.258	0.648	0.091
CNG	0.571	0.105	0.258	0.625	0.320	0.250	0.625	0.105	0.230	0.218
DOC	0.286	0.637	0.105	0.238	0.558	0.095	0.136	0.637	0.122	0.691

Table 4.6: Supermatrix, $\mathbf{W}$

	CNTVs	CNG	DOC	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}
CNTVs	0	0.75	0.167	0.143	0.258	0.637	0.136	0.122	0.655	0.238	0.258	0.648	0.091
CNG	0.833	0	0.833	0.571	0.105	0.258	0.625	0.32	0.25	0.625	0.105	0.23	0.218
DOC	0.167	0.25	0	0.286	0.637	0.105	0.238	0.558	0.095	0.136	0.637	0.122	0.691
s_1	0.04	0.167	0.079	0	0	0	0	0	0	0	0	0	0
s_2	0.114	0.016	0.211	0	0	0	0	0	0	0	0	0	0
s_3	0.278	0.192	0.034	0	0	0	0	0	0	0	0	0	0
s_4	0.019	0.274	0.059	0	0	0	0	0	0	0	0	0	0
s_5	0.053	0.021	0.152	0	0	0	0	0	0	0	0	0	0
s_6	0.154	0.038	0.03	0	0	0	0	0	0	0	0	0	0
s_7	0.029	0.083	0.016	0	0	0	0	0	0	0	0	0	0
s_8	0.08	0.029	0.106	0	0	0	0	0	0	0	0	0	0
s_9	0.218	0.058	0.029	0	0	0	0	0	0	0	0	0	0
s_{10}	0.016	0.122	0.283	0	0	0	0	0	0	0	0	0	0

4.4.3 Obtaining the Limiting Supermatrix and Global Priority Vector

Three typical value combinations of α_1 and α_2 are set for use with the weighted supermatrix, and the limiting supermatrices are calculated. The values of the global priority vectors are shown in Table 4.7. In all situations, s_3 has the greatest value among the ten states. As can be seen, s_3 is the most stable state (equilibrium) for this conflict. This coincides with the GMCR II finding.

Table 4.7: Global priority vectors

	The global priority vector $\mathbf{v}_\infty$		
	$\alpha_1 = \alpha_2 = 0.5$	$\alpha_1 = 0.9$, $\alpha_2 = 0.1$	$\alpha_1 = 0.1$, $\alpha_2 = 0.9$
CNTVs	0.2294	0.332	0.1724
CNG	0.2729	0.4068	0.1781
DOC	0.1643	0.1703	0.1757
s_1	0.034	0.009	0.0045
s_2	0.033	0.008	0.054
s_3	0.061	0.018	0.079
s_4	0.0444	0.0128	0.0562
s_5	0.021	0.005	0.036
s_6	0.025	0.007	0.035
s_7	0.016	0.0046	0.0203
s_8	0.022	0.006	0.034
s_9	0.035	0.01	0.048
s_{10}	0.042	0.01	0.067

4.5 Comparisons and Interpretation

ANP and the graph model employ different techniques to analyze the conflict model. Some distinct features and results of comparison are summarized as follows:

1. ANP and the graph model can identify the same state: s_3. Note that the DMs' preference information about state rankings in ANP and GMCR II are

consistent. For example, CNTVs' state ranking in GMCR II is $s_3 \succ s_9 \succ s_6 \succ s_2 \succ s_8 \succ s_5 \succ s_1 \succ s_7 \succ s_4 \succ s_{10}$, which is consistent with the ANP analysis results shown in Table 4.3. Therefore, based on consistent preference information, ANP and the graph model can generate similar results.

2. The graph model is a game-theory-realted approach which employs solution concepts based on human behaviour listed in Table 2.1, to determine the stability of states. ANP is a decision science approach which constructs the influence supermatrix to generate the limiting state(s). The results can be regarded as non-myopic solutions in Table 2.1. The graph model more closely mimics how people actually behave under conflict, while ANP depends more on subjective judgements which involve experts' experience and knowledge.

3. The graph model requires only ordinal preference information, essentially orderings of a finite number of states, and does not rely on cardinal preference information, which is usually hard to measure precisely. ANP requires the cardinal information obtained using pairwise comparisons to generate global cardinal priority information. Because of its lower information requirement, the graph model is easier to implement. The decision support system, GMCR II allows users to enter conflict models conveniently and expeditiously.

4. The graph model can indicate the evolution of a conflict: how a conflict model moves from the status quo to the final equilibrium as listed in Figure 4.10. ANP can furnish cardinal information about the relative strengths of both DMs and feasible states. For example, $\mathbf{v_N}$ gives the relative influences of DMs participating in the conflict. As can be seen in Table 4.7, CNG has the greatest influence on other DMs, indicating that CNG has the most power to control the evolution of the conflict. This is consistent with the evolution indicated by the graph model in Figure 4.10.

4.6 Conclusions

In this chapter, a comparison study of ANP with the graph model was carried out using the China-US TV dumping conflict. The graph model and ANP constitute two distinctively different techniques for conflict analysis. A key advantage of the graph model is that only rudimentary information is required to calibrate a model and execute an exhaustive stability analysis: the DMs; the options controlled by each DM; and relative preference information. The decision support software

GMCR II operationalizes the modeling and analysis processes based on the graph model technique.

ANP, on the other hand, is a decision analysis technique for ranking or choosing alternatives. It focuses on analyzing the global priorities of different elements in the system based on pair-wise comparisons. It does not focus on the investigation of evolution, but rather adapts expert knowledge to give subjective judgements and generate overall results. As shown in the case study, these two methods can be employed in a complementary fashion to increase understanding of a strategic conflict.

Chapter 5

Index Aggregation for Country-Performance Comparisons

5.1 Introduction

An index aggregation approach is proposed in this chapter for country-performance comparisons under the umbrella of multiple criteria decision analysis (MCDA). First, MCDA is briefly introduced. Then, country performance indices and the index aggregation procedure are explained in detail. Finally, a case study of comparisons of some developing and developed countries is carried out. This chapter is based upon the research of Su et al. (2006).

5.2 Multiple Criteria Decision Analysis

Multiple criteria decision analysis (MCDA) consists of a set of principles and tools to assist a decision maker (DM) to solve a decision problem with a finite set of alternatives compared according to two or more criteria, which are usually conflicting. It is a rapidly evolving domain which scientific developments are altogether based on fundamental sciences such as mathematics, computer science, operation research, engineering, etc. and in the social sciences and management science such as sociology, management, political sciences. Sometimes other terms are used, such as "multiple criteria decision aid", and "multiple objective (criteria, attribute) decision making".

The first step of MCDA is the serial process of defining objectives, arranging them into criteria, identifying all possible alternatives, and then measuring consequences. A consequence is a direct measurement of the success of an alternative according to a criterion (e.g. cost in dollars, capacity in millions of gallons per day). Note that a consequence is an objective physical measurement and does not include preferential information.

The basic structure of an MCDA problem established by the above process is shown in Figure 1. In this figure, $\mathbf{A} = \{A^1, A^2, \cdots, A^i, \cdots, A^n\}$ is the set of alternatives, and $\mathbf{Q} = \{1, 2, \cdots, j, \cdots, q\}$ is the set of criteria. The consequence on criterion j of alternative A^i is expressed as $c_j(A^i)$, which can be shortened to c_j^i when there is no possibility of confusion. Note that there are n alternatives and q criteria altogether.

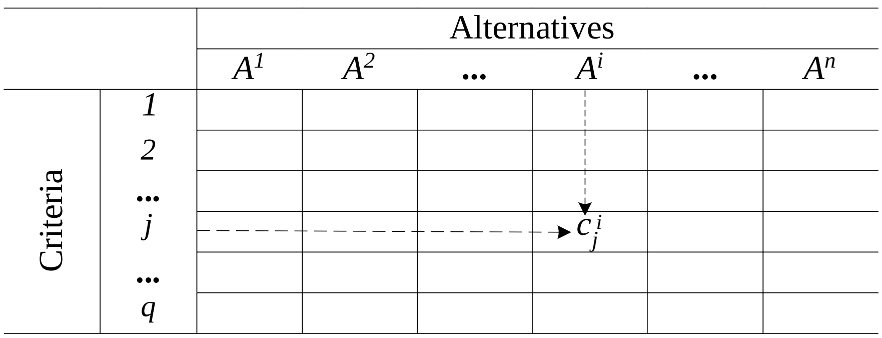


Figure 5.1: The structure of MCDA

Given this basic structure, the DM may conceive the decision problem in several ways. Roy (1996) proposed four different MCDA **problématiques** for a decision problem with alternative set **A**:

- α. **Choosing problématique**. Choose the best alternative from **A**.
- β. **Sorting problématique**. Sort the alternatives of **A** into predefined, relatively homogeneous groups, arranged in preference order.
- γ. **Ranking problématique**. Rank the alternatives of **A** from best to worst.
- δ. **Describing problématique**. Describe the alternatives of **A** in terms of their major distinguishing features.

Several methods have been proposed to solve these problématiques during the last thirty years. Multiattribute utility theory (MAUT) (Keeney and Raiffa, 1976), the Analytic Hierarchy Process (AHP) (Saaty, 1980), Outranking (Roy, 1996) are among the most famous approaches. The choice of the most appropriate model, depends on the problem at hand and may be, to some extent, determined by the model the DM is most comfortable with. Under the umbrella of MCDA, a novel approach to index aggregations is proposed to address the countries' overall performance comparisons and is applied to a case study in this chapter.

5.3 Country-Performance Comparisons

The world economy has changed dramatically over the past fifty years. The United States (US) dominated the global economy for a long time just after the end of World War II. Later on, with the rapid recoveries and fast economic growth, European Union (EU) countries and Japan became strong economic competitors of the United States. The Group of Seven (G7) countries consisting of Canada, France, Germany, Italy, Japan, the United Kingdom (UK), and the United States (US) accounts for about two-thirds of the world's economic output and is regarded as an unofficial "world economics government". Currently, new players are challenging the world economic order. The leading investment banking firm, Goldman Sachs Group, Inc., reports that in less than forty years, the BRICs economies (Brazil, Russia, India and China) combined, could be larger than the Group of Six (G6) which includes the US, Japan, Germany, UK, France, and Italy in US dollar terms (Wilson and Purushothaman, 2003), as shown in Figure 5.2.

Some highlights from Wilson and Purushothaman (2003) are as follows:

- Currently, the BRICs economies together are worth less than 15% of the G6's economic value in US dollars. But in less than 40 years, the BRICs economies could be larger than the G6. By 2025 they could account for over half the size of the G6, and, furthermore, only the US and Japan of the current G6 may be among the six largest economies in 2050.

- About two-thirds of the increase in US dollar GDP (gross domestic product) from the BRICs should come from higher real growth, with the balance through currency appreciation. The real exchange rates of BRICs could appreciate by up to 300% over the next 50 years (an average of 2.5% a year).

- The growth for the BRICs is likely to slow significantly by 2050, with only India having a growth rate significantly above 3%. Moreover, individuals in the BRICs are still likely to be poorer on average than the ones in the G6 economies, with the exception of Russia. China's per capita income could be roughly what the developed economies are now (about US $30,000 per

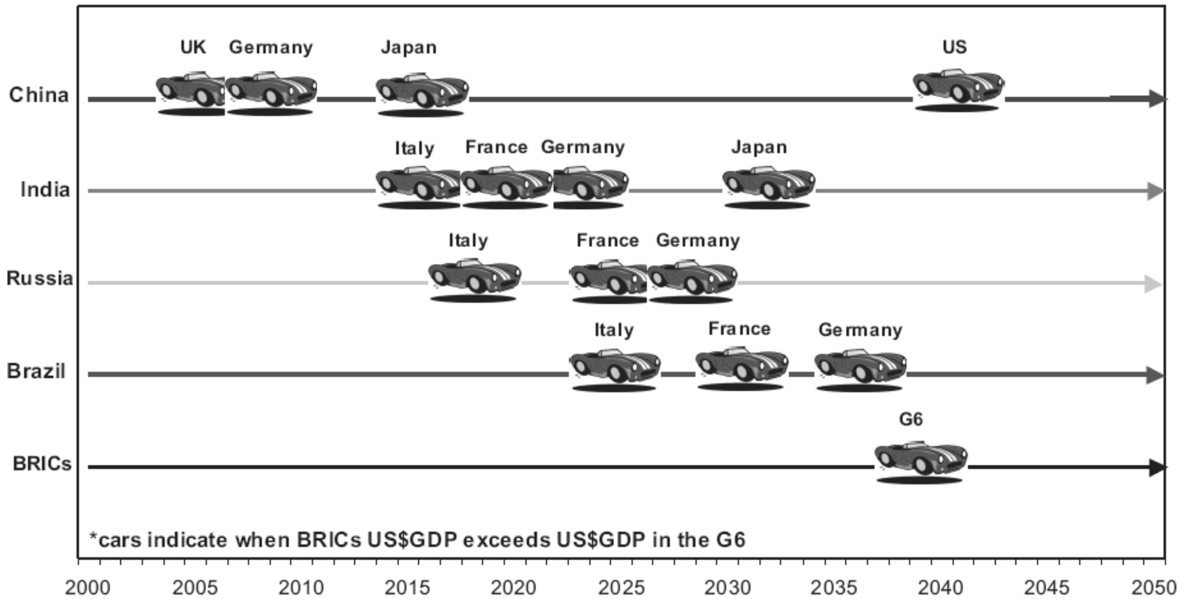


Figure 5.2: Overtaking the G6: when BRICs' US$GDP would exceed G6, adapted from Wilson and Purushothaman (2003)

capita). The shift in GDP relative to the G6 will take place steadily over the period, but will be most dramatic in the first 30 years.

- As early as 2009, the annual increase in US dollar spending from the BRICs could be greater than that of the G6 and more than twice as much as it was in 2003. By 2025 the annual increase in US dollar spending of the BRICs could be twice that of the G6, and four times higher by 2050.

Recently, many BRICs-related studies have been conducted from different perspectives. The British Broadcasting Corporation (BBC) hosted the program, "Who runs your world", to introduce BRICs and their potential new powers in the global economy (BBC, 2005). In global economic papers published within the Goldman Sachs Group, O'Neill (2001), and Wilson and Purushothaman (2003) examined the economical potential of BRICs by employing a long-term growth model. The study of BRICSAM countries, which extends BRICs by including South Africa, ASEAN (Association of South-East Asian Nations), and Mexico, is a major research endeavor of the Centre for International Governance Innovation (CIGI), located in Waterloo, Ontario, Canada (CIGI, 2005).

Following the research direction of the BRICSAM program in CIGI, this chapter presents an index aggregation approach to carry out a comparison study of BRICSAM and G7 countries by employing both economical and non-economical indices such as sustainable development, global responsibility and transparent practices. There are two unique features of this index aggregation approach: (1) Based on the concept of data envelopment analysis (DEA), the comparison is conducted in a fair manner by permitting a country to maximize its possibility of obtaining the best aggregate evaluation result. (2) Different kinds of indices, expressed both in cardinal and ordinal formats, are utilized in a reasonable way to generate the aggregated results. The remainder of the Chapter is organized as follows. Section 5.4 and 5.5 provide a background introduction of several indices employed in the comparison study. Section 5.6 proposes a DEA-based index aggregation approach. Then, in Section 5.7, the comparison of BRICSAM and G7 countries is carried out based on the proposed method. Finally, conclusions are drawn in Section 5.8.

5.4 Country Indices Introduction

Many country-ranking indices, such as the indices given in the global competitiveness report by the World Economic Forum (Porter et al., 2005), and the environmental sustainability index by Yale University (Yale, 2005), constitute evaluations of countries from different perspectives. These indices are developed by several researchers to reflect their viewpoints in estimation of the performances of different countries, and, therefore provide valuable information to utilize in the comparisons carried out in Section 5.7. The indices employed are explained next.

5.4.1 Economics Related Indices

Three economics related indices are selected: the growth competitiveness index (GCI), business competitiveness index (BCI) and economic freedom index (EFI).

- *Growth Competitiveness Index*: As an indicator used in the global competitiveness program within the World Economic Forum (WEF, www.weforum.org), the GCI is designed to measure the capacity of a national economy to achieve sustained economic growth over the medium term, taking into account the current level of economic development (Porter et al., 2005). It consists of three sub-indices: the level of technology in an economy, the quality of public institutions and the macro-economic conditions related to growth. The GCI uses a combination of hard data, such as university enrolment rates, inflation performance, the state of the public finances, the level of penetration of new technologies (for example mobile telephones and the Internet), and data drawn from executive opinion surveys executed by WEF. The latter helps to capture concepts for which hard data are typically unavailable, but which are, nevertheless, central to an appropriate understanding of the factors fuelling economic growth. Examples of the latter might include such concepts as judicial independence, the prevalence of institutionalized corruption, or the extent of inefficient government intervention in an economy (Porter et al., 2005).

The GCI used here is *GCI 2005-2006*, is available at WEF's website. The details are explained by Porter et al. (2005). The GCI 2005-2006 includes cardinal data based on the ranking of 117 countries. The best performance country is Finland with a score of 5.94; the worst performance country is Chad with a score of 2.37. A larger score number represents a better performance of GCI. Table 5.1 lists the scores of BRICSAM countries. The founding members of ASEAN, Indonesia, Malaysia, Philippines, Singapore and Thailand, are selected as being representative for ASEAN.

Table 5.1: The GCI 2005-2006 for BRICSAM and G7

Country	Brazil	Canada	China	France	Germany	India	Indonesia	Italy	Japan
GCI	3.69	5.10	4.07	4.78	5.10	4.04	3.53	4.21	5.18

Country	Malaysia	Mexico	Philippines	Russia	Singapore	South Africa	Thailand	UK	US
GCI	4.90	3.92	3.47	3.53	5.48	4.31	4.50	5.11	5.81

- *Business Competitiveness Index*: BCI is another important index studied in the global competitiveness program of WEF. The BCI focuses on the underlying microeconomic factors which determine economies' current sustainable levels of productivity and competitiveness, thus providing a complementary approach to the macroeconomic approach of the GCI. The BCI rests on the idea that microeconomic factors are critical for national competitiveness, since wealth is actually created at the level of firms operating in an economy. The BCI specifically measures two areas that are critical to the microeconomic business environment in an economy: the sophistication of company operations and strategy, as well as the quality of the overarching national business environment in which they are operating (Porter et al., 2005).

The BCI is *BCI 2005-2006*, is also available at WEF's website. The BCI 2005-2006 includes ordinal data based on the ranking of 117 countries. The top ranking country is the US; the lowest one is Chad. A lower number of ranking represents a better performance of BCI. Table 5.2 lists the rankings of the BRICSAM and G7 countries.

Table 5.2: The BCI 2005-2006 for BRICSAM and G7

Country	Brazil	Canada	China	France	Germany	India	Indonesia	Italy	Japan
BCI	49	13	57	11	3	31	59	38	8
Country	Malaysia	Mexico	Philippines	Russia	Singapore	South Africa	Thailand	UK	US
BCI	23	60	69	74	5	28	37	6	1

- *Economic Freedom Index*: There are a few studies focusing on the study of economic freedom of different countries, such as the economic freedom of the world annual report developed by the Fraser Institute (www.fraserinstitute.ca), the economic freedom index (EFI) co-published by the Heritage Foundation (www.heritage.org) and the Wall Street Journal (www.wsj.com). The EFI data provided by the Heritage Foundation and the Wall Street Journal are used because they have been studied by these two research institutes for over ten years.

  The goal of the EFI is to develop a systematic, empirical measurement of economic freedom in countries throughout the world. The EFI used here is *EFI 2005*, which measures 161 countries' or regions' rankings using cardinal data. The EFI is based on a list of 50 independent variables which are divided into 10 broad factors of economic freedom: trade policy, fiscal burden of government, government intervention in the economy, monetary policy, capital flows and foreign investment, banking and finance, wages and prices, property rights, regulation, and informal market activity. The best country or region is Hong Kong with a score of 1.35; the worst one is North Korea with a score of 5. Lower scores are more desirable. The higher the score, the greater the level of government interference in the economy and the less economic freedom a country enjoys (Heritage, 2005). Table 5.3 lists the scores of BRICSAM and G7 countries.

Table 5.3: The EFI 2005 for BRICSAM and G7

Country	Brazil	Canada	China	France	Germany	India	Indonesia	Italy	Japan
EFI	3.25	1.91	3.46	2.63	2.00	3.53	3.54	2.28	2.46
Country	Malaysia	Mexico	Philippines	Russia	Singapore	South Africa	Thailand	UK	US
EFI	2.96	2.89	3.25	3.56	1.60	2.78	2.98	1.75	1.85

5.4.2 Non-economic Indices

Although this study intends to focus on economics, some non-economic indices are also considered in order to obtain more comprehensive and balanced comparisons. The indices considered are the environmental sustainability index (ESI), foreign policy globalization index(FPGI), and corruption perceptions index (CPI).

- *Environmental Sustainability Index*: ESI was developed by the Center for Environmental Law and Policy at Yale University in collaboration with the Center for International Earth Science Information Network at Columbia University, and the WEF. ESI aims to shift environmental decision-making to firmer analytic foundations using environmental indicators and statistics. The ESI is a composite index tracking 21 elements of environmental sustainability covering natural resource endowments, past and present pollution levels, environmental management efforts, contributions to protection of the global commons, and a society's capacity to improve its environmental performance over time (Yale, 2005).

  The newest ESI information is *ESI 2005*, which measures 146 countries using cardinal data. The best performance country is Finland with a score of 75.1; the worst performance one is North Korea having a score of 29.2. A larger number of score represents a better performance of ESI. Table 5.4 lists the scores of BRICSAM and G7 countries.

- *Foreign Policy Globalization Index(FPGI)*: FPGI was developed by the consulting firm, A.T. Kearney, Inc. (www.atkearney.com). It is designed to track and assess a country's performances in four key components of global integration: adopting measures such as trade and investment flows, movement of people across borders, volume of international telephone traffic, Internet usage, and participation in international organizations (Kearney, 2005).

Table 5.4: The ESI 2005 for BRICSAM and G7

Country	Brazil	Canada	China	France	Germany	India	Indonesia	Italy	Japan
ESI	62.20	64.40	38.60	55.20	56.90	45.20	48.80	50.10	57.30
Country	Malaysia	Mexico	Philippines	Russia	Singapore	South Africa	Thailand	UK	US
ESI	54.00	46.20	42.30	56.10	41.84	46.20	49.70	50.20	52.90

The latest FPGI statistics are given in *FPGI 2005*, which include an ordinal data based ranking of 62 countries or regions. The most highly rated country is Singapore; the lowest one is Iran. A lower number of ranking represents a better performance of FPGI. Table 5.5 lists the rankings of BRICSAM and G7 countries.

Table 5.5: The FPGI 2005 for BRICSAM and G7

Country	Brazil	Canada	China	France	Germany	India	Indonesia	Italy	Japan
FPGI	57	6	54	18	21	61	60	27	28
Country	Malaysia	Mexico	Philippines	Russia	Singapore	South Africa	Thailand	UK	US
FPGI	19	42	32	52	1	48	46	12	4

- *Corruption Perceptions Index*: CPI is developed by the Berlin-based organization Transparency International (TI) (www.transparency.org). CPI focuses on corruption in the public sector and defines corruption as the abuse of public office for private gain. The surveys used in compiling CPI data pose questions that relate to the misuse of public power for private benefit, with a focus, for example, on bribe-taking by public officials in public procurement. CPI is a composite index, drawing on corruption-related data in expert surveys carried out by a variety of reputable institutions. It reflects the views of business people and analysts from around the world, including experts who are residents in the countries evaluated (TI, 2005).

  The CPI data used are contained in *CPI 2005*, which measures 159 country or region's rankings using cardinal data. The best performance country is Iceland with a score of 9.7; the worst performance one is Chad with a score of 1.7. A higer score represents a better performance of CPI. Table 5.6 lists the scores of BRICSAM and G7 countries.

Table 5.6: The CPI 2005 for BRICSAM and G7

Country	Brazil	Canada	China	France	Germany	India	Indonesia	Italy	Japan
CPI	3.7	8.4	3.2	7.5	8.2	2.9	2.2	5.0	7.3
Country	Malaysia	Mexico	Philippines	Russia	Singapore	South Africa	Thailand	UK	US
CPI	5.1	3.5	2.5	2.4	9.4	4.5	3.8	8.6	7.6

5.5 Index Classification and Data Processing

As described above, the foregoing six indices rank countries according to different criteria and obtain diverse results for BRICSAM and G7 countries. Also, the provided ranking information follows different formats: some are cardinal, such as GCI; some are ordinal, such as BCI. For the case of cardinal indices, some indices indicate a better performance using a larger value, such as ESI; some use a smaller value to represent a better one, for example, EFI. An aggregation approach should be able to handle both cardinal and ordinal information in a proper way. Firstly, the index information is classified according to cardinal and ordinal information and then methods for information processing of the index data are provided.

5.5.1 Index Information Classification

The country set, $\mathbf{A} = \{A^i, i = 1, 2, ..., 18\}$, is assigned to the 18 countries listed in Table 5.7. The cardinal index set, $\mathbf{I}^c = \{I^c_j, j = 1, 2, ..., 4\}$, and the ordinal index set, $\mathbf{I}^o = \{I^o_k, k = 1, 2\}$, are assigned to the aforementioned indices and are shown in Table 5.8 and 5.9, respectively.

Table 5.7: The settings of BRICSAM and G7 in $\mathbf{A}$

Country	Brazil	Canada	China	France	Germany	India	Indonesia	Italy	Japan
A^i	A^1	A^2	A^3	A^4	A^5	A^6	A^7	A^8	A^9
Country	Malaysia	Mexico	Philippines	Russia	Singapore	South Africa	Thailand	UK	US
A^i	A^{10}	A^{11}	A^{12}	A^{13}	A^{14}	A^{15}	A^{16}	A^{17}	A^{18}

Table 5.8: The cardinal indices

Index	GCI	EFI	ESI	CPI
I_j^c	I_1^c	I_2^c	I_3^c	I_4^c

Table 5.9: The ordinal indices

Index	BCI	FPGI
I_k^o	I_1^o	I_2^o

5.5.2 Index Information Processing

Cardinal Index Information Processing

For a cardinal index, $I_j^c \in \mathbf{I}^c$, the rank score of country A^i is defined as c_j^i. For example, the rank scores of GCI 2005-2006 for Canada and China in Table 5.1 are 5.10 and 4.07, and, hence, $c_1^2 = 5.10$ and $c_1^3 = 4.07$, respectively.

Based on c_j^i, the variable u_j^i is used to represent the performance of A^i on I_j^c and is defined as follows.

- If a larger value of c_j^i, represents a better performance,

$$u_j^i = \frac{c_j^i - c_j^{\min}}{c_j^{\max} - c_j^{\min}}; \tag{5.1}$$

- If smaller value of c_j^i, represents a better performance,

$$u_j^i = \frac{c_j^{\max} - c_j^i}{c_j^{\max} - c_j^{\min}}, \tag{5.2}$$

  where $c_j^{\min}$ and $c_j^{\max}$, are the minimum and maximum value of the score for I_j^c, for $j = 1, 2, 3, 4$. Note that u_j^i constitutes a normalized datum based on c_j^i, so that $u_j^i \in [0, 1]$, for $i = 1, ..., 18$ and $j = 1, ..., 4$, and a larger value of u_j^i represents a better performance.

Ordinal Index Information Processing

For an ordinal index, $I_k^o \in \mathbf{I}^o$, the ranking of country A^i is defined as d_k^i. For example, the rankings of BCI 2005-2006 for Canada and China in Table 5.2 are 13^{th} and 57^{th}, and therefore, $d_1^2 = 13$ and $d_1^3 = 57$, respectively.

Similarly, based on d_k^i, the variable v_k^i is used to represent the performance of A^i on I_k^o, where $0 < v_k^i \leq 1$, for $i = 1, ..., 18$ and $k = 1, 2$. A larger value of v_k^i represents a better performance. Next, an indifference threshold, α_k for $k = 1, 2$, is defined so that differences in values of v_k^i less than α_k are not meaningful and can be ignored. For simplicity, α_k is set to $\alpha_k = \alpha$ for all ordinal indices. Because of cognitive characteristics of decision makers, indifference thresholds exist widely in practice. For example, in the negotiation of purchasing of a car, people might bargain over prices in \$ 10 intervals instead of \$1. A suggested value of α could be $\frac{1}{gn}$, where n is the number of countries and $g \in \mathbb{R}^+$ is an adjustment factor.

As aforementioned, the proposed method provides a fair overall assessment of a country's standing by maximizing its possibility of obtaining the best aggregate evaluation result. One such "fair" mechanism is that A^i is permitted to set v_k^i as it wishes (the determination of v_k^i is calculated using mathematical programming which is explained in detail in Section 5.6) as long as the following constraints are satisfied:

- For any two countries, A^m and A^l,

$$\text{if } d_k^m > d_k^l,\ v_k^l - v_k^m \geq (d_k^m - d_k^l)\alpha; \tag{5.3}$$

$$\text{if } d_k^m < d_k^l,\ v_k^m - v_k^l \geq (d_k^l - d_k^m)\alpha. \tag{5.4}$$

- For any country, A^i,

$$\text{for } k = 1, 2, \text{ and } i = 1, 2, ..., 18,\ \alpha \leq v_k^i \leq 1. \tag{5.5}$$

Based on the definition of the indifference threshold, Equation (5.3) or Equation (5.4) sets a lower bound of performance value for two countries with different rankings. This represents the minimum gap of performance value between two ordinal rankings, and Equation (5.5) sets lower and upper bounds of performance values for each country. For example, because the rankings of BCI 2005-2006 for Canada and China in Table 5.2 are 13^{th} and 57^{th}, then $v_1^2 - v_1^3 \geq (57 - 13)\alpha$, where $\alpha \leq v_1^2 \leq 1$ and $\alpha \leq v_1^3 \leq 1$, respectively.

5.6 Index Aggregation Model Design

The proposed index aggregation method is based on the general concept of data envelopment analysis (DEA) (Charnes et al., 1978), and hence, a brief introduction of DEA is given first. This is followed by the design of the index aggregation model and how it can be solved using a mathematical program.

5.6.1 Data Envelopment Analysis

DEA is an increasingly popular management decision tool initially proposed by Charnes et al. (1978). DEA is a linear programming based technique for measuring the relative performance of a number of producers or decision making units (DMUs) where the presence of multiple inputs and outputs makes comparisons difficult. Charnes et al. (1978) recognized the difficulty in seeking a common set of weights (relative importance) of inputs and outputs to determine the relative efficiency of DMUs and a DMU might value inputs and outputs differently and therefore adopt different weights. Hence, Charnes et al. (1978) proposed that each DMU should be allowed to adopt a set of weights which shows it in the most favourable light in comparison to the other DMUs. For example, considering the comparison of the efficiency of a set of banks, each bank has a certain number of inputs: tellers, working space and managers and a certain number of outputs such as cheques cashed, loan applications processed, and so on. A bank is efficient if it can be identified as a best bank by adopting a set of weights to maximize its performance in comparison to the other banks; it is non-efficient if the bank cannot be found as a best one whatever the settings of criterion weights might be.

During the last twenty years there are many researches focusing on DEA for both theoretical extensions and practical applications. For example, Cook and Kress (1994) discussed the relationship between DEA and multiple criteria decision analysis (MCDA) and proposed a DEA-based MCDA method to handle both cardinal and ordinal criteria. Here, the method of Cook and Kress (1994) is adapted to aggregate different indices to permit meaningful comparisons of the performances of different countries. The details are explained next.

5.6.2 The Index Aggregation Model

To aggregate the performances of a country over different indices, the linear additive function, which is widely used in many practical evaluations, is defined as

$$V(A^i) = \sum_{j=1}^{4} w_j^c \cdot u_j^i + \sum_{k=1}^{2} w_k^o \cdot v_k^i, \tag{5.6}$$

where $w_j^c, w_k^o \in \mathbb{R}^+$ are weights (relative importance) for I_j^c and I_k^o, respectively, and $V(A^i)$ is the aggregation performance for A^i based on indices $\mathbf{I}^c$ and $\mathbf{I}^o$. Here, a greater value of $V(A^i)$ represents a better performance.

As another "fair" mechanism, A^i is permitted to set w_j^c, w_k^o for $j = 1, ..., 4$ and $k = 1, 2$ to maximize its performance as long as the following constraints are satisfied:

- For easy comparisons, $V(A^i)$, is assumed to be bound into the range between 0 and 1.
$$0 \leq V(A^i) \leq 1, \text{ for } i = 1, ..., 18. \tag{5.7}$$
- An indifference threshold, β, is attached to w_j^c and w_k^o for $j = 1, ..., 4$ and $k = 1, 2$, so that differences in values of w_j^c and w_k^o less than β are not meaningful and can be ignored. A suggested value of β is $\frac{1}{hq}$, where q is the number of indices and $h \in \mathbb{R}^+$ is an adjustment factor.
$$w_j^c \geq \beta, \ w_k^o \geq \beta, \text{ for } j = 1, ..., 4 \text{ and } k = 1, 2. \tag{5.8}$$
- Since this study intends to focus on economic performance, it is assumed that weights of economics-related indices are more important than non-economic-related indices. Hence, the weight of an economics index in $\{w_1^c, w_2^c, w_1^o\}$ is greater than the one of a non-economic index in $\{w_3^c, w_4^c, w_2^o\}$ for at least the value of β. Of course, it is not always necessary to make this assumption, depending on the decision maker's research objective.

$$w_1^c - w_3^c \geq \beta; \ w_1^c - w_4^c \geq \beta; \ w_1^c - w_2^o \geq \beta;$$
$$w_2^c - w_3^c \geq \beta; \ w_2^c - w_4^c \geq \beta; \ w_2^c - w_2^o \geq \beta;$$
$$w_1^o - w_3^c \geq \beta; \ w_1^o - w_4^c \geq \beta; \ w_1^o - w_2^o \geq \beta;$$

5.6.3 Mathematical Program for Aggregated Performances

A given country, denoted by A^i, would like to achieve the best possible aggregated performance with respect to all of the indices. In other words, it would like to have the highest possible aggregated value for $V(A^i)$ as defined in Equation (5.6). However, the variables used in calculating $V(A^i)$ must satisfy certain constraints, as just discussed. Therefore, the country being considered desires to obtain the greatest "feasible" value of $V(A^i)$ in which no constraints are violated, and hence, the values of the variables producing the best values of $V(A^i)$ all lie within the so called "feasible region".

In the literature, the mathematical description of this problem is called a "mathematical program" in which one wishes to optimize (maximize or minimize) an objective function subject to a set of mathematical constraints. When the objective function and all of the constraints are linear, the mathematical program is called a "linear program". If at least one nonlinear term, such as two variables which are multiplied, is present in either the objective function or a constraint, the mathematical program is deemed to be a "nonlinear mathematical program". Both linear and nonlinear mathematical programs are often called constrained optimization models. Optimization and a rich range of other types of models for addressing complex systems problems were developed within the fields of operational research, systems engineering and elsewhere. Many well-explained textbooks, such as the ones written by Taha (2003), and Hillier and Lieberman (2001) are available while Hipel et al. (1999) provide a brief overview of formal models used in decision making.

For the case of the aggregated indices in this research, the mathematical program for country A^i is to maximize its objective function subject to satisfying the constraints, which is mathematically written as follows:

Maximize the objective function:

$V(A^i) = \sum_{j=1}^{4} w_j^c \cdot u_j^i + \sum_{k=1}^{2} w_k^o \cdot v_k^i$

Subject to the constraints:

$0 \leq \sum_{j=1}^{4} w_j^c \cdot u_j^i + \sum_{k=1}^{2} w_k^o \cdot v_k^i \leq 1$, for $i = 1, 2, ..., 18$;

For any two countries, A^m and A^l ($m, l = 1, 2, .., 18$ and $m \neq l$)
if $d_k^m > d_k^l$, $v_k^l - v_k^m \geq (d_k^m - d_k^l)\alpha$;
if $d_k^m < d_k^l$, $v_k^m - v_k^l \geq (d_k^l - d_k^m)\alpha$;

$\alpha \leq v_k^i \leq 1$ for $k = 1, 2,$ and $i = 1, 2, ..., 18$;

$w_j^c, w_k^o \geq \beta,$ for $j = 1, ..., 4$ and $k = 1, 2$;

$w_1^c - w_3^c \geq \beta$; $w_1^c - w_4^c \geq \beta$; $w_1^c - w_2^o \geq \beta$;

$w_2^c - w_3^c \geq \beta$; $w_2^c - w_4^c \geq \beta$; $w_2^c - w_2^o \geq \beta$;

$w_1^o - w_3^c \geq \beta$; $w_1^o - w_4^c \geq \beta$; $w_1^o - w_2^o \geq \beta$;

For the above mathematical program which calculates the maximum aggregated value of A^i, the input information is u_j^i for $j = 1, 2, ..., 4$; d_k^i for $k = 1, 2$; α and β. The outputs are as follows: (1) the best aggregation performance, $V(A^i)$, (2) the weight information, w_j^c, w_k^o, $j = 1, 2, ..., 4$ and $k = 1, 2$, and (3) the value information , v_k^i, for $k = 1, 2$. Since the constraints in the above program involve the multiplication of variables, it is a nonlinear mathematical program. Researchers have developed algorithms for solving the above mathematical program and other types of optimization problems. In addition, computerized versions of these algorithms are available from a number of sources (see, for instance, Lingo (2005) and Matlab (2005)).

Major advantages of the above mathematical program for index aggregation optimization are:

- All of the input data - the cardinal scores and ordinal rankings - are readily available and the indifference thresholds, α and β, can be easily assigned for a range of sensible values;

- The information - the weights and the cardinalized ordinal values (i.e. the v_k^i) - are automatically calculated when determining the optimal value of the objective function and, hence, do not have to be furnished by a user;

- Since the nonlinear constraints are smooth, which means that derivatives of these functions with respect to each variable, i.e. the function gradients, are continuous, the global optimum will be found if it exists;

- For country, A^i, the best possible objective value is always obtained.

The aggregation performance of each country, $V(A^i)$ for $i = 1, 2, ..., 18$, can be separately calculated using the above mathematical program. If $V(A^i) = 1$, A^i is an efficient country representing the best aggregation performance; if $V(A^i) < 1$, A^i is not efficient and a greater value represents a better performance. Note that since the selections of α and β may affect the results, sensitivity analyses need to be carried out to check the robustness of the results by appropriately changing the values of α and β.

5.7 Comparison Study of BRICSAM and G7 countries

The mathematical program for index aggregation optimization is employed for obtaining meaningful comparisons of BRICSAM and G7 countries. The cardinal input data are discussed in Section 5.1, output information from the mathematical program is generated in the next section, and interesting insights contained in the output are brought to the forefront in Section 5.3.

5.7.1 Data Processing

Based on the rank scores given in Tables 5.1, 5.3, 5.4 and 5.6, the performance data of all 18 countries over four cardinal indices are generated by employing Equations (5.1) and (5.2), to obtain the results as listed in Table 5.10. As mentioned in Section 4.3, a key benefit of employing the proposed mathematical program for index aggregation is that the indices, v_k^i, $i = 1, 2$, for the ordinal information are automatically determined during the optimization calculations - the user only has to supply the ordinal ranking information furnished in Tables 5.2 and 5.5 for the BCI and FPGI indices, respectively.

5.7.2 Model Computation

The best aggregation performance, $V(A^i)$ for $i = 1, 2, ..., 18$, can be generated separately for each of the 18 countries by employing the mathematical program in Section 4.3. Here, the sensitivity analyses are carried out by setting different value combinations of α and β. Additionally, $\alpha = \frac{1}{gn}$, where $n = 18$ and $g = 100/18$ or $100/9$; $\beta = \frac{1}{hq}$, where $q = 6$, and $h = 10/6$, $20/6$, $100/6$ or $200/6$. Hence, the combinations for each pair of α and β are as follows: (0.01, 0.1), (0.01, 0.05), (0.01, 0.01), (0.005, 0.01) and (0.005, 0.005). The software, Lingo (Lingo, 2005), is employed to find the optimal results. The detailed calculations are omitted. The final results are shown in Table 5.11.

5.7.3 Comparisons and Explanation

Based on the information in Table 5.11, some of the main observations and explanation are summarized below:

Table 5.10: The performance data, u_j^i, in cardinal indices for each country

Index	GCI	EFI	ESI	CPI
Brazil	0.3697	0.4375	0.7190	0.2500
Canada	0.7647	0.7725	0.7669	0.8375
China	0.4762	0.3850	0.2048	0.1875
France	0.6751	0.5925	0.5664	0.7250
Germany	0.7647	0.7500	0.6035	0.8125
India	0.4678	0.3675	0.3486	0.1500
Indonesia	0.3249	0.3650	0.4270	0.0625
Italy	0.5154	0.6800	0.4553	0.4125
Japan	0.7871	0.6350	0.6122	0.7000
Malaysia	0.7087	0.5100	0.5403	0.4250
Mexico	0.4342	0.5275	0.3704	0.2250
Philippines	0.3081	0.4375	0.2854	0.1000
Russia	0.3249	0.3600	0.5861	0.0875
Singapore	0.8711	0.8500	0.2754	0.9625
South Africa	0.5434	0.5550	0.3704	0.3500
Thailand	0.5966	0.5050	0.4466	0.2625
UK	0.7675	0.8125	0.4575	0.8625
US	0.9636	0.7875	0.5163	0.7375

Table 5.11: The aggregation performance, $V(A^i)$, based on different α, β values

Country	Different value combinations of (α, β)					
	(0.01, 0.1)	(0.01, 0.05)	(0.01, 0.01)	(0.005, 0.01)	(0.005, 0.005)	Average
Brazil	0.4384	0.5424	0.5779	0.7439	0.7519	0.6109
Canada	0.9309	0.9652	0.9925	1.0000	1.0000	0.9777
China	0.3789	0.4731	0.4900	0.7034	0.7117	0.5514
France	0.8007	0.8576	0.8915	0.9387	0.9444	0.8866
Germany	0.9053	0.9441	0.9728	0.9837	0.9868	0.9585
India	0.4457	0.5946	0.6789	0.8220	0.8360	0.6754
Indonesia	0.3192	0.4295	0.4549	0.6895	0.6998	0.5186
Italy	0.6377	0.7400	0.7880	0.8172	0.8210	0.7607
Japan	0.8381	0.8891	0.9218	0.9563	0.9606	0.9132
Malaysia	0.7154	0.7691	0.7880	0.8790	0.8845	0.8072
Mexico	0.4443	0.5651	0.6095	0.6959	0.7005	0.6031
Philippines	0.3515	0.4727	0.5068	0.6472	0.6536	0.5263
Russia	0.3071	0.4309	0.4696	0.6234	0.6292	0.4920
Singapore	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
South Africa	0.5818	0.6755	0.7191	0.8471	0.8561	0.7359
Thailand	0.5587	0.6280	0.6426	0.8061	0.8131	0.6897
UK	0.9246	0.9582	0.9735	0.9827	0.9846	0.9647
US	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

- By examining values from left to right across a given row, one can see that when the values of α and β decrease, the optimal value of the objective function $V(A^i)$ increases for the country under consideration. Therefore, greater values of α and β mean improved overall performance by the country with respect to economical and non-economical indices.

- Although the results exhibit some variations when employing different values of α and β, these 18 countries can be roughly classified into four groups, as shown in Figure 5.3 (countries are listed from highest to lowest within each group): the best performance group ($\mathbf{S}_1$) includes US, Singapore and Canada; the second performance group ($\mathbf{S}_2$) contains UK, Germany, Japan and France; the third performance group ($\mathbf{S}_3$) includes Malaysia, Italy, South Africa, Thailand and India; the fourth performance group ($\mathbf{S}_4$) contains Brazil, Mexico, China, Philippines, Indonesia and Russia.

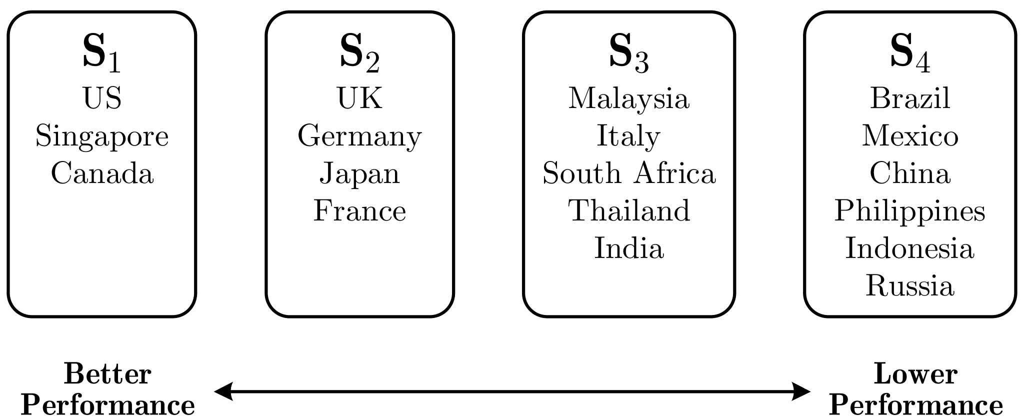


Figure 5.3: Performance of countries according to economic and noneconomic indices

- Generally speaking, the aggregation performances of the G7 countries are much better than BRICSAM countries when considering these six indices. The best performance countries in G7 are Canada and the US, while Singapore and Malaysia perform the best in BRICSAM. The worst performance country in G7 is Italy and the worst performance country in BRICSAM is Russia.

- In BRICs, India is the leading country with an average value of 0.6754. The average aggregation performances of Brazil, China and Russia are 0.6109, 0.5514 and 0.4920, respectively. The performances of BRICs countries are far behind the ones of G7 and are even less than the average of ASEAN. This observation is consistent with the economist, Bardhan's arguments, which point out that there is great need for improvement in both the economic and non-economic areas for BRICs in the near future, before BRICs countries can become significant players in the international economic scene on a sustained basis (Bardhan, 2005).

- In ASEAN, Singapore is the leading country and is one of the best countries among all 18 countries. The performances of other countries are diverse and the worst one is Indonesia with a score of 0.5186. This indicates that there still exist huge diversities in ASEAN countries in different areas, such as economics (although major products of ASEAN countries include electronics, oil, and wood), culture, governance and political process, including practices in areas such as suffrage and representation (Wikipedia, 2005).

5.8 Conclusions

An index aggregation approach is designed and employed to compare both BRISCAM and G7 countries according to both economic and noneconomic indices. An attractive feature of this unique procedure is that a given country can fairly ascertain its best performance based on both cardinal and ordinal index information. As pointed out in Section 5.3, only easily obtainable input information is required and the values of different variables are automatically estimated when determining the overall optimal performance for a given country. Moreover, as demonstrated by the applications, meaningful comparisons can be made among and within different groups.

Chapter 6

Generic Strategic Policy Analysis

In this chapter, a framework of generic strategic analysis for regions' competence analysis is designed based upon the theory of generic strategic analysis in business as proposed by Porter (1980), and a case study of the competence analysis of provinces in China is used to demonstrate the analysis procedure. First, a background introduction of Porter's generic strategic analysis is given below based upon an online tutorial provided by Research Solutions Ltd. (2006).

6.1 Porter's Generic Strategic Analysis

Porter's generic strategies framework constitutes a major contribution to the development of the strategic management literature. Generic strategies were first presented in two books by Dr. Michael Porter of the Harvard Business School in the US (Porter, 1980, 1985). Porter suggested that some of the most basic strategies faced by companies are essentially the scope of the markets that the company would serve and how the company would compete in the selected markets. Competitive strategies focus on ways in which a company can achieve the most advantageous position that it possibly can in its industry. The profit of a company is essentially the difference between its revenues and costs. Therefore, high profitability can be achieved through implementation of the lowest costs or the highest prices via the competition. Porter used the terms "cost leadership" and "differentiation", wherein the latter is the way in which companies can earn a price premium.

Companies can achieve competitive advantages essentially by differentiating their products and services from those of competitors and through low costs. Firms can target their products using a broad target, thereby covering most of the marketplace, or they can focus on a narrow target in the market as shown in Figure 6.1. According to Porter, there are three generic strategies that a company can undertake to attain competitive advantage: cost leadership, differentiation, and focus.

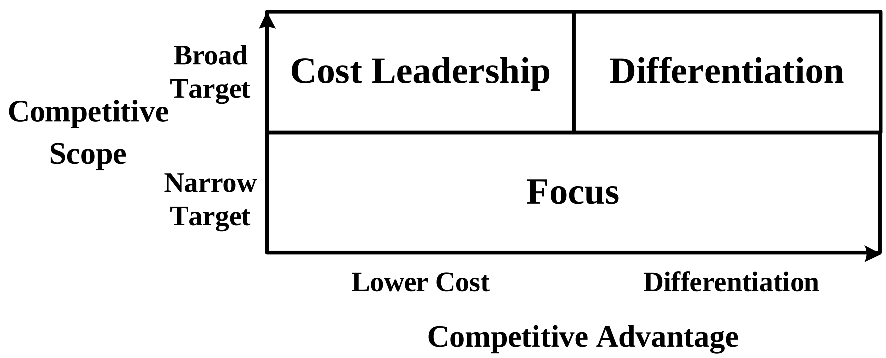


Figure 6.1: Porter's generic strategies, adapted from Porter (1985)

- *Cost leadership*: The companies that attempt to become the lowest-cost producers in an industry can be referred to as those following a cost leadership strategy. The company with the lowest costs would earn the highest profits in the event when the competing products are essentially undifferentiated, and selling at a standard market price. Companies following this strategy place emphasis on cost reduction in every activity in the value chain. It is important to note that a company might be a cost leader but that does not necessarily imply that the company's products would have a low price. In certain instances, the company can, for instance, charge an average price while following the low cost leadership strategy and reinvest the extra profits into the business (Lynch, 2003). The risk of following the cost leadership strategy is that the company's focus on reducing costs, even sometimes at the expense of other vital factors, may become so dominant that the company loses vision of why it embarked on one such strategy in the first place.

- *Differentiation*: When a company differentiates its products, it is often able to charge a premium price for its products or services in the market. Some general examples of differentiation include better service levels to customers and better product performance in comparison with the existing competitors.

Porter (1980) has argued that for a company employing a differentiation strategy, there would be extra costs that the company would have to incur. Such extra costs may include high advertising spending to promote a differentiated brand image for the product, which in fact can be considered as a cost and an investment. McDonalds, for example, is differentiated by its very brand name and brand images of Big Mac and Ronald McDonald. Differentiation has many advantages for the firm which makes use of the strategy. Some problematic areas include the difficulty on the part of the firm to estimate if the extra costs entailed in differentiation can actually be recovered from the customer through premium pricing. Moreover, a successful differentiation strategy of a firm may attract competitors to enter the company's market segment and copy the differentiated product (Lynch, 2003).

- *Focus*: Companies employ this strategy by focusing on the areas in a market where there is the least amount of competition. Organizations can make use of the focus strategy by concentrating on a specific niche in the market and offering specialized products for that niche. Competitive advantage can be achieved only in the company's target segments by employing the focus strategy. The company can make use of the cost leadership or differentiation approach with regard to the focus strategy. In this way, a company using the cost focus approach would aim for a cost advantage in its target segment only. If a company is using the differentiation focus approach, it would aim for differentiation in its target segment only, and not the overall market. This strategy provides the company the possibility to charge a premium price for superior quality (differentiation focus) or by offering a low price product to a small and specialized group of buyers (cost focus).

6.2 Framework of Generic Strategic Policy Analysis

Following Porter's generic strategic analysis, a framework to carry out generic strategic policy analysis for regions' competence analysis is designed and shown in Figure 6.2. The two dimensions in the figure measure the competence efficiency and potentiality, respectively. It is easy to see that any region with high competence efficiency and potentiality is in the best position. If a region falls into low scores for both directions, the policy makers should improve the region's performance through the arrows 1 or 2, as indicated in Figure 6.2. Similarly, more effort needs to be conducted for regions with high performance on one side and low performance on the other to get improvements through arrow 3 or 4 in Figure 6.2.

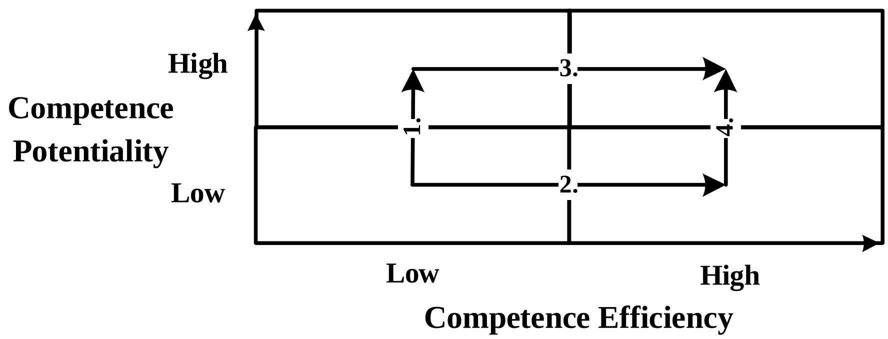


Figure 6.2: Generic strategic policy analysis

To quantify the study, two decision tools are applied to carry out the measure of the competence efficiency and potentiality, respectively. Specifically, the data envelopment analysis (DEA) (Charnes et al., 1978), as mentioned in Chapter 5, is used for the analysis of competence efficiency and the analytic hierarchy process (AHP), introduced in Chapter 3, is utilized to solve the analysis of competence potentiality.

6.3 Competence Analysis of Provinces in China

The aforementioned analysis framework is applied to the competence analysis of provinces in China. The details are explained below.

6.3.1 Competence Efficiency Analysis

Model Selection

The basic model, CCR, which is named for the three inventors, Drs. Charnes, Cooper, and Rhodes, is used to measure the competence efficiency of provinces in China. The basic idea of DEA is to measure the relative efficiency of different product units or decision making units (DMUs) which have multiple possibly incommensurate inputs and outputs using a weighted linear-additive equation.

$$\text{Efficiency} = \frac{\text{Weighted sum of outputs}}{\text{Weighted sum of inputs}}$$

Charnes et al. (1978) recognized the difficulty in seeking a common set of weights (relative importance) of inputs and outputs to determine the relative efficiency of DMUs, and that a DMU might value inputs and outputs differently and therefore adopt different weights. Hence, Charnes et al. (1978) proposed an optimization model so that each DMU was allowed to adopt a set of weights which shows it in the most favourable light in comparison to the other DMUs. The detailed mathematical model construction is skipped here and can be found in the paper by Charnes et al. (1978). Overall, the final results of the relative efficiency of DMUs are normalized and measured by real-value numbers between 0 and 1. Large values indicate high relative efficiency and if a DMU can obtain the value of 1, it is efficient, otherwise it is non-efficient. Here, the software, Frontier Analyst (2006), is employed for the calculations.

Data Collection

Three criteria are selected as inputs, which are:

- *Investment in Fixed Assets* (IFA). Fixed assets, also known as property, plant and equipment, are a term used in accountancy for assets and property which cannot easily be converted into cash. Fixed assets normally include items such as land and buildings, motor vehicles, furniture, office equipment, computers, fixtures and fittings, and plant and machinery. IFA is the essential means for social reproduction of fixed assets and is a comprehensive indicator which shows the size, pace, proportional relations and use orientation of the investment (Statistics China, 2006). IFA is measured in units of hundred million RMB, where RMB is the Chinese monetary unit.

- *The Number of Industrial Employees* (NIE). The number of employee for all industry sectors is an indictor to reflect the actual utilization of the labor force during a certain period of time. NIE is measured in units of ten thousand people.

- *Area of Industrial Property* (AIP). The area of industrial property estimates the land used for industrial purposes and is measured in square kilometers (km^2).

Two criteria are utilized as outputs:

- *Gross Domestic Product* (GDP). GDP is defined as the market value of all final goods and services produced within a region, usually a country, in a given period of time. Here, the GDP of a province is estimated in hundreds of million RMBs.

- *Tax Revenue* (TR). TR is the income that is gained by governments because of taxation of the person or business. It is measured in units of hundred million RMBs.

DEA Efficiency Calculation

Table 6.1 shows the information of the inputs and outputs for all province level administrative divisions in mainland China which includes 22 provinces as well as 5 autonomous regions and 4 direct-controlled municipalities. The data are collected from Statistics China (2006). The final results of DEA efficiency for all provinces in China are listed in the last column of Table 6.1.

6.3.2 Competence Potentiality Analysis

Criterion Selection

Lopez-Claros et al. (2006) proposed nine key elements to evaluate the sustainable growth of a region, which is demonstrated in Figure 6.3. The overall goal is to assess the competence potentiality of provinces in China and the evaluation criteria are organized hierarchically, as shown in Figure 6.4. Note that the factor of market efficiency in the efficiency enhancers is dropped from Figure 6.4 since it is related to competence efficiency.

Model Construction

The linear additive value function is used to conduct the evaluation, since it has been widely used in practical applications:

$$V(A^i) = \sum_{j \in \mathbf{Q}} w_j \cdot v_j(A^i), \tag{6.1}$$

Table 6.1: DEA efficiency of provinces in China

Provinces	Inputs			Outputs		DEA Efficiency
	IFA	NIE	AIP	GDP	TR	
Anhui	1418.69	3416	1044.2	3972.38	220.7	0.7716
Beijing	2169.26	858.6	1180.1	3663.1	592.5	0.7703
Chongqing	1161.51	1659.5	523.7	2250.56	161.6	0.5847
Fujian	1496.37	1756.7	598.4	5232.17	304.7	1.000
Gansu	619.82	1304	478.3	1304.6	87.7	0.6038
Guangdong	4813.2	4199.5	2546.9	13625.87	1315.5	0.9361
Guangxi	921.3	2601.4	685.4	2735.13	203.7	0.8805
Guizhou	748.12	2118.4	348.1	1356.11	124.6	0.5924
Hainan	280.02	353.8	176.7	670.93	51.3	0.7243
Hebei	2477.98	3389.5	1171	7098.56	335.8	0.8126
Heilongjiang	1166.18	1622.4	1362.5	4430.00	248.9	1.0000
Henan	2262.97	5535.7	1345.9	7048.59	338.1	0.8717
Hubei	1809.45	2537.3	1415.6	5401.71	259.8	0.8186
Hunan	1590.32	3515.9	959.4	4638.73	268.6	0.8164
Inner Mongolia	1174.66	1005.2	679.3	2150.41	138.7	0.5815
Jiangsu	5233	3610.3	2119.5	12460.83	798.1	0.8079
Jiangxi	1303.22	1972.3	598.5	2830.46	168.2	0.6208
Jilin	969.03	1044.6	850.5	2522.62	154.0	0.7607
Liaoning	2076.36	1861.3	1694.6	6002.54	447.0	0.9018
Ningxia	317.99	290.6	206.1	385.34	30	0.3764
Qinghai	255.62	254.3	101.8	390.21	24	0.4636
Shaanxi	1200.68	1911.3	508.3	2398.58	177.3	0.6099
Shandong	5315.14	4850.6	2195.4	12435.93	713.8	0.7310
Shanghai	2499.14	771.5	549.6	6250.81	886.2	1.0000
Shanxi	1100.86	1469.5	678.7	2456.59	186.1	0.6736
Sichuan	2336.34	4449.6	1357.4	5456.32	336.6	0.6662
Sinkiang	973.36	721.3	564.8	1877.61	128.2	0.6391
Tianjin	1039.39	419.7	487.5	2447.66	204.5	0.9005
Tibet	133.96	130.7	72.4	184.5	8.1	0.4197
Yunnan	1000.12	2349.6	410.5	2465.29	229	0.8132
Zhejiang	4740.27	2961.9	1397	9395.00	706.6	0.6917

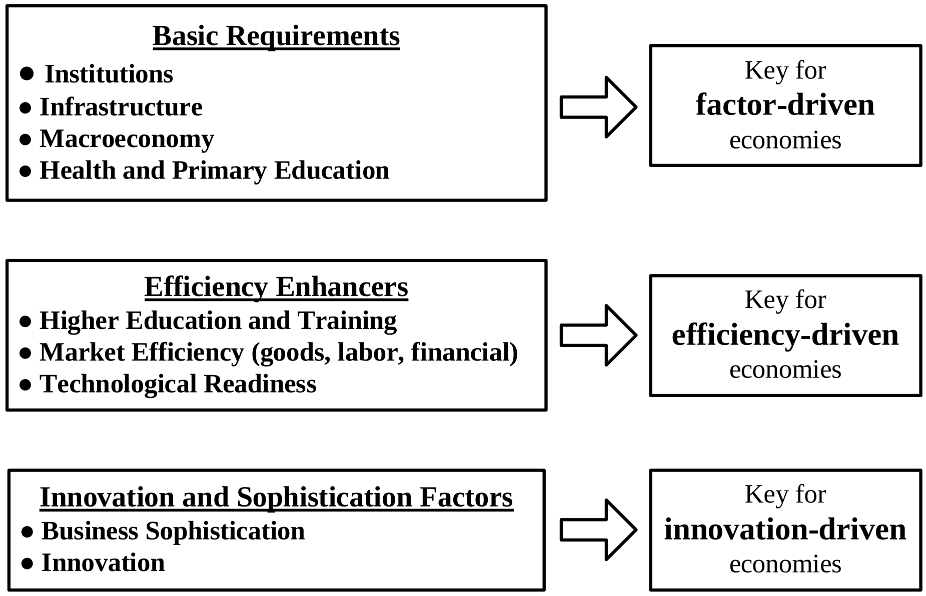


Figure 6.3: Key elements to the sustainable growth, adapted from Lopez-Claros et al. (2006)

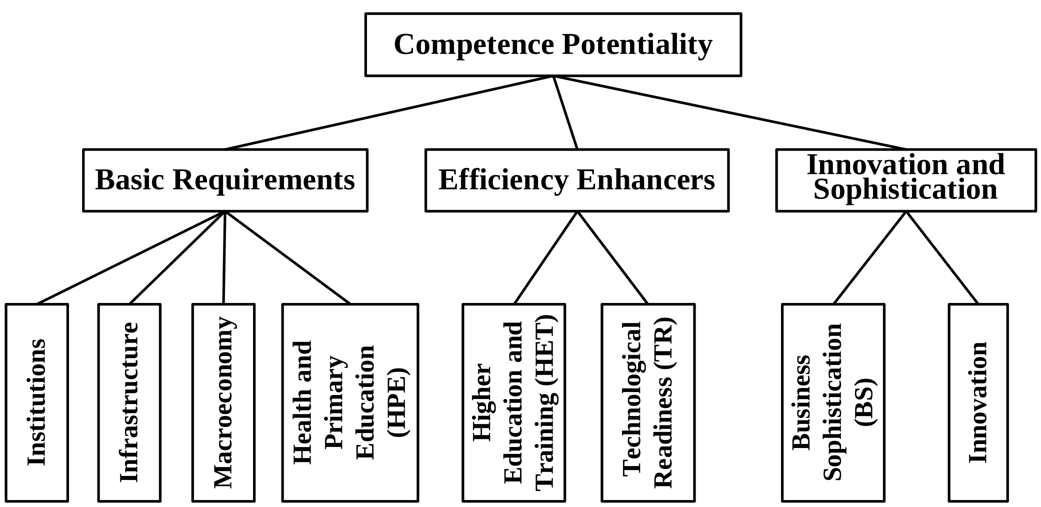


Figure 6.4: Criteria set for competence potentiality

where A^i is a province (alternative) for evaluation as listed in Table 6.1; w_j is the weight for a criterion j, as shown in Figure 6.4; $v_j(A^i)$ is the value (performance) of A^i on criterion j; and $V(A^i)$ is the overall evaluation result for A^i, which is summarized in the tenth column of Table 6.3.

Lopez-Claros et al. (2006) suggested that the weights of basic requirements, efficiency enhancers, and innovation and sophistication for developing countries like China could be 0.5, 0.4 and 0.1, respectively. But they did not specify weights for the subcriteria. Here, the AHP method as explained in Chapter 3 is used to estimate the weights at the subcriteria levels. The pairwise comparison matrices are constructed based on my experience in strategic policy analysis. The results are listed in Table 6.2.

Table 6.2: The weight information

Criteria	Subcriteria	Local Weights	Global Weights
Basic Requirements (0.5)	Institutions	0.2	0.1
	Infrastructure	0.3	0.15
	Macroeconomics	0.3	0.15
	HPE	0.2	0.1
Efficiency Enhancers (0.4)	HET	0.6	0.24
	TR	0.4	0.16
Innovation and Sophistication (0.1)	BS	0.6	0.06
	Innovation	0.4	0.04

Data Collection and Calculations

The values of each province over different criteria are represented by the numbers arranged between 0 and 1. These data are estimated by me and some other graduate students in the Conflict Analysis Group in the Department of Systems Design Engineering at the University of Waterloo (A survey may be needed to obtain more representative data for a practical case study.). Table 6.3 shows the estimated values as well as the final results for competence potentiality of provinces in China.

Table 6.3: The competence potentiality of provinces in China

Provinces	Institutions	Infrastructure	Macroeconomy	HPE	HET	TR	BS	Innovation	Final
Anhui	0.6	0.5	0.6	0.4	0.7	0.6	0.6	0.7	0.593
Beijing	0.8	0.85	0.75	0.85	0.9	0.9	0.9	0.8	0.851
Chongqing	0.5	0.6	0.5	0.5	0.6	0.5	0.6	0.6	0.549
Fujian	0.6	0.7	0.75	0.6	0.6	0.7	0.9	0.75	0.6775
Gansu	0.4	0.4	0.45	0.45	0.45	0.5	0.4	0.5	0.4445
Guangdong	0.8	0.85	0.9	0.85	0.7	0.8	0.95	0.8	0.8125
Guangxi	0.6	0.65	0.55	0.55	0.5	0.5	0.65	0.55	0.556
Guizhou	0.5	0.4	0.5	0.55	0.4	0.5	0.55	0.5	0.469
Hainan	0.5	0.5	0.6	0.5	0.4	0.4	0.65	0.6	0.488
Hebei	0.5	0.65	0.6	0.55	0.6	0.45	0.5	0.5	0.5585
Heilongjiang	0.5	0.65	0.65	0.55	0.7	0.7	0.65	0.55	0.641
Henan	0.4	0.65	0.7	0.5	0.45	0.55	0.6	0.5	0.5445
Hubei	0.65	0.6	0.7	0.65	0.75	0.65	0.7	0.65	0.677
Hunan	0.65	0.65	0.65	0.65	0.6	0.6	0.6	0.5	0.621
Inner Mongolia	0.4	0.65	0.65	0.4	0.4	0.4	0.5	0.4	0.481
Jiangsu	0.85	0.85	0.9	0.75	0.85	0.85	0.8	0.8	0.8425
Jiangxi	0.6	0.55	0.5	0.55	0.6	0.65	0.6	0.55	0.5785
Jilin	0.6	0.55	0.5	0.55	0.65	0.6	0.55	0.55	0.5795
Liaoning	0.65	0.65	0.65	0.55	0.6	0.55	0.65	0.6	0.61
Ningxia	0.3	0.4	0.4	0.4	0.4	0.35	0.35	0.4	0.379
Qinghai	0.25	0.35	0.4	0.35	0.35	0.3	0.4	0.3	0.3405
Shaanxi	0.55	0.65	0.65	0.55	0.65	0.7	0.6	0.6	0.633
Shandong	0.7	0.75	0.85	0.65	0.7	0.7	0.75	0.65	0.726
Shanghai	0.85	0.85	0.85	0.85	0.9	0.9	0.95	0.8	0.874
Shanxi	0.55	0.7	0.7	0.5	0.5	0.55	0.65	0.5	0.582
Sichuan	0.65	0.65	0.65	0.6	0.7	0.65	0.65	0.6	0.655
Sinkiang	0.4	0.65	0.7	0.55	0.45	0.5	0.5	0.5	0.5355
Tianjin	0.75	0.7	0.7	0.7	0.75	0.7	0.7	0.7	0.717
Tibet	0.4	0.55	0.35	0.3	0.4	0.4	0.55	0.4	0.414
Yunnan	0.5	0.5	0.55	0.45	0.5	0.5	0.4	0.4	0.4925
Zhejiang	0.8	0.85	0.9	0.85	0.85	0.85	0.9	0.9	0.8575

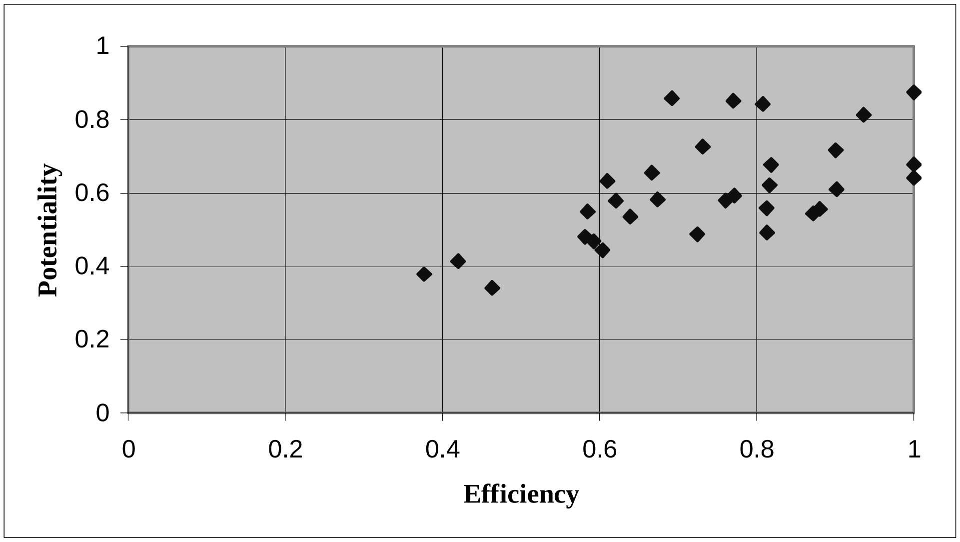


Figure 6.5: Generic strategic analysis

6.3.3 Generic Strategic Analysis

Based on the analysis results of competence efficiency and competence potentiality explained above, Figure 6.5 shows these two values for each province in two dimensions, efficiency and potentiality. Some observations are as follows:

- There are high correlations between the performance of competence efficiency and competence potentiality of provinces in China. Usually, if a province has a high value of competence efficiency, its competence potentiality is also high. Similarly, a low performance of competence efficiency is linked with a low value of competence potentiality for a province. For example, three provinces, Ningxia, Qinghai and Tibet have the lowest scores in both dimensions.

- There are some provinces which have relatively low competence efficiency but high competence potentiality such as Beijing, Zhejiang and Shaanxi. For example, Beijing will host the 2008 Olympic Games which is expected to boost the economy of China, especially in Beijing.

- There are also a few provinces which have relatively low scores of competence potentiality compared with the value of competence efficiency including

Guangdong, Liaoning and Tianjin. These provinces are inshore regions which have taken advantages of the Chinese policy of "reform and openness" which began in the 1980s. Their economic situations are better than other inland provinces. But with the rapid development of energy requirements in China, the inland provinces such as Shaanxi, which can provide oil and coal, will have more development opportunities.

6.4 Conclusions

In this chapter, a framework of generic strategic analysis for regions' competence analysis was designed based upon the theory of generic strategic analysis proposed by Porter (1980). First, the theory of generic strategic analysis was briefly presented. Next, a framework to carry out generic strategic analysis in policy was explained and the quantitative models to implement the analysis were introduced. Finally, a case study of the competence analysis of provinces in China was used to demonstrate the analysis procedure.

Chapter 7

Conclusions

Two strategic policy topics, strategic conflict analysis and country performance comparisons, have been investigated in this thesis and practical applications have been presented. The main contributions of the thesis and suggestions for future research are summarized in the next two subsections.

7.1 Main Contributions of the Thesis

The main contributions of this thesis are as follows:

1. In Chapter 4, a comparison of two decision analysis tools for the analysis of strategic conflicts, the ANP and GMCR, was carried out by applying them to the China-US TV dumping conflict. The framework for employing ANP to analyze strategic conflicts was designed and then used to compare ANP to GMCR. The case study of the China-US TV dumping conflict provides a basis for the graph model and ANP to be compared; different features of the approaches are highlighted. The study shows that because of different theoretical backgrounds, ANP and GMCR for conflict analysis both provide useful information which can be combined to furnish a better understanding of a strategic conflict. A journal paper has been published based on the content of this chapter (Su et al., 2005).

2. In Chapter 5, An index aggregation approach is proposed to carry out comparisons of BRICSAM nations, a populous rapidly-growing economic group consisting of Brazil, Russia, India, China, South Africa, ASEAN (Association

of South-East Asian Nations), and Mexico, with the G7 (Group of Seven), the most developed country club including Canada, France, Italy, Japan, Germany, the United Kingdom and the United States. Many country-ranking indices, such as the indices given in the global competitiveness report by the World Economic Forum, and the environmental sustainability index by Yale University, constitute evaluations of countries from different perspectives. In Chapter 5, a data envelopment analysis based approach to aggregate different ranking indices was proposed for BRICSAM and the G7 countries. The method can provide a fair overall assessment of a country's standing by maximizing its possibility of obtaining the best aggregate evaluation result. The contents of this chapter have been presented at an international conference (Su et al., 2006)

7.2 Suggestions for Future Research

Some suggestions for further research are as follows:

1. Further research is required to study strategic conflicts from interdisciplinary points of view to gain strategic insights about the dispute and to compare the capability of different decision tools. For example, rough set theory-based conflict analysis approach proposed by Pawlak (2005) has the potential to be integrated into the graph model framework to provide a new function, case-based reasoning, for GMCR.

2. In terms of the index aggregation approach, a comparison study of these countries over a few years could be carried out to check the trends of countries' performances over time.

3. A software-based decision support system (DSS) could help a DM implement decision tools easily and expeditiously. Hence, a computer-based DSS should be developed to integrate the procedures discussed in the thesis and to assist in practical applications.

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