Conflicting Attitudes in Environmental Management and Brownfield Redevelopment

by

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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. I understand that my thesis may be made electronically available to the public.

Sean Glenn Walker

Abstract

An enhanced attitudes methodology within the framework of the Graph Model for Conflict Resolution (GMCR) is developed and applied to a range of environmental disputes, including a sustainable development conflict, an international climate change negotiation and a selection of brownfield conflicts over a proposed transfer of ownership. GMCR and the attitudes framework are first defined and then applied to a possible Sino-American climate negotiation over reductions in greenhouse gas emissions. A formal relationship between the attitudes framework and relative preferences is defined and associated mathematical theorems, which relate the moves and solution concepts used in both types of analysis, are proven. Significant extensions of the attitudes methodology are devised in the thesis. The first, dominating attitudes is a methodology by which the importance of a decision maker's (DM's) attitudes can be used to evaluate the strength of a given state stability. The second, COalitions and ATtitudes (COAT), is an expansion of both the attitudes and coalitions frameworks which allows one to analyze the impact of attitudes within a collaborative decision making setting. Finally, the matrix form of attitudes is a mathematical methodology which allows complicated solution concepts to be executed using matrix operations and thus make attitudes more adaptable to a coding environment. When applied to environmental management conflicts, these innovative expansions of the attitudes framework illustrate the importance of cooperation and diplomacy in environmental conflict resolution.

Acknowledgements

Finishing a research milestone such as a PhD thesis is something that is certainly accomplished with the mentoring and moral support of many people. To that end, I wish to express my sincere gratitude and appreciation to my supervisor, Professor Keith W. Hipel, for his encouragement and advice throughout the course of my development of many original research ideas and associated applications appearing in my dissertation. I enjoyed the many meetings that we had together over the years to discuss exciting research projects. Furthermore, Professor Takehiro Inohara of the Tokyo Institute of Technology has been a creative and inspiring collaborator as we worked together to write various journal papers in the area of attitudes in conflict resolution. Professors Hipel and Inohara have had a dramatic impact on my professional development and have helped to hone my research skills.

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It has been an exciting journey, carrying out my doctoral research, and certainly not one that I have travelled alone. I would never have completed this thesis without the inspiration and support of my wife, Elizabeth, who has inspired me to accomplish things I never dreamed I could.

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Acronyms

AP	Aggressive preference
CGMR	Coalition general metarational stable state
CNash	Coalition Nash stable state
CRGMR	Coalition relational general metarational stable state
CRNash	Coalition relational Nash stable state
CRSEQ	Coalition relational sequentially stable state
CRSMR	Coalition relational symmetric metarational stable state
CSEQ	Coalition sequentially stable state
CSMR	Coalition symmetric metarational stable state
CWAM	Cooperative water allocation management
DM	Decision maker
DNC	United States Democratic Party
DP	Devoting preference
DSS	Decision support system
E	Equilibrium state
EA	Environmental Agreement
G8	Group of 8 Industrialized Nations
GDU	Garrison Diversion Unit
GMCR	Graph Model for Conflict Resolution
GMR	General metarational stable state
GOP	United States Republican Party
I	Indifferent preference
IEA	International Environmental Agreements
IJC	International Joint Commission
MCDA	Multiple Criteria Decision Analysis
MOE	Ontario Ministry of the Environment
Nash	Nash stable state
PRC	People's Republic of China
RGMR	Relational general metarational stable state
RNash	Relational Nash stable state
RP	Relational preference
RSEQ	Relational sequentially stable state
RSMR	Relational symmetric metarational stable state
SEQ	Sequentially stable state
SMR	Symmetric metarational stable state
SoS	System of Systems
TRP	Total relational preference
TRR	Total relational reply list
U	Unstable state
UI	Unilateral improvement
UM	Unilateral move
UNFCCC	United Nations Framework on Climate Change Convention

USA	United States of America
USEPA	United State Environmental Protection Agency
USO	United States Opposition
USS	United States Support
WRGMR	Weak Relational general metarational stable state
WRNash	Weak Relational Nash stable state
WRSEQ	Weak Relational sequentially stable state
WRSMR	Weak Relational symmetric metarational stable state
X	Non equilibrium state

Chapter 1

Introduction

1.1 Environmental Management

The study of environmental management is an essential field in which complex problems and conflicts are systematically addressed in order that environmental resources are managed effectively, fairly and responsibly. Within the realm of environmental management, there are a myriad of different problem types, ranging from local issues, such as the redevelopment of a former industrial property that is environmentally blighted, to international environmental negotiations, such as the Kyoto Protocol, or more recently, the Copenhagen Accords, whereby nations have come together to make attempts to reduce their output of carbon dioxide and other greenhouse gases, and thus, slow down global warming.

In this thesis, conflicts and negotiations related to the redevelopment of brownfields are analyzed using novel systems methodologies, in order to provide insights into the types of issues that are faced by stakeholders in this field. Brownfields, which are best described as properties which are idled, abandoned, and likely contaminated (USEPA, 1997), constitute a common difficulty faced by cities in North America and Europe. Developing new strategic methods to formally examine these particular conflicts is thus of great importance. Currently, the vast majority of decision tools and analytical methods related to brownfield redevelopment focus almost exclusively on issues related to the fiscal viability of projects, using methods such as those developed by Sounderpandian et al. (2005) and Witlox (2005), or the impacts of brownfields upon the ecosystem and human health, employing techniques developed by the United States Environmental Protection Agency (1997) and other organizations.

The other key environmental management problem tackled in this thesis is the development of an international environmental treaty between the United States of America (USA) and People's Republic of China (PRC). Although previous studies have examined the effectiveness of cap-and-trade, or emissions permits in the context of such a bilateral agreement, there is a lack of examination into the strategic options available to each party in this conflict.

To address the research gap that is present in both of the foregoing environmental management areas, a number of systems methodologies are developed in this thesis to model these strategic conflicts. In the following subsection, the motivation for developing new systems tools is discussed.

1.2 Systems Methodologies

The development of new systems methodologies is essential in order to intelligently manage the types of complex real world problems present today. Under the broad umbrella of systems methodologies, there are a wide number of quantitative and qualitative methods, as will be discussed in Chapter 2. In the area of environmental management, the focus has traditionally been on the development of systems tools which are used and applied to areas of fiscal or ecological management, and largely ignore the importance of conflict and negotiation. Because there are many different types of environmental conflicts, ranging from the local to international level, it is essential, therefore, that intelligent systems tools be developed to aid environmental managers in understanding of the strategic importance of the decisions they make.

In the area of conflict resolution, systems tools such as Metagame Analysis (Howard, 1971), Conflict Analysis (Fraser and Hipel, 1984) and the Graph Model for Conflict Resolution (GMCR) (Fang et al., 1993) provide a systematic structure that allows decision analysts to determine the strategic implications that occur when decision makers (DMs) adopt specific courses of action. These related tools have been successfully applied to environmental decision making, such as analysis of the Garrison Diversion Unit (GDU) (Fang et al., 1993), or historical conflicts, such as the War of 1812 (Inohara et al., 2007).

In order to better understand how DMs' behavior impacts the final resolution of complex problems, it is imperative that new systems methodologies be developed that utilize the proven structure of game theoretic methods, such as GMCR, while also providing new strategic insights. The previously developed structure of attitudes (Inohara et al., 2007; Walker, 2008) provides a tool for examining the impacts that occur when DMs behave with consideration, either positive or negative, for their fellow DMs' preferences. Because of the great import and complexity of attitudes, there exists a need for further refinements to the attitudes framework. For example, the attitudes method can restrict a DM's movements within a conflict model and thus a model which allows greater flexibility to consider attitudes of varying strength can be used to derive insights into how DMs realistically behave. In addition, the attitudes framework does not consider the impact of attitudes upon coalitions. As cooperation and coalition formation is a common part of negotiation, it is crucial that the attitudes methodology be extended to this area. Further, the attitudes structure can be seen as a tool for representing complex DM desires and thus it is informative to determine just how attitudes and preferences are related. Finally, logical definitions of attitudes analysis are difficult to encode and hence, herein, they are transformed into a matrix form which can be used to create a codeable Decision Support System. These important expansions of attitudes in GMCR create a set of flexible methodologies that can be used to improve our understanding of complex disputes in the face of conflicting attitudes.

1.3 Environmental Conflicts

Within the field of environmental management, there is a high level of complexity, uncertainty and conflict as a disparate group of DMs comes together in an attempt to arrive at agreements that satisfy both a financial imperative whilst acting with responsible stewardship towards the environment. Some elements of environmental management are written into law, such as the thresholds of contaminants that can be present in potable water. Other components of this management paradigm are not so clear. For example, how does a government properly encourage the redevelopment of blighted properties within its jurisdiction from a financial, environmental and social perspective? A second conflict, which is of interest from an environmental management and systems analysis perspective, is the behavior of corporations. Specifically, how willing are companies, which are geared to maximize profits, able to behave in a sustainable manner in the face of protest or government intervention? Understanding this type of corporate behavior is essential to better grasping how lobbying, advocacy and government control affect the environmental behavior of industry. A third type of environmental conflict to be analyzed is the possible bilateral environmental agreement of two nations at political odds with one another. Although both the USA and China have knowledge of the problems facing the global environment, and are aware that they are by far the largest polluters of greenhouse gases, their past conflicts are a possible impediment to creating a viable working agreement.

All three of these conflicts within the paradigm of environmental management will be analyzed using new systems tools, specifically significant enhancements to the attitudes framework within the GMCR (Fang et al., 1993). In this context, attitudes refer to situations in which DMs behave in order to help or hurt one or more other DMs that are taking part in the negotiations. Throughout the course of these chapters, attitudes within coalitions, dominating attitudes, the relationship between attitudes and preferences and a matrix form of attitudes will be formally defined and applied to environmental management disputes of which three main types are considered, as mentioned above.

1.4 Outline of the Thesis

The overall objective of the research is to employ formal approaches for rigorously analyzing attitudes within GMCR in order to investigate the strategic consequences of attitudes in brownfield redevelopment, sustainability and international environmental agreements. To accomplish this, the redevelopment of the Kaufman Shoe Factory in downtown Kitchener, Ontario, Canada, a generic conflict between industry, government, and activists and a strategic analysis of a bilateral Sino-American climate regime are analyzed. While considering these novel environmental applications, the attitudes framework developed by Inohara et al. (2007) is significantly extended in order to provide significant strategic insights into how attitudes impact conflict outcomes.

Figure 1.1 displays an overview as to how the contributions of this thesis are organized. Chapter 1 provides the motivation for the research in this thesis and an overview of its main contributions. As can be seen in the third row from the top of Figure 1.1, three applications in environmental management, indicated by the three entries in the centre of the third row, will be employed for illustrating conflict resolution concepts presented in the thesis. Lines below each application indicate in which chapter or chapters this application is utilized. The four chapters contained within the dotted lines on the left furnish the foundations for the new advancements presented within the four chapters listed on the right of Figure 1.1. At the beginning of the foundational chapters, a literature review of systems methodologies in environmental management is given in Chapter 2. Next, the previously defined frameworks of GMCR, coalitions in GMCR and attitudes in GMCR are explained in Chapters 3 and 4, respectively. In Chapter 5, attitudes in GMCR are applied to the Sino-American climate regime. Following these chapters, new attitude methodologies, which build upon these foundations, are developed within the four Chapters displayed on the right. Specifically, in Chapter 6 the complex relationship between attitudes and preferences is formally examined. Understanding this relationship greatly improves the comprehension of how a decision analyst can utilize information about a particular DM's desires under conflict. In Chapter 7, a dominating attitudes methodology is developed, which can be used to consider strong and weak attitudes and provide flexibility to attitudes analysis. Next, in Chapter 8, the idea of attitudes within coalitions is mathematically defined to illustrate their strategic impact. Finally, in Chapter 9, a matrix form of attitudes is designed in order to improve the codeability of the attitudes framework by reducing the complex definitions to a series of matrices and matrix operations. A brownfield redevelopment conflict is utilized to illustrate the efficacy of these novel methodologies for providing a rich range of strategic insights. All of these developments furnish significant improvements to the attitudes framework within GMCR, while also allowing for new insights into the impact of DMs' behavior under conflict. In Chapter 10, conclusions are drawn regarding the many original research contributions developed in the thesis and future research projects are proposed.

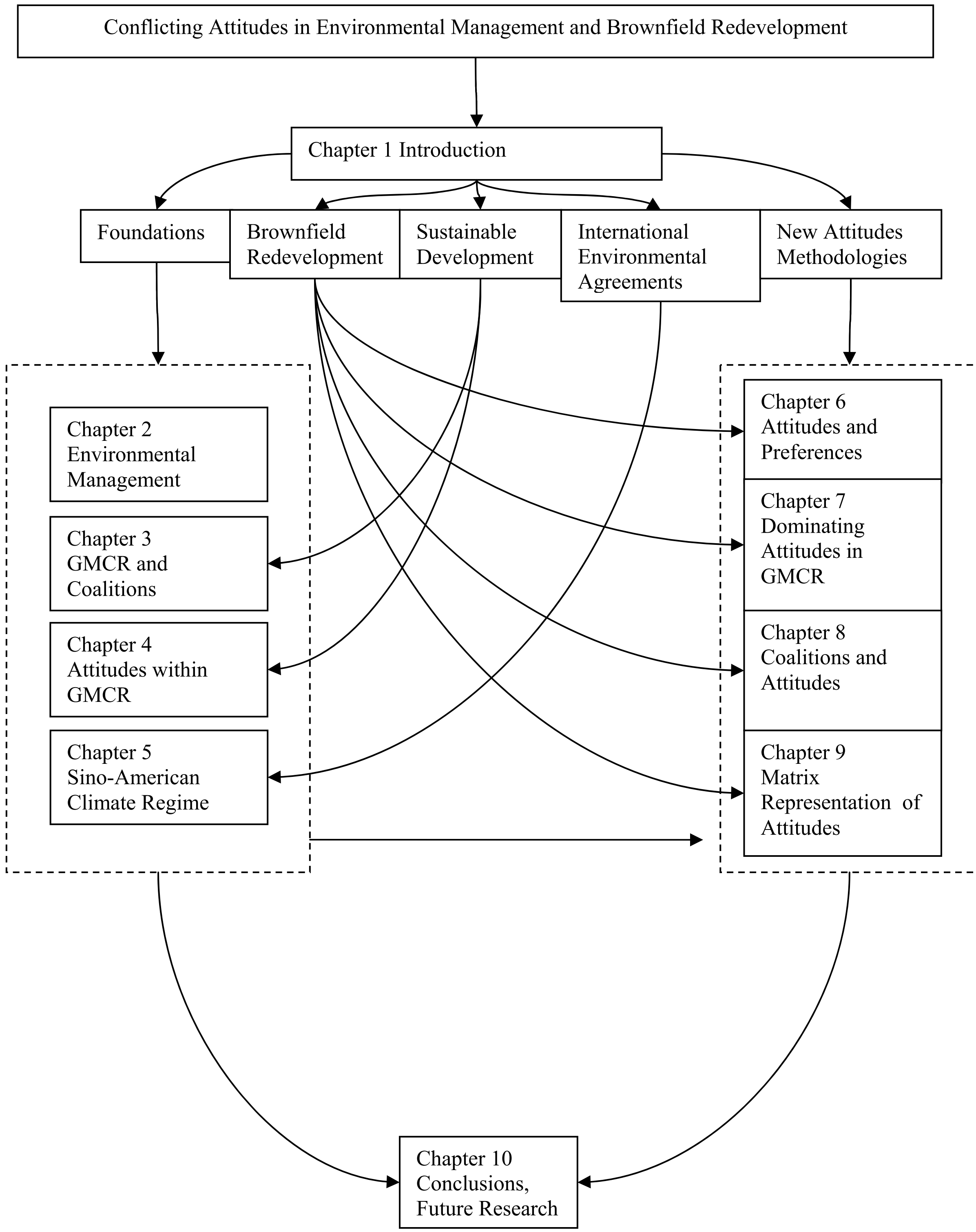


Figure 1.1: Outline of Thesis

Chapter 2

Environmental Conflict Management

2.1. Introduction

With the growing awareness of the impacts that our actions have upon the natural environment and the ongoing development of environmental laws and regulations, an increasing number of environmental conflicts have unfolded. Conflicts are a common part of human existence and often take place among multiple parties with different objectives. Environmental conflicts can arise even among those who wish to preserve the environment because their environmentalist ideologies may differ (Clapp and Dauvergne, 2005). In order to better understand conflict, provide a communication tool for expressing the different interests and positions of participants, and lead conflict towards more positive win/win results, formal conflict methodologies and techniques have been developed for employment by environmental stakeholders, facilitators and interested third parties involved in a dispute. Moreover, these methods have been applied to conflicts arising in a wide range of environmental areas, such as environmental agreements, environmental enforcement and resource management.

Environmental agreements are a significant area of research in environmental conflict management. International environmental agreements (IEA) such as the Kyoto Protocol, have been analyzed in-depth politically (Walker et al., 2007; Barrett, 1994) and at the emissions trading level (Bernard et al., 2008). As a subsection of environmental agreement research, environmental enforcement studies are used to examine the cost of inspecting and enforcing environmental laws and regulations. Resource management, which is of great economic and environmental concern, has long been of interest to decision analysts and others. Hardin (1968), for instance, outlines a popular resource allocation conundrum called "The Tragedy of the Commons" in which multiple users share a common finite resource and find it advantageous to overuse the resource assuming that this strategy, when undertaken alone, will not exhaust the resource and will allow for a competitive advantage over other decision makers. When all the stakeholders follow this strategy, however, eventually the resource is consumed or destroyed. Similarly, conflict models which have been applied to the division of a physical object, such as Brams and Taylor's (1992) and Bram's (1995) pie-slicing approaches, examine essentially the same dilemma: the fair and equitable sharing of resources among different stakeholders, whether the natural resource being managed is fish stocks, harvesting of forests, additional land utilizations, or absorption of greenhouse gases and other pollutants by the atmosphere, the underlying controversy is, in essence, identical.

Formal conflict analysis models are useful tools for shaping policy and guiding strategic decision-making in environmental management. The application of these models to environmental conflicts allow decision makers (DMs) to examine the strategic impacts of their decisions such that they may negotiate successfully with competing DMs or make intelligent selections of environmental project alternatives. A literature review of a range of available conflict analysis tools is presented in Subsection 2.2 while in Subsection 2.3 two main categories of environmental conflicts are examined with respect to the application of conflict analysis models: Environmental Agreements, including formal agreements and enforcement, and Resources Management. Finally, in Subsection 2.4, the literature review is summarized and the results of this chapter are discussed. The contents of this chapter are based upon the paper of Hipel and Bernath Walker (2012a).

2.2. Conflict Resolution Models

2.2.1 Classification of Conflict Models

Conflict analysis is a multidisciplinary field with roots in economics, sociology, politics, mathematics and elsewhere, as exemplified in the set of articles published in the books edited by Hipel (2009a,b). In this literature review the focus is on an examination of formal conflict models, which are founded upon rigorous mathematical structures originating in the field of game theory. As Arrow (2003) notes, game theory has a long and storied past dating back to the early 18th century in France. Game theory's more recent history begins in the mid 1940s. Specifically, in 1944, Von Neumann and Morgenstern published *Theory of Games and Economic Behaviour* considered by many to be the start of modern game theory. However, it was Nash (1950, 1951) whose determination of equilibrium points from the assertion that Decision Makers (DMs) in a given conflict would not move from an outcome unless it was immediately advantageous, paved the way for significant research into the applications of Von Neumann and Morgenstern's theories. Formal game theoretic conflict models can be classified into two distinct yet closely related branches of research: quantitative and non-quantitative modeling, as portrayed in Figure 2.1, which is based upon a diagram provided by Hipel and Fang (2005). Both of these types of models have been applied to a wide range of conflict studies including environmental conflict analysis (Benchkouroun and van Long, 2002; Benchkouroun and Gaudet, 2003), historical analyses (Inohara et al., 2007), and economics, among other topics.

As shown in Figure 2.1, environmental conflict analysis models fall under one of two main classifications: quantitative and non-quantitative approaches. Quantitative models are labeled this way to indicate that the preferences of a DM regarding states or scenarios are usually represented as real numbers, such as dollars or cardinal utility values (Von Neumann and Morgenstern, 1944). On the other hand, non-quantitative models are based upon relative preferences in which a DM may prefer or equally prefer one state with respect to another. Within quantitative models, three popular model types are normal form, extensive form, as well as cooperative game theory. Normal form models consider two or more DMs who are interacting one time only while extensive form models deal with multiple interactions among DMs, which are depicted using a tree-like structure. Additionally, extensive form and normal form are shown visually in very different ways, as will be explained in Subsection 2.2.1. Cooperative models are used to examine the interaction of individuals who must cooperatively decide how to fairly divide a "pie" or some resource in an equitable manner. These models are often used to analyze coalition formation, voting problems or optimal resource allocation problems. Non-quantitative models use relative preferences instead of cardinal preferences when describing human behavior under conflict and can be used to model environmental conflicts. Metagames, Conflict Analysis (Hipel and Fraser, 1980; Fraser and Hipel, 1984) and the Graph Model for Conflict Resolution (GMCR) (Fang et al., 1993) are all important non-quantitative models used in the study of environmental conflicts, as shown in the left branch of Figure 2.1.

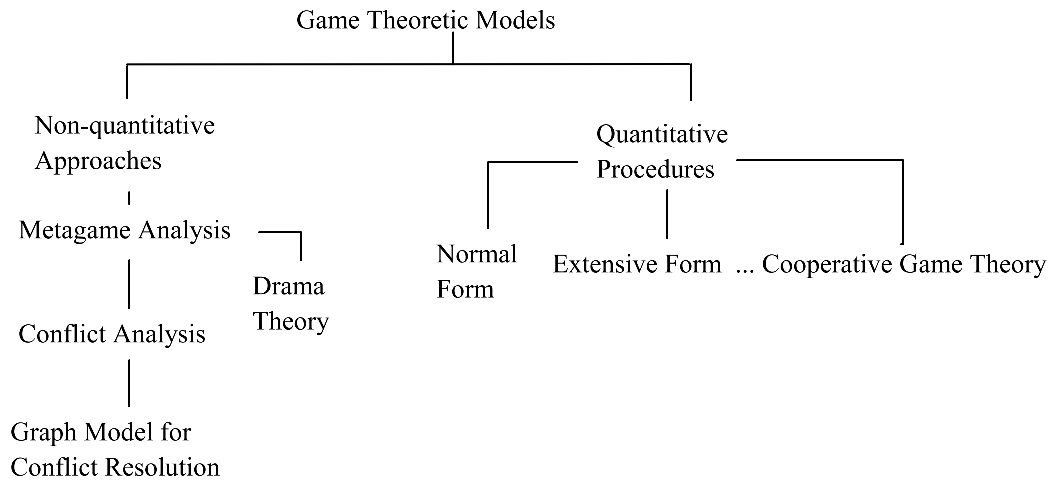


Figure 2.1: Genealogy of Conflict Analysis Methodologies
(Hipel and Fang, 2005)

Just as the genealogy of game theoretic conflict methods can be used to understand the relationships between different tools according to the criteria of non-quantitative and quantitative preferences as depicted in Figure 2.1, conflict types and their associated properties can also be classified in a tree diagram, as shown in Figure 2.2, with respect to pure competition, cooperation and compliance. As expected, there is significant crossover between the different methods and the problem types that can be examined. After all, some conflicts may be competitive in nature yet have some cooperative or compliance issues attached to them.

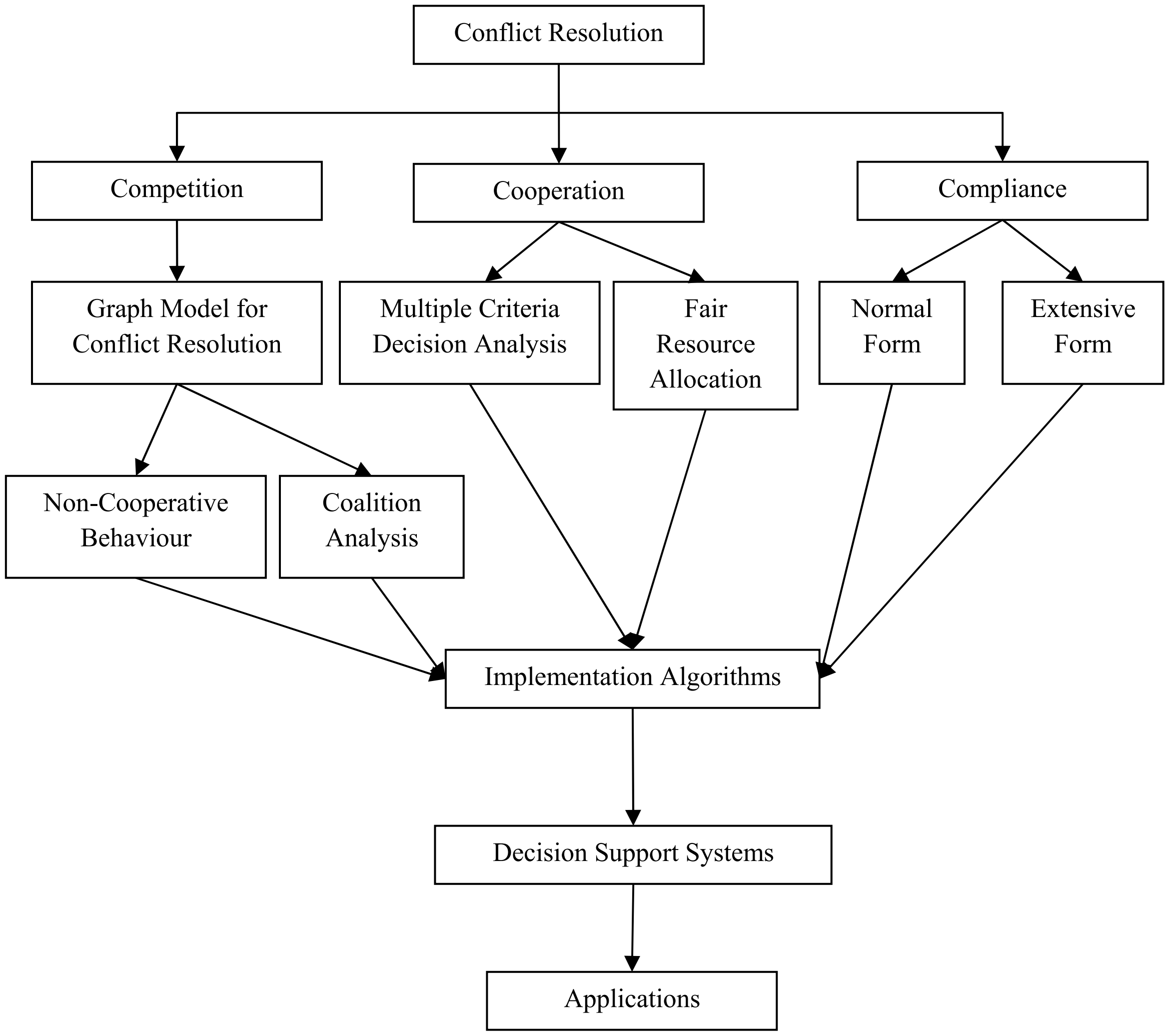


Figure 2.2: Application of Conflict Analysis Tools

The three main conflict categories consisting of competition, cooperation and compliance can all be formally modeled using the various conflict analysis tools listed in the third row of Figure 2.2. In fact, this categorization of conflict models reflects the type of research executed by members of the Conflict Analysis Group in the Department of Systems Design Engineering at the University of Waterloo, as discussed further in Subsection 2.3.3. The development of an implementation algorithm, as shown in Figure 2.2, then leads to the creation of a Decision

Support System (Sage, 1991; Hipel et al., 2008a; Fang et al., 2003a,b). In Subsections 2.2.1, 2.2.2 and 2.2.3, the various kinds of models classified according to quantitative procedures, non-quantitative methods and cooperative analyses are outlined. For each method type, different tools developed for the resolution of environmental conflicts are examined and their contributions to environmental conflict analyses are explained. In Subsection 2.3, the key types of environmental conflict models are discussed. One might conclude that all environmental agreement problems are cooperative in manner and that all resource allocation problems are non-cooperative. However, the types of conflict analysis methods they employ do not necessarily follow this trend and vary case by case. Enforcement conflicts, shown in Figure 2.2 as *compliance,* are considered to be a part of environmental agreement problems in Subsection 2.4.1. A simple example of such a conflict is shown in Subsection 2.2.

2.2.2. Quantitative Procedures

Quantitative approaches to game theory, shown in the right branch of Figure 2.1, use cardinal values, commonly called payoffs or utilities, to define the value of a given outcome or state to a DM in a conflict. In classical game theory methods, which is another label for the techniques falling under the right branch of Figure 2.1, participants in a dispute are often called players or actors. However, especially within the non-quantitative game theory literature, participants are often called decision makers (DMs) or stakeholders. In this thesis, the participants will usually be referred to as DMs. Whatever the case may be, In conflicts where DMs have multiple objectives the payoff in quantitative methods could be a function of various factors. For example, cost, land area and ecological impacts could all be used to determine the payoff of a development project in a land use planning conflict. Under the topic of quantitative game theoretic procedures, there are a variety of approaches for determining conflict resolutions;

however the three main decision models that will be discussed here are extensive form and normal form games, as well as cooperative game theory.

2.2.2.1 Extensive Form

In an extensive form game, also referred to as a sequential or dynamic game, each player makes a move in a specified order. This sequence is followed until some sort of resolution, or equilibrium state, is achieved. Benchokouron and van Long (2002) use dynamic games to explore the impact of fishing intensity on fish stocks and also examine what effects changing the fishing strategy of the leading player have on the other players in the game. For example, if a nation were to decrease its fishing in order to preserve fish stocks, would other nations comply or take advantage of this by overfishing? Extensive form games with well defined payoffs are often represented using a tree diagram in which a starting state and all the possible moves available to the first player are drawn as arcs denoting the movements and nodes representing the states. From the states representing the outcome of the first DM’s move, the second DM's moves are shown in the same way, and so forth. An important element of extensive form games is the modeling of how a DM’s strategies and preferences can change over time in a dynamic fashion.

In Figure 2.3, the tree diagram of a compliance conflict is shown. In the province of Ontario, Canada, the Ministry of the Environment would take the role of DM 2, the inspector, by inspecting sites for possible violations of environmental regulations. DM 1, the inspected, can be thought of as a corporate entity of some sort. Starting at the top of Figure 2.3, DM 1 has the option to either violate or not violate a particular environmental regulation. After DM 1 has made its choice, the conflict moves to state 2 where the inspector must decide whether or not to inspect. Both resulting nodes in the second row are enclosed in a dashed ellipse to signify that

DM 2 cannot distinguish between either points and thus they are both at the same state of knowledge, referred to as an “information set”, for DM 2. The pairs written beside the four terminal nodes represent the payoffs for DMs 1 and 2, respectively, at each conflict outcome. Using the payoffs for each player at each state and probability information about how likely DM 1 is to violate or DM 2 is to inspect, the expected payoffs can be determined (Fang et al., 1994, 2009). Although this method uses probability information to determine the expected payoffs, it is similar to Bahn et al.’s (2008) approach to ascertaining the impact of environmental agreements upon technological innovation using stochastic methods.

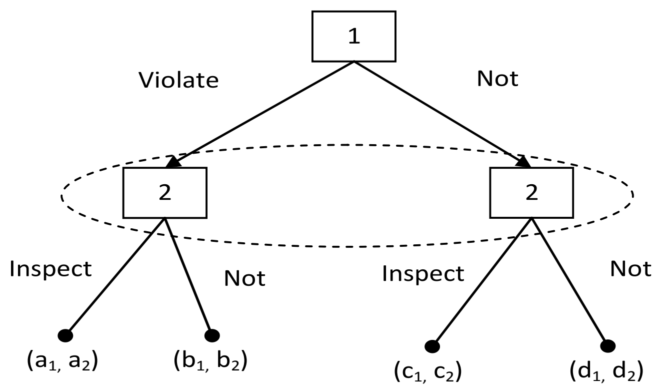


Figure 2.3: Simple Enforcement Game (adapted from Fang et al., 1994, 2009)

DM 1: Inspected, DM 2: Inspector

2.2.2.2 Normal Form

In contrast to the extensive form is the normal form game. In normal or matrix form, the combination of possible strategies the players may take is referred to as a conflict outcome or state. Sometimes the normal form of the game is deemed as being static because there is thought to be only one interaction between players, where the players independently decide which strategies to select before the game is played once. The simplest type of game, modeled by Rapaport and Chammah (1965), is the 2x2 game, represented in normal form as a 2x2 matrix. In a 2x2 game, two DMs, choose between two strategies, determining a final game state. In addition, repeated 2x2 games are often studied over time in an iterative fashion to ascertain how this may affect the outcome. A range of 2x2 games, reflecting conflicts that could arise in water resources management, are discussed by Madani (2010) and Madani and Hipel (2011). Figures 2.4 and 2.5 display two versions of the "Sustainable Development Game" proposed by Hipel (2009a) between Environmentalists and Developers, for which the Developers are environmentally responsible and irresponsible, respectively. Listed to the left of the matrix are the two strategies controlled by the Environmentalist (sometimes called the Row Player or DM 1): act proactively (P) and reactively (R) with respect to having a clean environment. Above the matrix are the two strategies available to Developers (also referred to as the Column Player or DM 2): practice sustainable development (S) and adhere to unsustainable development (U). When each DM selects a strategy, a state or outcome is formed. As can be seen in Figures 2.4 and 2.5, the four possible states in the Sustainable Development Conflict are PS, PU, RS and RU. For each state, the payoffs or preferences for the DMs are contained in the brackets for which the first and second numbers in brackets represent the preferences for the Environmentalists (DM 1) and Developers (DM2), respectively, where a higher number means more preferred. Often these preferences stand for cardinal utility values for the DMs with respect to states but for the purposes of this discussion only the ordering or ranking of the states for each DM is of interest. Hence, in Figure 4, the ordering of states from most to least preferred for the Environmentalists is PS, RS, PU and RU, since the Environmentalists prefer to be proactive and have the Developers practice sustainable development. When the Developers are environmentally responsible, as in Figure 2.4, their ranking of states is RS, PS, RU and PU, because they prefer to practice sustainable development and not be pushed by the Environmentalists in a proactive manner. On the other hand, as can be seen in Figure 2.5, when the Developers are irresponsible their ordering of states is RU, PU, RS and PS. In both of these models, the Environmentalists prefer to behave proactively. That is, they prefer to be aware and responsive towards environmental problems caused by the Developers. Most importantly, however, to the Environmentalists, is that the Developers behave sustainably and thus reduce their environmental impacts.

Briefly, a state is considered to be stable for a given DM if it is not advantageous for the DM to unilaterally move to another state by changing his or her strategic choice. Suppose, for instance, one is examining state PS for stability in Figure 2.4. Notice that if the Environmentalists can unilaterally change their strategy selection from P to R, the conflict would move from state PS to RS which is less preferred by the Environmentalists since their payoff goes from 4 to 3. Because the Environmentalists cannot unilaterally improve from state PS, the state is said to be Nash stable. State PS is also Nash stable for the Developer since if they change their strategy selection from S to U the conflict will move from state PS to PU, which is less preferred by them (their payoff goes from 3 at state PS to 1 at PU). Because state PS is Nash stable for both DMs, it constitutes Nash equilibrium. In fact the only Nash equilibrium in Figure 2.4 is state PS, which is beneficial for the environment, while PU is the only Nash equilibrium in Figure 2.5, which is harmful to the environment.

		Developers	
		Practice Sustainable Development (S)	Practice Unsustainable Development (U)
Environmentalists	Proactive (P)	(4,3) PS	(2, 1) PU
	Reactive (R)	(3,4) RS	(1,2) RU

Figure 2.4: Sustainable Development Conflict for Environmentally Responsible Developers (Hipel 2009a)

		Developers	
		Practice Sustainable Development (S)	Practice Unsustainable Development (U)
Environmentalists	Proactive (P)	(4,1) PS	(2,3) PU
	Reactive (R)	(3,2) RS	(1,4) RU

Figure 2.5: Sustainable Development Conflict for Environmentally Irresponsible Developers (Hipel 2009a)

2.2.2.3 Cooperative Game Theory

The third conflict methodology shown in the right branch of Figure 2.1, called cooperative game theory, can be used to analyze cooperation and coalition formation among DMs under conflict when deciding how to fairly divide a resource. Therefore, the community has a fixed-sized "pie" and the problem is how to cut the pie in order for each competitor to get a "fair" slice of the pie or resource. Driessen (1988) explains that in cooperative games there exists a set of N DMs $\{1, 2, ..., n\}$ and a real valued set-function v. The set-function $v(S)$ is said to represent the "worth of the coalition *S*". The players in the conflict can refer to both individual stakeholders, such as people or corporations having conflicting interests that need to be met by a satisfactory solution or solution set.

Examples of cooperative models include Littlechild and Owens' 1973 analysis of airport cost allocation and Suzuki and Nakayama's (1976) Japanese water resource conflict. Of course, cooperative game theory looks not only at cost allocation but at the value of various coalitions. Shapely and Shubik (1967) propose a number of simple games that illustrate the importance of cooperation. They include, among others, the scenario where farmers harvest a collectively shared forest. With the increase in farmers harvesting the same land, the total yield increases until the number of farmers becomes too great for the area of land and thus the food output peaks and decreases. More complicated models by Shapely and Shubik (1967) focus on the interrelationship between landowners and peasants (or labor) and the value of the coalitions that they form based on their potential production.

The Cooperative Water Allocation Model (CWAM) is a large-scale optimization model based on ideas from cooperative game theory, economics and hydrology to fairly allocate water among competing users in a river basin (Wang et al., 2003, 2008a,b). Using a systems approach, CWAM takes into account not only the physical systems of hydrological and environmental factors but also the societal system. The system is applied in two steps: first the water is allocated among the existing water rights, regimes or agreements. Next, the water is redistributed to benefit the entirety of the river basin. The flow diagram in Figure 2.6 illustrates these two main steps along with some of the key components of each step. Concepts from cooperative game theory are employed in the second step to ascertain how water can be fairly shared among various coalitions consisting of all of the stakeholders in the river basin.

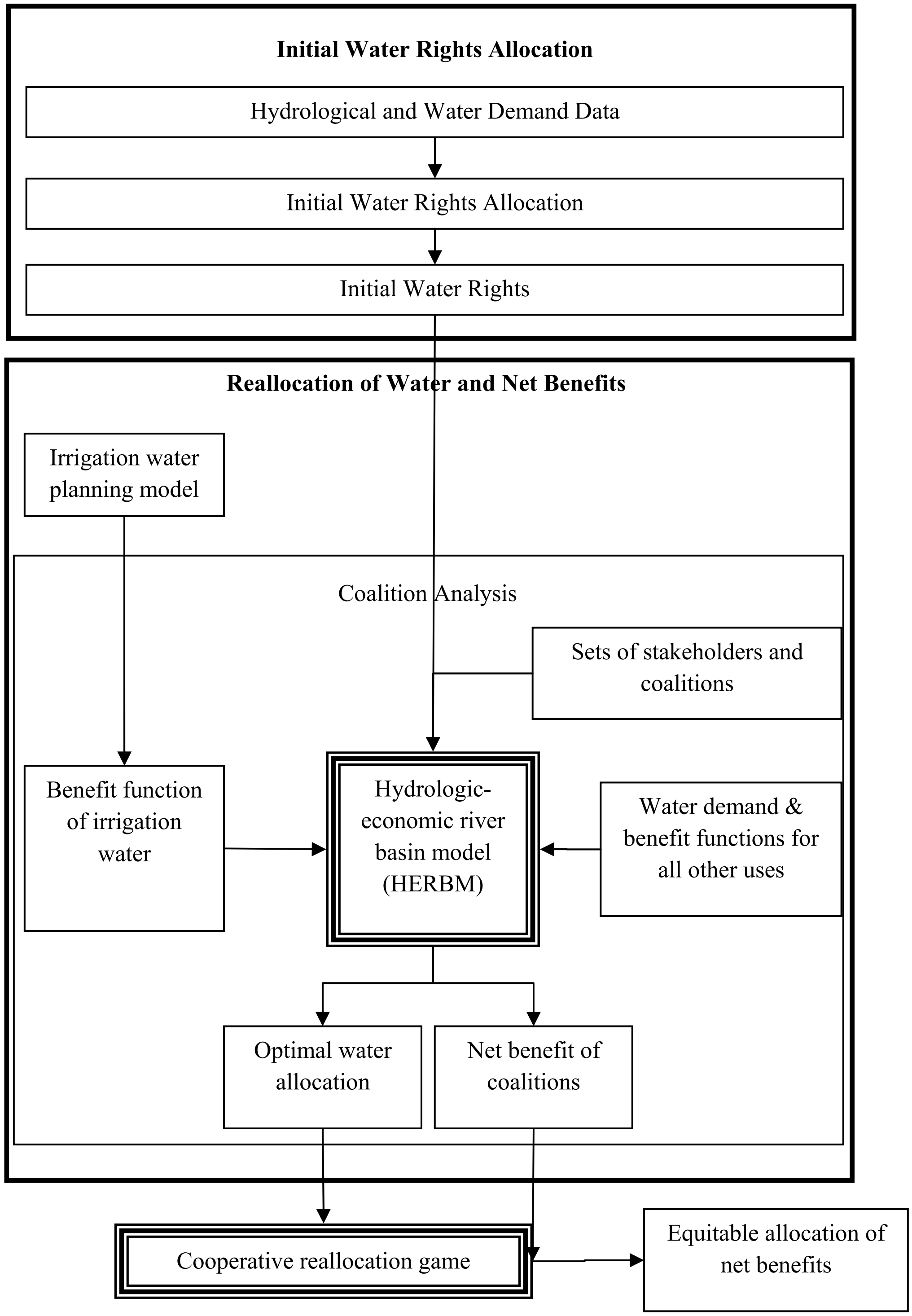


Figure 2.6: Cooperative Water Allocation Method (Wang et al., 2008a)

2.2.3. Non-quantitative Procedures

The left branch of Figure 2.1 contains the non-quantitative conflict analysis techniques in which only relative preference information is utilized. Metagame analysis, developed by Howard (1971), was an attempt to make conflict models more intuitive and realistic by using relative preferences in place of cardinal payoffs. To analyze and determine state stabilities and thus overall equilibrium states, Howard introduced the solution concepts of General Metarational (GMR) and Symmetric Metarational (SMR) stability. Both GMR and SMR stabilities assume that opposing DMs may make moves to harm their opponents without considering their own personal risk. These solution concepts applied under conflict situations allow decision analysts to observe the strategic implications of specific moves.

The development of metagame analysis has given rise to two non-quantitative branches of conflict analysis, as shown on the left of Figure 2.1. Of these two, Howard himself developed drama theory, a methodology that structures conflicts as a three act play complete with a problem introduction (Act I), climax (Act II) and resolution (Act III) (Howard, 1994a,b). Howard's 1999 book, *Confrontation Analysis,* laid out the structure of drama theory and provided the general structure that Howard would use to analyze conflicts. In addition to the three act display, Howard (1999) provides a six unit analytical approach, shown in Figure 2.7. Howard (1999) employs the Six Units of Conflict Resolution illustrated in Figure 2.7 to determine how decision makers can solve dilemmas. As Howard (1999) notes, often it is worth making moves that are not advantageous in the short term in order to find a solution that is viable in the long term. Finally, Bryant (2003) furnishes a good description of drama theory while Levy et al. (2009a,b) provide an explanation of recent advances in drama theory.

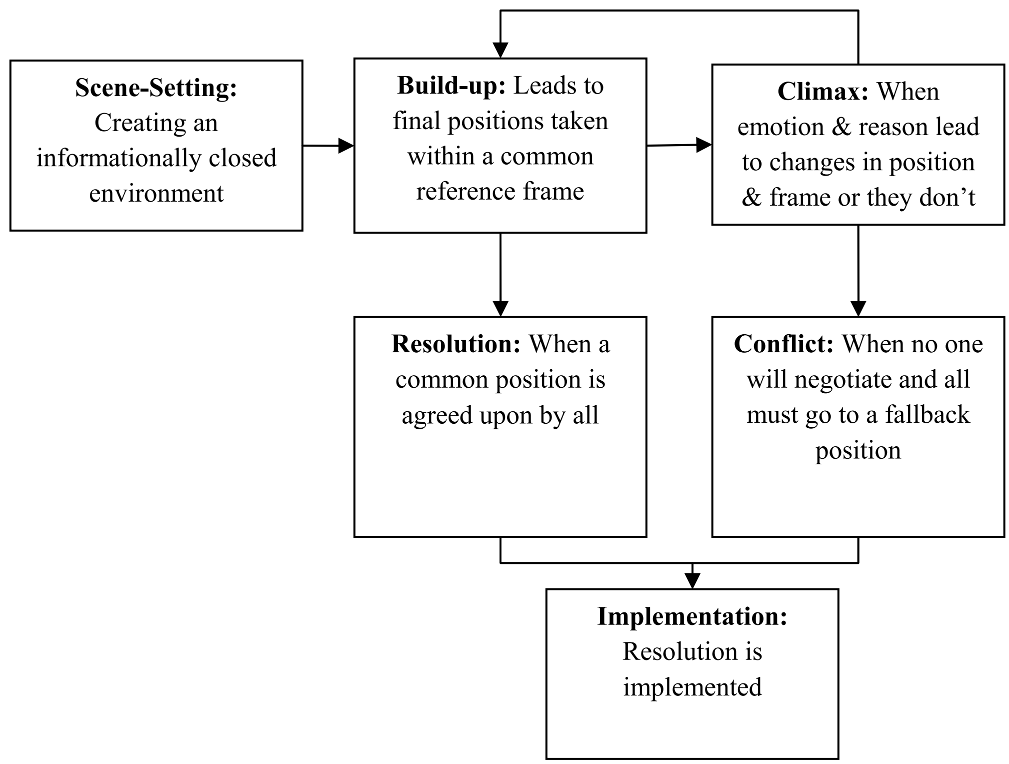


Figure 2.7: Six Units of Conflict Resolution (Howard, 1999)

The second methodology developed from metagame analysis was conflict analysis (Fraser and Hipel, 1984). In addition to using the option form of the game for recording a conflict model, Fraser and Hipel (1984) introduced the tableau form for conveniently displaying a conflict model and calculating stability. Moreover, they introduced the new solution concepts of simultaneous and sequential stability. Simultaneous stability examines the strategic impact of two or more DMs moving at the same time from a given starting state. Such a combination of moves can move the conflict to a new unexpected outcome. Sequential stability assumes that all DMs make "credible moves" and thus will not compromise their own interests when blocking another DM's improvements. From conflict analysis, Fang et al. (1993) developed the Graph Model of Conflict Resolution (GMCR) which combines elements of graph theory and game theory. GMCR creates a graphic representation of a given conflict, with nodes representing states and arcs with arrows representing unilateral movements. Formal definitions for GMCR will be discussed in detail in Chapter 3.

2.2.4. Multiple Criteria Decision Analysis (MCDA)

As shown in the central portion of Figure 2.2, Multiple Criteria Decision Analysis (MCDA) can be useful for modeling cooperation in decision making. More specifically, suppose that managers within a large environmental agency, such as a national ministry of the environment, wish to devise a plan for regulating an emergent chemical pollutant which has entered ecosystems within a large region. In a process called "group decision making" they may compare a set of alternative solutions according to a range of both quantitative and qualitative criteria in an attempt to ascertain the most preferred alternative or set of alternative solutions. As depicted in Figure 2.8, the set of *m* alternative solution, $\{A_1, A_{2,...}, A_m\}$ are evaluated according to each criterion in the set $\{C_{1,} C_2, ... , C_n\}$ giving rise to *mn* different scores for which V_{ij} is the score of Criterion *i* for Alternative *j*. The criteria often consist of a wide variety of social, economic, risk, environmental, legal and health considerations which frequently reflect the values or objectives of various stakeholders. In fact, as explained by Hipel (1992) and Hipel et al. (1993, 2008b, 2009a), MCDA and conflict analysis tools are closely related to one another and can be used in a highly complementary fashion when investigating environmental problems. A rich range of publications regarding MCDA are available including contributions by Belton and Stewart (2002), Hobbs and Meier (2000), Roy (1996) and Saaty (1980, 2001).

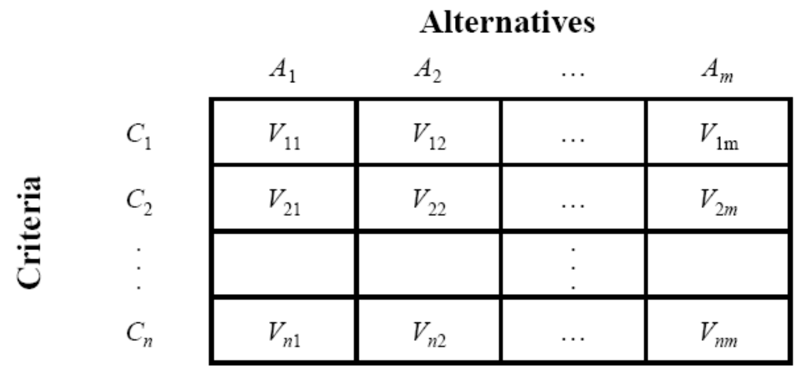


Figure 2.8: Multiple Criteria Decision Analysis (Hipel et al., 1993)

Solving an MCDA problem is usually a three step process that involves: 1) defining the available alternatives, objectives that must be met and the criteria used to meet them, 2) the collection of data into a matrix similar to that of Figure 2.8, with the value of each alternative measured at each criterion and 3) determining the results of a decision analysis. Step 1 is often undertaken through a literature review of the given problem. A systematic method developed by Keeney (1992) uses an approach termed "value-focused thinking" to aid decision makers in completing this first step. The second step is usually the result of intensive study of available data and independent research. Within the context of environmental conflict, this data may include social, economic or environmental data. In Step 3, an appropriate decision protocol is utilized depending on whether the decision maker requires the alternatives to be ranked, sorted, screened, or a final choice be made (see, for instance, Hipel et al. (2009a) and Chen et al. (2007; 2008)).

2.3 Environmental Conflicts

Environmental conflicts, in which multiple DMs with disparate objectives negotiate over the utilization of environmental resources or pollution of the environment, represent a large myriad of problem types that encompass political, social and economic concerns as well as challenging physical systems components. The successful resolution of environmental conflict is complex, however, due to the large number of factors and interactions at play in ecosystems and societal-environmental systems. In the following subsections, both quantitative and non-quantitative methodologies have been applied to various aspects of these conflicts which have been categorized according to environmental agreements and resource management in Subsections 2.3.1 and 2.3.2, respectively. The objective of this survey is to present representative, and generally more recent research contributions in those areas rather than being an exhaustive list of references. Comments regarding the effectiveness of formal models in the environmental area are put forth in Subsection 2.3.3.

2.3.1. Environmental Agreements (EA)

Non-enforcement EAs are agreements between nations, corporations, government bodies or non-governmental organizations to monitor, abate or share the impacts of specific pollutants. Enforcement theory, as illustrated in Figure 2.3 in Subsection 2.2.2.1, deals with the efforts of government agencies to uphold the law – in this case, environmental law. Numerous EAs and their related negotiations have come to the forefront of both environmental and political debates. Fraser and Hipel (1980, 1984) model the conflict arising from the Garrison Diversion Unit (GDU), a project that would send foreign biota and fertilizer runoff into Canadian waterways, from the United States. The EA in this case is the Boundary Water Treaty, a treaty signed by both Canada and the United States in 1909 and overseen by the International Joint Commission (IJC). In this analysis Fraser and Hipel determine decision makers, options, and overall preferences in order to create their conflict model. Then an analysis, using conflict analysis, is undertaken to determine which outcomes are equilibriums, based on the solution concepts developed by Nash (1950, 1951), Howard (1971) and Fraser and Hipel (1984). The methodology used here is non-quantitative, with ordinal preferences.

Ma et al. (2008) use MCDA to compare the effectiveness of four transboundary water treaties, including the 1909 Boundary Waters Treaty between Canada and the United States. The flexible MCDA decision technique called the Elimination Method was used to evaluate the four treaties according to non-quantitative criteria falling under three main classes: enforcement capability, treaty implementation and dispute resolution mechanism. Furthermore, they make specific recommendations for EAs based on their analyses.

International EAs, such as the Kyoto Protocol have given rise to a considerable amount of study. Strategic concerns such as the forming of coalitions and the use of political enticement (Walker et al., 2007) as well as the allocation of investment (Bahn et al., 2008) and the trading of emission permits (Bernard et al., 2008) are areas of important research for conflict analysts.

Barrett (1994) examines how making international EAs self-enforceable may not yield stronger coalitions or have a large impact upon how groups that are formed by an international EA behave. The premise of Barrett's model is that the nations participating in the EA will increase their abatement to reward newcomers and decrease their abatement to punish nations that leave the coalition. To accomplish this analysis Barrett used both cooperative and non-cooperative game theoretic models. After considerable analyses he found that self-enforced international EA's modeled using cooperative game theory may not be able to have a significant impact on the sustainable practices of the member nations.

Like Barrett, numerous other conflict analysts have modeled EAs using coalition models. Research by Breton et al. (2006, 2008) in the area of international EAs has focused on the stability of the large coalitions needed to undertake such multinational abatement programs. Breton et al.'s 2006 paper is an examination of the need for cooperation among decision makers in order to form a large stable coalition and deter free-riders in the EA. Within this analysis, the payoff of each state in the conflict is determined as a function of financial benefits and the damage done to the environment through polluted emissions. Examining numerous solution concepts, including partial Nash and Nash equilibria and the impact of punishing behavior on the part of the coalition members, led to the conclusion that only through cooperative behavior can larger coalitions hold. Carraro and Siniscalos (1993) have also examined this problem and determined that smaller coalitions could be used to deter free-riding while larger coalitions would only be able to form in the presence of what Breton et al. (2008) refer to as 'punishing behavior' on the part of the coalition members. Chou and Sylla (2008) employ a two-stage cartel game which also illustrates the desire of developed nations to form small steady coalitions before creating the 'grand coalition'. Rubio and Ulph (2007) extend the analysis of Carraro and Siniscalos (1993) by introducing dynamic properties into the analysis. Using a dynamic cooperative model, Rubio and Ulph show the transient nature of the coalitions in the absence of binding agreements. Walker et al. (2007) use a non-quantitative analysis of coalition building in EAs to examine the impact of political coalition formation in the ratification of the Kyoto Protocol.

The GEMINI-E3 model, developed by Bernard et al. (2008), provides a wealth of information to decision analysts by modeling the energy usage, financial and trade impacts of climate change and the implementation of abatement programs, such as the Kyoto Protocol (Bernard and Vielle, 2003). Bernard et al. (2008) use a computable general equilibrium model within Gemini-E3 to examine emissions permit values and the impact of developing nations. Their analyses show that the presence of developing nations, such as China, in the permit trading marketplace would cause a general decrease in the price of emissions permits. Drouet et al. (2008) also uses the computable general equilibrium model GEMINI-E3 to analyze the negotiation of the Kyoto Protocol. Differing from Bernard et al. (2008), the analysts use a non-cooperative model where the stakeholders are subject to losses or gains to their utility value, based on the timing of their commitment to the protocol instead of specifically examining emissions permit values.

Other environmental negotiations, outside of legal international or formal EAs, herein referred to as informal EAs, are also an area of intense interest for decision analysts. As with formal EAs, the models are of the extensive form such that numerous interactions between decision makers are allowed to take place. Bahn et al. (2008), for example, use a dynamic model to examine the timing of its EAs and their impact upon technological development. More specifically, Bahn's model examines the investment in carbon-free technology and compares it with the current carbon-based economy. The problem of determining an optimal policy is set up as a dynamic programming problem to be solved using stochastic methods. This research of Bahn et al relates, of course, to the way that technology has impacted our 21st century lifestyle. Inohara and Hipel (2008a; 2008b) and Kilgour et al. (2001) use a coalition model to examine the informal EA between the Ontario Ministry of the Environment (MOE) and Uniroyal, located in Elmira, Ontario, Canada. The conflict resulted from Uniroyal's release of toxins into the underlying aquifer and nearby stream and MOE's response of issuing a Control Order requiring Uniroyal to decontaminate the area. While the local government attempted to pressure Uniroyal to adhere to the control order, Uniroyal delayed cooperating and finally a coalition was formed between Uniroyal and the MOE in which MOE would modify the control order which Uniroyal agreed to accept.

EA among organizations is another area of important conflict study. Hipel and Obeidi (2005) examine the impact of sustainable practices upon negotiations between industry and environmental stewards or protesters. The conflict examined here is not only a conflict between two players, but two economic models: Global Market Driven Economy (GMDE) and Sustainable Ecosystem (SES). Similarly, Howard (2006) examines the social implications of introducing sustainable development practices into a local government structure. Using simple two player games, Howard illustrates the strategy of resistance held by those who will not adopt the new practices. In the context of enforcement, Fukuyama et al. (1996) use the "enforcement model" to examine the implications of environmental regulation enforcement using both a simple normal form game and an extensive form game that uses utility penalties to punish environmental offenders.

2.3.2. Resource Management

Resource management, due to its economic implications, has been examined thoroughly by engineers and economists over a long period of time. Hardin's "Tragedy of the Commons", outlines the basic premise that underlies the majority of resource management modeling (Hardin, 1968). Hardin's philosophical concept is that when there is a natural resource that is desired by multiple parties, it is in each party's best interest to overuse that resource. However, if all of the parties decide upon this strategy and the group overexploits the resource, it will be depleted or damaged. Resource management, in this context, thus becomes an optimization problem of maximizing the payoff for each party while not compromising the resource.

Numerous applications of game theoretic methods deal with the management of a natural resource in this manner. Fisheries (Benchekroun and van Long, 2002), forestry (Tecle et al., 1998), water allocation (Wang et al., 2003, 2008a,b) and even ecological tourism resources (Bimonte, 2008) are among many such applications covered in the environmental conflict literature. The methodologies for analyzing the resource management problems seem focused mainly in the areas of cooperative game theory (Wang et al., 2003, 2008a,b; Tecle et al., 1998) and dynamic games (Benchekroun and van Long 2002; Benchekroun and Gaudet 2003).

Benchekroun and van Long (2002) use an extensive form theory to model a transboundary fishing conflict where the fish migrate from one nation's waterways to another's, thus defining the order in which they may be harvested. This type of sequential fishing conflict is certainly accurate and justifiable, an example being the catching of Pacific Salmon off the coasts of Alaska and British Columbia. As the fish swim through Alaskan waters first, Alaskan fishers have the right to harvest these fish first. Benchekroun and van Long pose interesting theoretical questions, such as "does the leader [first nation] have an incentive to restrain its catch rate relative" to the situation where both players choose the strategies simultaneously? The net benefit for each player is given as a product of their 'effort' and the stock of fish available. The effort and harvest rate of each player acts as the control variables in this model, while the fish stock remains out of the players' control. After performing analyses using a differential game theory model, they reach the conclusion that it is in the best interest of the first nation to fish responsibly, thus not goading the second nation into also overfishing and eventually eroding the stock. Finally, Noakes et al. (2005) use GMCR to analyze the strategic stability of the revised Pacific Salmon Treaty between Canada and the United States.

Martin-Herran et al. (2006) also use a Stackelberg game, where players play in a prescribed order, to analyze an environmental conflict. The conflict model that they develop examines the interaction between a nation that is funding a less developed nation on the condition that it improves its forestry practices. The sequential nature of the conflict is important: first the donor nation funds the receiving nation in good faith, based on the sustainability of their forestry practices, and secondly, the receiving nation executes forestry practices consistent with their own customs and the agreement with the funding nation. The receiving nation attempts to maximize its financial gains by optimizing its agricultural, timber and donation revenue streams. The donor nation, of course, attempts to influence the receiver's forestry practices while giving as little money as possible and maintaining the forest stock. Thus, accurate models allow analysts to determine the impact of differing strategies.

Other applications of game theory to natural resources problems, such as Plourde's (1970) examination of maximum yield programs, examine situations involving one decision maker with multiple objectives using an adapted version of a dynamic cooperative game theory method. Plourde (1970) illustrates that the yield limiting programs are optimal for cases where resource prices are considered within the model. As mentioned in Subsection 2.2.3 and summarized in Figure 2.6, using cooperative game theory, Wang et al. (2003, 2008a,b) developed the cooperative water allocation management (CWAM) system for allocating water use among various users at the water basin level. CWAM consists of two steps, the first being the initial allocation of water rights and secondly, subsequent water and net benefits reallocation. To accomplish the first step, the priority-based maximal multiperiod network flow (PMMNF) method and the lexicographic minimax water shortage ratios (LMWSR) technique, are developed by Wang et al., while in the second step, cooperative game theoretic approaches are utilized to investigate how the net benefits can be fairly reallocated. This method is then applied in a case study of the South Saskatchewan River Basin. A similar type of problem, modeled using cooperative game theory by Tecle et al. (1998), is the determination of proper forestry practices in order to find a compromise solution to five forestry objectives. The researchers apply both compromise programming and cooperative game theory methods to the problem in order to satisfy wildlife habitat conditions, herbage production, aesthetic values, water yield, and on-site merchandise timber value by substituting objectives for stakeholders in the cooperative game theory model.

In contrast to implementing cooperative game theory to examine a single participant-multiple criteria problem, multiple criteria decision analysis (MCDA) can be used. Geldermann et al. (2009) examine the application of MCDA to the selection of a nuclear remediation strategy in case of a nuclear accident in Europe. Chen et al. (2008) use an MCDA-based analysis to compare alternatives for managing ground water resources in the region of Waterloo, Canada. Chen implements a screening process to reduce the alternatives from a larger set to a smaller set, thereby enhancing the decision process.

Differing from traditional natural resource management is the management of environmental resources that are not designated for direct economic gain. Starkl et al. (2009) examine the management of urban water streams using non-cooperative game theory, while Carraro and Sgobbi (2008) study the division of natural resources. Using a generalized 'pie cutting model', Carraro and Sgobbi find that in the face of uncertainty, decision makers are more likely to act in a positive manner towards each other. Bimonte (2008) examines the indirectly used resource of environmental beauty, as it applies to the industry of tourism. Through the use of normal form and extensive form games, Bimonte illustrates the interaction between the users of environmental tourist resources and proposes a resolution of self-enforced cooperation between tourists and primary users of environmental resources.

2.3.3. Environmental Conflicts and Formal Conflict Models

Environmental justice, as described by Čapek (1993), entails not only environmental components but elements of social and economic justice; likewise, environmental conflicts must be said to encompass elements of social and economic conflict. To meet all three of these aspects of environmental conflict resolution, it is necessary to employ versatile decision tools. The goal of those implementing decision tools is to determine environmentally just solutions to environmental conflicts by finding win-win resolutions which satisfy all parties.

Game theoretic models, which form the basis of conflict analysis, gained wide acceptance in economics due to the work of Von Neumann and Morgenstern (1944) as well as Nash (1950, 1951). Thus, the application of conflict models to problems such as resources management and emissions permit trading is natural due to the inherent economic nature of these problems. For example, the trading of emissions permits relies heavily upon an economic model of buying and selling and natural resource management problems are often modeled as the efficient and responsible management of financial investments. The social aspects of environmental conflict, reinforced by the concept of environmental justice (Čapek 1993), also bode well for the application of such tools to environmental conflict. For example, problems such as the brokering of a compromise between the MOE and Uniroyal or the acceptance of environmental protocols within an organization are environmental conflicts that are social in nature.

The Conflict Analysis Group at the University of Waterloo is at the forefront of research into the utilization of conflict analysis methods to solve environmental conflicts. Research into the employment of cooperative game theory (Wang et al., 2003, 2008a,b; Kilgour et al., 1988), MCDA (Hipel, 1992; Hipel et al., 1993; Chen et al., 2007) and non-cooperative game theory (Fang et al., 1993) within the application domain of environmental conflict is an important part of the strategic research that has been undertaken. Specifically, research is ongoing into all three areas of environmental conflict modeling shown in Figure 2.2: competition, cooperation and compliance. Research regarding preference structures includes strength of preference (Hamouda et al., 2004, 2006; Xu et al., 2009a), unknown preferences (Li et al., 2004a, 2005a), emotions (Obeidi et al., 2005; 2009a,b), attitudes (Inohara et al., 2007; Bernath Walker et al., 2009), fuzzy preferences (Al Mutairi et al., 2008; Bashar et al., 2012; Hipel et al., 2011), and information gap modeling in preference sensitivity analyses (Ben-Haim and Hipel, 2002; Hipel and Ben-Haim, 1999). These advancements in preference research have all been applied to natural resources, brownfield redevelopment and waste management conflicts. For example, Bernath Walker et al. (2010) consider the effects of attitudes of decision makers in a strategic study of a brownfield redevelopment project which took place in Kitchener, Ontario, Canada. The study of the evolution of conflicts (Li et al, 2004b, 2005b), coalitions (Hipel and Fraser, 1991; Kilgour et al., 2001; Inohara and Hipel, 2008a; 2008b), and misunderstanding (Wang et al., 1989; Okada et al., 1985) have also been important in the development of conflict analysis methods. Within all three types of environmental conflict modeling (Figure 2.2), implementation algorithms are needed to perform the analysis. A new algorithm which makes use of matrix properties (Xu et al., 2007, 2009b) to reduce computational complexity and increase overall efficiency is currently being developed.

2.4. Summary

Decision making under conflict or negotiation remains an important element of business, engineering and science practices and thus a key part of coping with the changing environment and its associated conflicts. In order to take the actions needed to improve society and our physical environment, two elements are needed: data and decision support. Environmental, financial and social data are often collected to aid decision makers; however, systematic tools used in conjunction with these data elements are also often required to make sense of the information and to help provide insight into the conflict situation in order to make more informed decisions. The management of fragile ecosystems, agricultural land, contaminated properties and other environmentally sensitive areas require more insightful decision making and more sophisticated tools and, indeed, more research is needed in this area (Jain and Singh, 2003; Hipel and McLeod, 1994; Hipel et al., 2009a,b).

In the previous subsections, strategic tools sensitive to the various complexities inherent to a myriad of environmental conflicts were introduced. Additionally a review of the conflict analysis literature in the field of environmental conflicts, trends and popular application areas were given. Within Environmental Agreement (EA) conflicts, the application of coalition models, both quantitative and non-quantitative, to formal EA and informal EAs is the predominant method of study. Bernard et al.'s (2008) GEMINI-E3 model is also of importance in this area, especially to those interested in the implementation of the Kyoto and Copenhagen Protocols and the far-reaching implications it has on the economy as well as the environment. Sustainable practices, the acceptance of environmental regulations within a government structure and the enforcement of environmental regulations were all modeled effectively using quantitative models in the normal and extensive forms. Resources management, due to its economic nature and the easily definable physical meaning of cardinal payoffs was modeled almost exclusively using quantitative models. Extensive form models were used in the examination of non-cooperative behavior between competing interests for resources such as fisheries and forests while cooperative game theory was applied to show the possible beneficial outcomes in a water resource allocation problem. All of these methodologies have been shown to aid decision analysts in performing useful analysis of environmental conflicts. Using these conflict analysis models, the environmental, social and economic factors at play within environmental conflicts were successfully examined, leading to the determination of effective problem resolutions. With the ongoing threat of major climate change effects in our future, the ongoing negotiation over greenhouse gas emissions thresholds and the constantly increasing interaction between humanity and the environment, the need for these environmental strategic decision support tools is growing.

Chapter 3

Graph Model for Conflict Resolution

3.1 Introduction

Conflict is an unfortunately common consequence of human interaction which is often driven by a difference in objectives and values (Fraser and Hipel, 1984; Fang, et al., 1993; Hipel and Obeidi, 2005). Thus, the study of conflict is useful for determining better courses of action when multiple stakeholders are involved. This is true whether the conflict is the negotiations surrounding an internal environmental agreement, a brownfield renovation project, or the conflict between a company and environmental activists. In conflicts, disparate decision makers (DMs) must come to some sort of resolution, be it through cooperation, strategy or both.

In order to effectively determine how to approach conflict situations successfully, a number of different formal tools have been proposed to model conflicts. Many of these tools find their basis in game theory, a branch of work which truly originated with the 1944 publication of "Theory of Games and Economics" by Von Neumann and Morgenstern, as was mentioned in Chapter 2. Of course, there have been further innovations from this essential starting point. Howard (1971) furthered the concepts of game theory with his development of 'metagames' and further 'drama theory' (Howard, 1999) which considers conflicts as being broken into three acts. Metagames was a major innovation for game theoretic approaches and allowed for new flexible modeling that could be applied to more practical conflict situations (Fraser, et al., 1983). Part of the flexibility that Howard (1971) introduced was the creation of a number of new solution concepts which are related to whether a conflict outcome is stable for a DM and labeled states as being rational, symmetric, general metarational or unstable. One element of these solution concepts which made them accurate mimics of human behavior were that they assumed a DM in a conflict has knowledge only of whether a state is more preferred, equally preferred or less preferred by himself, with respect to another state (Fraser, Hipel and del Monte, 1983). The creation of these solution concepts opened the way for interesting analyses to be performed.

In 1984, Fraser and Hipel (1979; 1984), extended metagame analysis by introducing sequential stability and simultaneous sanctioning as well as the tableau form to carry out stability calculations. Sequential sanctioning allows for the consideration of situations where a DM is aware of his opponents' preference and thus 'credible' solutions in which a sanctioner will not harm himself in the process of levying a sanction. In 1993, Fang, Hipel and Kilgour developed the Graph Model for Conflict Resolution (GMCR) which provides a useful structure for recording the movements and countermoves of the various DMs and defining solution concepts. Within the graph model, a set of arcs represents the potential movements between vertices which stand for different conflict outcomes or states.

In Figure 3.1, the implementation of GMCR to a practical conflict is shown. First, the Real-World Conflict is considered. Next, from a careful examination of this conflict, the analyst must determine which DMs have a direct impact on the conflict. The options available to these DMs are ascertained and from these options a set of feasible states are then added to the conflict model. The total set of states consists of all combinations of options as selected by all the involved DMs is then generated using the DM and option information already developed. Feasible states represent an important subset of the total set and include all states formed by feasible combinations of options. The removal of infeasible states is an often important element of developing a conflict model. In this stage, the analyst must balance a need to reduce the overall size of the model in order to increase computability, with the desire not to remove feasible states or transition states, which would create false results. The allowable state transitions, determined from background research of the conflict being analyzed are used to determine how the different DMs can move between states. Finally, relative preferences are determined from historical data or information provided directly by the DMs. If the preferences are ordinal the feasible states are ranked from most to least preferred, where ties are allowed. Relative preferences can be determined using a number of techniques. For example, if the preferences are known to be both ordinal and transitive, the analyst could easily apply the elimination method within MCDA (Fang et al., 1993). Moreover, cardinal preferences can also be handled by the graph model, since ordinal preference information is contained within the cardinal structures. After these steps have been completed, solution concepts are applied to the model to determine individual stabilities for each DM at each state. Using these stability results, states that are stable for every DM involved in the conflict are determined and labeled as being equilibrium states (Fang, et al. 1993).

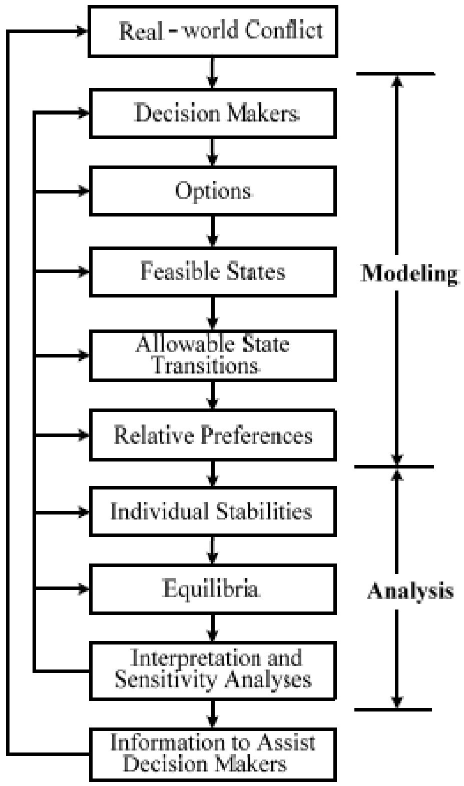


Figure 3.1: Implementation of GMCR

There are numerous advantages to the application of GMCR in strategic decision support. One is that GMCR is a very flexible framework for conflict analysis which can used to analyze numerous types of conflicts with various kinds of information about DMs, preferences and options. Also, the graph model can be applied using both transitive and intransitive preference information as ranking information used for determining stability is used relative to a starting state. Because all transitive preferences can be handled by the model, cardinal utility values that express a DM's preferences for different states are not necessary as in classical game theoretic methods but can still be taken care of by the model (Fang et al., 1993). GMCR can also accommodate different types of moves including reversible, irreversible and common moves. Reversible moves refer to options that, if selected by a DM, can be unselected by that same DM while irreversible moves refer to moves that once selected, cannot be undone. A common move refers to the situation where multiple DMs can make unilateral moves from the same starting state to the same final state (Fang, et al., 1993).

In the following subsection, GMCR is defined in a manner that lays out the formal framework of this conflict analysis methodology. This work previously was published originally by Hipel, Fang, and Kilgour (1993), and was based on Conflict Analysis which was developed by Fraser and Hipel (1984, 1980). As this provides the basis for the important extensions that make up the research of my thesis, their inclusion here is essential.

3.2 Graph Model for Conflict Resolution – Formal Definitions

GMCR, developed by Kilgour et al. (1987) and Fang et al. (1993) allows conflicts to be analyzed analytically, formally and visually. Through the application of solution concepts developed by Fang et al. (1993), Fraser and Hipel (1984), Howard (1971) and Nash (1950, 1951), the Graph Model can be utilized to determine stability information about states within the conflict. From this information, state equilibria can be determined.

Definition 1 (The Graph Model for Conflict Resolution): A graph model for conflict resolution is a 4-tuple $(N, S, (A_i)_{i \in N}, (\succ_i, \sim_i)_{i \in N})$, where N: the set of all decision makers (DMs) ($|N| \geq 2$), S: the set of all states in the conflict ($|S| \geq 2$), (S, A_i): DM i's graph (S: the set of all vertices, $A_i \subset S \times S$: the set of all arcs such that $(s, s) \notin A_i$ for all $s \in S$ and all $i \in N$), and $(\succ_i, \sim_i)$: DM i's preferences on S. For $s, t \in S$, $s \succ_i t$ means that DM i prefers state s to t, while $s \sim_i t$ indicates that DM i is indifferent between s and t. Relative preferences are assumed to satisfy the following properties:

$\succ_i$ is asymmetric; hence, for all s, $t \in S$, $s \succ_i t$ and $t \succ_i s$ cannot hold true simultaneously.

$\sim_i$ is reflexive; therefore, for any $s \in S$, $s \sim_i s$.

$\sim_i$ is symmetric; hence, for any s, $t \in S$ if $s \sim_i t$ then $t \sim_i s$.

$(\succ_i, \sim_i)$ is complete; therefore, for all s, $t \in$ S one of $s \succ_i t$, $t \succ_i s$ or $s \sim_i t$ is true.

The arcs between states in Definition 1 represent the set of unilateral movements that a DM has between those states. As defined, GMCR provides a basis for the following definitions which outline how DMs move between states and how state stabilities and equilibria are calculated.

Definition 2 (Reachable list ($R_i(s)$)): For $i \in N$ and $s \in S$, DM i's reachable list from state s is the set of arcs $\{t \in S \mid (s, t) \in A_i\}$, denoted by $R_i(s) \subset S$. The reachable list is a record of all the states that a given DM can reach from a specified starting state in one step. In the Graph Model, all states that are joined by an arc A_i beginning at state s, are part of DM i's reachable list from s. A more complete, inductive definition for reachable lists follows.

When assessing the stability of a state for a given DM, it is necessary to examine possible responses by other DMs. In a two-DM model, the opponent is a single DM, while in an n-DM model with $n \geq 2$, two or more opposing DMs exist within the model. To extend the stability definitions to n-DM models, the definition of countermoves by a group of DMs must be introduced first. Let $H \subseteq N$ be a nonempty subset of all DMs. A unilateral move (UM) by a group of DMs is defined as a legal sequence of UMs, defined below, by individual DMs who are members in the group. In a legal sequence, a DM may move more than once, but not consecutively. Let $R_H(s)$ denote the set of all states that can be reached through any legal sequence of UMs from state s by some or all DMs in H. If $s_1 \in R_H(s)$, let $\Omega_H(s, s_1)$ be the set of all last DMs in legal sequences from s to s_1.

To determine $R_H(s)$ two steps must be undertaken: i) add states that are UMs from state s by all DMs in H, and ii) add those other states that can be attained via sequences of "joint moves" by some or all DMs in H. In the latter case, it is necessary to screen out sequences containing consecutive moves by any DM. This is achieved by distinguishing $|\Omega_H(s, s_1)| = 1$ from $|\Omega_H(s, s_1)| > 1$: if there is only one DM in H who can move to s_1, a state $s_2 \in R_j(s_1)$, $j \in H$ is a member of $R_H(s)$ if and only if $j \neq i$; if there are two or more DMs who can make a move from s_1 to a state $s_2 \in R_j(s_1)$, i.e., $|\Omega_H(s, s_1)| > 1$, then any state $s_2 \in R_j(s_1)$, $j \in H$ can be added to $R_H(s)$ because there exists a sequence from s to s_1 in which the last move is not made by j. The set $R_H(s)$ can be regarded as the reachable list of H, in that all states in $R_H(s)$ can be achieved by some or all DMs in H without participation of any DM in N-H.

In order to accurately model conflict, one needs to understand the goal of each DM in the conflict. Ordinal rankings are an intuitive manner for handling information about DM preferences. In order to adequately describe the three most common preference structures: more preferred, equally preferred and less preferred, sets that define DM preferences for given strategies and options are utilized. The symbol $\phi_i^{\simeq}(s)$ represents the set of states that are less than or equally preferred by DM i to state s and $\phi_i^{+}(s)$ represents the set of states preferred by DM i to state s.

Definition 3 (Unilateral Improvement (UI) list for a DM ($R_i^+(s)$)):

For $i \in N$ and $s \in S$, DM i's UI list from state s is the set $\{t \in R_i(s) \mid t \succ_i s\}$, denoted by $R_i^+(s) \subset S$. The UI list is a subset of the reachable list and includes all states which are more preferred than the starting state for DM i. More inductively, UI lists are defined as the intersection of a reachable list as defined in Definition 2 and the set of more preferred states, written as $R_i^+(s) = \phi_i^+(s) \cap R_i(s)$.

In order to apply this information, it is necessary to define solution concepts which can be used to determine state stability and equilibria. The concepts given in Definitions 4 through 10 are used to define the said solution concepts which are then used to determine the overall equilibrium states for the conflict.

Definition 4 (Reachable list of a coalition ($R_H(s)$)): To define the reachable list inductively, let $s \in S$ and $H \subseteq N, H \neq \phi$. A UM from state s by the subset of DM's, H, a member of $R_H(s)$, is defined inductively such that:

i) if $i \in H$ and $s_1 \in R_i(s)$, then $s_1 \in R_H(s)$ and $i \in \Omega_H(s, s_1)$.

ii) if $s_1 \in R_H(s)$, $j \in H$ and $s_2 \in R_j(s_1)$, then

a) if $|\Omega_H(s, s_1)| = 1$ and $j \notin \Omega_H(s, s_1)$, then $s_2 \in R_H(s)$ and $j \in \Omega_H(s, s_2)$

b) if $|\Omega_H(s, s_1)| > 1$, then $s_2 \in R_H(s)$ and $j \in \Omega_H(s, s_2)$ For $H \subset N$ and $s \in S$. If the graphs of all DMs in H are transitive the reachable list of coalition H from state s is defined inductively as the set $R_H(s)$ that satisfies the two conditions: (i) if $i \in H$ and $t \in R_i(s)$, then $t \in R_H(s)$, and (ii) if $i \in H$ and $t \in R_H(s)$ and $u \in R_i(t)$, then $u \in R_H(s)$.

This recursive definition for coalition movement ensures that even in the presence of intransitive moves, no single DM moves more than once in a coalition move. Next, in Definition 5, a similar method is applied to ensure that intransitive moves are accounted for when a coalition of DMs make unilateral improvements.

Definition 5 (Unilateral Improvement list of a coalition ($R_H^+(s)$)): Let $k \in S$ and $H \subseteq N$, $H \neq \phi$. A unilateral improvement by H is a member of $R_H^+(k) \subseteq S$, where $\Omega_H^+(k, k_1)$ represents the set of last DM's in the sequence of moves from k to k_1, is defined inductively by

i) if $j \in H$ and $k_1 \in R_H^+(k)$ and $j \in \Omega_{Hk}^+(k_1)$,

ii) if $k_1 \in R_j^+(k)$, $j \in H$ and $k_2 \in R_H^+(k_1)$, then

a) if $|\Omega_{Hk}^+(k_1)| = 1$ and $j \notin \Omega_{Hk}^+(k_1)$, then $k_2 \in R_H^+(k)$ and $j \in \Omega_{Hk}^+(k_2)$,

b) if $|\Omega_{Hk}^+(k_1)| > 1$, then $k_2 \in R_H^+(k)$ and $j \in \Omega_{Hk}^+(k_2)$.

Note that if all of the DM's graphs are transitive, the definition of UI lists can be modified such that for $H \subset N$ and $s \in S$, the strictly unilateral improvement list of coalition H from state s is defined inductively as the set $R_H^+(s)$ that satisfies the two conditions: (i) if $i \in H$ and $t \in R^+{}_i(s)$, then $t \in R^+{}_H(s)$, and (ii) if $i \in H$ and $t \in R^+{}_H(s)$ and $u \in R^+{}_i(s)$, then $u \in R^+{}_H(s)$.

Definition 6 (Nash stability (Nash)): For $i \in N$, state $s \in S$ is Nash stable for DM i, denoted by $s \in S_i^{Nash}$, if and only if $R_i^+(s) = \phi$. Thus, Nash stability occurs when a DM has no UIs from a given state and thus is better off to remain at that state.

Definition 7 (General metarationality (GMR)): For $i \in N$, state $s \in S$ is general metarational for DM i, denoted by $s \in S_i^{GMR}$, if and only if for all $x \in R^+{}_i(s)$, $R_{N \setminus \{i\}} \cap \phi_i^{\simeq}(s) \neq \phi$.

General Metarationality is a solution concept that can be used by a DM to determine a 'worst case' scenario for a particular state in the sense that the preferences of the sanctioning DMs, meaning those DMs who would prevent the first DM from moving, are not taken into account. Hence, opponents may make moves that appear not to be credible in order to block an improvement by the particular DM.

Definition 8 (Symmetric metarationality (SMR)): For $i \in N$, state $s \in S$ is symmetric metarational for DM i, denoted by $s \in S_i^{SMR}$, if and only if for all $x \in R_i^{+}(s)$, there exists $y \in R_{N\backslash\{i\}}(x) \cap \phi_i^{\simeq}(s)$ such that $z \in \phi_i^{\simeq}(s)$ for all $z \in R_i(y)$.

Symmetric metarationality looks ahead one step further than GMR and is a more conservative solution concept with respect to risk.. First, the particular DM determines if a unilateral improvement can be sanctioned by opposing DMs, using either a credible or non-credible move. Next, the DM seeks to find out if he or she can escape from this sanction. If the opposing DMs can enforce a sanction and the DM cannot escape from it, than the state is said to be GMR stable. If all possible unilateral improvements by the DM from the new state can be blocked the state is stable according to symmetric metarationality.

Definition 9 (Sequential stability (SEQ)): For $i \in N$, state $s \in S$ is sequentially stable for *DM i*, denoted by $s \in S_i^{SEQ}$, if and only if for all $x \in R_i^{+}(s)$, $R_{N\backslash\{i\}}^{+}(x) \cap \phi_i^{\simeq}(s) \neq \phi$.

Sequential sanctioning is a situation in which a DM will avoid moving unilaterally to a more improved state because an opposing DM can sanction the DM, moving the conflict to a less desired state for the particular DM. In this case, the opposing DM will only sanction the initial DM using a 'credible move'. After performing these various analyses, the goal is to provide some form of useful information to DMs who are taking part in the conflict. The information that is provided is dependent upon the type of solution concepts used to perform the stability analyses and thus different solution concepts can be applied, dependent upon the nature of the conflict being analyzed. In Table 3.1 the amount of foresight and risk each of the solution concepts incorporates are listed.

Table 3.1: Solution Concepts and Risk

Solution Concept	***Original Reference***	***Risk***	***Foresight***	***Disimprovements***
Nash stability	Nash (1950, 1951); van Neumann and Morgenstern (1953)	Ignores risk	Low	Never
Symmetric metarational	Howard (1971)	Avoids risk	Medium	By opponents
General metarational	Howard (1971)	Avoids risk	Medium	By opponents
Sequential stability	Fraser and Hipel (1979, 1984)	Takes some risk	Medium	Never
Adapted from Kilgour, Fang and Hipel (1996)				

Other solution concepts, that have not been defined herein, are available to allow for higher foresight. These include non-myopic stability (Brams and Witman, 1981) and limited move stability (Zagare, 1984; Kilgour, 1985) which allow high and variable foresight while taking into account strategic disimprovements. Limited move stability examines multiple moves ahead in a conflict and is often completed by examining the potential evolution of a conflict with a tree diagram. At each state, potential movements by each DM are examined and compared to the status quo state. This analysis may be extended further to create a non-myopic analysis where DMs look more than a selected number of states ahead, but infinitely ahead in search of a stable state or states.

These solution concepts can be said to represent the movements of independent DMs who are only concerned with satisfying their own preferences. In Subsection 3.3, coalition definitions developed by Inohara and Hipel (2008 a,b) and Kilgour et al. (2001) will be discussed and laid out. Further, new solution concepts developed by the aforementioned authors will be given for the case of coalition movements.

3.3 Coalition Solution Concepts in the Graph Model for Conflict Resolution

It is quite common in conflict situations for a group of DMs to work together and form a coalition that benefits all coalition members. Thus, it is useful to extend the solution concepts outlined in Subsection 3.2 to accommodate coalition behavior, in order to consider its strategic impact. The following definitions extend the theory and solution concepts to include this group behavior using the research completed by Inohara and Hipel (2008 a,b) and Kilgour et al. (2001). In addition, these definitions, in conjunction with those found in Chapter 4, will form the basis for the Coalition and Attitudes framework presented in Chapter 8.

Definition 10 (Coalition improvement list ($R_H^{++}(s)$)): The coalition improvement list of a coalition $H \subset N$, with states $s, t \in S$, $R_H^{++}(s)$ is defined as the set $\{t \in R_H(s) | \ \forall i \in H, t \succ_i s\}$. For a coalition movement to be a coalition improvement it must satisfy the equality $R_H^{++}(s) = \phi_H^{+}(s) \cap R_H(s)$. This means that a coalition improvement is reachable by the coalition and preferred by all DMs in the coalition.

Definition 11 (Coalition less improved state): Let $\phi_H^{\simeq}(s)$ represent the set of all states that are less or equally preferred to state s by at least one DM in coalition H. That is, $\{x \in S \ | \ \exists i \in H, (s \succ_i x \text{ or } s \sim_i x)\}$. The set $\phi_H^{\simeq}(s)$ thus represents all the states that are not more preferred than s by every member of the coalition H. It can be seen here that a coalition behaves according to a unanimous decision rule.

In the following definitions, $P(H)$ is a notation that refers to the class that a DM or coalition is part of, where $P(N)$ represents the class of DMs in the whole set N. Additionally, subclasses are defined such that for $H \subset N$, $P(H)$ denotes the subclass $\{K \in \mathrm{P}(N) \mid K \subset H\}$ of $P(N)$.

Definition 12 (Coalition Nash stability for a coalition (CNash)): A state $s \in S$ is coalition Nash stable for coalition $H \in \mathrm{P}(N)$, denoted by $s \in S_H^{CNash}$, if and only if $R_H^{++}(s) = \phi$ (Kilgour et al., 2001; Inohara and Hipel, 2008).

Definition 13 (Coalition Nash stability for a DM): For $i \in N$, state $s \in S$ is coalition Nash stable for DM *i*, if and only if $s \in S_H{}^{\mathrm{CNash}}$ for all $H \in \mathrm{P}(N)$ such that $i \in H$.

Thus, parallel to Definition 6 for Nash stability, a state is CNash stable for the coalition only if there are no coalition improvements from the starting state. Further, when a state is CNash stable for a coalition *H*, and a DM *i* belongs to that coalition such that it can be said $i \in H$, then the state is CNash stable for that DM also.

Definition 14 (Coalition general metarationality for a coalition (CGMR)): For $H \in \mathrm{P}(N)$, state $s \in S$ is coalition general metarational for coalition *H*, denoted by $s \in S_H{}^{\mathrm{CGMR}}$, if and only if for all $x \in R_H{}^{++}(s)$, $R_{\mathrm{P}(N\text{-}H)}(x) \cap \phi_H^{\simeq}(s) \neq \phi$.

Definition 15 (Coalition general metarationality for a DM): For $i \in N$, state $s \in S$ is coalition general metarational for DM *i*, if and only if $s \in S_H{}^{\mathrm{CGMR}}$ for all $H \in \mathrm{P}(N)$ such that $i \in H$.

CGMR stability is parallel to GMR stability, defined previously in Definition 7. Definition 14 shows that if there exists a sanction to a coalition improvement, such that the conflict is moved to a state this less preferred by at least one coalition member, the starting point is CGMR stable for the coalition, by Definition 14, and for each DM within the coalition, by Definition 15.

Definition 16 (Coalition symmetric metarationality for a coalition (CSMR)) For $H \in \text{P}(N)$, state $s \in S$ is coalition symmetric metarational for coalition H, denoted by $s \in S_H^{\text{CSMR}}$, if and only if for all $x \in R_H^{+}(s)$, there exists $y \in R_{\text{P}(N\text{-}H)}(x) \cap \phi_H^{\simeq}(s)$ such that $z \in \phi_H^{\simeq}(s)$ for all $z \in R_H(y)$.

Definition 17 (Coalition symmetric metarationality for a DM) For $i \in N$, state $s \in S$ is coalition symmetric metarational for DM i, if and only if $s \in S_H^{\text{CSMR}}$ for all $H \in \text{P}(N)$ such that $i \in H$.

Similar to SMR stability from Definition 8, CSMR stability looks three moves ahead. First, the coalition determines if their coalition improvement can be sanctioned by an opposing DM or coalition. Then, the coalition tries to determine if they can escape from this sanction. If they cannot escape the sanction, the state is CSMR stable for the whole coalition, as in Definition 16, and for each member of the coalition, as in Definition 17.

Definition 18 (Coalition sequentially stable for a coalition (CSEQ)): A state $s \in S$ is coalition sequentially stable for coalition $H \in \text{P}(N)$, denoted by $s \in S_H^{CSEQ}$, if and only if for all $x \in R_H^{++}(s)$, $R_{P(N \backslash H)}^{++}(x) \cap \phi_H^{\simeq}(s) \neq \phi$.

Definition 19 (Coalition sequential stability for a DM) For $i \in N$, state $s \in S$ is coalition sequentially stable for DM i, if and only if $s \in S_H^{\text{CSEQ}}$ for all $H \in \text{P}(N)$ such that $i \in H$.

CSEQ stability in parallel to SEQ, defined in Definition 9, is a situation in which a coalition will avoid making a coalition improvement because the opposing DM or coalition is able to sanction their improvement, by moving the conflict to a state which is less preferred by at least one member of the coalition, as shown in Definition 18. Each member of the coalition would also then be stable by CSEQ as explicitly defined in Definition 19.

3.4 Application of GMCR to an Expanded Sustainable Development Conflict

As explained in Subsections 3.1 through 3.4, GMCR is an attractive decision support system for analyzing complex strategic conflicts. Using this framework, an environmental management conflict, based around the issue of sustainable development, as was previously introduced in Subsection 2.2.2.2 and Figures 2.4 and 2.5, is examined. Subsequently, the literature on environmental conflict analysis is surveyed in Subsection 3.4 prior to the concluding remarks.

In Figure 3.1, shown previously, the implementation of GMCR is illustrated, starting with an investigation of the DMs: their identity, options and relative preferences are needed to form a conflict model. Next, individual stability, equilibrium and sensitivity analyses are performed. When applying the graph model methodology to a real world dispute, one can utilize the decision support system (Sage, 1991) called GMCR II (Fang et. al., 2003a,b; Hipel et al., 2008a,b). In the following example, the generic environmental conflict studied is that of the strategic interactions of developers and environmentalists described in Subsection 2.2.2.2. Next, the DMs and their options are determined and the feasible states are found, as illustrated later in Table 3.2. Finally, assuming that all moves are reversible and after ordering the states from most to least preferred for both DMs, the model is completed and the analysis carried out.

3.4.1. Stability Analysis of the Sustainable Development Conflict

The Normal or Matrix Form for displaying a conflict, as depicted previously in Figures 2.4 and 2.5 of Chapter 2, for the Sustainable Development Conflict, constitutes a convenient way to record a conflict model having only two DMs and a small number of strategies, such as is the case for 2x2 games. Likewise, the Integrated Graph Model shown in Figure 3.2 for visualizing a conflict in normal form, works well for smaller disputes. As this conflict is expanded it is necessary to show the conflict in Integrated Graph form and avoid the use of the matrix or Normal Form. However, an especially flexible format for writing down a dispute consisting of any finite number of DMs, each of whom controls any finite number of options, is the Option Form shown in Table 3.1 for the Expanded Sustainable Development Conflict. The Option Form was first proposed by Howard (1971) and can be employed with the methodology of the Graph Model for Conflict Resolution when the selection of options is used to create states. However, the theory of the Graph Model methodology still forms the rigorous mathematical structure for which the Option Form is employed to display the conflict model and analytical findings.

In Option Form, the left column in Table 3.2 lists the three DMs in the Expanded Sustainable Development Conflict: the Environmentalists (E), Developers (D), and Government (G). The second column gives the options that each of the DMs controls: E can be proactive or reactive while D can practice sustainable or unsustainable development and G can be vigilant or lax in enforcing environmental regulations. If more than three DMs were participating in a conflict, the first two columns on the left could be extended as much as required. Next, moving to the right, different combinations of selecting and not selecting options, denoted by a Y, for yes, and N, for no, respectively, give rise to the various states within the conflict. For example, in Table 3.2 when the Environmentalists choose to act proactively (Y), the Developers choose not to act sustainably (N), and the Government chooses to act vigilantly (Y) the resulting state is PUV. As illustrated, choosing not to pursue an option is akin to selecting the complementary option; for example in state RSV, the Environmentalists choose to behave reactively and thus decide not to be proactive.

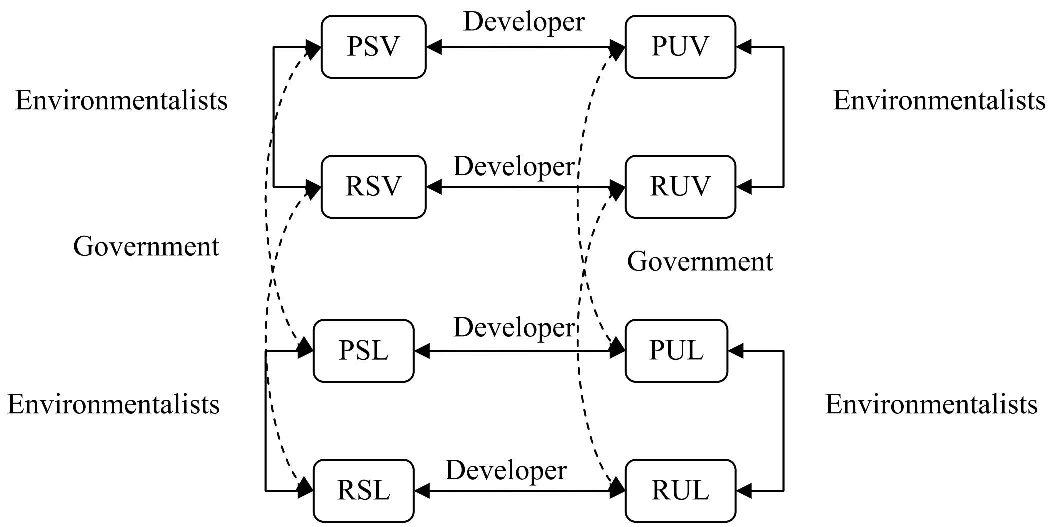
Using this new state notation, the relative stability of all eight states within the conflict is given in Table 3.3, for each of the aforementioned solution concepts defined in Subsection 3.2. For example, as neither E nor D has unilateral improvements away from state PUL, state PUL is Nash stable for both DMs. Because PUL is Nash stable for both DMs, it forms Nash equilibrium.

Table 3.2: Modified Sustainable Development Conflict Presented in Option Form

DM	Option								
Environmentalist (E)	Proactive (P)	Y	Y	N	N	Y	Y	N	N
	Reactive (R)	N	N	Y	Y	N	N	Y	Y
Developer (D)	Sustainable (S)	Y	N	Y	N	Y	N	Y	N
	Unsustainable (U)	N	Y	N	Y	N	Y	N	Y
Government (G)	Vigilant (V)	N	N	N	N	Y	Y	Y	Y
	Lax (L)	Y	Y	Y	Y	N	N	N	N
STATE ID		PSL	PUL	RSL	RUL	PSV	PUV	RSV	RUV

As was noted in Chapters 2, it can be assumed that the Environmentalists (E) tend to be proactive and would prefer that the Developer (D) act in a sustainable manner. Further, one can assume that the Environmentalists would prefer that the Government (G) behave in a strict manner toward the activities of the Developer that would have a negative environmental impact. The Developer, of course, still prefers to behave unsustainably, that the Environmentalists (E) not be too proactive and further, they likely prefer that the Government (G) is lax. That being said, it is likely that the Government (G) would prefer that the Developer (D) behave sustainably on their own, that the Environmentalists (E) not be too proactive and that they remain lax (L), in order to reduce federal or provincial/state spending. In this way the preference vectors shown at the bottom of Figure 3.2 are developed.

The integrated graph model for the Expanded Sustainable Development Conflict is shown in Figure 3.2. As can be seen, the eight states in this conflict are depicted as nodes while movement between states under the control of a given DM are drawn as arcs, for which arrows indicate the direction of possible movement. Arrows are given at both ends of all arcs, since all of the movements are considered to be reversible for the purposes of this study. In practice, some moves can be irreversible which is shown by having only one arrow on a given arc. For instance, a devastating pollution spill cannot be immediately reversed once the incident has occurred. Finally, the ordinal preferences for each DM are given at the bottom of Figure 3.2, where '>' means more preferred. In practice, one could also have equally preferred states, which can be suitably marked using equality signs. Moreover, although transitivity is assumed for the ordinal preferences used in this example, GMCR can also handle intransitive preference information which occasionally arises in practice.



<u>Ranking of States</u>

Environmentalists: PSV > RSV > PUV > PSL > RSL > RUV > PUL > RUL

Developers: RUL > PUL > RSL > PSL > RUV > PUV > RSV > PSV

Government: RSL > RSV > PSL > PSV > RUL > RUV > PUL > PUV

Figure 3.2: Graph Model of the Expanded Sustainable Development Conflict for Environmentally Irresponsible Developers, Proactive Environmentalists and Fiscally Conservative Government

With the preferences developed according to the DM's desires stated above, the conflict can be written in ‘tableau form’, a method from Conflict Analysis, developed by Fraser and Hipel (1984). In tableau form, the equilibria are written in the top row, but apply to all of the DMs in the conflict. For example, state RUV is an equilibrium for all three DMs in the conflict.

Table 3.3: Modified Sustainable Development Conflict Presented in Tableau Form

	x	x	x	x	x	E	E	x
	r	s	r	r	s	s	r	u
E	PSV	RSV	PUV	PSL	RSL	RUV	PUL	RUL
		PSV			PSL	PUV		PUL
	r	r	u	u	r	r	u	u
D	RUL	PUL	RSL	PSL	RUV	PUV	RSV	PSV
			RUL	PUL			RUV	PUV
	r	s	r	s	r	s	r	u
G	RSL	RSV	PSL	PSV	RUL	RUV	PUL	PUV
		RSL		PSL		RUL		PUL

Note – states with an 'r' above them are Nash stable, those with an 's' above them are Sequentially stable, and those with a 'u' above them are unstable by those two solution concepts. 'E' refers to equilibrium states, while non-equilibriums are denoted by an 'x'.

As can be seen in Table 3.3, the modified conflict gives rise to 2 distinct equilibriums: RUV, where the Environmentalists are reactive, the Developers unsustainable and the Government vigilant, and PUL where the Environmentalists are proactive, the Developers unsustainable and the Government is lax in its environmental regulation. State stabilities in Table 3.3 were found using Nash stability, Definition 6 and Sequential stability, Definition 9. For example, state PUV is Nash stable for E as R_E^+(PUV) = $\emptyset$, according to Definition 6. State PSV is Sequentially stable for G as R_G^+(PSV) = {PSL} and $R_{N\text{-}G}^+$(PSL) = {PUL}. As PSV $>_G$PUL, it is disadvantageous for G to move from PSV and thus PSV is Sequentially stable by Definition 6.

As can be seen from the preference vectors of all 3 DMs, these particular outcomes are highly preferred by the Environmentalists (E) or Government (G), but are highly preferred by the Developers (D). Thus, it is likely that some sort of new approach would be needed by either the Government (G) or the Environmentalist (E) in order to move the conflict to a better outcome. For example, if G has positive attitudes towards E, perhaps they can work together to pressure D to behave sustainably.

3.4.2 Coalition Analysis of an Expanded Sustainable Development Conflict

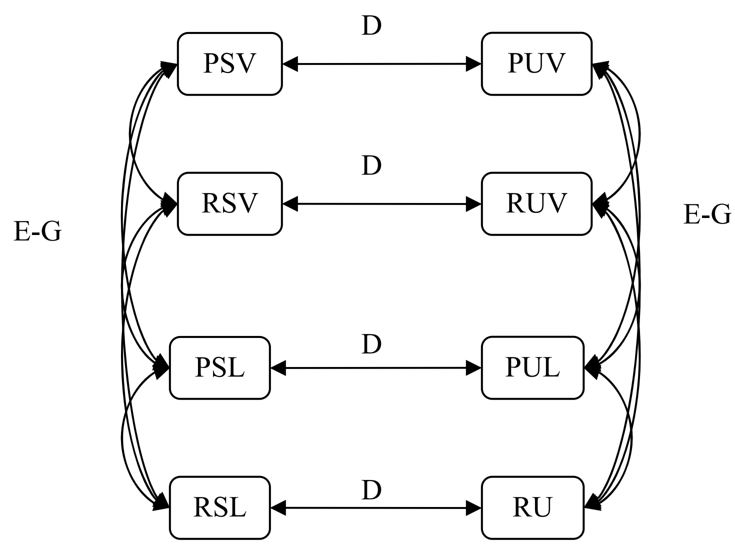
Given this analysis of the Sustainable Development Conflict, it is compelling to determine whether DMs could act in a partnership to bring about an effective coalition result. Employing Definitions 10 through 19, it is possible to apply the Coalition Analysis developed by Inohara and Hipel (2008 a,b) to this novel environmental conflict. In this particular case study, the idea of a coalition between the Environmentalists (E) and the Government (G) will be considered, as both groups are concerned with the safety and well-being of their constituent citizens. In Table 3.4, the possible coalition movements of E and G (denoted E-G), and their possible joint improvements are considered.

Table 3.4: Coalition Improvements for Coalition E-G

S	$R_G(s)$	$R_E(s)$	$R_{E\text{-}G}(s)$	$R^{++}_{E\text{-}G}(s)$
PSV	*PSL*	*RSV*	*PSL, RSV, RSL*	--
PSL	*PSV*	*RSL*	*PSV, RSL, RSV*	*RSV*
PUV	*PUL*	*RUV*	*PUL, RUV, RUL*	--
PUL	*PUV*	*RUL*	*PUV, RUL, RUV*	*RUV*
RSV	*RSL*	*PSV*	*RSL, PSV, PSL*	--
RSL	*RSV*	*PSL*	*RSV, PSL, PSV*	--
RUV	*RUL*	*PUV*	*RUL, PUV, PUL*	--
RUL	*RUV*	*PUL*	*RUV, PUL, PUV*	

As can be seen in Table 3.4, the application of coalition analysis to this particular conflict greatly reduces the number of movements that are made by these two DMs. Moving from left to right across the table, the UMs of *G* and *E* are listed and then combined in the fourth column. Where the UMs of *G, E,* and the combination of their UMs are added together, the set of coalition reachable states for G-E is created by combining G's and E's UMs, as shown in Definition 4. For example, from state *PSV* , $R_G(PSV) = PSL$ and $R_E(PSV) = RSV$. Further, from

RSV $R_G(RSV) = RSL$, and thus $R_{E\text{-}G}(PSV) = \{PSL, RSL, RSV\}$. Finally, a coalition improvement list is determined by taking the coalition reachable list and selecting only those movements which result in a better final state for both DMs. As, in this particular conflict, DM *G* has a propensity to behave selfishly and not enforce regulations on behalf of the citizenry, there are only two movements which constitute coalition improvements, by Definition 11. The coalition movements are further shown in Figure 3.3, where the connections between the states are visible as the arcs A_i given in Definition 1, of the Graph Model for Conflict Resolution. In Table 3.5, the coalition analysis is applied in tableau form.



Ranking of States

Environmentalists: PSV > RSV > PUV > PSL > RSL> RUV > PUL > RUL

Developers: RUL > PUL > RSL > PSL > RUV > PUV > RSV > PSV

Government: RSL > RSV > PSL > PSV > RUL > RUV > PUL > PUV

Figure 3.3: Graph Model of the Expanded Sustainable Development Conflict for Environmentally Irresponsible Developers (D), and Proactive Environmentalists and Fiscally Conservative Government acting in Coalition (E-G)

Table 3.5: Coalition Analysis

	x	x	E	E	E	E	x	E
	cr	cr	cr	cs	cr	cr	u	cr
E	PSV	RSV	PUV	PSL	RSL	RUV	PUL	RUL
				RSV			RUV	
	r	r	u	s	r	r	u	u
D	RUL	PUL	RSL	PSL	RUV	PUV	RSV	PSV
			RUL	PUL			RUV	PUV
	cr	cr	cs	cr	cr	cr	u	cr
G	RSL	RSV	PSL	PSV	RUL	RUV	PUL	PUV
			RSV				RUV	

Examining Table 3.5, it is apparent that the formation of a coalition between E and G was not particularly effective. Now, there are 5 equilibrium states, due to the lack of cooperative moves between the coalition DMs. The stabilities for D were calculated precisely the same way that they were in Subsection 3.4.1. However, if one examines the coalition, the results are interesting. For example, *E-G* has a coalition improvement from PSL to RSV, denoted as $R^{++}_{E\text{-}G}(PSL)$ = {RSV}. From RSV, D has a UI to RUV, denoted as $R^{+}_{D}(RSV) = \{RUV\}$. As $PSL >_E RUV$ and $E \in E\text{-}G$.

CNash stability is arrived at in a similar fashion as Nash stability is in subsection 3.4.1. In this case, the coalition improvement list of the given state must be empty, according to Definition 12 and 13. For example, state *RUV* is CNash stable for the coalition *E-G*, as $R^{++}_{E\text{-}G}(RUV) = \{0\}$, by Definition 13. As *E* and *G* are both elements of the coalition *E-G*, the state is also CNash stable for each of these DM. This relationship between Definitions 12 and 13, allows for a complete stability analysis of the conflict, using the coalition framework.

By performing this coalition analysis a more complete view of the conflict has been formed which shows whether cooperation between the Government and Environmentalists can, indeed, lead to a number of new outcomes in this conflict. In this particular case, the conflict model first tested in Subsection 3.4.1 led to a set of results that were more preferred by the coalition members.

3.5 Summary

Conflict analysis is a field of study which examines the potential actions and motivations of DMs under conflict in an effort to provide insights into the actions needed for successful win-win outcomes to occur, to determine causes of past conflict outcomes that were not mutually beneficial for all DMs and to inform policy makers. As seen in the Expanded Sustainable Development Conflict, GMCR can be applied to strategic negotiations to determine real life conflict outcomes, based on information know about the problem. Further, the coalition analysis framework allows conflict analysts to determine what the strategic repercussions of cooperation are upon the conflict outcome. In Chapter 4, a further extension of this methodology, attitudes, is formally defined.

Chapter 4

Attitudes within the Graph Model for Conflict Resolution

4.1 Introduction

As was shown in Chapters 2 and 3, game theoretic methodologies are beneficial for modeling conflicts at the strategic level (Fang et al, 1993). In order to increase the ability of GMCR to accurately model human behavior under conflict, certain additions to GMCR have been proposed. For example, Li et al (2004a) created a framework for handling uncertain preferences, while extending those solution concepts mentioned in Subsection 3.2 to this new structure. AL-Mutairi et al. (2008) and Bashar et al. (2012), examined the structuring of preferences using fuzzy logic. Obeidi, et al. (2005) examined the impact of emotions on conflict by proposing that subsets of feasible states remained hidden in conflicts due to the type of emotions DMs hold. These methods are attempts to take into account misunderstanding, misinformation or irrational behavior. A further, effective methodology for considering the strategic impact of these three aspects on conflict is the attitudes methodology, developed by Inohara, et al., (2007). The attitudes methodology provides a framework to consider what the strategic implications would be of a DM who acts based not only on his own interest but with concern for the interests of others. Further, the method can be used to test the robustness of conflict analysis results. Within GMCR, preferences, UIs and coalition improvements all assume that DMs or coalitions of DMs act in a manner to improve their position while promoting indifference to the positions of others

(Fraser and Hipel, 1984; Fang, et al, 1993). When applying attitudes, however, a conflict analyst can consider what would occur when DMs possibly make moves and countermoves that align with their attitude towards or against the fortunes of one or more other DMs, in spite of the DM's own preferences.

A further reason to use attitudes is that it allows for a simple method to model cooperation under conflict, or further, to model the potential strategic price of spite. Cooperation has previously been studied by Inohara and Hipel (2008 a,b) and Kilgour et al. (2001) using coalition analysis, which was laid out in Chapter 3, Subsection 3.3. Although GMCR is concerned with the study of non-cooperative conflicts, the application of attitudes can be used to examine cooperative negotiations as well as more overtly aggressive conflicts (Inohara, et al., 2007; Bernath Walker, et al., 2009). These expansions give GMCR a broader range of applicability and allow for interesting insights into the type of real-world decisions made by engineers, politicians and businesses. Further, in Chapters 6 through 9, refinements will be made that represent significant theoretical expansions to the attitude methodology.

4.2 Attitudes Definitions

To properly apply attitudes, a new set of definitions is given which create a proper mathematical framework. In this framework, a DM is allowed to consider whether their moves or countermoves hurt or help his fellow DM, according to their own desires. In this way, attitudes represent a simple way to model complex changes in a DM's own preferences, as will be illustrated in Chapter 6.

In Definitions 20 through 24, and 27, attitudes and a special set of relational preference types will be defined. In Definitions 25 and 26, preference structures from Definitions 20 and 24 will be combined with movement definitions from Chapter 3 to give an attitude variation of 'credible moves'. Finally, in Definitions 28 to 31, special solution concepts will be defined to allow for the determination of state stabilities under attitudes. These attitudes have been related to important psychological phenomena by Yousefi et al (2010).

Definition 20 (Attitudes): For DMs $i, j \in N$, let $E_i = \{+, 0, -\}^N$ represent the set of attitudes of DM i. An element $e_i \in E_i$ is called the attitude of DM i for which $e_i = (e_{ij})$ is the list of attitudes of DM i towards DM j for each $j \in N$ where $e_{ij} \in \{+, 0, -\}$. The e_{ij} is referred to as the attitude of DM i to DM j where the values $e_{ij} = +$, $e_{ij} = 0$ and $e_{ij} = -$ indicate that DM i has a positive, neutral and negative attitude towards DM j, respectively.

If one were to consider a conflict, such as the Expanded Sustainable Development Conflict analyzed in Chapter 3 using GMCR and coalitions within GMCR, where 3 DMs *i, j,* and *k* are in conflict with each other, then it is possible to show the relationship between them as shown in Table 4.1 below. In each cell one element of each DMs set of attitudes is displayed. For example the cell in the i^{th} row and the j^{th} column, displays the attitude e_{ij}, or *i's* attitude towards DM *j.*

Table 4.1: Tabular Representation of Attitudes in a 3-DM Conflict

DM	i	j	k
i	e_{ii}	e_{ij}	e_{ik}
j	e_{ji}	e_{jj}	e_{jk}
k	e_{ki}	e_{kj}	e_{kk}

Each element in Table 4.1 can be either a +, 0, or -, as defined in Definition 20. In the case of a 'rational conflict', where DMs are assumed to positive towards themselves and indifferent towards their opponents, the attitudes of the DMs are represented as shown in Table 4.2.

Table 4.2: Tabular Representation of Attitudes in a Traditionally Considered 3-DM Conflict

DM	i	j	k
i	+	0	0
j	0	+	0
k	0	0	+

As can be seen in Definition 20 attitudes are simply defined as a set of 3 possibilities: negative, positive and neutral. In the following definitions, different types of preferences are defined that will eventually be connected with these attitudes.

Definition 21 (Devoting preference (DP)): The devoting preference of DM $i \in N$ with respect to DM $j \in N$ is $\succeq_j$, denoted by $\mathbf{DP}_{ij}$, such that for s, $t \in$ S, s $\mathbf{DP}_{ij}$ t if and only if $s \succeq_j t$.

If a DM i holds a devoting preference towards another DM j such that s $\mathbf{DP}_{ij}$ t, then DM j must prefer state s to state t. A similar definition can be written for aggressive preference.

Definition 22 (Aggressive preference (AP)): The aggressive preference of DM $i \in N$ with respect to DM $j \in N$ is $NE(\succ_j)$, denoted by $\mathbf{AP}_{ij}$, where $NE(\succ_j)$ is defined as follows: for s, $t \in$ S, s $NE(\succ_j)$ t if and only if $s \succ_j t$ is not true. That is, for s, $t \in$ S, s $\mathbf{AP}_{ij}$ t if and only if s $NE(\succ_j)$ t (if and only if $t \succeq_j s$ under completeness of $\succeq_j$).

If a DM i holds an aggresive preference towards another DM such that s $\mathbf{AP}_{ij}$ t, then DM j must not prefer state s to state t.

Definition 23 (Relational preference): The relational preference $\mathbf{RP}(e)_{ij}$ of DM $i \in N$ with respect to DM $j \in N$ at e is defined as follows:

$\mathrm{RP}(e)_{ij} = \mathrm{AP}_{ij}$ if $e_{ij} = -$, DP_{ij} if $e_{ij} = +$, I_{ij} if $e_{ij} = 0$;

where $\mathbf{I}_{ij}$ denotes that DM i is indifferent with respect to j's preference and, hence, $s\ \mathbf{I}_{ij}\ x$ means that DM i's preferences between state s and x is not influenced by DM j's preference.

Here, Definition 20 links up to Definitions 21 and 22 such that if a DM i has a positive attitude towards DM j, then they will behave according to a devoting preference, $\mathbf{DP}ij$, if DM i has a negative attitude towards DM j, then they will behave according to an aggressive preference, $\mathbf{AP}ij$, and if DM i has a neutral attitude towards DM j, then they will behave according to an indifferent preference, $\mathbf{I}ij$.

Definition 24 (Total relational preference(TRP)): The total relational preference of DM $i \in N$ at e is defined as the ordering $\mathbf{TRP}(e)_i$ such that for s, $t \in S$, $s\ \mathbf{TRP}(e)_i\ t$ if and only if $s\ \mathbf{RP}(e)_{ij}\ t$ for all $j \in N$.

In Definition 24, the Total Relational Preference is defined as the combination of all of DM i's RPs towards all $j \in N$. Thus, all states that are preferred to s, according to all of i's RPs with respect to s are part of the set of Total Relational Preferences to s. In this sense, the Total Relational Reply defined here is analogous to the standard preference, $\succ_i$, included in the definition of GMCR in Definition 1. Thus, with a new type of preference defined formally, it is possible to define new types of 'improvement' and solution concepts.

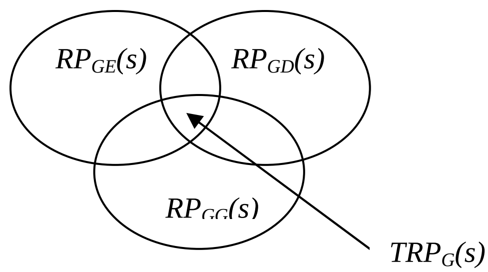


Figure 4.1: Venn Diagram for Total Relational Preference of *G* within Expanded Sustainable Development Conflict

As can be seen in Figure 4.1, the Total Relational Preference from a given state *s* for *G* in the Expanded Sustainable Development Conflict is found by determining the intersection of the all of *G*'s individual Relational Preferences. This, of course, means that the Total Relational Preference list of *G* may differ greatly from *G's* own preferences.

Definition 25 (Total relational reply (TRR)): The total relational reply list of DM $i \in N$ at e for state $s \in S$ is defined as the set $\{t \in R_i(s) \cup \{s\} \mid t\ \mathbf{TRP}(e)_i\ s\} \subset R_i(s) \cup \{s\}$, denoted by $\mathbf{TRR}(e)_i(s)$.

The Total Relational Reply for a DM *i* is the list of states that *i* can reach that satisfy his Total Relational Preferences. In this sense, the Total Relational Reply is analogous to a Unilateral Improvement, Definition 3 in Chapter 3, only now the DM is considering their Total Relational Preference, which corresponds to his attitudes.

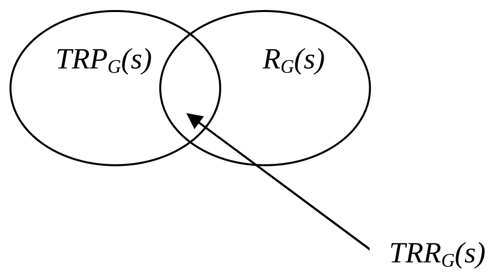


Figure 4.2: Venn Diagram for Total Relational Replies of *G* within Expanded Sustainable Development Conflict

In Figure 4.2, it can be seen that *G's* Total Relational Replies from state *s* correspond to the states that are in the intersection of his Total Relational Preferences and Reachable List from state *s*.

Definition 26 (Total relational reply list of a coalition): The total relational reply list of a coalition, $\mathbf{TRR}(e)_{i}(s) \subseteq S$, where $\Omega_{Hs}^{TRR}(k)$ is the set of last DMs in the sequence between *s* and *k*, is defined inductively, for $H \subset N,\ H \neq \phi$ at *e* for state $s \in S$ such that:

i) if $j \in H$ and $k \in TRR(e)_j(s)$, then $k \in TRR(e)_H(s)$ and $j \in \Omega_{Hs}^{TRR}(k)$,

ii) if $k \in TRR(e)_H(s)$, $j \in H$ and $k_1 \in TRR(e)_j(k)$, then

a) if $\left|\Omega_{Hs}^{TRR}(k)\right| = 1$ and $j \notin \Omega_{Hs}^{TRR}(k)$, then $k_1 \in TRR(e)_H(s)$ and $j \in \Omega_{Hs}^{TRR}(k_1)$,

b) if $\left|\Omega_{Hs}^{TRR}(k)\right| = 1$ then $k_1 \in TRR(e)_H(s)$ and $j \in \Omega_{Hs}^{TRR}(k_1)$

If the graph of all DMs in *H* are transitive, the total relational reply list of coalition $H \subset N$ at attitude *e* for state $s \in S$ is defined inductively as the set $\mathbf{TRR}(e)_H(s)$ that satisfies the next two conditions: (i) if $i \in H$ and $t \in \mathbf{TRR}(e)_i(s)$, then $t \in \mathbf{TRR}(e)_H(s)$, and (ii) if $i \in H$ and $t \in \mathbf{TRR}(e)_H(s)$ and $u \in \mathbf{TRR}(e)_i(t)$, then $u \in \mathbf{TRR}(e)_H(s)$.

The Total Relational Reply list of a coalition refers to the set of states that is reachable by a combination of Total Relational Replies made by members of said coalition. The movements in Definition 26 are especially useful for calculating stabilities, when the DM concerned only considers 'credible' moves by his opponents.

Definition 27 (Relational less preferred or equally preferred states): The symbol $R\phi^{\simeq}(e)_i(s)$ is an analogue of $\phi_i^{\simeq}(s)$ given in Chapter 2. Hence, $R\phi^{\simeq}(e)_i(s)$ is the set $\{t \in S \mid \text{NE}(t\ \mathbf{TRP}(e)_i\ s)\}$ of all states which are not relationally preferred to s by DM i under attitude e. Note that NE(t $\mathbf{TRP}(e)_i$ s) means that "t $\mathbf{TRP}(e)_i$ s" is not true. Keep in mind that $s \notin R\phi^{\simeq}(e)_i(s)$ always holds.

The set of relational less preferred or equally preferred states for a DM i refers to the set of states that are not Total Relational Preferred states from a given starting state. This set of states is especially useful when performing stability analyses, as they represent possible sanctions to moves that DM i might make.

Definition 28 (Relational Nash stability (RNash)): For $i \in N$, state $s \in S$ is relational Nash stable at e for DM i, denoted by $s \in S_i^{RNash(e)}$, if and only if $\mathbf{TRR}(e)_i(s) = \{s\}$.

RNash stability is analogous to Nash stability, defined in Definition 6 of Chapter 3, in that it looks only one move ahead and assumes that if a DM i cannot make a desired move, they will remain at the same state. The only difference between these definitions is that RNash stability is concerned with the availability of a new Total Relational Reply and Nash stability is concerned with the presence of a Unilateral Improvement (Definition 3).

Definition 29 (Relational general metarationality (RGMR)): For $i \in N$, state $s \in S$ is relational general metarational at *e* for DM *i*, denoted by $s \in S_i^{RGMR(e)}$, if and only if for all $x \in$ **TRR**$(e)_i(s) \setminus \{s\}$, $R_{N\setminus\{i\}}(x) \cap R\phi^{\simeq}(e)_i(s) \neq \phi$.

Looking ahead one step further, RGMR stability considers whether or not a DM *i's* Total Relational Reply from a state *s* to another state *x* will be sanctioned by some DM or group of DMs in conflict with *i*. This particular solution concept is very conservative with respect to risk as DM *i* considers the implications of any moves his opponents could make, whether they are credible or not.

Definition 30 (Relational symmetric metarationality (RSMR)): For $i \in N$, state $s \in S$ is relational symmetric metarational at *e* for DM *i*, denoted by $s \in S_i^{RSMR(e)}$, if and only if for all $x \in$ **TRR**$(e)_i(s) \setminus \{s\}$, there exists $y \in R_{N\setminus\{i\}}(x) \cap R\phi^{\simeq}(e)_i(s)$ such that $z \in R\phi^{\simeq}(e)_i(s)$ for all $z \in R_i(y)$.

In Definition 30 RSMR stability, which is analogous to SMR stability, defined in Definition 8 of Chapter 3. Here, RGMR stability is extended one step further and DM *i* asks if it is possible to escape from the sanction being levied against him by his opponents. If it is not possible to move to a state that is more Total Relationally Preferred to the starting state, the state is RSMR stable.

Definition 31 (Relational sequential stability (RSEQ)): For $i \in N$, state $s \in S$ is relational sequential stable at *e* for DM *i*, denoted by $s \in S_i^{RSEQ(e)}$, if and only if for all $x \in$ **TRR**$(e)_i(s) \setminus \{s\}$,

$$\text{TRR}(e)^{N\setminus\{i\}}(x) \cap R\phi^{\simeq}(e)_i(s) \neq \emptyset$$

Relational Sequential stability, a natural attitudes analogue of Sequential stability (Definition 9), occurs when each Total Relational Reply by a DM *i* from some starting state *s* can be relationally sanctioned (Definition 27) by the Total Relational Reply of the opposing DM (Definition 25) or coalition of opposing DMs (Definition 26).

These unique definitions, developed by Inohara et al (2007), create a framework within the greater framework of GMCR that allows for a straight forward analysis of unexpected behavior within strategic conflicts. Further, the attitudes methodology allows a decision analyst to quickly compare the strategic impacts of aggression or devotion, while checking the robustness of stability results obtained using the definitions shown in Chapter 3. In the following Subsection, 4.3, the attitudes framework will be applied to the Expanded Sustainable Development conflict.

4.3 Application of Attitudes in GMCR to the an Environmental Conflict

The Sustainable Development conflict that was first discussed in Chapter 2, and was subsequently expanded and analyzed using GMCR in Chapter 3, will now be analyzed using the attitudes methodology. This conflict is shown in option form again in Table 4.3, as it was previously displayed in Table 3.1. As can be seen, the conflict has 8 states as each DM has two possible strategies, and must select only one of his possible options. In this case, the Environmentalists have the option of being proactive (P) or reactive (R), the developer has the option of using sustainable (S) or unsustainable (U) practices and the Government has the option of strictly enforcing (S) or being lax (L) about environmental standards, with respect to sustainability.

Table 4.3: Expanded Sustainable Development Conflict Presented in Option Form

DM	Option								
Environmentalist (E)	Proactive	Y	Y	N	N	Y	Y	N	N
	Reactive	N	N	Y	Y	N	N	Y	Y
Developer (D)	Sustainable	Y	N	Y	N	Y	N	Y	N
	Unsustainable	N	Y	N	Y	N	Y	N	Y
Government (G)	Strict	N	N	N	N	Y	Y	Y	Y
	Lax	Y	Y	Y	Y	N	N	N	N
STATE ID		PSL	PUL	RSL	RUL	PSV	PUV	RSV	RUV

To analyze this conflict, it is necessary to use the preferences determined in Chapter 3, which are based upon the properties of the DMs that have been previously discussed. It was found in Chapter 3 that the formation of a coalition between E and G did not necessarily lead to a more equitable outcome. It may be better, then, to consider whether a difference in the attitudes held by the DMs may have a more beneficial impact on the outcome.

If one were to consider the possibility of G behaving with positive attitudes towards E and behaving indifferently towards itself, in order to sacrifice short term gains in preference for an environmental improvement, the possible attitudes table would be as shown in Table 4.4.

Table 4.4: New Attitudes for a Modified Sustainable Development Conflict

	E	*D*	*G*
E	+	0	0
D	0	+	0
G	+	0	0

Given this new set of attitudes for DM G, it is necessary to calculate G's Total Relational Preferences and Total Relational Replies, as shown in Definitions 24 and 25. As G's attitudes are such that $e_{GE} = +$, and $e_{GG} = e_{GD} = 0$, G's Total Relational Preferences and Replies will be entirely dependent on E's preferences. In Table 4.5, G's new Total Relational Preferences and Replies are given.

Table 4.5: G's TRPs and TRRs in Modified Sustainable Development Conflict with Attitudes

State	*TRP*	*TRR*
PSV	-	-
RSV	*PSV*	-
PUV	*PSV, RSV*	-
RUV	*PSV, RSV, PUV, PSL, RSL*	-
PSL	*PSV, RSV, PUV*	*PSV*
RSL	*PSV, RSV, PUV, PSL,*	*RSV*
PUL	*PSV, RSV, PUV, PSL, RUV, RSL*	*PUV*
RUL	*PSV, RSV, PUV, PSL, RUV, RSL, PUL*	*RUV*

Given this entirely new set of preferences and movements for G, the conflict is likely to have significant changes in stable and equilibrium states. The new analysis of the conflict, shown in Table 4.6 incorporates these changes and results in a new equilibrium at state RSV, and the dissolution of the two equilibriums previously found in the conflict.

Table 4.6: Attitude Analysis of Modified Sustainable Development Conflict

	x	E	x	x	x	x	x	x
	r	s	r	r	s	u	r	u
E	PSV	RSV	PUV	PSL	RSL	RUV	PUL	RUL
		PSV			PSL	PUV		PUL
	r	r	s	s	r	r	s	u
D	RUL	PUL	RSL	PSL	RUV	PUV	RSV	PSV
			RUL	PUL			RUV	PUV
	u	rr	u	rr	u	rr	u	u
G	RSL	RSV	PSL	PSV	RUL	RUV	PUL	PUV
	RSV		PSV		RUV		PUV	

Note – states with an 'r' above them are Nash stable, those with an 's' above them are Sequentially stable, those with an 'rr' above them are Relational Nash stable, those with an 'rs' above them are Relational Sequentially stable and those with a 'u' above them are unstable by those two solution concepts. 'E' refers to equilibrium states, while non-equilibriums are denoted by an 'x'.

As shown in Table 4.6, an equilibrium that is more preferred for the Environmentalists has been reached. Curiously, E is silenced, or at least rendered 'reactive' by the threat of the D practicing unsustainable development if E becomes proactive. This particular outcome is far better for G also, being in the 1st half of G's preference vector, thus justifying G's ignoring of his own preferences in this instance. Essentially, E agrees to silence its criticism in exchange for G's strict management of environmental regulations. This allows a more beneficial result for both of these DMs to occur.

The Nash and Sequential stabilities from Definitions 6 and 9, shown in Chapter 3 are still applied to DMs E and D. The calculation of these particular solution concepts has not changed from before. The states in G's preference vector, however, have been tested using relational solution concepts, such as those outlined in Definitions 28 through 31. For example, when RSEQ stability is applied to state *PSL* for G, it can be seen that $\mathrm{TRR}(e)_G(PSL) = \{PSL, PSV\}$. Next, by Definition 31, it is essential to determine what Total Relational Replies the other two DMs – E and D – might make from *PSV*. In this case $\mathrm{TRR}(e)_E(PSV) = \{PSV\}$ and $\mathrm{TRR}(e)_D(PSV) = \{PUV, PSV\}$. As the only Total Relational Reply from *PSV* is *PUV,* besides the state *PSV* itself, it is essential to determine if *PUV* belongs to the set $R\phi^{\leq}(PSL)$, making it a sanction state. As $PUS \notin R\phi_G^{\leq}(PSL)$, the state is not a sanction and thus it is unstable according to Definition 31 for RSEQ stability.

4.4 Summary

The attitudes framework represents a new way to examine the way DMs may interact under conflict within the larger framework of GMCR. Specifically, the model allows decision analysts to study aggression and devotion in non-cooperative game while also providing a unique methodology for determining the robustness of the stabilities and equilibria ascertained using the definitions given in Chapter 3. The definitions and framework shown here provide the basis for the interesting analysis presented in Chapter 5 and the theoretical innovations completed in Chapters 6 through 9.

Chapter 5

Sino-American Climate Regime

5.1. Introduction

Due to the detrimental impact of expanding industrialization upon the global climate, it is important for humanity to begin reducing its climatic impact and to adapt to the changes it has already caused. Homer-Dixon (2008) notes that there has been a “sea change” within the scientific community in that a more urgent view of climate change has been adopted by most researchers who study the science of climate change, as data increasingly point towards a greater than expected change in global temperatures, an increase in ice cap melting and the need for more immediate political action. Complicating matters, the global environment is a complex system whose behavior is difficult to predict due to the non-linear and delayed reactions of the climate’s response to our actions (Homer-Dixon, 2007). Connected to this complex environmental system are complicated economic and social systems which are interdependent upon each other and the environment. Thus, actions to mitigate climate change must account for their effect on these social, economic and environmental systems in order to be effective. To analyze these interconnected systems and the impact of possible actions to combat climate change, the employment of a system of systems (SoS) approach (Hipel et al., 2007, 2008a,b, 2009a,b, 2010) whereby social, environmental and economic systems are tied together, may provide significant insights. One element of this complex SoS, the socio-political system, is investigated herein. A decision model based on the social and political negotiations is developed in the following subsections using the Graph Model for Conflict Resolution (GMCR) (Fang et al., 1993). The development of a Sino-American climate agreement may be difficult because of the important financial issues associated with reducing carbon emissions and the historic differences between the two nations. Such an agreement may, however, drive a cultural change towards reductions of greenhouse emissions within both countries, as Bailey (2008) suggests with respect to agreements between industry and environmental regulators. The United States of America (USA) and the People's Republic of China (PRC) have been in opposition as a result of the stark contrast between USA's capital-driven society and PRC's Maoist communism, at least within its political system, since the late 1940s. This ideological difference has caused both nations to be pitted against each other in two regional Asian conflicts: the Korean (Edwards, 2005) and Vietnam (Zhai, 2000) wars. In recent years, however, their relationship has improved, partially due to the PRC's communist ally, the Soviet Union, becoming a capitalist state at the end of the Cold War. This new era in Sino-American relations has led to increased trade between the two nations (Song, 2006).

In Subsection 5.2, the current climate regime (5.2.1) and the political relationships between China and the United States (5.2.2) are outlined. In Subsection 5.3, a simple model (5.3.1) and a more complex model (5.3.2) are determined for the conflict between the USA and PRC over negotiating a climate regime using GMCR are outlined. In Subsection 5.4, attitudes, as conceptualized within GMCR, are applied to the previously modeled conflict. Finally, in Subsection 5.5, insights from the application of the graph model methodology in Subsections 5.3 and 5.4 are discussed and final conclusions are made.

5.2. Conflict over Climate Change

To appreciate the complex negotiations that must take place in order for these two powerful nations to agree to a climate strategy, it is important to consider the structure of the current global climate regime, and the relationship between the USA and PRC. In the following subsection, the current state of climate negotiations including the Kyoto Protocol, and the diplomatic history between the USA and PRC are discussed.

5.2.1 The Current Climate Regime

5.2.1.1 Overview

In response to global climate change, governments, corporations and citizens have recognized the need to reduce the emission of greenhouse gases. Internationally, the first step in this process has been the initialization of the international environmental agreement referred to as the Kyoto Protocol. The Kyoto Protocol, a legal instrument under the United Nations Framework Convention on Climate Change, is designed to encourage a reduction in the emission of the gases that cause climate change. Under the protocol there are six main gases that must be reduced: carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons. The protocol was first signed during the period from March 1998 until March 1999 and ratified thereafter, with distinct climate goals set for the 2008-2012 period (United Nations, 2007). During the first commitment period of the protocol, developed nations ratified the protocol and thus agreed to limit or reduce their CO_2 emissions to between -8% and +10% of 1990 levels. The protocol allows for the trading of emissions certificates by nations that exceed their reduction goals. Thus, it was in the best interest of nations to overstate the impediments to their potential reduction of emissions or to overstate their 1990 emissions levels. Former Soviet

Bloc nations held a particular advantage as their emissions had actually dropped significantly since the fall of the Soviet Union and were thus significantly lower than 1990 levels to begin with (Walker et al., 2007).

The protocol also placed heavier responsibility for climate change upon the developed nations that caused it, in a structure referred to as "differential responsibility". Thus, the developed nations became responsible for the significant emissions reductions needed to help reverse, or at least slow down, global climate change. Unfortunately, difficult problems arose in the negotiation of the protocol. Most notably, some developed nations balked at signing an agreement in which developing nations with large carbon emission levels, specifically the PRC and India, were not included. The aftermath of this disagreement was that the largest emitter of greenhouse gases, the USA, refused to ratify the agreement (Senate, 1997). Therefore, in order for the agreement to come into force it was necessary for Russia to ratify it, thereby satisfying the stipulation that at least 55 nations making up 55% of the world's greenhouse gas emissions were needed before the protocol could be implemented. The most troubling issue of the newly ratified agreement, however, was whether the protocol could actually help reduce emissions of greenhouse gases without the agreement of the world's two greatest emitters of greenhouse gases: the USA and PRC. Certainly, the USA's withdrawal threatened to affect the very legitimacy of the agreement; however, it is the exclusion of the rapidly industrializing developing nations which deterred the USA from taking part and still remains a major stumbling block to American participation.

In recent years, the various parties to the Kyoto Protocol have met to discuss their progress and plan for future negotiations. At the meeting of the Group of 8 (G8) industrialized nations in L'Aquila Italy from 8-10 July, 2009, G8 delegates met to discuss, among other things, the Kyoto Protocol and climate change. Like the industrializing nations of the world, the G8 industrialized nations came to the agreement that action should be taken to assure that global temperature increase by no more than 2^0C (Polusen, 2009).

In 2009, world leaders came to meet once again to discuss what would be the next steps in the global effort to reduce harmful CO_2 emissions. Held in Copenhagen at the Bella Center between December 7th and 18th, the conference was an opportunity for world leaders to discuss potential strategies for the ongoing climate problem. By the end of the conference, however, it appeared that very little headway had been made and indeed, many people saw the outcome as a "weak political statement" and nothing more (Taylor, 2009).

Negotiations between the developing and developed nations have suffered from an ideological difference. Fisher and Green (2004) note that for the most part the developing world is disenfranchised from the international environmental agreement (IEA) process, as not only do the agreements not meet the goals of developing nations but implementing the various agreements that have been introduced taxes the infrastructure of the developing world such that it is harder to implement further environmental initiatives. These arguments certainly apply to many of the world's poorer nations, but what of the world's fastest developing and industrializing nation, China?

Within the last 20 years, the economy of the PRC has grown by leaps and bounds. In fact, in early 2009, PRC overtook Germany to become the third largest world economy behind only the USA and Japan (Seager, 2009). Unfortunately, coupled with PRC's quick economic growth has been a tremendous increase in the output of greenhouse gases. Auffhammer and Carson (2007) modeled PRC's CO_2 emissions to simulate future outcomes and found that while the 37 industrialized nations that make up Annex I – the Annex of developed economies – may be able to reduce greenhouse gases by about 115.9 million tonnes of carbon relative to business-as-usual by 2010, the increase in output by the PRC will be approximately 600 million tonnes of carbon. Weber et al. (2008) suggest that a significant increase in PRC's emissions of CO_2 comes not only from its rapidly growing energy sector but from the shipping of goods from PRC to the developed nations. Both reports would suggest a need to include the PRC within the framework of an international climate regime. Indeed, the PRC has already begun to introduce an internal framework for limiting its impact on climate change (China, 2007).

5.2.1.2 Previous Analyses of the Current Climate Regime

The governance of climate change is organized internationally through the United Nations' Kyoto Protocol. The structure of the Protocol is typical of the environmental liberalism approach favored by the world's economic leaders in that the environmental goals are reached through the use of market tools (Bernstein, 2005). Thus, systems analyses of the Kyoto Protocol have focused predominantly on the trading of emissions permits at the tactical or lower-decision level – an aspect of the protocol which lends itself very well to game theoretic analyses. Bernard et al. (2008), for example, analyzed the trading of emissions permits between Russia and Annex I nations using game theoretic methods; numerous others have also analyzed the trading of emissions permits within the protocol (Ellerman et al., 1998; McKibbin et al., 1999). In contrast to these tactical analyses, a strategic analysis of Russia's negotiations with the European Union (EU) and the USA which led to Russia's ratification of the protocol, has been performed (Walker et al., 2007). With the end of the Kyoto Protocol's time period coming in 2012, and with PRC's inability to come to an agreement in Copenhagen, decision makers are desperately looking for a post-2012 climate regime of which PRC must definitely be a part. In the next section, a US-PRC bilateral climate agreement is discussed.

5.2.2 US-PRC Bilateral Climate Agreement

One possible post-Kyoto climate regime would be a coalition between the USA and China which could encourage both nations to significantly reduce their carbon emissions. Indeed, before Russia finally ratified the Kyoto Protocol, there had been talk of the USA and Russia forming a bilateral climate change coalition (Karas, 2006). An agreement between the USA and PRC, as explored by the Pew Centre for Climate Change with the Asia Group, is discussed, in part because of the USA's previous objections to China's exclusion from emissions limits within the Kyoto Protocol (Pew and Asia, 2009; Whitehouse, 2001). The Pew Centre and Asia Group's report suggests that as a basis for America and China to engage cooperatively to deal with climate change, economic matters such as the global recession and economic competition should not threaten negotiations but be seen as matters that may be manageable by such an agreement. In the following subsections, some of the issues which could possibly impact the implementation of such a bilateral agreement are explored in more detail.

5.2.2.1 Differential Responsibility

One of the key elements of climate negotiations between developed and developing nations, both within the context of the United Nations Framework on Climate Change Convention (UNFCCC) and the Kyoto Protocol, is the concept of differentiable responsibility (United Nations, 2007). PRC itself recognizes this concept and states plainly that greater responsibility lies upon the developed nations. Historically, there is certainly a much higher level of total carbon emissions from the USA, due to its longer history of industrialization. The very rapidly growing economy of PRC has, however, quickly caught up to the USA in terms of annual carbon emissions. It is differential responsibility that resulted in no quantified cap for PRC's carbon emissions within the Kyoto Protocol and thus the USA's withdrawal (United Nations, 2007). As PRC has included differential responsibility into its own environmental protocol, it is likely that negotiations between PRC and the USA would need to address both nations' historic and current emissions.

5.2.2.2 US Domestic Opposition

Within the American political system there is a great divide about what action needs to be taken with respect to climate change. Although an environmentalist candidate, Ralph Nader of the Green Party, has run for the office of the President, the system is essentially a two-party system made up of Republicans (Grand Old Party, or GOP) and Democrats (Democratic National Committee, or DNC). Historically, the GOP has opposed working on resolutions dealing with climate change while the DNC has supported such resolutions (Kennedy, 2004). Within the DNC, however, there are certainly a number of different approaches to the climate change dilemma. Tellingly, although President Bill Clinton, a Democrat, was in favor of ratifying the Protocol, the bipartisan Senate, which included GOP and DNC Senators, voted unanimously against it (Senate, 1997).

5.2.2.3 Current Economic Crisis

Starting in 2007, a credit crisis began to affect the American economy. Vast amounts of personal and corporate debt exacerbated the situation, creating an extremely high volume of foreclosures, further causing some financial institutions to fail (Elliott, 2008). This financial climate may reduce each nation's desire to invest in the technology needed to combat climate change. Significantly, PRC has invested heavily in the American economy and is the largest holder of US Treasury Bonds (Baker and Barrioneuvo, 2009; Ferguson, 2010). With the lack of growth in the current American economy, the PRC's communist government may decide to diversify its foreign investment.

5.2.2.4 Political Differences

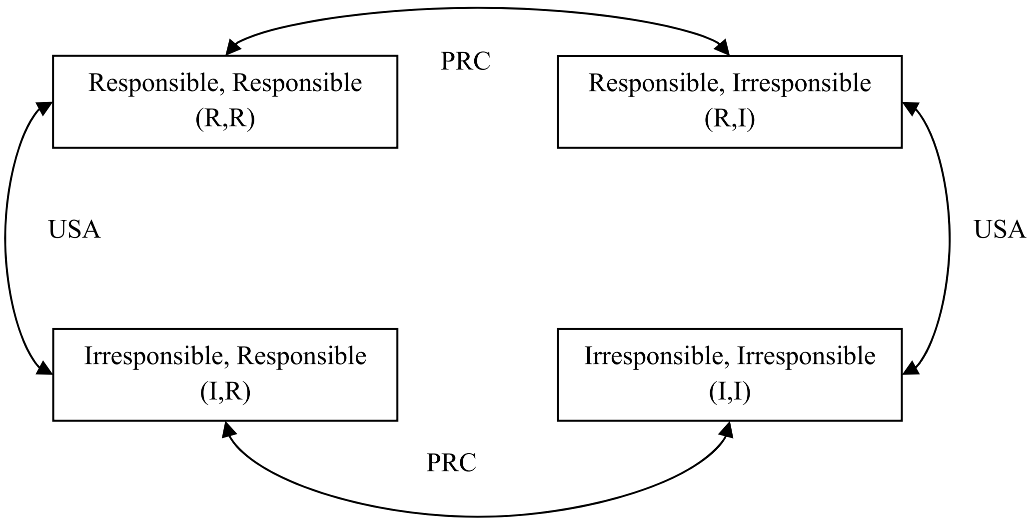
Complicating matters further is the political tension between the two nations. In a very real way, these two nations are fierce rivals both economically and ideologically. The rise of communism in China in 1949, coupled with the threat of Soviet aggression, put these two nations at odds. Indeed, the US fought the Chinese in both Korea and Vietnam (Matray 1991; Zhai 2000). Now, with the Cold War over and the Soviet Union a seemingly democratized nation, PRC is the strongest remaining communist nation. Further, the various human rights abuses by the PRC government have made it difficult for a republic, such as America, to negotiate in good faith (Sorman, 2008).

5.3. Conflict Modeling of the USA-PRC Bilateral Negotiations

Using GMCR and Conflict Analysis, previously discussed in Chapters 3 and 2, respectively, it is possible to create interesting and insightful models to the climate negotiations between PRC and the US. In this subsection, a simple 2-DM conflict is considered as well as a more complex 3-DM model.

5.3.1 Two-DM Model

Pittel and Rubbelke (2008) model a two stakeholder climate regime using 2x2 conflict models developed by Rappaport and Chammah (1965) wherein two DMs each have two strategies, generating four conflict outcomes. One of the simplest of such conflicts is the game of ‘chicken’ in which two opponents drive their cars towards each other as fast as possible. The person who swerves out of the way is said to be ‘chicken’ and loses the game. Of course, if both players decide not to swerve out of the way, they both die – a far worse outcome than losing the game. Similarly, Pittel and Rubbelke (2008) postulate that negotiations surrounding the implementation of a bilateral climate change agreement are similar in that neither nation wants to be the one to ‘swerve’ or begin to act alone on the problem of climate change. Alternatively, neither party wants the situation to reach a point where neither of them ‘swerves’, thus causing the problem to reach a deadly level for humanity. Each DM has the same possible strategies it controls: be irresponsible (labeled as I) with respect to reducing greenhouse gases and be responsible (R). In Figure 5.1, the conflict is shown in graph form with the preferences of the two nations given below the graph. Within each node, the pairing of actions by the two nations is given with the first entry representing the strategy selected by the USA, while the second is the strategy selected by PRC. For example, RR in the bottom right corner of the figure represents the outcome or state where both nations act in a responsible manner towards the environment.



USA: IR > RR > RI > II

PRC: RI > RR > IR > II

Figure 5.1: Bilateral Climate Negotiations Modelled as a Game of Chicken

As can be seen by the arcs, the USA controls movements between II and RI, as well as IR and RR, while PRC is in charge of moves between II and IR, as well as RR and RI. After performing a stability analysis of this conflict, two equilibria occur at states RI and IR. Both of these occur because of the recognition by both parties of the cost of working alone to deal with climate change, the desire for the other party to lead or act alone and the recognition that not acting at all would be catastrophic. This model shows the need for cooperation and negotiation between the two nations to begin to act in unison and shift the negotiations to state RR where both parties are responsible and act to combat climate change. A resolution where both nations act responsibly, RR, does not occur naturally. Both states IR and RI constitute Nash equilibria. To explain why this is so, consider state IR. Notice that if USA causes the conflict to move from state IR to RR in Figure 1, USA is moving to a less preferred state and therefore does not possess a unilateral improvement. Hence, according to Definition 6, state IR is Nash stable for USA. In a similar fashion, if PRC causes the conflict to shift from state IR to II by changing its strategy from R to I, PRC will move to a less preferred state. Accordingly, state IR is Nash stable for PRC and because it is Nash stable for both DMs in the conflict, it is Nash equilibrium. Likewise, one could explain why state RI is Nash equilibrium.

Although this model very succinctly describes the possible hazard of not ratifying the Kyoto Protocol as well as the need for cooperation between USA and PRC, it is extremely limited. The model does not address numerous questions that an analyst may have, such as: How can the USA and PRC share technology to address climate change? Will PRC want to invest further in the USA in spite of its flagging economy? Will USA take on a greater responsibility than PRC, as PRC desires?

5.3.2 Three-DM Model

Although there are two nations involved directly in the negotiations, there are numerous peripheral DMs connected to the conflict, both for and against a bilateral climate change agreement. For the purposes of this model, the sides at work with the USA are dissected and a new conflict model is given. Within this model, the US Support represents members of the DNC who have expressed the desire to reduce carbon emissions 80% from 1990 levels by 2050 and may thus be open to a bilateral agreement with PRC (Reilly, 2008). Under the Pew Center's roadmap (2009), there are numerous possible actions that President Obama could take. The opposition to a climate change agreement with PRC may come about for numerous causes. The first reason, as alluded to by the Pew report on a possible USA-PRC bilateral agreement, is the history of cold relationships between the two nations (Pew and Asia, 2009). Secondly, the anti-environmental leanings of the GOP have been well-documented both by scholars and news sources (Kennedy, 2004). The possibility of joint investment with PRC towards environmental ends in the middle of a global recession may also go against the values of fiscal conservatives.

An example of what a three party conflict could look like is shown in Tables I and II, using a format referred to in GMCR as 'option form', which was originally proposed by Howard (1971). In option form, each DM is listed above each possible option that it could choose. The three DMs are: US Support (USS), US Opposition (USO) and the government of the PRC.

Table 5.1: Decision Makers and Options for the Expanded Conflict

USS
1) Propose bilateral emissions trading system (Propose)
2) Joint investment in alternative energy sources (JI)
USO
3) Propose alternative domestic system (Oppose)
PRC
4) Accept American terms (Accept)
5) Demand differential responsibility (DR)

If the negotiations between the USS, USO and PRC are as simple as those shown in Table 5.1, the number of possible outcomes is exponentially larger than the 4 outcome conflict modeled in the previous subsection. Each option is selected, denoted by a 'Y', or not, denoted by an 'N'. Therefore, the total possible number of states in this conflict has grown to $2^5 = 32$ possible conflict outcomes. Using the option form of the conflict, the full set of states is realized and the state identification numbers are chosen using a decimalized numeric format. In decimalized form each option is assigned a numerical value. Option 1 has a value of $2^0 = 1$, option 2 has a value of $2^1 = 2$ and so forth. For example, if option 1 and option 3 are selected, the decimalized form used to identify the state is $2^0 + 2^2 = 5$.

Now this conflict model better reflects what is happening within the negotiations, but it has also become more tedious to analyze in the process. In order to create a feasible model where logical infeasibilities are removed, it is necessary to remove the infeasible states from the total set of states. For instance, it is necessary to remove states where option 4 is selected without options 1 or 2 being selected, as it is impossible for PRC to accept USS's conditions unless the USS has offered something. After having removed the infeasible states, the total set of states in the conflict is S = {0, 1, 2, 3, 5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23}.

Table 5.2: Feasible States in Option Form

DMs and Options	Feasible States																			
USS																				
1) Propose	N	Y	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	N	Y	N	Y	Y	N	Y
2) JI	N	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	N	N	Y	Y	N	Y	Y
USO																				
3) Oppose	N	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N	N	Y	Y	Y
PRC																				
4) Accept	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N
5) DR	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y
STATE #s	0	1	2	3	5	6	7	9	10	11	13	14	15	16	17	18	19	21	22	23

With ranking and movement information, the conflict is rewritten in tableau form as shown in Table 5.2. Here, the states are listed in order of descending preference from left to right for each DM. Below each state are the UIs from that state while above each state is the solution concept satisfied for that DM at that state. Finally, along the top of the tableau, state equilibrium conditions are given, corresponding to the states as they appear in the first DM's list of states.

Table 5.3: Static Analysis

	x	E	E	x	x	x	x	x	x	E	x	E	x	x	x	x	x	x	E	x
	r	s	r	u	r	r	r	r	u	r	r	r	r	r	r	r	u	r	r	r
USS	11	9	15	13	(0	1	2	3	10)	(16	17	18	19)	(5	6	7	14)	(21	22	23)
		11		15					9								13			
									11								15			
	r	r	r	s	s	r	r	r	r	r	r	s	u	r	r	r	r	r	u	u
USO	(0	5	13)	(1	9)	(2	6	7	10	14	15)	(3	11)	(16	18	21	22	23)	(17	19)
				5	13							7	15						21	23
	r	r	r	r	u	r	u	r	u	r	u	u	u	u	u	u	u	u	u	u
PRC	13	15	(9	18	21	22)	(10	11	14	16	23)	(2	5	6)	(0	7	17)	19	1	3
					13		18		22		15	10	13	14	16	15	9	11	9	11
												18	21	22		23			17	19

Symbols: E-Equilibrium state, X-non-equilibrium state, r-Nash stable state, s-sequentially stable state, u-unstable state

In Table 5.3, the tableau form of the conflict is given. As can be seen, each of the three DMs are shown: United States Support (USS), United States Opposition (USO) and the People's Republic of China (PRC). To the right of each DM the states are listed in descending order of preference from left to right. Below each state are the unilateral improvements available to the given DM from that particular state. In order to determine stabilities and equilibria, the two aforementioned solution concepts, Nash and Sequential stability (Definitions 2 and 3), were applied to this conflict. For example, state 3 for USO is sequentially stable and is thus marked with an 's'. This occurs because from state 3, USO makes a unilateral improvement (UI) to state 7. This can be written as: $R^{+}_{USO}(3) = 7$. Thus, as $R^{+}_{USO}(3) \neq \{\}$, the state is not Nash stable. Next, to test for Sequential stability, it is important to test for possible sanctions from state 7 by the remaining set of DMs, labeled *N – USO*, which means the set of N DMs without USO. From state 7 USS has no UIs, while PRC has two UIs to state 15 and 23. To test for the complete set of credible sanctions, it is necessary to see if USS can make any further moves from 15 or 23. However, as USS has no UIs from these states, the total set of sanctions is $R_{N\text{-}USO}(7) = \{15, 23\}$.

As state 23 is less preferred by USO to state 3, written as $3 >_{USO} 23$, the move to state 23 is an effective sanction and thus the state is stable by Sequential stability. From this analysis there are five equilibrium states, each marked with an E: states 9, 15, 16, 18 and 22. A state is called an equilibrium state when it is stable for all of the DMs in the conflict and thus the state is likely to persist, if it is reached. Although state 9 is a strong outcome for this negotiation because it allows both nations to work together on a joint climate project, the conflict could proceed to state 16, whereby PRC demands differential responsibility and the negotiations go no further.

As is clearly visible in Figure 5.2, there are numerous paths from the status quo at state 0. Starting at state 0, it is possible to reach all of the potential equilibrium states. There is, however, only one state that can be reached by a credible move, marked in Figure 5.2 in bold, state 16. Credible moves occur when DMs move the conflict from one state to another, according to their preferences.

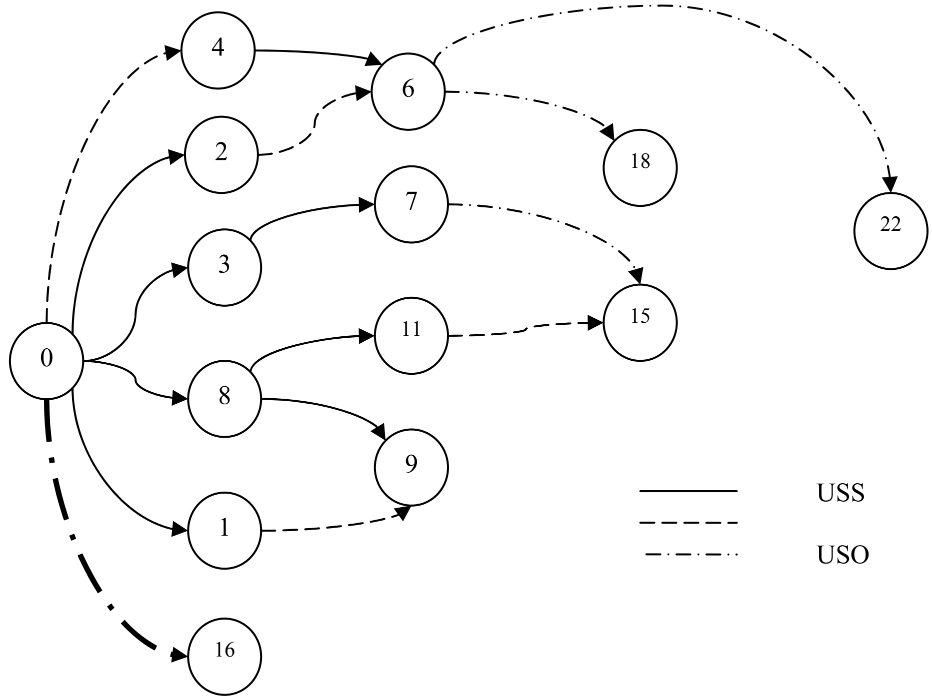


Figure 5.2: Possible Evolutions of 3-DM Climate Conflict from Status Quo

In Table 5.4 the movement from the status quo or initial state, State 0, to the final state, State 16, is shown in option form. The black arrow represents the change in option selection by PRC. PRC moves from doing nothing to demanding different responsibility. Unfortunately, state 16 is not the kind of positive resolution that the USS, or the world for that matter, is looking for. Thus, it is important to analyze the attitudes and relationships that may be leading to this lose-lose outcome. In Subsection 5.4., the attitudes framework defined previously in Chapter 4 is applied to the three-DM conflict.

Table 5.4: Evolution of the Conflict in Option Form

DMs and Options	Transition from Initial State to Final State		
USS			
1) Propose	N		N
2) JI	N		N
USO			
3) Oppose	N		N
PRC			
4) Accept	N		N
5) DR	N	→	Y
STATE #s	0		16
	Initial State		Final State

5.4. Attitudes within GMCR

5.4.1 Attitudes Analysis

In order to gain insight into how a climate change agreement between USA and PRC could occur given their 70-year history of political and financial opposition, attitudes will be applied to the previously completed analysis. In Table 5.5, the attitudes associated with a regular analysis are shown on the left and the new attitudes associated with a devoting US support, due to the new American administration, are given.

Table 5.5: Attitudes Analysis

Regular				Devoting USS/Aggressive PRC			
DM	PRC	USS	USO	DM	PRC	USS	USO
PRC	+	0	0	PRC	+	-	0
USS	0	+	0	USS	+	0	0
USO	0	0	+	USO	0	0	+

By implementing the second set of attitudes, new possible conflict outcomes can be contrasted with the results determined in the previous section. Here, PRC holds negative attitudes against USS specifically and opposes a possible agreement, while USS wishes to make a deal that is equitable not only for USA but for PRC and the rest of the international community. Applying these new attitudes to the tableau analysis given in Table 5.3, some UIs that gave rise to more preferred states for PRC and USS are now no longer palatable to the PRC. These new attitudes give rise to the tableau analysis shown in Table 5.6.

Table 5.6: Static Attitude Analysis

	x	E	x	x	x	x	x	x	x	x	x	E	x	x	x	x	x	x	x	x
	rr	rr	u	rr	u	u	rr	u	u	u	u	rr	u	rr	rr	u	u	rr	rr	u
USS	11	9	15	13	(0	1	2	3	10)	(16	17	18	19)	(5	6	7	14)	(21	22	23)
			13		2	0		0	9	18	16		16			5	13			21
						2		1			18		17			6	15			22
								2					18							
	r	r	r	s	s	r	r	r	r	r	r	s	u	r	r	r	r	r	u	u
USO	(0	5	13)	(1	9)	(2	6	7	10	14	15)	(3	11)	(16	18	21	22	23)	(17	19)
				5	13							7	15						21	23
	rr	rr	rr	rr	rr	rr	u	rr	u	rr	rr	u	u	u	u	u	u	u	u	u
PRC	13	15	(9	18	21	22)	(10	11	14	16	23)	(2	5	6)	(0	7	17)	19	1	3
							18		22			18	21	22	16	23			17	19

Symbols: E-Equilibrium state, X-non-equilibrium state, r-Nash stable state, s-sequentially stable state, u-unstable state, rr-Relational Nash stable state, rs-Relational sequentially stable state

Similar to the static analysis performed previously, state stabilities are checked using RNash, RSEQ, Nash and SEQ solution concepts. For example, state 11 is unstable, which is denoted by a 'u'. As $TRR_{USS}(11) \neq \{11\}$, the state is not RNash stable for USS by Definition 28. As USS's attitudes are such that USS has a positive attitude towards PRC ($e_{USS\text{-}PRC} = +$) and is indifferent towards itself and USO ($e_{USS\text{-}USS} = e_{USS\text{-}USO} = 0$), any sanction against USS's move to state 9 from state 11 must be such that $\exists\ x \in TRR_{N/USS}(11) \mid 11 >_{PRC} x$. In this case, from state 9 USO can move to state 13 ($R^{+}_{USO}(9) = 13$), which is more preferred to state 11 by PRC ($13 >_{PRC} 11$). Thus, the total relational reply is not sanctioned and hence the state is unstable by both RNash and RSEQ stabilities.

Employing the relational solution concepts, 5 conflict equilibria were determined: 9, 13, 18, 21 and 22. This time, the troublesome equilibrium state 16 has been removed because USS now has credible movements from state 16 to state 18. However, this state is no more of a resolution than state 16 is. Both states 9 and 13 are welcome equilibria which would occur under conditions of agreement between USS and PRC.

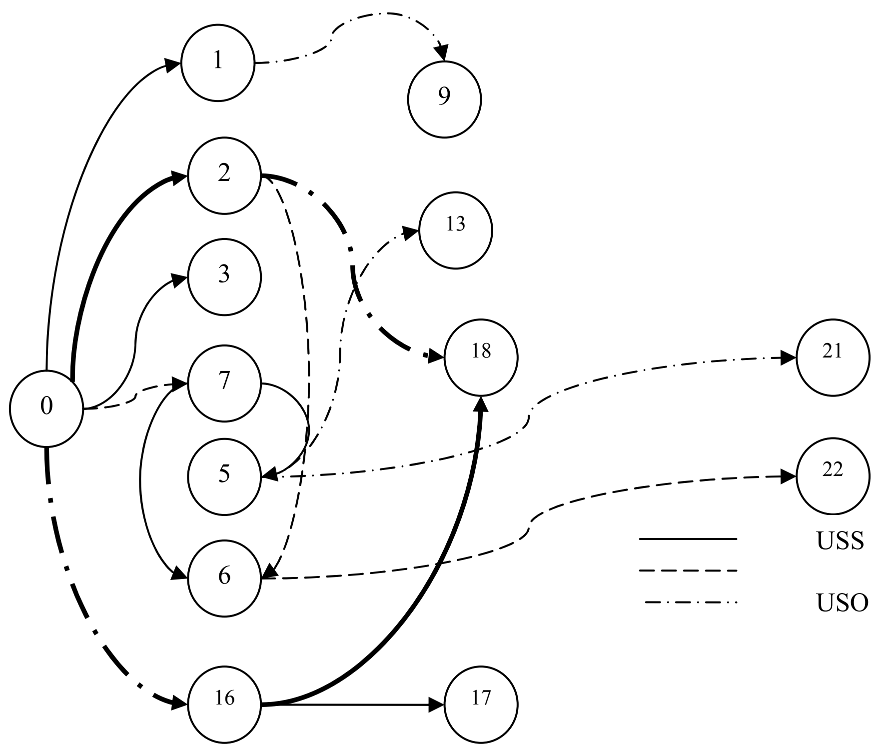


Figure 5.3: Possible Evolutions of 3-DM Climate Conflict from Status Quo

In Figure 5.3, it can be seen how the conflict evolves from the status quo. The credible moves, where DMs act according to their attitudes, are shown in bold. Thus, the move from state 0 to state 18 is the only one that can occur. This movement is shown in option form in Table 7. Paths do exist to other equilibrium states; however, they all require one or more moves that are not credible. For example, from the status quo to state 6 there are two paths: i) USS moves to state 2 and USO moves from 2 to 6 or, ii) USO moves to state 4 and USS moves from state 4 to 6. By path i) USS can make a credible move to state 2 as $2 >_{PRC} 0$ and thus, $2\ TRP_{USS}\ 0$ as $e_{USS\text{-}PRC} = +$, $e_{USS\text{-}USS} = e_{USS\text{-}USO} = 0$. However, $2 >_{USO} 6$, and thus as USO behaves according to his own preferences, it is not a credible move for USO. Thus, path i) can not work using credible moves. Examining path ii), the initial move by USO from state 0 to state 4 is not credible as $0 >_{USO} 4$ and thus path ii) can also be followed using credible moves.

As can be seen in both Figure 5.3 and Table 5.7, the combination of American devotion and Chinese aggression leads to a stalemate situation where PRC demands differential responsibility, USS agrees to a technology transfer and no further move is taken. Although numerous equilibrium states occur under the new attitudes applied to the conflict in Tables 5.5 and 5.6, only state 18 is reachable by any set of credible moves from the status quo. This outcome may suggest that it is in the interest of USS to not concede too heavily to the PRC negotiators and that, further, a different strategy, set of attitudes, or type of movement is needed in order for a more beneficial outcome to be reached.

Table 5.7: Evolution of 3-DM Conflict in Option Form

USS											
1) Propose Bilateral Regime	N	→	N		N		N		N	→	N
2) Technology Transfer	N		Y		Y		N		N		Y
USO											
3) Oppose	N		N		N		N		N		N
PRC											
4) Accept Proposition	N		N	→	N		N	→	N		N
5) Differential Responsibility	N		N		Y		N		Y		Y
STATE #s	0		2		18		0		16		18
	Initial State		Trans. State		Final State		Initial State		Trans. State		Final State

To that end, a new set of attitudes is presented in Table 5.8. Here, the movements of the PRC are not constrained by a negative attitude towards USS, while USS still has a positive attitude towards PRC and an indifferent attitude towards itself. This set of attitudes suggests that perhaps PRC is more open to the negotiation of an agreement and USS is willing to put itself out to make an agreement occur.

Table 5.8: Second Attitudes Analysis

Regular				Devoting USS			
DM	PRC	USS	USO	DM	PRC	USS	USO
PRC	+	0	0	PRC	+	0	0
USS	0	+	0	USS	+	0	0
USO	0	0	+	USO	0	0	+

If the negotiations can be brought about in a manner that encourages a level of cooperative negotiation, it may be wiser and indeed more accurate to model the conflict with devoting attitudes on the part of USS and rational attitudes on the part of PRC. This change of attitudes means that PRC's unilateral credible movements will be unilateral improvements, as in the first static analysis. USS and USO will maintain the same unilateral movements from the previous attitudes analysis. The tableau form of this new analysis, shown below in Table 5.9, illustrates that there are now three possible equilibria, one of which involves PRC agreeing to join a climate regime with the USS. Of these outcomes, state 18 sees PRC asking for differential responsibility and thus the negotiation of a climate agreement does not occur, and state 22 is identical except for the inclusion of USO providing domestic political pressure against the agreement. It is state 13 that is the best resolution, potentially, to the problem. At state 13, the USS offers a reasonable climate agreement, to which PRC agrees and the USO objects. Figure 5.4 below illustrates the possible moves from the status quo state to each of the three equilibria.

Table 5.9: Second Attitudes Analysis

	x	x	x	E	x	x	x	x	x	x	x	E	x	x	x	x	x	x	E	x
	rr	rr	u	rr	u	u	rr	u	u	u	u	rr	u	rr	rr	u	u	rr	rr	u
USS	11	9	15	13	(0	1	2	3	10)	(16	17	18	19)	(5	6	7	14)	(21	22	23)
			13		2	0		0	9	18	16		16			5	13			21
						2		1			18		17			6	15			22
								2					18							
	r	r	r	s	s	r	r	r	r	r	r	s	u	r	r	r	r	r	u	u
USO	(0	5	13)	(1	9)	(2	6	7	10	14	15)	(3	11)	(16	18	21	22	23)	(17	19)
				5	13							7	15						21	23
	r	r	r	r	u	r	u	r	u	r	u	u	u	u	u	u	u	u	u	u
PRC	13	15	(9	18	21	22)	(10	11	14	16	23)	(2	5	6)	(0	7	17)	19	1	3
					13		18		22		15	10	13	14	16	15	9	11	9	11
												18	21	22		23			17	19

Symbols: E-Equilibrium state, X-non-equilibrium state, r-Nash stable state, s-sequentially stable states, u-unstable state, rr-Relational Nash stable state, rs-Relational sequentially stable state

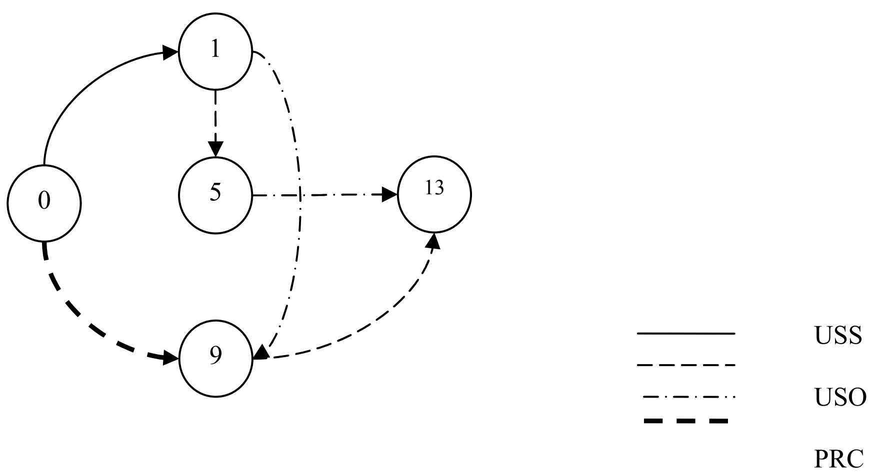


Figure 5.4: Evolution 3-DM Climate Regime to Amicable Agreement at State

As can be seen in Figure 5.4, there are numerous paths by which DMs' actions can lead to the final outcome of state 13 which is preferred by all involved. The hitch, however, is that again none of the paths are composed entirely of credible moves and they are based on the assumption that these DMs are acting in a totally independent manner. If one were to look at credible moves alone, the conflict would move to state 18, as it had in the previous attitudes analysis. In such a case, as shown in Table 5.10, credible moves by USS and PRC would cause the USS to offer technology transfer and PRC to demand differential responsibility.

Table 5.10: Evolution of 3-DM Conflict in Option Form

USS											
1) Propose Bilateral Regime	N	→	N		N		N		N	→	N
2) Technology Transfer	N		Y		Y		N		N		Y
USO											
3) Oppose	N		N		N		N		N		N
PRC											
4) Accept Proposition	N		N	→	N		N	→	N		N
5) Differential Responsibility	N		N		Y		N		Y		Y
STATE #s	0		2		18		0		16		18
	Initial State		Trans. State		Final State		Initial State		Trans. State		Final Stat

Thus, in order for a resolution which would ensure the two DMs come to an agreement, it is necessary that they move cooperatively from the status quo. Although further literature, such as Inohara and Hipel (2008a,b), explores the implications of full coalition formation, what is useful to consider here is the possibility of a coalition jump, as described by Kilgour et al. (2001). Although USO makes a move from state 9 by objecting and thus moving the conflict to state 13, the coalition jump by USS and PRC is essential to the final outcome whereby the two nations agree to a climate agreement. This coalition jump is similar to the "equilibrium jump" made by multiple DMs from one equilibrium state to another. In this case, careful negotiations between the DMs allow for a cooperative move which avoids the posturing of state 18 and ultimately leads to the final outcome of state 13. The option form of this jump is seen in Table 5.11.

Table 5.11: Coalition Jump for Conflict under 2nd Set of Attitudes

DMs and Options	Transition from Initial State to Final State via Trans. State				
USS					
1) Propose Bilateral Regime	N	→	Y		Y
2) Technology Transfer	N		N	→	Y
USO					
3) Oppose	N		N		N
PRC					
4) Accept Proposition	N	→	Y		Y
5) Differential Responsibility	N		N		N
STATE #s	0		9		13
	Initial State		Trans. State		Final State

5.5. Attitudes and Preferences

As was explained previously, attitudes are a structure which allows a decision analyst to incorporate a DM's desires to hurt or help itself or other DMs. As the structure of movements and solution concepts are parallel to those defined in Definitions 1 through 3, it is possible to rewrite a new set of preferences which incorporate attitudes (Bernath Walker et al., 2012). For example, in the second relational analysis, USO's set of attitudes, $e_{USO\text{-}USO} = 0$, $e_{USO\text{-}PRC} = +$, $e_{USO\text{-}USS} = 0$, means that it only wishes to take actions that are more preferred for PRC. Thus, its preferences could be rewritten to be the same as PRC's. Similarly, in the first relational analysis, PRC's attitudes are $e_{PRC\text{-}PRC} = +$, $e_{PRC\text{-}USS} = -$, $e_{PRC\text{-}USO} = 0$. Here, PRC's preferences must reflect a desire to improve its own position while hurting USS. In Table 5.12, a new parallel set of preferences are developed for PRC using these attitudes. Instead of a linear preference ranking, the new preferences, which were previously represented by the attitudes, are intransitive. For example, in the preference rankings determined in Section 3.0, 10 $>_{PRC}$ 2, 2 $>_{PRC}$ 17 and thus, 10 $>_{PRC}$ 17, due to the transitive nature of the preferences. Under the new preferences, transitivity does not always work: 14 $>_{PRC}$ 2, 2 $>_{PRC}$ 19, however 2 NE($>_{PRC}$) 14 (where NE denotes Not Equal).

Table 5.12: Parallel Preferences for Relational Analysis

PRC	13	15	(9	18	21	22)	(10	11	14	16	23)	(2	5	6)	(0	7	17)	19	1	3
USS	11	9	15	13	(0	1	2	3	10)	(16	17	18	19)	(5	6	7	14)	(21	22	23)
a	0	1	2	3	5	6	7	9	10	11	13	14	15	16	17	18	19	21	22	23
$x >_{PRC} a$	2, 5, 6, 10, 14, 16, 18, 21, 22, 23	2, 5, 6, 7, 10, 14, 16, 17, 18, 19, 21, 22, 23	10, 14, 16, 18, 19, 21, 22, 23	5, 6, 7, 10, 14, 16, 17, 18, 19, 21, 22, 23	21, 22, 23	21, 22, 23	21, 22, 23	13, 15	18, 21, 22	9, 13, 15, 18, 21, 22	-	21, 22	13	21, 22	5, 6, 7, 14, 21, 22, 23	-	5, 6, 7, 14, 21, 22, 23	-	-	-

Using these new preferences, it is possible to implement a standard static analysis in GMCR. This parallelism between standard analyses and relational attitudes means that attitudes analysis can be used as a "short hand" which allows for easier modeling of complex preferences due to attitudes held by DMs. This particular insight will be discussed in much more detail in Chapter 6.

5.6. Summary

The application of GMCR and the attitudes framework to the conflicts surrounding the negotiation of a bilateral climate regime between the PRC and USA illustrates the need for cooperation, the importance of DM attitudes and the role of strategic thinking. Clearly, without cooperative movements there is essentially no chance that the DMs will come to any sort of agreement (Bernath Walker et al., 2012). Indeed, as all three analyses show, the DMs tend to work towards a stalemate when they are acting independently. Thus, it would be the responsibility of any moderator to ensure that the DMs do not act independently. This applies to all three DMs, although it specifically applies to PRC and USS whose coalition jump in the third analysis is responsible for bringing about a final win-win outcome. Additionally, the implementation of the attitudes analysis helps illustrate the complexity of DMs' preferences and their dependencies upon each other's decisions. Attitudes within GMCR provide a methodology for representing the intricate relationships between DMs in complex international conflicts, such as the negotiation of a Sino-American climate regime. Such a methodology has useful applications in the development of climate management strategies by allowing a clear understanding of complex decisions.

Chapter 6

Attitudes and Preferences

6.1. Introduction

The development of methodologies to investigate attitudes of individual decision makers and coalitions of decision makers is important to the study of conflict not only from a theoretical perspective, but also from a practical viewpoint due to the prevalent role that attitudes and preferences play in negotiations and decision making. For example, Kopelman et al. (2006) studied the impact of attitudes upon business conflicts and concluded that positive attitudes aided the negotiators in reaching better and quicker resolutions. Druckman and Olkalns (2007) have suggested that the exposure to certain attitudes within the structure of a corporation can impact the attitudes of the employees, thus impacting the course taken by the corporation.

The concept of attitudes has been one of the primary research topics in psychology, in particular, in social psychology. In fact, attitude is defined as ‘‘an enduring system of positive or negative evaluations, emotional feelings and pro and con action tendencies, with respect to social object’’ by Krech et al. (1962). Jung (1923) defines attitudes as the readiness of a DM to act in a certain way, while Yousefi et al. (2010) have incorporated such psychological definitions into an attitudes compass, when examining construction projects. In this chapter, three types of attitudes are explicitly considered within a formal modeling framework: positive, negative, and neutral attitudes, as earlier described by Inohara et al. (2007, 2008), Inohara (2008), Inohara and Hipel (2009), Bernath Walker et al. (2009), and Bernath Walker et al. (2010), and as previously defined in Chapter 4. This formal framework for attitudes is compared to the structure of DM's attitudes, previously analyzed by Bernath Walker et al. (2012).

In this chapter, a clear relationship between attitudes and preferences is proven using mathematical theorems. This both allows for greater understanding of the attitudes framework, and illustrates its usefulness for expressing complex preferences that are difficult to elicit in practice. In Subsection 6.2.1, relationships between attitudes and preferences are examined using formal theorems and are subsequently applied to the Expanded Sustainable Development Conflict in Subsection 6.2.2. Next, in Subsection 6.3, the relationships are illustrated using an application of attitudes to a brownfield property procurement conflict. Finally, in Subsection 6.4, appropriate conclusions are drawn.

6.2. Relationships between Attitudes and Preferences

6.2.1 Theorems Relating Attitudes and Preferences

The development of attitudes within the framework of GMCR has been made under the simple assumption that each DM's preferences are based upon improving his own utility or gain. Thus, a change in a DM's attitudes represents a change in how the DM arrives at his preference rankings. The basis of the relationship that is established here between attitudes and preferences is based upon a simple assertion: in a conflict with two DMs i and j, with states a and $b \in S$, it is possible to form a parallel conflict without attitudes that would have the same outcome. Particularly, if $a\text{TRP}_i b$ within the conflict with attitudes, $a \succeq_i b$ for the conflict without attitudes must be true. This is correct because if there exists a set of preferences and attitudes such that $a\ TRP_i\ b$, then $a\ RP_{ij}\ b$ for all $j \in N$, and thus, if $a\ I_{ij}\ b$, $e_{ij} = 0$; $a\ AP_{ij}\ b$, $e_{ij} = -$; $a\ DP_{ij}\ b$, $e_{ij} = +$.

Thus, by the definitions of AP, DP and I, any parallel preference must include both the $\succ_i$ and $\sim_i$ relations.

For each set of attitudes belonging to the set e_i = {0, +, -}^{N}, a TRP_i b is parallel to $a \succeq_i b$, if all attitudes are satisfied. Further, by definition, if $a \in TRR_i(b)$, it is equivalent to saying that $a \in R_i^+(b)$. Formally, one can define the basis of the following set of theorems as a simple lemma.

Lemma: Given states $a, b \in S$ and DM $i \in N$, with attitudes e_i and preferences p_i such that a TRP_i b, it is possible to represent the relational preference as a regular preference by forming a parallel regular analysis with preferences p_i', whereby $a \succeq_i b$.

Proof: If a TRP_i b, under p_i and e_i, then regardless of the ordering of a and b under p_i, a RP_{ij} b for all $j \in N$. Thus, according to Definition 24, $a \sim_i b$ or a RP_i b. Thus, under equivalent parallel preferences, p_i', $a \succeq_i b$.

Using this lemma, which illustrates the relationship between the relational analysis and the parallel regular analysis, the following theorems are proposed.

Theorem 1 (RNash and Nash Stability): If a state a is RNash stable for a DM i under attitudes e_i, there must exist a state a under a parallel regular analysis whereby a is Nash stable.

Proof: If state a is RNash stable for DM i, there must exist no elements of the set $TRR_i(a)$ except for a itself, according to Definition 28. As $TRR_i(a)$ is a set of states that are both TRPs and are reachable (i.e., they belong to the set $R_i(a)$) by Definition 25, if a is RNash, there are no reachable states that are TRPs to a. Thus, for all states $b \in S$, a TRP_i b, which is akin to the regular preference $a \succ_i b$. Therefore, if a TRP_i b for all states $b \in S$, there could be said to exist a parallel regular preference whereby $a \succ_i b$ for all $b \in S$. As $a \succ_i b$ for all $b \in S$, $R_i^+(a) = \phi$, and thus, state *a* is Nash stable by Definition 6.

As illustrated in Theorem 1 and alluded to in the preceding lemma, the existence of a relational preference between two states is analogous to a regular preference between two states. One can use the conflict presented in Figure 6.1 to illustrate how a conflict with attitudes can be recreated in a parallel conflict with the same DMs, options and feasible states, but with differing preferences and no attitudes.

Theorem 2 (RGMR and GMR Stability): If a state *a* is RGMR stable for DM *i* under attitudes e_i, there must exist a state *a* under a parallel regular analysis whereby *a* is GMR stable.

Proof: If state *a* is RGMR stable for DM *i*, then for every element $b \in TRR_i(a)$, there must exist a unilateral movement *c* by *j* from state *b*, such that $a\ TRP_i\ c$, as outlined in Definition 29. As $TRR_i(a)$ is a set of reachable and relationally preferred states that is analogous to the set of unilateral improvements in a parallel regular analysis, as implied by Definition 25. Similarly, by Definition 24, the total relational preference $a\ TRP_i\ c$ is analogous to $a \succ_i c$ within a parallel regular conflict with different preferences. Thus, within the parallel regular conflict, for every $b \in R^+_i(a)$, there must exist a unilateral movement to *c* by *j* ($c \in R_j(b)$), such that $a \succ_i c$. Therefore, if state *a* is RGMR stable under attitudes e_i, there exists a parallel regular analysis with distinct preferences, such that *a* is GMR stable for DM *i*.

Theorem 3 (RSEQ and SEQ Stability): If a state *a* is RSEQ stable for DM *i* under attitudes e_i, there must exist a state *a* under a parallel regular analysis whereby *a* is SEQ stable.

Proof: If state a is RSEQ stable for DM i then for every element $b \in TRR_i(a)$ there must exist a total relational reply c by j from state b, such that a TRP_i c as outlined in Definition 31. As $TRR_i(a)$ is a set of reachable and relationally preferred states that is analogous to the set of unilateral improvements in a parallel regular analysis, as implied by Definition 25. Similarly, by Definition 24, the total relational preference a TRP_i c is analogous to $a \succ_i c$ within a parallel regular conflict with different preferences. Thus, within the parallel regular conflict, for every $b \in R^+_i(a)$, there must exist a unilateral improvement to c by j ($c \in R^+_j(b)$) such that $a \succ_i c$. Therefore, if state a is RSEQ stable under attitudes e_i, there exists a parallel regular analysis with distinct preferences such that a is SEQ stable for DM i.

Theorem 4 (RSMR and SMR Stability): If a state a is RSMR stable for DM i under attitudes e_i, there must exist a state a under a parallel regular analysis whereby a is SMR stable.

Proof: If state a is RSMR stable for DM i, then for every element $b \in TRR_i(a)$, there must exist a unilateral movement c by j from state b, such that a TRP_i c, and from every movement c, there must exist no reachable state d, such that $d \in R_i(c)$ and d TRP_i a, as outlined in Definition 30. As $TRR_i(a)$ is a set of reachable and relationally preferred states that is analogous to the set of unilateral improvements in a parallel regular analysis, as implied by Definition 25, there must exist a parallel set of unilateral improvements whereby $b \in R_i^+(a)$. Similarly, by Definition 24, the total relational preferences a TRP_i c and d TRP_i a are analogous to $a \succ_i c$ and $d \succ_i a$, respectively, within a parallel regular conflict with distinct preferences. Thus, within the parallel regular conflict, for every $b \in R^+_i(a)$, there must exist a unilateral improvement to c by j ($c \in R^+_j(b)$), such that $a \succ_i c$. Further, by Definition 15, there must exist a parallel set of movements by which every response by i from state c results in state d such that $a \succ_i d$. Therefore, if state a is RSMR stable under attitudes e_i, there exists a parallel regular analysis with distinct preferences such that *a* is SMR stable for DM *i*.

In Theorems 1 through 4, it is posited that due to the analogous relationship between regular preferences within game theory and relational preferences (Inohara et al., 2007) – as applied within GMCR – it is possible to create a parallel set of regular preferences that will give an analogous result to a model being analyzed with relational preferences. This suggests that these methods of representing DMs' desires are closely related and both can be made to represent the same information. In Subsection 6.3, an environmental conflict is used to illustrate how this relationship allows attitudes to be used to represent complex preference information.

6.2.2. Attitudes and Preferences in the Expanded Sustainable Development Conflict

Returning to the Expanded Sustainable Development Conflict developed in Chapter 3, and shown in Figure 3.2, it is interesting to consider a self-interested, yet spiteful, version of the DM *E,* as shown in Table 6.1. Here, it can be seen that *E* holds a positive attitude towards himself and negative attitudes towards both *D* and *G*.

Table 6.1: Attitudes in Expanded Sustainable Development Conflict

	E	D	G
E	+	–	–
D	0	+	0
G	0	0	+

Using the preference information, as well as the moves available to *E*, shown in Figure 3.2, the Relational Preferences of *E* with respect to each DM, as well as *E's* overall Total Relational

Preferences can be determined. As shown in Table 6.2, the Total Relational Preferences differ greatly from E's own preferences. If we consider the bolded states in Table 6.2, which are both reachable and Total Relational Preferences, and thus are Total Relational Replies, it can be seen that *E* has four RNash stable states.

Table 6.2: *E's* TRPs and TRRs in Expanded Sustainable Development Conflict

s	$TRP_E(s)$, $\boldsymbol{TRR_E(s)}$
PSV	∅
RSV	***PSV***
PUV	*PSV, RSV*
RUV	***PUV***
PSL	*PSV, PUV*
RSL	*PSV, RSV, PUL,* ***PSL***
PUL	*PSV, RSV, RUV*
RUL	*PUV, RUV,* ***PUL***

In Figure 6.1 the relationship between *E's* Total Relational Replies under attitudes and his Unilateral Improvements in a normal parallel analysis are determined. As is clearly illustrated in Figure 6.1, and born out in Theorems 1 through 4, it is possible to represent an attitudes analysis as a parallel regular analysis. On the left side of Figure 6.1 is a table representing the Total Relational Replies available to *E* at each state in the Expanded Sustainable Development conflict. The arrow represents the transformation of the conflict into a parallel standard analysis where *E's* former Total Relational Replies are now Unilateral Improvements. Further, the RNash Stable states in the attitudes analysis become Nash stable states. In Subsection 6.3, this interesting analysis is applied to a brownfield procurement conflict.

s	$\boldsymbol{TRR_E(s)}$
PSV	∅
RSV	***PSV***
PUV	∅
RUV	***PUV***
PSL	∅
RSL	***PSL***
PUL	∅
RUL	***PUL***

→

s	$\boldsymbol{R^+_E(s)}$
PSV	∅
RSV	***PSV***
PUV	∅
RUV	***PUV***
PSL	∅
RSL	***PSL***
PUL	∅
RUL	***PUL***

Figure 6.1: Attitudes and Preferences in a Sustainable Development Conflict

6.3. Attitudes and Preferences in Brownfield Procurement

A brownfield property is defined by the USEPA (2006) as a property that is thought to be contaminated such that there may be risk to human health or the environment. Often, such contaminated properties can have negative impacts not only on the wildlife and human health, but also on the financial and social well-being of the community (Greenberg et al., 1998; De Sousa, 2003). As all of these elements are so important to community health, it is often in the interest of all parties if the property can be sold and redeveloped – provided that the redevelopment is positive for the community and that some fair agreement is made regarding the future liability due to the potential for exposure to underground toxins.

Within the context of brownfield negotiations, the previously defined GMCR, as well as attitudes, are applied to a generic brownfield property transfer negotiation problem. Using the theorems developed in Subsection 6.2, the relationship between an analysis using attitudes and one using a parallel set of preferences is examined. A 2-DM conflict between DM 1, the seller, and DM 2, the buyer, will be used to explain the relationship between attitudes and preferences theorized above. In this simple conflict, two DMs, referred to here as the seller and buyer, as noted above, are disputing over a given piece of brownfield land. DM 1 wants to sell the land to DM 2, but at a higher price than 2 would like to pay, especially given the possibility for future liability. Their conflict is represented in matrix form, as a 2x3 conflict, in Table 6.3.

Table 6.3: Conflict in Normal Form

		DM 1 (Seller)		
DM 2 (Buyer)		1. high price	2. market value	3. low price
	4. purchase	*a*	*b*	*c*
	5. don't purchase	*d*	*e*	*f*

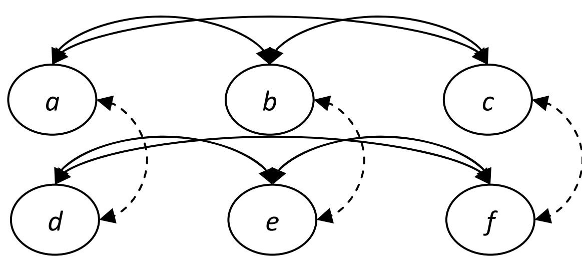


Figure 6.2: Graph Model of a 2x3 Conflict

P_1 = {*a*, *b*, *f*, *d*, *e*, *c*}

P_2 = {*c*, *d*, *e*, *b*, *f*, *a*}

In such a conflict, both the row and column DMs would rank the six states from most to least preferred based on their preferences. As shown at the bottom of Figure 6.2, the preference ranking of states for DMs 1 and 2 are given as P_1 and P_2, respectively. Their preferences are based on the assumption that DM 1 does not wish to sell at the lowest prices and DM 2 does not wish to pay the highest price. From this preference information, one can ascertain the unilateral improvements for each DM and subsequently determine the stability of each state for DM 1 and DM 2 under specific solution concepts. Further, if attitudes are considered and new state stabilities are determined, it is possible to work backwards and figure out a parallel set of preferences which would lead to the same outcome. For example, imagine a conflict where the preferences are as shown in Table 6.4.

Table 6.4: Preferences and Unilateral Improvements in the Example Conflict

n	$>_1 n$	$R_1^+(n)$	$>_2 n$	$R_2^+(n)$
a	--	--	*b, c, d, e, f*	*d*
b	*a*	*a*	*c, d, e*	*e*
c	*a, b, d, e, f*	*a, b*	--	--
d	*a, b, f*	*f*	*c*	--
e	*a, b, d, f*	*d, f*	*c, d*	--
f	*a,b*	--	*b, c, d, e*	*c*

If one were to apply attitude to such a conflict, one would arrive at a number of new movements and state stabilities. For example if e_{22} = +, e_{21} = 0, e_{11} = +, e_{12} = -, the following set of movements would occur, as shown in Table 6.5.

Table 6.5: Total Relational Replies

n	$\text{TRR}_2(n)$	$R_1(n)$	$>_2 n$	$>_1 n$	$\text{TRP}(e)_1\ n$	$\text{TRR}_1(n)$
a	*d*	*b, c*	*b, c, d, e, f*	--	--	--
b	*e*	*a, c*	*c, d, e*	*a*	*a*	--
c	--	*a, b*	--	*a, b, d, e, f*	*a, b, d, e, f*	*a, b*
d	--	*e, f*	*c*	*a, b, f*	*a, b, f*	*f*
e	--	*d, f*	*c, d*	*a, b, d, f*	*a, b, f*	*f*
f	*c*	*d, e*	*b, c, d, e*	*a, b*	*a*	--

As DM *j* holds attitudes in line with a traditional game theoretic analysis, in that he prefers to make moves that improve his own utility, but is indifferent to the utilities of his adversaries, her Total Relational Reply list ($\text{TRR}_2(n)$) is the same as his unilateral improvement list ($R_2^+(n)$) from

Table 6.4. DM 1, on the other hand, must take into account both his own preferences $\succ_i$ as shown in column 5 and DM 2's preferences $\succ_j$ as shown in column 4. Using both of these preferences, DM 1 can arrive at her Total Relational Preferences ($TRP_1(n)$) by choosing states that are more preferred for himself and less preferred for him opponent. Finally, the Total Relational Reply list in the far right column is determined as the intersection between her reachable list $R_1(n)$ in column 3 and her Total Relational Preferences TRP_1. Using the sets of total relational replies developed in Table 6.5, it is possible to determine the overall relational state stabilities for both DM 1 and DM 2.

Table 6.6: Relational State Stabilities

n	*RNash*	*RSEQ*	*RGMR*	*RSMR*	*# of EQ*
a	1	1	1	1	*0*
b	1	1, 2	1, 2	1	*2*
c	2	2	2	2	*0*
d	2	1, 2	1, 2	2	*2*
e	2	1, 2	1,2	2	*2*
f	1	1,2	1,2	1	*2*

As can be seen from Table 6.6, there exist four equilibrium states: *b, d, e* and *f.* These states are RSEQ and RGMR stable for both DM 1 and DM 2. Further, this means that the state is an overall RSEQ equilibrium state. Notably, all the other states in the conflict are RNash stable for one DM and totally unstable for the other, resulting in no RNash equilibria. Next, using preferences alone, the results of this analysis will be recreated without attitudes. What is also noticeable here is that state *b* is the only state that results in a deal being completed. And thus, there is some difficulty, due to the attitudes and preferences of the DMs involved, to reach a positive outcome of this kind.

In order that the conflict be recreated as a regular conflict without attitudes, it is necessary to recreate the relational preferences and replies shown in Table 6.5 as shown in Table 6.7 below. Using this new information, the regular stability analysis can be completed and the new preferences can also be determined.

Table 6.7: Unilateral Improvements and Preferences in Parallel Conflict

n	$R_1^+(n)$	$>_1 n$	$R_2^+(n)$	$>_2 n$
a	--	--	*d*	*b, c, d, e, f*
b	--	*a*	*e*	*c, d, e*
c	*a, b*	*a, b, d, e, f*	--	--
d	*f*	*a, b, f*	--	*c*
e	*f*	*a, b, f*	--	*c, d*
f	--	*a*	*c*	*b, c, d, e*

As can be seen in Table 6.7, although DM 2's unilateral improvements have not changed at all, DM 1's unilateral improvements have changed significantly. Specifically, both states *d* and *e* have the same list of more preferred states for DM 1, as do *a, b* and *f*, which are all blank. Thus, while DM 2 maintains a transitive ranking of states, DM 1's preferences are best thought of as pair-wise relationships. Using these relationships, as well as the connectivity of states shown above, it is possible to determine the state stability of each state for both DMs.

By performing stability calculations, analogous results to those of the relational analysis are found. For example, state *d* is *RSEQ* and *RGMR* stable for DM 1 in the relational conflict and is *GMR* and *SEQ* stable for the parallel regular conflict. From state *f*, in the relational analysis, DM 2 has a TRR to state *c,* as shown in Figure 6.3. From state *c*, DM 2 can sanction DM 1 by moving the conflict to state *a*, which is not relationally preferred to state *f.* From state *a*, DM 1 can move to state *d.* Fortunately for DM 1, state *d* is relationally preferred to state *f*, and thus, state *f* is not RSMR for DM 1. As DM 2's move from state *c* to state *a* is a TRR for DM 2 from state *c* and not relationally preferred by DM 1 to state *f*, state *f* is RGMR and RSEQ stable for DM 1.

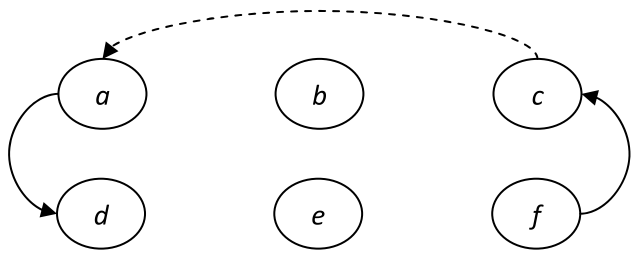


Figure 6.3: DM 2's movements from state *f* as well as DM 1's countermoves in the relational conflict

What is most interesting is that by setting up a parallel conflict using different preferences and no attitudes, the exact same result was obtained using regular GMR and SMR solution concepts. If one specifically compares state *c* in both the relational and parallel regular analysis, it can be seen that the only difference in the equilibria and stabilities of each state for each DM is that the relational analysis uses relational solution concepts, while the parallel analysis employs regular ones. The only difficulty that one might have in obtaining the preferences is that they may be intransitive for the parallel analysis, as they are in this example, and thus, might not be intuitive.

6.4. Summary

The implementation of an attitudes analysis allows decision analysts to take into account the types of relationships that exist between cooperative and uncooperative DMs under conflict without needing to account for the likely intransitivities that arise from having more than one set of criteria to determine preferences. Within the simple brownfield procurement example in subsection 6.3, it was easy to determine that out of the four possible equilibria, only 1 result guaranteed a settlement (specifically, state *b*). This type of information is important for both DMs and may be used by a consultant or intermediary to help the two parties come to an agreeable price.

By developing theorems that allow a relational analysis to be reconstructed as a parallel regular analysis, it is possible to see the way that attitudes shape the preferences of DMs, and thus, the outcome of conflicts. The example shown above illustrates that attitudes can act as a sort of shorthand for preferences that are difficult to elicit in practice by allowing a DM to consider different conflict situations without needing to totally reconfigure the preferences of a given DM. The mathematical basis which allows us to understand this comes from the definitions of the preferences themselves, thus giving a solid foundation for determining the impact of attitudes and preferences. Certainly, future conflicts could well be examined using this methodology, which would allow DMs to take into account changes in preferences quickly and easily.

Chapter 7

Dominating Attitudes in the Graph Model for Conflict Resolution

7.1. Introduction

The weighing of priorities is a key part of decision making, be it in the case of a single decision maker (DM) choosing amongst multiple options, or the interaction of multiple DMs in a conflict situation. Even more important is the consequences one's attitudes and decisions may have on oneself and others in a given conflict. Dominating attitudes, a formal framework with game theoretic roots, are proposed to allow decision analysts to determine the strategic impacts of concentrating on each DM's key attitudes towards himself and others in the process of resolving the conflict. By focusing on the most important attitudes that a DM may have, both the theory and practice of investigating the role of attitudes in conflict resolution are made significantly more flexible by using this new methodology. For example, complex attitudes may exist between environmentalists and industrialists involved in a serious dispute over the proper disposal of industrial wastes. However, the dominating attitude of the environmentalists is that the industrialists make a concerted effort to clean up their wastes, while the industrialists' overriding attitude is that the environmentalists do not significantly endanger their profitability.

In Subsection 7.2.1, the concept of dominating attitudes is introduced and the corresponding solution concepts are developed as an extension of those attitudes definitions given in Chapter 4. In Subsection 7.2.1, dominating attitudes are applied to the Expanded Sustainable Development conflict for illustrative purposes. Next, in Subsection 7.3, a simple environmental conflict is discussed and analyzed using the analytical methods developed in 7.2. Finally, in Subsection 7.4, insights based on the theoretical developments and the case studies are discussed.

7.2. Dominating Attitudes

7.2.1. Dominating Attitudes Definitions

The concept of dominating attitudes is a method which allows decision analysts to group a DM's set of attitudes into sets of most important and least important attitudes. For example, in a large conflict a given DM may have attitudes towards many DMs, but he may feel most strongly about certain DMs whom he has dealt with on numerous occasions. The utility of creating sets this way is twofold: first of all, it will improve the accuracy of conflict modeling by providing flexibility to the attitudes framework and secondly, it will allow realistic solution concepts to be defined. The definition of 'dominating attitudes', given below, is a partition of the attitudes defined previously in Chapter 4, Definition 20.

Definition 32 (Dominating Attitudes): For $i \in N$, with attitudes $e_i = \{e_{ii}, e_{ij},...., e_{in}\}$, the set of dominant attitudes considered most consequential is denoted as $e_i^d \subseteq e_i$, where $e_i^d = \{e_{ik}, ..., e_{im}\}$. The set of non-dominating attitudes considered least consequential is denoted as $e_i^{nd} \subseteq e_i$, where $e_i^{nd} = (e_i - e_i^d) - e_i^*$, where e_i^* is the set of indifferent attitudes.

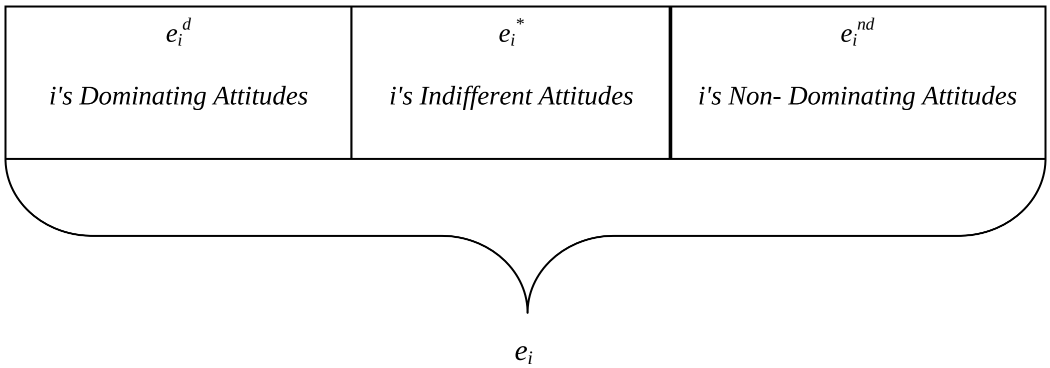


Figure 7.1: Partition of DM *i*'s Attitudes

Using these sets of attitudes shown in Figure 7.1, as defined in Definition 32, four new solution concepts are developed based on the relational definitions given in Chapter 4, Definitions 28 to 31.

Definition 33 Weak Relational Nash stability (WRNash): For $i \in N$, state $s \in S$ is weak relational Nash stable at $e_i = e_i^d \cup e_i^{nd} \cup e_i^*$ for DM i, denoted by $s \in S_i^{WRNash}(s)$, if and only if $\mathbf{TRR}(e_i)(s) = \{s\}$ and there exists $y \in S$ such that $\mathbf{TRR}(e_i^d)(s) = \{y, s\}$.

By Definition 33, if a state is RNash stable, but there exists a total relational reply that satisfies its set of ranked attitudes, e_i^r, then the RNash stability is "weak", as DM *i* may have a strong temptation to satisfy one or more of these dominant attitudes.

Definition 34 Weak Relational Sequential stability (WRSEQ): For $i \in N$, state $s \in S$ is weak relational sequential stable at $e_i = e_i^d \cup e_i^{nd} \cup e_i^*$ for DM i, denoted by $s \in S_i^{WRSEQ}(s)$, if and only if for all $x \in \mathbf{TRR}(e_i)(s)$, there exists $y \in \mathbf{TRR}_{N-i}(x)$ such that $s\mathbf{TRP}(e_i^{nd})y$ and $NE(s\mathbf{TRP}(e_i^d)y)$.

In Definition 34, a state is seen to be Weak Relational Sequentially stable if after DM i makes a Total Relational Reply according to her attitudes, the opposing DMs can only make TRRs that are sanctions according to her non-dominating attitudes. That is to say, by her dominating attitudes the final state is more preferred and thus she may risk making the TRR.

Definition 35 Weak Relational General Metarational stability (WRGMR): For $i \in N$, state $s \in S$ is weak relational general metarational at $e_i = e_i^d \cup e_i^{nd} \cup e_i^*$ for DM i, denoted by $s \in S_i^{WRGMR}(s)$, if and only if for all $x \in \mathbf{TRR}(e_i)(s)$, there exists $y \in \mathbf{R}_{N-i}(x)$ such that $s\mathbf{TRP}(e_i^{nd})y$ and $NE(s\mathbf{TRP}(e_i^d)y)$.

In Definition 35, a state is seen to be Weak Relational Sequentially stable if after DM i makes a Total Relational Reply according to her attitudes, the opposing DMs can only make moves that are sanctions according to her non-dominating attitudes. That is to say, by her dominating attitudes the final state is more preferred and thus she may risk making the TRR.

Definition 36 Weak Relational Symmetric Metarational stability (WRSMR): For $i \in N$, state $s \in S$ is weak relational symmetric metarational at $e_i = e_i^d \cup e_i^{nd} \cup e_i^*$ for DM i, denoted by $s \in S_i^{WRSMR}(s)$, if and only if for all $x \in \mathbf{TRR}(e_i)(s)$, there exists $y \in \mathbf{R}_{N-i}(x)$ such that $s\mathbf{TRP}(e_i)y$ and for all $z \in \mathbf{R}_i(s)$, $s\mathbf{TRP}(e_i^{nd})z$ and $NE(s\mathbf{TRP}(e_i^d)z)$.

From Definition 36, if a state is RSMR stable by Definition 13 and DM i's escape from the sanction is less preferred to the original state by only her non-dominating attitudes, the state is WRSMR stable. Thus, the DM may decide that it is in her own interest to make a move in spite of the sanction.

7.2.2 Applying Dominating Attitudes

To better understand the dominating attitudes framework, it is useful to again consider the Expanded Sustainable Development conflict found in Figure 3.2 of Chapter 3. If one again considers *E'*s attitudes, it is possible to find a situation such as is shown in Table 7.1.

Table 7.1: *E's* Dominating Attitudes in Expanded Sustainable Development Conflict

	E	D	G
E	$+^{nd}$	$-^{d}$	$+^{nd}$
D	0	+	0
G	0	0	+

Here, *E* has non-dominating positive attitudes towards himself and *G*, denoted by the $+^{nd}$ in the 1st and 3rd columns, and has a negative dominating attitude towards *D*, denoted by $-^{d}$ in the 2nd column. To determine states which may be WRNash stable for *E* by Definition 33, it is useful to calculate *E*'s Total Relational Preferences and Total Relational Replies for all of *E*'s attitudes and for the case where *E* only considers his dominating attitude such that, in this particular case $TRP^{d}(s) = RP_{ED}(s)$. In Table 7.2, the centre column lists those states that *E* prefers according to his attitudes. In the far right column, one can see those moves that correspond to *E*'s dominant attitudes.

Table 7.2: *E's* TRPs and TRP^d in Expanded Sustainable Development Conflict

s	$TRP_E(s)$, $\boldsymbol{TRR_E(s)}$	$TRP^d{}_E(s)$, $\boldsymbol{TRR^d{}_E(s)}$
PSV	∅	∅
RSV	∅	***PSV***
PUV	*PSV, RSV*	*PSV, RSV*
RUV	*PSV, RSV,* ***PUV***	*PSV, RSV,* ***PUV***
PSL	*RSV*	*PSV, RSV, PUV, RUV*
RSL	∅	*PSL, RUV, RUV, PUV*
PUL	*PSV, RSV, PUV, PSL, RSL*	*RSL, PSL, RUV, PUV, RSV, PSV*
RUL	*PUV, RUV, PSL, RSL*	**PUL,** *RSL, PSL, RUV, PUV, RSV, PSV*

Thus, it can be seen that there exist two states, *RSV* and *RUL,* in which where there are no Total Relational Replies under all the attitudes, but there is when only the dominating attitudes are considered. Focusing on *RSV*, and applying Definition 33, it is observed that *RSV* is RNash stable for *E*, but there exists a dominant Total Relational Reply to state *PSV*. Therefore, *E's* RNash stability at *RSV* is weak and the state is WRNash for *E*. In this development of the dominating attitudes definitions, the importance of weighing the DMs' individual attitudes has been considered. There is, however, another approach which leads to the same result through a slightly different path. In this alternate case, a DM considers giving different weights to particular DMs in the conflict and then calculating which moves satisfy his attitudes towards the more important DMs. In this sense, the solution concepts are similar, only now the decision analyst does not need to categorize the particular attitudes; the categorization of one DM's views of other DMs does this. In subsection 7.3, these new definitions of dominating attitudes, as well as the definitions for GMCR and Attitudes discussed earlier, are applied to the problem of a brownfield redevelopment in Kitchener, Canada.

7.3. Redevelopment of a Brownfield Property in Kitchener, Ontario, Canada

In this subsection, an environmental conflict over the purchase of an abandoned factory on a brownfield location will be examined using this new preference structure discussed above. A brownfield is defined as land that has been polluted through industrial or commercial activities (USEPA, 1997; Hipel and Bernath Walker, 2012b). The redevelopments of brownfields, which are properties that are perceived to be environmentally contaminated (USEPA, 1997), provide an opportunity for communities and businesses to improve their quality of life and commerce (Bernath Walker et al. 2009, 2010; Greenberg et al. 2000; Greenberg and Lewis 2000). Local governments, which are of course aware of this, are thus under pressure to encourage development of these lands in order to benefit local interests.

The objective of using a formal systems model to analyze this particular conflict is not intended to be predictive. Rather, as this particular type of conflict is a commonly occurring one in brownfield redevelopments, this formal analysis is meant to provide insight as to what specific preferences and attitudes will aid the decision makers in arriving at a win-win resolution, as they did in the redevelopment of an abandoned factory located on a brownfield site, discussed in the next subsection (Bernath Walker et al., 2010). For comparative analyses of a range of approaches, including game theoretic methods, for forecasting decisions in conflicts, the reader can refer to the interesting research of Green (2002, 2005) or Green and Armstrong (2007) and references contained therein.

7.3.1 Brownfield Acquisition Conflict

Walker et al. (2007) developed a three-step process outlining the redevelopment of brownfield properties beginning with the important step of property acquisition, followed by remediation and redevelopment. This process is based on case studies of private brownfield renovations and, in particular, focuses on the conversion of the Kaufman Shoe Factory, located in Kitchener, Ontario, Canada, into condominiums called the Kaufman Lofts. In the property acquisition step of the Kaufman renovation, the current property owner, the local government and the potential developer were all involved. The current property owner (PO) and the buyer or property developer (D) needed to negotiate a market-value price for the property, while the city government (CG) had to decide whether to offer incentives to the developer to take on the blighted property. In the case of the Kaufman Lofts, and many other brownfield properties throughout the developed world, government involvement is essential in order to not only fund the cleanup of the property, but to improve the living conditions of the residents in the area.

The option form of this conflict is shown in Table 7.3 where each option is either marked with a 'Y' or an 'N' denoting that either "Yes" the option is selected, or "No" it isn't, respectively. The state identifications (IDs) are derived by decimalizing the binary entries in each column. As expected, the Property Owner (PO) has the opportunity to sell the land at a high or low value, the City Government (CG) has the option to offer incentives or not, and the Developer (D) has the option to make an offer to purchase the property or not. The bottom row of Table 7.1 is made up of the corresponding states labels. For example, the 3rd state from the left is state '2' in which PO is selling low, CG is not providing incentives and D is not purchasing the property.

Table 7.3: Acquisition Conflict in Option Form

PO	Sell High	N	Y	N	N	Y	N	N	Y	N	N	Y	N
	Sell Low	N	N	Y	N	N	Y	N	N	Y	N	N	Y
CG	Incentives	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
D	Buy	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
	State IDs	0	1	2	4	5	6	8	9	10	12	13	14

Given this set of feasible states in Table 7.3 shown in option form, it is necessary to develop ordinal preference rankings of the states, from the perspective of each DM. For example, CG would prefer that PO sell the property at either price, as opposed to not selling it, and that D purchases the property so that the land will be used. Using this type of logical ordering, the preferences are developed, as shown in Table 7.4. Here, the states are listed from most to least preferred, when reading from left to right, while equally preferred states are grouped together in parentheses. For example, PO prefers states 13 and 9 equally to each other and more than any other state.

Table 7.4: Preference ranking for acquisition conflict

PO	(13	9)	(1	5)	(0	4	8	12)	(2	6	10)	14
CG	10	14	9	13	(0	1	2	8)	(4	5	6	12)
D	14	6	10	(0	2	4	8	12)	5	1	13	9

Next, the conflict is put into tableau form, as first shown by Fraser and Hipel (1984), by placing each preference ranking in a table with the unilateral improvements available to the given DM at a particular state shown below the state. Each state is tested for Nash and Sequential stability according to Definitions 6 and 9, laid out in Chapter 3, as can be seen in Table 7.5. For example, state 6 is SEQ stable for D, by Definition 3, as follows: $R_D^+(6) = 14$, $R_{N\text{-}D}^+(14) = \{8, 9,$

10, 12, 13} and $6 >_D$ {8, 9, 10, 12, 13}, thus state 6 is SEQ for D. When looking at likely outcomes, there is only one equilibrium state, state 1. At state 1, PO offers to sell the property at a high price, CG offers no incentives and D does not buy the property. From the standpoint of CG and D this is not a successful negotiation outcome. Thus, it is in the interest of both parties to see how they might best negotiate in order to reach a better outcome for the developer and greater community.

Table 7.5: Tableau form of static analysis

	X	x	E	x	x	x	x	x	x	x	x	x
	R	r	r	r	u	u	u	u	u	u	u	u
PO	(13	9)	(1	5)	(0	4	8	12)	(2	6	10)	14
					1	5	9	13	1	5	9	13
									0	4	8	12
	r	s	r	u	r	r	r	r	u	u	u	u
CG	10	14	9	13	(0	1	2	8)	(4	5	6	12)
		10		9					0	1	2	8
	r	s	r	r	u	r	r	r	r	r	u	u
D	14	6	10	(0	2	4	8	12)	5	1	13	9
		14			10						5	1

7.3.2. Attitudes in Brownfield Acquisition Conflict

In order to reach a conflict outcome where both CG and D are satisfied, both DMs need to make an effort to help each other. For example, CG would benefit the community by trying to do those things that would entice D to purchase the property, namely by providing incentives. At the same time, CG must make a commitment to preserving taxpayer monies and staying on budget. In this case, the attitudes would be formally written as shown in Table 7.6.

Table 7.6: Attitudes in brownfield negotiation

	PO	CG	D
PO	+	0	0
CG	0	+	+
D	0	0	+

In order to apply this new perspective to the conflict, it is necessary to examine the preference information as well as the reachable lists for all the DMs. As CG has positive attitudes towards itself and D, all of CG's moves must satisfy both CG's and D's preferences in order to be a credible move, by Definition 9. In Table 7.7 below, a list of all the states in the conflict is given. Below each state in this list is a set of states that are reachable by CG from the corresponding state in the top row. Those states that are preferred by CG and D, and are thus Totally Relationally Preferred by CG according to Definition 24, would be marked in bold. However, there are no moves that satisfy these attitudes.

Table 7.7: Unilateral Movements and Total Relational Replies (bolded) for CG

States	0	1	2	4	5	6	8	9	10	12	13	14
CG's Moves	4	5	6	0	1	2	12	13	14	8	9	10

As there are no TRRs, by Definition 9, for CG for any of the 14 states, each state is RNash stable for CG, by Definition 12. This is illustrated in Table 7.7, as none of the unilateral movements available to CG are bolded. This leads to a whole new profile of equilibria for our brownfield acquisition conflict, as shown in Table 7.8.

Table 7.8: Tableau form of Attitude Analysis – Case 1

	x	x	E	E	x	x	x	x	x	x	x	x
	r	r	r	r	u	u	u	u	u	u	u	u
PO	(13	9)	(1	5)	(0	4	8	12)	(2	6	10)	14
					1	5	9	13	1	5	9	13
									0	4	8	12
	rr	rr	rr	rr	rr	rr	rr	rr	rr	rr	rr	rr
CG	10	14	9	13	(0	1	2	8)	(4	5	6	12)
	r	s	r	r	s	r	r	r	r	r	u	u
D	14	6	10	(0	2	4	8	12)	5	1	13	9
		14			10						5	1

All of CG's states are RNash stable, denoted 'rr', by Definition 28, as the only states available to move from are the states themselves due to the restriction of CG considering multiple attitudes. As shown in Table 7.6, the new equilibrium is state 5 where PO tries to sell at a high price, CG offers incentives and D does nothing. For example, state 0 is RNash stable for CG as $TRR_{CG}(0) = \{0\}$ and therefore, $0 \in S_{CG}^{RNash}$. As this outcome is not advantageous to either D or CG, it is worth looking at what attitudes must change on the part of D, instead of CG, to arrive at a better outcome. These new possible attitudes are expressed in Table 7.9 below, much as they were in Table 7.8 above.

Table 7.9: Attitudes in Brownfield Negotiation – Case II

	PO	CG	D
PO	+	0	0
CG	0	+	0
D	0	+	+

Given this new set of DM attitudes, D will have to behave in a manner that satisfies not only her own preferences, but those of CG. Thus, D will need to determine if her possible moves satisfy her Total Relational Preference (TRP) according to Definition 24, in Chapter 4, before she can be certain of her Total Relational Replies (TRRs). The TRRs of D for the set of attitudes given in Table 7.10 are shown. The top row of the table is the complete set of states in this conflict. Below each state is the set of unilateral movements available to D from the state. Of these movements, those that are bolded represent D's Total Relational Replies.

Table 7.10: Unilateral Movements and Total Relational Replies (bolded) for D

States	0	1	2	4	5	6	8	9	10	12	13	14
D's Moves	8	9	**10**	12	13	**14**	0	1	2	4	5	6

Given this new set of Total Relational Replies on the part of D, a whole new static analysis can be done, as shown in the tableau form of the conflict given in Table 7.11. As can be seen, there are now two equilibrium states.

Table 7.11: Tableau form of Attitude Analysis – Case 2

	x	E	E	x	x	x	x	x	x	x	x	x
	r	r	r	r	u	u	u	u	u	u	u	u
PO	(13	9)	(1	5)	(0	4	8	12)	(2	6	10)	14
					1	5	9	13	1	5	9	13
									0	4	8	12
	r	s	r	u	r	r	r	r	u	u	u	u
CG	10	14	9	13	(0	1	2	8)	(4	5	6	12)
		10		9					0	1	2	8
	rr	rs	rr	rr	rs	rr	rr	rr	rr	rr	rr	rr
D	14	6	10	(0	2	4	8	12)	(1	5)	13	9
		14			10							

With these new attitudes, there are now moves that can be undertaken to find new equilibria. From state 6, D can still move to state 14, even though she is under attitudes. State 6 is RSEQ stable according to Definition 31 because $14 \in TRR_{CG}(6)$ means that 6 cannot be RNash, by Definition 28. As $5, 4 \in TRR_{PO}(14)$ and $6TRP_{CG}5$, state 6 is thus RSEQ stable.

More generally, as can be seen in Table 7.13, there are now two equilibria at states 1 and 9. At state 1, PO attempts to sell the property at the highest price, CG does not offer incentives and D does not purchase it. At state 9, however, PO puts the property up for sale at the highest price, CG does not offer incentives and D does purchase it. Although it may seem optimistic to have such a state as an equilibrium state, it is unlikely that this state would be reached. The reason for this is that in order to reach state 9, moves must be made from the status quo state, 0. From 0 the only credible move available is for PO to move to state 1. As state 1, is the status quo and an equilibrium state, it is likely that the conflict will stay at this point.

In order to solve this dilemma, it is worth looking at how a DM may perhaps favor certain attitudes over others. This favoring, called dominating attitudes, is a way for the different DMs to test the strength of their stabilities, according to the definitions in Subsection 7.2.1.

Table 7.12: Dominant Attitudes in Brownfield Negotiation

	PO	CG	D
PO	+	0	0
CG	0	$+^{nd}$	$+^{d}$
D	0	$+^{d}$	$+^{nd}$

In Table 7.12, the dominant attitudes for both CG and D are shown. Here we can see that both D and CG hold positive attitudes towards themselves and each other but that the dominating attitudes they have are for each other. The dominating attitudes are marked with a superscript 'd', while the non-dominating attitudes are marked with a superscript 'nd'. Using this attitude information, it is possible to determine the TRRs of both CG and D. As previously, the movements for CG and D are shown in Table 7.13. Again, the movements that satisfy a DM's complete set of attitudes are in bold. In addition, however, states that satisfy dominant attitudes, but not the non-dominating attitudes, are denoted by an asterisk (*).

Table 7.13: Unilateral Improvements, Weak TRRs (*) and TRRs (bolded) for CG and D

States	0	1	2	4	5	6	8	9	10	12	13	14
CG's Moves	4	5	6*	0	1	2	12	13	14*	8	9	10
D's Moves	8	9*	**10**	12	13*	**14**	0	1	2	4	5	6

Applying these new movements to the conflict laid out previously results in new equilibria, as illustrated in Table 7.14. Applying the new dominant attitudes definitions, there are states that are 'rr' or RNash stable, by Definition 28, and those that are 'wrr' or Weak RNash stable, by Definition 33. For example, at state 2 $TRR_{CG}(2) = \{2\}$, meaning that the only Total Relational Reply from state 2 is itself, and thus the state is RNash for CG by Definition 28. However, as there exists a movement that satisfies $e_{CG}{}^{d}$, in this case CG's devoting attitude towards D, the state is WRNash. Specifically, $TRR(e_{CG})(2) = \{2\}$ and there exists a state, 6, such that $TRR(e_{CG}{}^{d})(2) = \{6, 2\}$. Thus, state 2 is WRNash for CG.

Table 7.14: Tableau Form Analysis of Unilateral movements and Total Relational Replies for CG and D

	E	WE	WE	WE	x	x	x	x	x	x	x	x
	r	r	r	r	u	u	u	u	u	u	u	u
PO	(13	9)	(1	5)	(0	4	8	12)	(2	6	10)	14
					1	5	9	13	1	5	9	13
									0	4	8	12
CG	wrr	rr	wrr	rr	rr	rr	wrr	rr	rr	rr	rr	rr
	10	14	9	13	(0	1	2	8)	(4	5	6	12)
	14*		13*				6*					
	rr	rs	rr	rr	rs	rr	rr	rr	wrr	wrr	rr	rr
D	14	6	10	(0	2	4	8	12)	5	1	13	9
		14			10				13*	9*		

In Table 7.14, the conflict is illustrated in tableau form, where the equilibria are written in the top line and correspond with the state in the top most row. As can be seen, there are four equilibria, all corresponding to states that are strongly preferred by PO: 13, 9, 1 and 5. Only one of these states, state 13, is enforced by "strong" solution concepts, meaning that there are no dominant moves that could be used by any of the DMs to move away from the state. Thus, it is reasonable to assume that if DMs are willing to follow their dominating attitudes, a final outcome at state 13 will occur. What this really means is that CG makes the sacrifice of offering incentives and D agrees to purchase the property at a higher price. In order to reach this state, however, both DMs have to make an agreement to move together to the stronger and more advantageous outcome. Such a movement, called an equilibrium jump (Kilgour et al. 2001), is a way for DMs to act as a temporary coalition in order to move to a state that is advantageous for all coalition members while not risking that their coalition partner(s) will not come through.

7.4 Summary

Through the careful application of attitudes in a logical manner and through the consideration of dominating and non-dominating attitudes, it is possible to develop new win-win resolutions to resolving brownfield conflicts. The importance of the dominating attitudes framework is that it enhances the flexibility of the original attitudes analysis procedure developed by Inohara et al. (2007) and creates possibilities for new moves and countermoves that better mimic human behaviors. Specifically, within the context of the brownfield acquisition problem in Subsection 7.3, two DMs are able to work together and act in tandem to achieve a resolution that benefits not only themselves but the community and environment at large. Such techniques and results can also be applied to military and political alliances as well as international environmental agreements – thus their development is essential, not just as a mathematical exercise but for the advancement of formal approaches to describing human behavior under conflict.

Chapter 8

Coalitions and Attitudes (COAT)

8.1 Introduction

The utilization of decision support systems which are flexible enough to handle information about cooperative behavior and stakeholder attitudes are useful for analyzing complex social conflicts. One such conflict which arose from the redevelopment of a private brownfield property in Kitchener, Ontario, Canada is examined using such a decision support tool. Specifically, in this chapter, a formal model for analyzing the strategic impact of Coalitions and Attitudes (COAT) is rigorously defined and then implemented within the framework of GMCR in order that insights may be gained on how the decision makers can reach win-win resolutions. Within Subsection 8.2.1 the solution concepts used in the Graph Model are expanded to encompass the possible movements of coalitions of decision makers, acting under attitudes. Next in Subsection 8.2.2, a brief example of the COAT methodology is applied to the Expanded Sustainable Development Conflict. In Subsection 8.3, a brownfield redevelopment in Kitchener, Ontario, Canada is examined using the conflict resolution tools developed in Subsection 8.2, based on those developed in Chapters 3 and 4 (Bernath Walker et al., 2009).

8.2. COalition and ATtitudes (COAT)

Groups of DMs, referred to as coalitions, commonly form under conflict situations. Thus, in this chapter the solution concepts defined in Chapter 3 are expanded to include attitudes, in order to better understand conflicts. The following definitions extend the theory and solution concepts developed by Inohara and Hipel (2008 a,b) and Kilgour et al. (2001) to include this group behavior within the attitudes framework.

Definition 37 (Attitudes of a coalition (e_H)) For a coalition H of size M where $H \subseteq N$, the attitudes of the coalition are a set of M attitude vectors of magnitude N. Thus, $e_H = \{e_i, e_j, e_k, e_l ... e_z\},\ \ where\ DMs\, i, j, k, l, ...z \in H$.

Definition 38 (Coalition relational less preferred states) The symbol $R\phi^{\simeq}(e)_H(s)$ is an analogue of $\phi_H^{\simeq}(s)$ given in Chapter 3. Specifically, $R\phi^{\simeq}(e)_i(s)$ is the set of all states that are not relational preferred to state s by at least one DM in coalition H, that is, $\{t \in S \mid \exists\, i \in H$, NE($t$ **TRP**$(e)_i\ s)\}$. **Note:** $s \notin R\phi^{\simeq}(e)_H(s)$ always holds. $R\phi^{\simeq}(e)_H(s) = \cup_{i \in H} R\phi^{\simeq}(e)_i(s)$.

Definition 39 (TRR$^{++}(e)_H(s)$: Relational Coalition improvement list): The relational coalition improvement list of a coalition $H \subset N$ with states $s \in$ S, **TRR**$^{++}(e)_H(s)$ is an analogue of the coalition improvement list $R_H^{++}(s)$ given in Definition 11, and is defined as the set $\{t \in R_H(s) \cup \{s\} \mid \forall\, i \in H, t$ **TRP**$(e)_i\ s\}$.

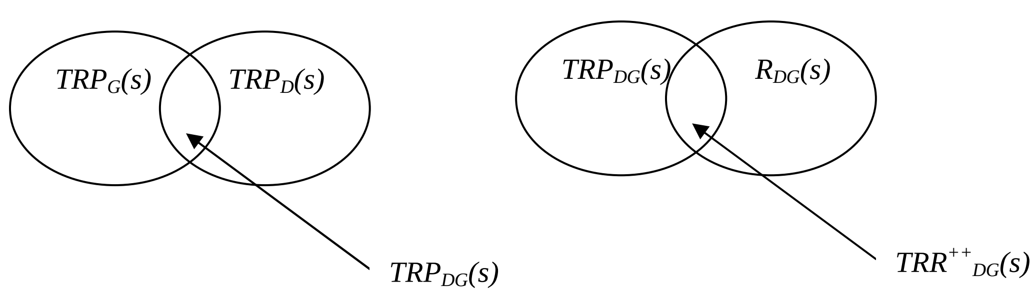


Figure 8.1: Venn Diagram for Total Relational Preferences and Replies of Coalition DG within the Expanded Sustainable Development Conflict

On the left side of Figure 8.1, it can be seen that the Total Relational Preference of the coalition *DG* is the intersection of each DM's, *D*'s and *G*'s, Total Relational Preference. On the right side of Figure 8.1, the Total Relational Replies of the coalition *DG* are shown to be the intersection of its Total Relational Preferences and Coalition Reachable List.

Note: $s \in \mathbf{TRR}^{++}(e)_H(s)$ always holds. Comparing Definition 11 and Definition B, one can see that $\mathbf{TRP}(e)_i$ in coalition relational analysis behaves like $\succ_i$ in coalition analysis.

In coalition analysis, the class improvement list $R_C^{++}(s)$ of subclass C from state *s* (hence, $R_{P(N-H)}^{++}(s)$) is defined from $R_H^{++}(s)$ by induction as follows: for a subclass C of P(*N*) and $s \in S$, the class improvement list of subclass C from state *s* is defined inductively as the set $R_C^{++}(s)$ that satisfies the next two conditions: (i) if $H \in C$ and $t \in R_H^{++}(s)$, then $t \in R_C^{++}(s)$, and (ii) if $H \in C$ and $t \in R_C^{++}(s)$ and $u \in R_H^{++}(t)$, then $u \in R_C^{++}(s)$.

Similarly, in coalition relational analysis, the class relational improvement list $\mathbf{TRR}^{++}(e)c(s)$ of subclass C from state *s* (therefore, $\mathbf{TRR}^{++}(e)_{P(N-H)}(s)$) is defined from $\mathbf{TRR}^{++}(e)_H(s)$ by induction as in the next definition.

Definition 40 ($\mathbf{TRR}^{++}(e)_C(s)$: Class relational improvement list): For a subclass C of P(*N*) and $s \in S$, the class relational improvement list of subclass C from state *s* is defined inductively as the set $\mathbf{TRR}^{++}(e)_C(s)$ for which $\Omega_{Cs}^{TRR++}(k)$ is the set of last DMs and $C \subset N,\ C \neq \phi$ at *e* for state $s \in S$ such that:

i) if $j \in C$ and $k \in TRR^{++}(e)_j(s)$, then $k \in TRR^{++}(e)_C(s)$ and $j \in \Omega_{Cs}^{TRR++}(k)$,

ii) if $k \in TRR^{++}(e)_C(s)$, $j \in C$, and $k_1 \in TRR^{++}(e)_j(k)$, then

a) if $\left|\Omega_{Cs}^{TRR++}(k)\right| = 1$ and $j \notin \Omega_{Cs}^{TRR++}(k)$, then $k_1 \in TRR^{++}(e)_C(s)$ and $j \in \Omega_{Cs}^{TRR++}(k_1)$,

b) if $\left|\Omega_{Cs}^{TRR++}(k)\right| > 1$ then $k_1 \in TRR^{++}(e)_C(s)$ and $j \in \Omega_{Cs}^{TRR++}(k_1)$.

If the graphs of each of the subsets of C are transitive the $\text{TRR}^{++}(e)_{\text{C}}(s)$ can be defined as follows:(i) if $H \in \text{C}$ and $t \in \mathbf{TRR}^{++}(e)_H(s)$, then $t \in \mathbf{TRR}^{++}(e)\text{c}(s)$, and (ii) if $H \in \text{C}$ and $t \in \mathbf{TRR}^{++}(e)\text{c}(s)$ and $u \in \mathbf{TRR}^{++}(e)_H(t)$, then $u \in \mathbf{TRR}^{++}(e)\text{c}(s)$.

Definition 41 ($S_H^{\text{CRNash}(e)}$: Coalition relational Nash stability (CRNash)): For $H \subseteq N$, $s \in S$, and e, state s is coalition relational Nash stable at e for coalition H, denoted by $s \in S_H^{\text{CRNash}(e)}$, if and only if $\mathbf{TRR}^{++}(e)_H(s) = \{s\}$.

Note: Comparing Definition 13 and Definition D, one can see that $\mathbf{TRR}^{++}(e)_H(s)$ in coalition relational analysis behaves like $R_H^{++}(s)$ in coalition analysis. As noted before, $s \in \mathbf{TRR}^{++}(e)_H(s)$ always holds, and hence, the definition "$\mathbf{TRR}^{++}(e)_H(s) = \emptyset$" does not work.

Definition 42 ($S_H^{\text{CRSEQ}(e)}$: Coalition relational sequential stability (CRSEQ)): For $H \subseteq N$, $s \in S$, and e, state s is coalition relational sequential stable at e for coalition H, denoted by $s \in S_H^{\text{CRSEQ}(e)}$, if and only if for all $x \in \mathbf{TRR}^{++}(e)_H(s) - \{s\}$, $\mathbf{TRR}^{++}(e)_{\text{P}(N-H)}(x) \cap (R\phi^{\simeq}(e)_H(s) \cup \{s\}) \neq \emptyset$

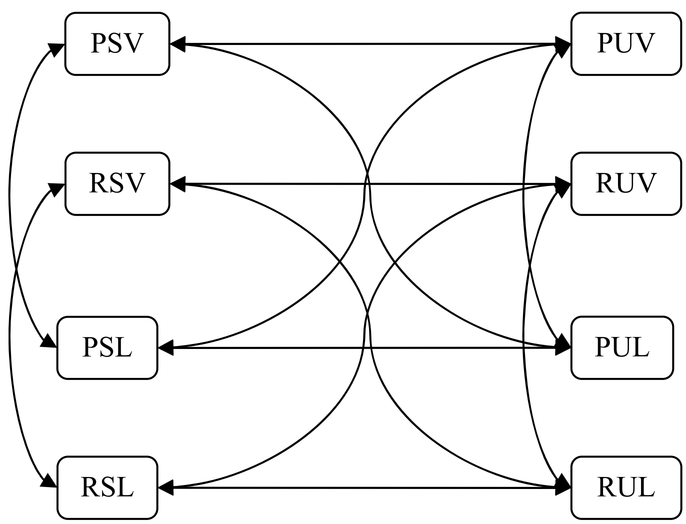
As pointed out before, $s \notin R\phi^{\simeq}(e)_H(s)$ always holds. The focal state s should work as a sanction and thus the term "$R\phi^{\simeq}(e)_H(s) \cup \{s\}$" is appropriate.

Definition 43 ($S_H^{\text{CRGMR}(e)}$: Coalition relational general metarationality (CRGMR)): For $H \subseteq N$, $s \in S$, and e, state s is coalition relational general metarational at e for coalition H, denoted by $s \in S_H^{\text{CRGMR}(e)}$, if and only if for all $x \in \text{TR}\mathbf{R}^{++}(\boldsymbol{e})_{\mathbf{H}}(\boldsymbol{s})$, $\mathbf{R}_{\text{P}(N-H)}(x) \cap (R\phi^{\simeq}(e)_H(s) \cup \{s\}) \neq \emptyset$.

Definition 44 ($S_H^{\text{CRMR}(e)}$: Coalition relational symmetric metarationality (CRSMR)): For $H \subseteq N$, $s \in S$, and e, state s is coalition relational symmetric metarational at e for coalition H, denoted by $s \in S_H^{\text{CRSMR}(e)}$, if and only if for all $x \in \mathbf{TRR}^{++}(e)_H(s)-\{s\}$, there exists $y \in R_{P(N-H)}(x) \cap (R\phi^{\simeq}(e)_H(s) \cup \{s\})$ such that $z \in R\phi^{\simeq}(e)_H(s) \cup \{s\}$ for all $z \in R_H(y)$.

8.2.2. Application of COAT

To illustrate the sometimes restrictive impact of attitudes in coalitions, consider the possibility of a coalition formed by DMs *D* and *G* in the Expanded Sustainable Development Conflict first described in Chapter 3. By removing *E* from the graph model and focusing on *D* and *G*, the new coalition's graph model is as shown in Figure 8.2. Note that although the DMs combine their movements, they maintain their individual preferences.



Ranking of States

Developers: RUL > PUL > RSL > PSL > RUV > PUV > RSV > PSV

Government: RSL > RSV > PSL > PSV > RUL > RUV > PUL > PUV

Figure 8.2: Graph Model of the Expanded Sustainable Development Conflict for the Developer – Government Coalition (DG)

If one examines the behavior of DG at state *RUV*, it can be easily seen that the coalition can move to states *RSL* and *RUL* while satisfying both DMs' preferences and thus $R_H^{++}(RUV)$ = {*RSL, RUL*}.

Applying attitudes to this analysis results in a change to the available moves DG can make. Considering the attitudes in Table 8.1, and the preferences and moves shown for *D* and *G* in Figure 3.2 of Chapter 3, it is possible to determine $TRR_H^{++}(RUV)$.

Table 8.1: *E's* Dominating Attitudes in Expanded Sustainable Development Conflict

	E	D	G
E	+	0	0
D	–	+	0
G	0	0	+

As shown in Table 8.2, *D* has Total Relational Preferences for states *PUL* and *RUL*, while *G* has Total Preferences for states *RSL*, *RSV, PSL, PSV,* and *RUL.* As any state that belongs to the set $TRR_{DG}^{++}(RUV)$ must be a Total Relational Preference for both *D* and *G*, then $TRP_{DG}(RUV)$ = {*RUL*}. As *RUL* is also reachable by DG, then $TRR_{DG}^{++}(RUV)$ = {*RUL*}. In graph form, this would be shown as one arc connecting state *RUV* to *RUL* for the coalition. Notably, the impact of attitudes in this circumstance has narrowed the possible movements for the coalition from two to one.

Table 8.2: *D* and *G's* Total Relational Preferences and Replies

$R_{DG}(RUV)$	*RSV, RUL, RSL*
$TRP_D(RUV)$	*PUL, RUL*
$TRP_G(RUV)$	*RSL, RSV, PSL, PSV, RUL*
$TRP_{DG}(RUV)$	*RUL*
$TRR_{DG}(RUV)$	*RUL*

In the following subsection, the methods defined and illustrated in Subsection 8.2 are applied to the case study of an interesting brownfield redevelopment.

8.3. Brownfield Redevelopment Case Study

In this subsection, a conflict over the use of a contaminated plot of land in Kitchener, Ontario, Canada is modeled using the aforementioned GMCR, defined in Chapter 3 and the COalitions and ATtitudes extension developed here in Chapter 8.

8.3.1 Background to the Dispute

The Intowns is a condominium development within the Mill-Courtland Woodside Park community which came into being through the collaboration of the City of Kitchener, concerned citizens and the developer, Stirling Bridge Limited. The property itself is a 3.38 ha expanse in the Highland Road and Woodside area of Kitchener, Ontario, Canada which has been the home of numerous industrial firms over the years. With tenants including Buffalo Forge Company, Canadian Blower & Forge Ltd. and Howden Fan Company, the site had been home to industry throughout its life. The property remained vacant from the time of Howden Fan's departure in the 1990s until 2000 when the property was purchased by a business interested in operating a contaminated soil recycling facility at the site. As the city began to look into plans for developing its former industrial properties and the mixed residential-commercial properties that surround the site, it became apparent to both the residents of the city and the government that an industrial development at that site would have a negative impact on the social, economic and environmental health of the city and run counter to city planning. After the passing of a bylaw in 2002 that essentially banned industrial development from certain spots within the city core, the soil recycling business came to pass. Shortly thereafter, a private developer, Stirling Bridge Ltd., invested in the property with the goal of building condominiums (City of Kitchener, 2005; Feick, 2007; Record Staff 2008).

8.3.2 Model Calibration and Initial Analysis

Although the final outcome of the project was a success, the initial negotiations over the use of the land were adversarial. The conflict will be modeled as a three DM conflict taking place between the developer (D) who wishes to run an unsustainable business on the site, the City of Kitchener (CK) and members of a local neighborhood activist group (A). The options available to each of the stakeholders, as well as the total set of feasible states, are shown in Table 8.1 above. Here, D can choose to (1) pursue a full project, (2) reduce the project to appease G or sell the property, denoted by choosing neither (1) nor (2). CK has the option of either (3) supporting the neighborhood by calling on the developer to hold public meetings regarding the development and by ensuring the business abides by local bylaws. Additionally, CK can support the company by (4) delaying response to the neighborhood's interest and A has the option of (5) protesting the development. Using the option form of the conflict, it is possible to generate a graph model of the conflict as defined in Definition 1, Chapter 3.

Table 8.3: Original Property Use Conflict In Tableau Form

			Feasible states											
D	1	Full project	N	Y	N	N	Y	N	N	Y	N	N	Y	N
	2	Reduction	N	N	Y	N	N	Y	N	N	Y	N	N	Y
CK	3	Support community	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N
	4	Delay	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
A	5	Protest	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
State IDs			1	2	3	4	5	6	7	8	9	10	11	12

From information known about the goals of each of the DMs a ranking of states was determined. To determine these rankings an option prioritization method was employed for all three DMs. These rankings represent the DMs preferences and thus form the basis of the analyses performed in GMCR. Using this option prioritization D's preferences assumed that D wanted to build a full project (1) while CK delays (4) and without protests from A (5). CK's preferences were that the project be at least reduced by D (2), that there be no protests (5) and that if protests did occur that they support N (3 IF 5) and that D sells the property (NOT 1 OR 2). Finally, A prefers that D sells the property (NOT 1 OR 2), and that CK support them (3). Using rules such as these the preference ranking of each DM was developed. In Figure 8.2, the graph model for this conflict is given. The preferences of each of the DMs is at the top of the figure and is denoted as P_{CK}, P_A and P_D. Note that in this figure equally preferred states are grouped together using parentheses.

CK P_{CK} = (3, 5), (9, 11), (2, 6), 8, 12, (1, 4), (7, 10)

A P_A = (1, (3, 9), (7, 10), (8, 11, 12), 4, (2, 5, 6)

D P_D = 3, 1, 5, 2, 7, (9, 11), 8, 4, 6, 10, 12

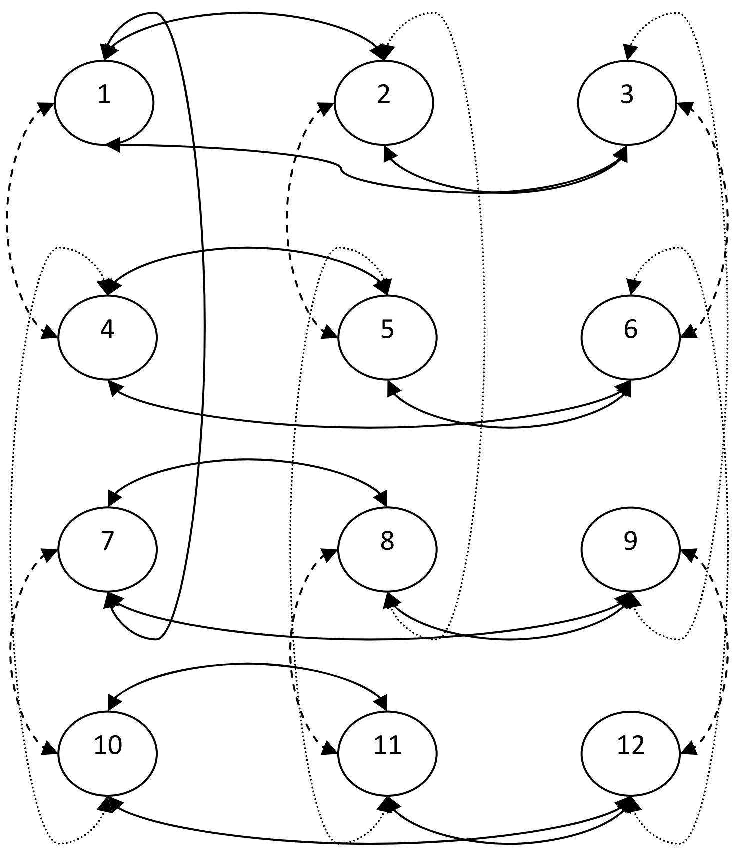


Figure 8.3: Graph Model of the InTowns Conflict

Armed with this information, a simple static analysis was undertaken using Nash and Sequential stabilities, given by Definitions 6 and 9 respectively, in Table 8.4. From the tableau form of the conflict shown in Table 8.4, it can be seen that there are equilibria at states 1, 3 and 11. Within the analysis in Table 8.4, Nash and Sequential stability were implemented to determine the overall state equilibriums. For example, state 5 was found to be unstable for CK. From state 5 CK can move according to $R_{CK}(5) = 9$. In order for a state to be sequentially stable, by Definition 9, either D or G must have a UI from 9 to a state that belongs to the set $\phi_{CK}^{\approx}(9)$. As $R^{+}_{D}(9) = 7$ and $R^{+}_{A}(9) = \{\}$, state 7 must be compared to state 5 using CK's preferences. As state 9 is not less preferred to state 5 by CK, i.e. $5 \notin \phi_{CK}^{\approx}(9)$, CK's unilateral improvement cannot be sanctioned and thus the state is unstable.

Table 8.4: Static Analysis of Property Use Conflict

	E	x	x	x	x	x	E	x	x	x	x	x
	r	u	r	u	r	u	r	u	u	u	u	u
D	3	1	5	2	7	(9	11)	8	4	6	10	12
		3		1		7		7	5	5	11	11
				3				9		4		10
	r	r	r	r	u	u	u	s	r	r	r	r
CK	(3	5)	(9	11)	(2	6)	8	12	(1	4)	(7	10)
					5	3	11	9				
	r	r	r	u	r	r	r	s	u	u	u	u
A	1	(3	9)	(7	10)	(8	11	12)	4	(2	5	6)
				1				6	10	8	11	12

Historically, the conflict started at state 11, where D is building the full project (1), CK is delaying its decision (3) and A (5) is protesting. From the Graph Model in Figure 1, the reachable lists of each of the DMs can be determined from state 11. As summarized in Table 8.5 the reachable lists of D, CK and A are $R_D(11) = \{10, 12\}$, $R_{CK}(11) = \{8\}$ and $R_A(11) = \{5\}$. As none of the unilateral movements away from state 11 are unilateral improvements, i.e. $10,12 \in \phi_{D}^{\approx}(11)$, $8 \in \phi_{CK}^{\approx}(11)$ and $5 \in \phi_{N}^{\approx}(11)$, it can be seen that the conflict will not move past the status quo state.

In such an instance, there is no way for the conflict to be pushed past the status quo point and both CK and G are stuck without a possible way to unilaterally escape this state in the conflict. The following subsection will examine how cooperative action and devoting attitudes can allow for new moves where CK and G can move the conflict to a better win/win result.

8.4 Attitudes and Coalitions

In conflict situations the consideration of coalition formation and attitudes is essential to fully comprehend the possible evolution of a conflict, as well as to determine what moves are required to result in a successful conflict outcome. Coalition analysis within GMCR originally established by Kilgour et al. (2001) and continued by Hipel and Inohara (2008a, 2008b) can be used to determine the impacts of cooperative moves and strategies. Attitudes within GMCR, developed and employed by Inohara et al. (2007), are used to examine the effect of the changing values and attitudes of one or more DMs upon the conflict outcome. By combining the attitudes and coalitions methodologies available within GMCR, separate types of coalitions can be analyzed, namely coalitions that exist to carry out specific strategic goals according to the attitudes of the coalition's constituent DMs (Bernath Walker, Hipel and Inohara, 2009). In this subsection, the creation of a coalition with attitudes that aid A in moving the conflict towards a preferred final conflict outcome is described.

Given the option form of the conflict found in Table 8.3, it is possible to describe the movements of the DMs using reachable lists as laid out in Definition 2. In Table 8.5, these reachable lists, as well as the reachable list of a coalition of DMs C and A, are given. The first three rows, which represent the unilateral movements of D, CK and A were used in the analysis of the conflict given in Table 8.4. Each reachable list is derived from the option form of the conflict using Definitions 2 and 4, found in Chapter 3. In order that the new coalition movements are utilized according to the values of A and CK it is necessary to employ the formal model of COalitions and ATtitudes defined in Definitions 37 to 44. To determine the relational moves of A-CK, the attitudes of all three DMs within the conflict are expressed in tabular form with the +, 0 or – representing positive, indifferent or negative attitudes by the row DM towards the column DM, respectively (Definition 20).

Table 8.5: Reachable Lists in Original Property Use Conflict

s	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
$R_D(s)$	2	1	1	5	4	4	8	7	7	11	10	10
	3	3	2	6	6	5	9	9	8	12	12	11
$R_{CK}(s)$	4	5	6	1	2	3	10	11	12	7	8	9
$R_A(s)$	7	8	9	10	11	12	1	2	3	4	5	6
$R_{A-CK}(s)$	4	5	6	1	2	3	1	2	3	1	2	3
	7	8	9	7	8	9	4	5	6	4	5	6
	10	11	12	10	11	12	10	11	12	7	8	9

As defined in Definition 37, e_H is the set of DM attitudes for some coalition H. The attitudes shown in Table 4 indicate that both CK and A are indifferent towards CK and D and devoting towards G. Thus, G-CK's attitudes can be written as $e_{A\text{-}CK} = \{ e_A , e_{CK} \} = \{(0, 0, +), (0, 0, +)\}$. With this information defining the attitudes of the coalition, it is possible to determine the TRPs and TRRs for the coalition using Definitions 38 and 39, respectively.

In order to apply the relational coalition definitions, coalition movements from Table 8.3 are taken and states that are relationally less preferred are removed, thus satisfying Definition 40. In this particular case, as both CK and A are working to make moves that are beneficial to A according to the attitudes expressed in Table 8.6; only those moves that are less preferred by A are removed from the coalition reachable lists to obtain the subsets. The result of the manipulation of the coalition reachable list and DM preferences is shown in Table 8.7, where the TRR for A-CK has been determined from the coalition movements of A-CK and A's preferences. This determination of A-CK's TRR list comes from Definition 39 which shows that for a coalition H, a state x is $x\text{TRR}_H y$ if $x \in R_H(y)$ and $x\text{TRP}_H y$, from Definition 40. For example, from state 5, $R_H(5) = \{2, 8, 11\}$ and $8\text{TRP}_H 5$, $11\text{TRP}_H 5$. Thus, both states 8 and 11 are TRRs from state 5.

Table 8.6: Decision Maker Attitudes in Original Property Use Conflict

	D	CK	A
D	+	0	0
CK	0	0	+
A	0	0	+

After having determined the relational coalition improvements and movements, it is possible to analyze the conflict for stable and equilibrium states. The tableau form of the conflict in Table 7 shows that there are now only two equilibria at state 1 and state 3 which is Nash stable for D, by Definition 6 and CRNash for A-CK by Definition 41. Definition 41 states that a state x is CRNash for coalition H if $\text{TRR}_H(x) = x$, meaning that the only relational improvement that coalition H can reach is state x itself. For A-CK, $\text{TRR}_{A\text{-}CK}(1) = \{1\}$ and thus the state is CRNash for A-CK. The same proof can be shown for A-CK at state 3 as well. Thus, as state 3 is stable for D and A-CK the state is a Coalition Relational Nash equilibrium state.

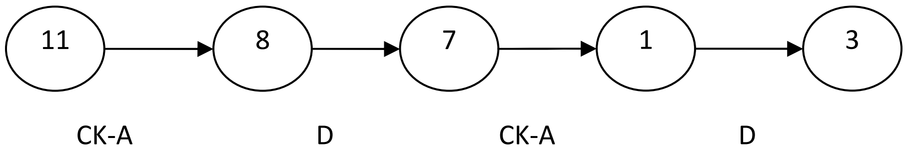


Figure 8.3: Conflict Evolution

Table 8.7: Coalition Total Relational Replies for G-CK

(s)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
$TRR(e)_{A\text{-}CK}(s)$				1	8	3	1			1	8	3
				7	11	9				7		9
				10		12						

Table 8.8: Tableau form of Property Use Conflict with Attitudes and Coalitions

	E	x	x	x	x	x	x	x	x	x	x	x
	r	u	r	u	r	u	r	u	u	u	u	u
D	3	1	5	2	7	(9	11)	8	4	6	10	12
		3		1		7		7	5	5	11	11
				3				9		4		10
	crn	u	crn	u	u	u	u	u	crn	u	u	u
CK	(3	5)	(9	11)	(2	6)	8	12	(1	4)	(7	10)
		8		8	5	3	11	9		1	1	1
		11			8					7		7
					11					10		
	crn	crn	crn	u	u	u	u	u	u	u	u	u
A	1	(3	9)	(7	10)	(8	11	12)	4	(2	5	6)
				1	1	11	8	3	1	5	8	3
					7			9	7	8	11	9

Table 8.9: CRGMR and CRSMR Stability for A-CK

(s)	1	2	3	4	5	6	7	8	9	10	11	12
CRSMR	Y	N	Y	N	N	N	Y	N	Y	Y	N	N
CRGMR	Y	N	Y	N	N	N	Y	N	Y	Y	N	N

The introduction of coalition moves with attitudes has introduced new moves and countermoves into the conflict. Now that state 11 is unstable, the coalition A-CK can move past this state to other conflict equilibriums. In Figure 8.3, the evolution of the conflict from state 11 is shown, illustrating how the application of COAT has illuminated potential moves for A-CK.

In Table 8.8 there is one state which is a Coalition Relational Nash (CRNash) Equilibrium, state 1, marked "crn". Applying CRNash and Coalition Relational Sequential (CRSEQ) stabilities, there are no relational sanctioned states. To determine if states with coalition TRRs are relationally sanctioned from a given state, Definition 38 is employed. Definition 38 simply states that if a state is not relationally preferred by at least one member of the coalition, it is relationally less preferred. Examining state 7 for CRSEQ stability yields some instability; from state 7 G-CK has a coalition total relational reply to state 1. In response to this movement D can make a unilateral move within the conflict to 3. However as $3 \notin R\phi_i^{\approx}(7)$, D's unilateral movement does not sanction G-CK and thus, state 7 is not CRSEQ stable for A-CK.

Employing the CRSMR and CRGMR solution concepts as defined in Definitions 43 and 44 can give additional information about the strength or weakness of the stable states in a conflict, as illustrated in Table 8.9. Within this conflict model the three states that were CRNash stable for G-CK were also CRGMR and CRSMR as well as state 10. State 10 is CRGMR and CRSMR stable for N-CK. At state 10, N-CK has a TRR^{++} to state 1 and a TRR^{++} to state 7. From state 1, D has a unilateral movement to state 2; as state 5 is not relationally more preferred, by Definition 38, it is possible for D to sanction N-CK's move from state 10 to 1. If N-CK moves to state 7, D can make a unilateral movement to state 8, such that $8 \in R\phi^{\approx}_{G-CK}(10)$. Thus state 10 is CRGMR for A-CK. Additionally, as A-CK cannot escape from either sanction the state is CRSMR. In the first sanction where D moves from state 1 to state 2 CK's possible moves are to states 5, 8 and 11, all of which belong to the set $R\phi^{\approx}_{G-CK}(10)$. From G-CK's move to state 7 and D's subsequent response to state 8, A-CK has no possible escapes. That is to say that from state 8 A-CK's reachable list is empty ($R_{A-CK}(8) = \{\}$).

It is found that by implementing coalitions and attitudes it is possible to envision how the conflict could evolve from a stalemate among the three DMs to a positive resolution. The strategic moves that coalition formation allows and that the inclusion of DMs' attitudes gives insight into how DMs work together in such negotiations. Specifically, with respect to the Intowns redevelopment project, insight into how CK, A and D combined to reach an outcome which was socially and environmentally just. The creation of coalitions, as previously modeled in conflict analysis research, has assumed that coalitions only form when different DMs can make improvements for themselves that were otherwise unattainable.

8.5. Summary

In conclusion, the incorporation of COAT within GMCR reveals the restrictions that attitudes places on coalitions, as well as the further strategic impacts of coalitions. The application of GMCR, and its extensions, allows decision analysts to determine what possible outcomes might occur or what is needed to reach win-win resolutions in a conflict and properly inform DMs. One should keep in mind that DMs within coalitions may have a diverse multitude of attitudes. As illustrated in the Intowns case, however, a coalition may form between DMs who have other aims besides personal gain. In this particular example, CK joined the coalition in order to improve the position of G.

Chapter 9

A Matrix Representation of Attitudes in Conflicts

9.1. Introduction

In this chapter, a formal matrix approach for representing and analyzing decision maker's attitudes in a conflict is defined and applied to the problem of negotiating the acquisition of a brownfield property. A decision maker's attitudes are expressed in her or his consideration of her own preferences, as well as those of her opponents. Understanding these attitudes is useful when one wishes to have a better grasp of the possible outcomes of a given conflict. However, these attitudes are often difficult to represent and even more difficult to encode effectively within a decision support system. Using a matrix representation, a more effective way to express attitudes in a programming environment is developed.

A variety of decision tools are available for modeling and analyzing strategic moves and counter-moves that could occur in a multiple party-decision making. These formal methods have links to game theory, as has been outlined in detail in Chapters 2, 3 and 4. The development of the decision support system (DSS) GMCR II, completed in 1998, allowed users to create their own conflict models, within the framework of GMCR (Hipel et al, 1997; Fang et al., 2003a,b). This new program opened up possibilities of analyzing more complex conflict problems while also bringing the use of GMCR to a wider audience of decision analysts in business and government. The conversion of GMCR from its traditional, logical form to a matrix form was designed with the hope of providing easier encoding and quicker calculations (Xu et al, 2007, 2009). In this chapter, the attitude methodology introduced in Chapter 4 is converted into a matrix format in an effort to improve the ease and speed of implementation of this particular extension to GMCR, thereby providing a new level of flexibility to attitudes calculations and making it easier to encode attitudes into a DSS based on a GMCR II-like platform. In Subsection 9.2, the matrix form of GMCR, as previously put forward by Fang et al. (1993) and Xu et al. (2007, 2009), is given. Next, in Subsection 9.3.1, Attitudes in GMCR are defined using a novel matrix form. In Subsection 9.3.2, a brief application of attitudes in matrix form is presented for the Expanded Sustainable Development Conflict from Chapter 3. Finally, in Subsection 9.4, this new form of the attitude methodology is applied to a brownfield redevelopment conflict and discussed further in Subsection 9.5, where the contributions of this new methodology are summarized.

9.2. Matrix Definitions for the Graph Model for Conflict Resolution

The following definitions form a basis for handling the complex social models needed to investigate real-world conflicts within the matrix form of GMCR. Using these formal definitions, not only are the rules which govern GMCR given, but a structure that can address a rich range of conflict is provided. This framework furnishes the basis for the various sophisticated attitude analyses that are to follow.

Definition 45 (Reachable and Unilateral Improvement Matrices): For the graph model G = (S, A), the **UM adjacency matrix** J_i and **UI adjacency matrix** J_i^+ for *DM i* are two m x m matrices, where $m = |S|$, with (s, q) entries

$$J_i = \begin{cases} 1 \, if \ (s,q) \in A_i \\ 0 \, otherwise, \end{cases} \text{ and } J_i^+ = \begin{cases} 1 \, if \ (s,q) \in A_i^+ \\ 0 \, otherwise, \end{cases} \text{, where } s,q \in S \text{ and } A_i^+ = \{(s,q) \in A_i : q \succ_i s\}.$$

Simply put, each element of $J_i(s,q)$ is equal to 1 only if the arc for DM *i*, A_i passes from state *s* to state *q*. Further, $J_i^+(s,q)$ is equal to 1 only if the arc for DM *i*, A_i passes from state *s* to state *q* and state *q* is more preferred to state *s* by DM *i*. Thus, the reachable lists by DM *i* from state *s*, defined above as $R_i(s)$ and $R_i^+(s)$ are expressed as $R_i(s) = \{q: J_i(s,q) = 1\}$ and $R_i^+(s) = \{q: J_i^+(s,q) = 1\}$.

Using the definition of a UI list, Nash stability (Nash, 1950; 1951) is simply the condition where a DM has no UI from a given state, thus making the state stable. Further, Nash stability can be properly analyzed in matrix form also.

Definition 46 (Matrix form of Nash Stability): State $s \in S$ is Nash stable for DM *i* *iff* $\varepsilon_s^T \cdot J_i^+ = \vec{0}^T$ (*T* denotes matrix transpose and ε_s^T is the transpose of the s^{th} standard basis vector of the *m-dimensional* Euclidean space.) This follows simply from Definition 6, where Nash stability is dependent upon the set of unilateral improvements from a given state being the null set.

To define the next three solution concepts, movements under the control of DMs who are members of a set H, which is often referred to as a coalition, must be defined (Hipel and Fraser, 1991; Fraser and Hipel, 1984; Kilgour et al., 2001; Inohara and Hipel, 2008a,b).

Definition 47 (Matrix form of Reachable List of a Coalition): Let $H \subseteq N$. For the graph model G = (*S, A*), the **UM reachability matrix** of coalition *H* is the *m x m* matrix M_H with (*s, q*) entries: $M_H(s,q) = \begin{cases} 1 \, if \ q \in R_H(s) \ for \, q \in S \\ 0 \quad otherwise \end{cases}$.

Similar to $J_i(s,q)$, $M_H(s,q)$ is a reachable list set that takes into account the combination of moves that can be accomplished by a coalition H, according to the inductive definition given previously in Chapter 2. Definition 48 looks at the possible combinations of 'credible' moves by competing DMs. In order to develop the definition of the coalition move, it is important to look at series of moves, as developed by Xu et al. (2009). First, we define the symbol V, such that Q = M $_V$ G is defined as follows:

$$Q(s,q) = \begin{cases} 1 \; if \; M(s,q) + G(s,q) \neq 0 \\ 0 \qquad\qquad otherwise \end{cases}$$

In order to construct the UM reachability matrix of a coalition, in Definition 5.1, such that it obeys the strict definition which takes into account intransitive movements by not allowing any DM to move more than once in a coalition movement, it is necessary to create a mathematical framework that keeps close track of each DMs movements. Let us define the following matrix

$$M_i^t(s,q) = \begin{cases} 1 \;\; if \;\; q \; is \; reachable \;\; from \; s \; in \; exactly \; t \\ legal \; UMs \; starting \; with \; 1^{st} \;\; mover \; DM \; i \\ \;\; 0 \qquad\qquad\qquad otherwise \end{cases}$$

Taking this matrix, which allows for a sequence of moves of length t, it is possible to define a general relationship between this specific movement matrix and other similar matrices. Specifically: $M_i^t = sign\left(J_i \cdot \left(\underset{j \in H - \{i\}}{\vee} M_j^{t-1} \right) \right)$

In such a way, it is possible to determine a large number of sets of paths of UMs written in matrix form in this way. Thus, a coalition movement matrix would be the combination of all of these path matrices, across all different lengths of path, as shown by Xu et al. (2009).

Thus, $M_H = \overset{\partial}{\underset{t=1}{\vee}} \underset{i \in H}{\vee} M_i^t$.

Here, all the states reachable from a given state, *s*, by a coalition *H,* are notated with a 1 in the appropriate column of the s^{th} row. The addition across all possible values of *t* assures that all path lengths are considered in the creation of the coalition movement sets.

Definition 48 (Matrix form of Unilateral Improvement List of a Coalition): Let $H \subseteq N$. For the graph model G = (*S, A*), the **UI reachability matrix** of coalition *H* is the *m x m* matrix M_H with (*s, q*) entries: $M_H^+(s,q) = \begin{cases} 1 \; if \; q \in R_H^+(s) \; for \, q \in S \\ 0 \qquad\qquad otherwise \end{cases}$. Similar to $J_i^+(s,q)$, $M_H^+(s,q)$ is a set that takes into account the combination of unilateral improvements that can be accomplished by a coalition *H*, according to Definition 5.

$$M_i^{t,+}(s,q) = \begin{cases} 1 \;\; if \;\; q \, is \, reachable \;\; from \, s \, in \, exactly \, t \\ legal \, UIs \, starting \; with \, 1^{st} \; mover \, DM \; i \\ 0 \qquad\qquad\qquad otherwise \end{cases}$$

Taking this matrix, which allow for a sequence of moves of length *t*, it is possible to define a general relationship between this coalition UI matrix and its relatives. Specifically, the matrix can be written as:

$$M_i^{t,+} = sign\left(J_i \cdot \left(\underset{j \in H - \{i\}}{\vee} M_j^{t-1,+} \right)\right)$$

In such a way, it is possible to determine a large number of sets of paths of UIs, written in matrix form in this way. Thus, a coalition UI matrix would be the combination of all of these path matrices, across all different lengths of path, as shown by Xu et al. (2009).

Thus: $M_H^+ = \overset{\partial}{\underset{t=1}{\vee}} \underset{i \in H}{\vee} M_i^{t,+}$.

Here, all the states reachable by UIs from a given state, *s*, by a coalition *H,* are notated with a 1 in the appropriate column of the s^{th} row. The addition across all possible values of *t* assures that all path lengths are considered in the creation of the coalition movement sets.

Definition 49 (Preference Matrices): To calculate the various solution concepts in Matrix forms, a variety of preference matrices have been developed by Xu et al. (2009). In particular, the set of less or equally preferred states is defined in matrix form as $P_i^{=,<}$.

$P_i^+(s,q) = \begin{cases} 1 if\ q \succ_i s \\ 0 \ \ otherwise \end{cases}$, $P_i^-(s,q) = \begin{cases} 1 if\ s \succ_i q \\ 0 \ \ otherwise \end{cases}$, $P_i^=(s,q) = \begin{cases} 1 if\ q \approx_i s \\ 0 \ \ otherwise \end{cases}$ It follows that:

$P_i^{-,=}(s,q) = \begin{cases} 1 - P_i^+(s,q) if\ s \neq q \\ 0 \ \ otherwise \end{cases}$, where $P_i^{-,=} = P_i^- \vee P_i^=$.

Using the preference vectors defined here in Definition 49 and the definition of single-DM moves found in Definition 45 the UI adjacency matrix can be defined as:

$J_i^+ = J_i \circ P_i^+$, where $\circ$ is defined as the Hadamard Product of matrices J_i and P_i^+ such that if J_i and P_i^+ are both m x m matrices, $J_i^+(s,q) = J_i(s,q) \cdot P_i^+(s,q)$.

Before being able to calculate GMR, SMR and SEQ stabilities, in Definitions 8 through 10, it is necessary to define the 'sign' function, developed by Xu et al. (2007).

$$sign[m(s,q)] = \begin{cases} 1 \ m(s,q) > 0 \\ 0 \ m(s,q) = 0 \\ -1 \ m(s,q) < 0 \end{cases}$$

This particular function makes it possible to consolidate all non-zero entries into positive and negative categories and thus differentiate between states where there are available movements and those where there are not.

GMR stability is a solution concept that can be used by a decision analyst to determine a 'worst case' scenario for a DM at a particular state. It is useful for examining the worst case scenario in the sense that the preferences of the sanctioning DMs are not taken into account. Hence, opponents may make moves that appear not to be credible in order to block an improvement by the particular DM.

Definition 50 (Matrix form of General Metarationality): Let $M_i^{GMR} = J_i^+ \cdot \left\lfloor E - sign\left(M_{N-i} \cdot \left(P_i^{-,=}\right)^T\right)\right\rfloor$, whereby a state $s \in S$ is GMR stable for i *iff* $M_i^{GMR}(s,s) = 0$.

In Definition 50, the first step occurs in the calculation of a matrix representing states where there are no available sanctions. This occurs when the 'sanction matrix' sign($M_{N\backslash i}$ * $(P_i^{-,=})^T$) is subtracted from the E matrix, where every entry of the E matrix is 1. Thus entries where each unilateral improvement by i is sanctioned will result in a diagonal entry of 0 for that particular state.

When applying SMR stability, a decision analyst must look three moves ahead. First, the particular DM determines if a unilateral improvement is available and secondly if it can be sanctioned by opposing DM(s), using either a credible or non-credible move. Next, the DM seeks to find out if he or she can escape from this sanction. If the opposing DMs can enforce a sanction and the DM cannot escape from it, then the state is said to be sanctioned. If all possible unilateral improvements by the DM from the initial state can be blocked, the state is stable according to symmetric metarationality.

Definition 51 (Matrix form of Symmetric Metarationality): Let $M_i^{SMR} = J_i^+ \cdot [E - sign(M_{N-i} \cdot G)]$, where: $G = \left(P_i^{-,=}\right)^T \circ \left[E - sign\left(J_i \cdot \left(P_i^+\right)^T\right)\right]$, and whereby a state $s \in S$ is GMR stable for *i iff* $M_i^{SMR}(s,s) = 0$.

Using the foregoing definitions, the matrix form of GMCR can be used to model and analyze a myriad of social and political conflicts. However, the methodology is enhanced even further in order to extend its realm of applicability by incorporating attitudes into its structure.

Definition 52 (Matrix form of Sequential Stability): Let $M_i^{SEQ} = J_i^+ \cdot \left[E - sign\left(M_{N-i}^+ \cdot \left(P_i^{-,=}\right)^T\right)\right]$ whereby a state $s \in S$ is SEQ stable for *i iff* $M_i^{SEQ}(s,s) = 0$.

As can be seen a wide range of definitions for GMCR have been represented in a matrix form for easy implementation and codeability. To further this framework definitions of attitudes within GMCR will be given in both the set notation and matrix notation found here.

9.3. Matrix form of Attitudes in the Graph Model for Conflict Resolution

In order to effectively model conflict under situations where DMs' attitudes may seem to be "non-regular", the attitudes framework can be applied. Developed by Inohara et al. in 2007 and further explained by Inohara (2008), the attitudes framework allows decision analysts to determine the impact on a conflict outcome that may arise when a DM takes other DMs' preferences into account. The following definitions and theorems, with their accompanying proofs, provide a formal structure for this concept.

As an example of attitudes, take a simple conflict involving 2 DMs: DM 1 and DM 2. Table 9.1 displays how attitudes held by each DM can be stored in a matrix, where an entry in row 1 and column 2 contains an element e_{12} which represents the attitudes of DM 1 toward DM 2. The underlying attitudes assumed in a standard analysis of a regular game are displayed in Table 9.2, whereby a given DM is positive towards herself and neutral towards her opponent.

Table 9.1: Tabular Representation of Attitudes

DMs	**1**	**2**
1	e_{11}	e_{12}
2	e_{21}	e_{22}

Table 9.2: Attitudes in a Regular Analysis

DMs	**1**	**2**
1	+	0
2	0	+

The matrix solution concepts presented earlier in Subsection 9.2 are referred to in this chapter as "regular" solution concepts, since they do not consider DM attitudes. These regular solution concepts are now expanded to explicitly account for DMs' attitudes and, hence, are altered to become "relational" solution concepts. Prior to providing these stability definitions, a range of preference structures and special types of movements among states must first be defined. In Definition 53, this arrangement of attitudes is put into a matrix form.

Definition 53 (Matrix form of DM Attitudes Table): Let $Att(i,j)=\begin{cases}1 if\ e_{ij} &=+\\ -1 if\ e_{ij} &=-\\ 0 if\ e_{ij} &=0\end{cases}$.

Here, the attitudes are encoded in an effective matrix format for easy retrieval during attitude analysis calculations. Consider the relational preference definitions defined in Chapter 4 where the types of relational preferences are matched with the three different attitudes. What this means is that if DM i has a positive attitude towards DM j, DM i will have a devoting preference with respect to DM j. If DM i has a negative attitude towards DM j, DM i will have an aggressive preference with respect to DM j. Thus, a DM behaves according to his or her attitudes.

Although a matrix form definition was not needed for either the devoting or aggressive preferences, a new relational preference matrix definition is given here which simply ties together the definitions of attitudes and preferences as Definition 14.0 does. This is shown in Definition 54, where the relational preference of DM *i* towards DM *j* is reflected in the type of preference is applied by *j*. Here, it can be seen that $P_{ij}{}^{R}$ is equivalent to one of DM *j's* preference matrices, depending on the types of attitudes DM *i* holds.

Definition 54 (Matrix form of Relational Preference of DM *i* with respect to DM *j*): Let

$$P_{ij}^{R}=\begin{cases}P_j^{-,=}\ if\ Att(i,j)=-1\\ P_j^{+,=}\ if\ Att(i,j)=1\\ P_j^{=}\ if\ Att(i,j)=0\end{cases}$$

A state satisfies a total relational preference for the situation in which it is a relational preference for DM i according to the attitudes of DM i towards all of the DMs in the conflict. Thus, if a state s is a relational preference by DM i to state t with respect to himself and DM j, and there are only the two DMs in the conflict, then state s is a total relational preference by DM i relative to state t.

Definition 55 (Matrix form of the Total Relational Preference):

Let $P_i^{RT(\text{int})} = \frac{\sum_{k=1}^{n} P_{i,k}^{R}}{|N|}, P_i^{RT}(s,q) = \begin{cases} 1\,if\ P_i^{RT(\text{int})}(s,q) = 1 \\ 0\,otherwise \end{cases}$. This relationship allows the TRP vector to be constructed by summing together the various RP vectors and dividing the sum by the size of the set of DMs. Any state that satisfies all of DM *i's* RPs will have a 1 in its space, all others will not – thus creating a TRP matrix.

Once the Total Relational Preference, which is analogous to the simple preference found in the standard GMCR definitions is given, it is necessary to create an analogous definition to the unilateral movements also found amongst those standard GMCR definitions. This definition, found below combines the TRP with the set of unilateral moves using the union function in standard form and element by element multiplication in the matrix form, as shown in Definition 56.

Definition 56 (Matrix form of the Total Relational Reply):

Let $M_i^{R+}(s,q) = \begin{cases} 1\ if\ J_i(s,q) = 1\,and\ P_i^{RT}(s,q) = 1 \\ 0 \qquad otherwise \end{cases}$. This matrix combines the reachability and preference aspects to create a matrix which catalogues all the Total Relational Replies from a given states that are available to a given DM.

Before creating solution concepts for attitudes in both the set and matrix form it is necessary to identify both sets of coalition improvements and what states are less preferred. Definitions 57 and 58 illustrate these respective ideas in matrix form, respectively. In Definition 57 the sets of TRRs of a coalition *H* is defined inductively as the combination of all TRRs that the coalition members can make from the given starting state. In Definitions 58, the relationally less or equally preferred state set which is used as the set of sanctioning states is defined as the set of states that are not preferred to the starting state.

Similar to the Definitions for M_H and M_H^+, it is necessary to create a definition for the Total Relational Reply coalition that takes into account the possibility of intransitive moves, as the logical form of the definition does. Thus, in a manner similar to Definition 6.1, a matrix is created such that the entry at the s^{th} row and the q^{th} column is 1 if state q can be reached from state s in t legal Total Relational Replies, beginning with some DM i. Thus, by Definition 57:

Definition 57 (Matrix form of the Unilateral Total Relational Replies of a Coalition): In order to determine the unilateral TRR list of a coalition, it is necessary to look at sequences of TRRs, as follows:

$$M_i^{t,R+}(s,q) = \begin{cases} 1 \;\; if \;\; q \, is \, reachable \;\; from \, s \, in \, exactly \, t \\ legal \, TRRs \, starting \;\, with \, 1^{st} \;\; mover \; DM \; i \\ \;\; 0 \qquad\qquad\qquad otherwise \end{cases}$$

This matrix is found by multiplying each Total Relational Reply matrix

$$M_i^{t,R+} = sign\left(J_i \cdot \left(\bigvee_{j \in H - \{i\}} M_j^{t-1,R+} \right) \right)$$

In such a way, it is possible to determine a large number of sets of paths of UIs, written in matrix form in this way. Thus, a coalition Total Relational Reply matrix would be the combination of all of these path matrices, across all different lengths of path, as shown by Xu et al. (2009).

Thus: $M_H^{R+} = \bigvee_{t=1}^{\partial} \bigvee_{i \in H} M_i^{t,R+}$.

Here, all the states reachable by UIs from a given state, *s*, by a coalition *H,* are notated with a 1 in the appropriate column of the s^{th} row. The addition across all possible values of *t* assures that all path lengths are considered in the creation of the coalition movement sets.

Definition 58 (Matrix form of the Relationally Less Preferred Set of States):

$P_i^{R-}(s,q) = \begin{cases} 1 \text{ if } P_i^{RT}(s,q) = 0 \\ 0 \quad otherwise \end{cases}$ **.** Here, the set of relationally less preferred states, which will be used as sets of 'sanction' states in the following definitions, which take the solution concepts within GMCR, defined previously, and transform them into 'attitudes' definitions. The similar structure of these solution concepts will make their transformation into relational definitions quite straightforward. Bernath Walker et al. (2012) have previously shown the formal relationship between these models and solution concepts.

In Theorem 5, Relational Nash (RNash) stability is given in matrix form, based on the formal Definition 28 found in Chapter 4. RNash stability follows, of course, from Nash stability defined in Definitions 6 in Chapter 3.

Theorem 5 (Matrix form of Relational Nash Stability):

State $s \in S$ is RNash stable for DM *i iff* $e_s^T \cdot M_i^{R+} = \vec{0}^T$ (*T* denotes matrix transpose and $e^T{}_s$ is the transpose of the s^{th} standard basis vector of the *m-dimensional* Euclidean space.)

Proof In order for state *s* to be RNash stable for a DM *i*, $TRR_i(s) = \{s\}$, that is, the s^{th} row of $M_i^{R+} = 0$ row vector. Thus, obviously: $e_s^T \cdot M_i^{R+} = \vec{0}^T$.

Relational general metarationality, defined here in Theorem 2, is best described as a situation in which a DM makes a unilateral move and opposing DMs sanction that move with moves of their own. In RGMR, these sanctioning moves do not have to be total relational replies by the other DMs – they only have to be possible moves by the sanctioning DMs.

Theorem 6 (Matrix form of Relational General Metarational Stability):

$M_i^{RGMRn} = M_i^{R+} \cdot \left[E - sign\left(M_{N\setminus i} \cdot \left(P_i^{R-}\right)^T\right)\right]$ whereby a state s is RGMR stable iff $M_i^{RGMRn}(s,s) = 0$ and $n = |N|$.

Thus, in matrix form it is necessary to combine the sanctioned states for DM i, and the movements for the set N-i, in order to come up with the possible sanctions using the matrix multiplication, sign and subtraction operations.

Proof As the diagonal element $M_i^{RGMRn}(s,s) = \left\langle \left(M_i^{R+}\right)^T e_s, \left(E - sign\left(M_{N\setminus i} \cdot \left(P_i^{R-}\right)^T\right)\right) e_s \right\rangle$

$$= \sum_{s_1=1}^{m} M_i^{R+}(s,s_1)\left[1 - sign\left(\left\langle \left(M_{N\setminus i}\right)^T e_{s_1}, \left(P_i^{R-}\right)^T e_s \right\rangle\right)\right]$$

Thus $M_i^{RGMRn}(s,s) = 0$ iff $\left(e_{s_1}^T M_{N\setminus i}\right) \cdot \left(e_s^T P_i^{R-}\right)^T \neq 0 \quad \forall s_1 \in TRR(e)_i(s)$ (1)

Equation (1) means that, for any $s_1 \in TRR(e)_i(s)$, there exists $s_2 \in S$ such that the m-dimensional row vector $e_{s_1}^T M_{N\setminus i}$ has s_2^th element 1 and the m-dimensional column vector has $\left(P_i^{R-}\right)^T e_s$ has s_2^th element 1. Therefore, $M_i^{RGMRn}(s,s)=0$ iff for any $s_1 \in TRR(e)_i(s)$, there exists at least one state $s_2 \in R_{N\setminus i}(s_1)$ such that $s_2 \in R\phi_i(s)$.

RSMR stability, mirroring SMR stability, defined in its matrix form in Definition 51 look 3 moves ahead. As in the case of RGMR, the sanctioning moves need only be possible moves by the other DMs and do not have to be either credible or relational.

Theorem 7 (Matrix form of Relational Symmetric Metarational stability): $M_i^{RSMRn} = M_i^{R+} \cdot \left[E - sign\left(M_{N\backslash i} \cdot G\right)\right]$, where $G = \left(P_i^{R-}\right)^T \circ \left[E - sign\left(J_i \cdot \left(P_i^{R+}\right)^T\right)\right]$ and thus: state $s \in S$ is RSMR stable for *i iff* $M_i^{RSMRn}(s,s) = 0$.

Proof

$$M_i^{RSMRn}(s,s) = \left\langle \left(M_i^{R+}\right)^T e_s, \left(E - sign\left(M_{N\backslash i} \cdot G\right)\right) e_s \right\rangle = \sum_{s_1=1}^{m} M_i^{R+}(s,s_1)\left[1 - sign\left(\left\langle \left(M_{N\backslash i}\right)^T e_{s_1}, G \cdot e_s \right\rangle\right)\right]$$

$M_i^{RSMRn}(s,s) = 0$ iff $M_i^{R+}(s,s_1)\left[1 - sign\left(\left\langle \left(M_{N\backslash i}\right)^T e_{s_1}, G \cdot e_s \right\rangle\right)\right] = 0 \quad \forall s_1 \in S.$

This is only satisfied when $\left(e_{s_1}^T M_{N\backslash i}\right) \cdot \left(G \cdot e_s\right) \neq 0 \quad \forall s_1 \in TRR(e)_i(s).$ (2)

Let $G(s_2, s)$ denote the (s_2, s) entry of matrix G. Since

$$\left(e_{s_1}^T M_{N\backslash i}\right) \cdot \left(G \cdot e_s\right) = \sum_{s_2=1}^{m} M_{N\backslash i}(s_1, s_2) \cdot G(s_2, s)$$

then (2) holds iff for any $s_1 \in TRR(e)_i(s)$, there exists $s_2 \in R_{N\backslash i}(s_1)$ such that $G(s_2,s) \neq 0$.

Because $G(s_2, s) = P_i^{R-}(s, s_2)\left[1 - sign\left(\sum_{s_2=1}^{m} J_i(s_2, s_3) P_i^{R+}(s, s_3)\right)\right]$ then $G(s_2,s) \neq 0$ implies that for $s_2 \in R_{N\backslash i}(s_1)$:

$P_i^{R-}(s, s_2) \neq 0$ (3)

and

$$\sum_{s_3=1}^{m} J_i(s_2, s_3) P_i^{R+}(s, s_3) = 0 \ (4)$$

Obviously, $\forall s_1 \in TRR_i(s) \exists s_2 \in R_{N\backslash i}(s_1)$, such that (3) and (4) hold iff for every $s_1 \in TRR(e)_i(s)$ there exists $s_2 \in R_{N\backslash i}(s_1) \,|\, s \geq_i s_2 \textit{ and } s \geq_i s_3 \ \forall s_3 \in R_i(s_2)$.

Sequential stability occurs when one DM makes a move according to his or her total relational reply list and opposing DMs can sanction the move by moving to a state in their total relational reply lists. In this way, RSEQ stability is similar to SEQ stability whereby a DM's unilateral improvement is sanctioned by opposing DMs' unilateral improvements.

Theorem 8 (Matrix form of Relational Sequential Stability):

$M_i^{RSEQn} = M_i^{R+} \cdot [E - sign(M^{+}{}_{N/i} \cdot (P_i^{R-})^T] = 0$ whereby a state $s \in S$ is RSEQ stable for i *iff* $M_i^{RSEQn}(s,s) = 0$.

Proof $M_i^{RSEQn}(s,s) = \left\langle \left(M_i^{R+}\right)^T e_s, \left(E - sign\left(M_{N\backslash i}^{+} \cdot \left(P_i^{R-}\right)^T\right)\right) e_s \right\rangle$

$$= \sum_{s_1=1}^{m} M_i^{R+}(s, s_1) \left[1 - sign\left(\left\langle \left(M_{N\backslash i}^{+}\right)^T e_{s_1}, \left(P_i^{R-}\right)^T e_s \right\rangle\right)\right]$$

Thus $M_i^{RSEQn}(s,s) = 0$ iff $\left(e_{s_1}^T M_{N\backslash i}^{+}\right) \cdot \left(e_s^T P_i^{R-}\right)^T \neq 0 \ \ \forall s_1 \in TRR(e)_i(s)$ (5)

Equation (5) means that, for any $s_1 \in TRR(e)_i(s)$, there exists $s_2 \in S$ such that the m-dimensional row vector $e_{s_1}^T M_{N\backslash i}^{+}$ has s_2^{th} element 1 and the m-dimensional column vector has

$\left(P_i^{R-}\right)^T e_s$ has s_2th element 1. Therefore, $M_i^{RSEQn}(s,s)=0$ iff for any $s_1 \in TRR(e)_i(s)$, there exists at least one state $s_2 \in R^+_{N\backslash i}(s_1)$ such that $s_2 \in R\phi_i(s)$.

From (7), it can be seen that $(e_{s1}^T M^+_{N/i}) \cdot (e_s^T (R\phi)^T) \neq 0, \forall s_1 \in TRR_i(s)$. This implies that for any TRR s_1 there exists at least one sanction s_2, accessible by N/*i*.

9.3.2 Applying the Matrix form of Attitudes

To clarify the way that attitudes are applied in Matrix Form, consider what an attitudes analysis of *E* would look like given *E's* attitudes shown in Table 9.3.

Table 9.3: *E's* Attitudes in Expanded Sustainable Development Conflict

	E	D	G
E	+	–	–
D	0	+	0
G	0	0	+

Thus, the attitudes matrix can be written as $Att = \begin{bmatrix} 1 & -1 & -1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$, according to Definition 53.

This attitudes matrix can be used to determine the Total Relational Preference matrix using Definition 55, such that:

$P_E^{RT(\text{int})} = \frac{\sum_{k=1}^{n} P_{E,k}^R}{|N|}, P_i^{RT}(s,q) = \begin{cases} 1 if\ P_i^{RT(\text{int})}(s,q) = 1 \\ 0\, otherwise \end{cases}$. Here, N = 3 and the three values of k are E, G, and D. $P_E^{RT(\text{int})} = \frac{\sum_{k=1}^{n} P_{E,k}^R}{|N|} = \frac{P_E^+ + P_D^- + P_G^-}{3}$.

After calculating $P_E^{RT(int)}$, P_E^{RT} can be determined by converting all non-one entries into zeroes, resulting in the matrix below.

$$P_E^{RT} = \begin{bmatrix} & PSV & RSV & PUV & RUV & PSL & RSL & PUL & RUL \\ PSV & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ RSV & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ PUV & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ RUV & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ PSL & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ RSL & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ PUL & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ RUL & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \end{bmatrix}$$

In order to determine all of *E's* Total Relational Replies, it is necessary multiple P_E^{RT} entry-by-entry with $J_{E,}$ the reachability matrix, as shown in Definition 56. Thus:

$M_E^{R+} = J_E \circ P_E^{RT}$,

$$= \begin{bmatrix} & PSV & RSV & PUV & RUV & PSL & RSL & PUL & RUL \\ PSV & 0x0 & 1x0 & 0x0 & 0x0 & 0x0 & 0x0 & 0x0 & 0x0 \\ RSV & 1x1 & 0x0 & 0x0 & 0x0 & 0x0 & 0x0 & 0x0 & 0x0 \\ PUV & 0x1 & 0x1 & 0x0 & 1x0 & 0x0 & 0x0 & 0x0 & 0x0 \\ RUV & 0x0 & 0x0 & 1x1 & 0x0 & 0x0 & 0x0 & 0x0 & 0x0 \\ PSL & 0x1 & 0x0 & 0x1 & 0x0 & 0x0 & 1x0 & 0x0 & 0x0 \\ RSL & 0x1 & 0x1 & 0x1 & 0x1 & 1x1 & 0x0 & 0x0 & 0x0 \\ PUL & 0x0 & 0x0 & 0x1 & 0x0 & 0x0 & 0x0 & 0x0 & 1x0 \\ RUL & 0x0 & 0x0 & 0x1 & 0x1 & 0x0 & 0x0 & 1x1 & 0x0 \end{bmatrix}$$

$$= \begin{bmatrix} & PSV & RSV & PUV & RUV & PSL & RSL & PUL & RUL \\ PSV & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ RSV & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ PUV & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ RUV & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ PSL & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ RSL & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ PUL & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ RUL & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Using matrix multiplication, as discussed in Theorem 5, one can determine if a given state is RNash stable for *E*. For example, if one wanted to determine if state *RUV* is RNash stable for *E* the calculation is as follows. One takes the transpose of the RUVth basis vector and multiplies this by P_E^{RT}.

$$\varepsilon_{RUV}{}^{T} \cdot P_E^{RT} = \begin{bmatrix} PSV & 0 \\ RSV & 0 \\ PUV & 0 \\ RUV & 1 \\ PSL & 0 \\ RSL & 0 \\ PUL & 0 \\ RUL & 0 \end{bmatrix} \cdot \begin{bmatrix} & PSV & RSV & PUV & RUV & PSL & RSL & PUL & RUL \\ PSV & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ RSV & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ PUV & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ RUV & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ PSL & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ RSL & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ PUL & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ RUL & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \neq \vec{0}$$

As can be seen by the calculation above, state *RUV* is not RNash stable for *E*. Specifically, *PUV* (the 3rd possible state) is available as a Total Relational Reply for *E* from state *RUV*. This result can be confirmed from the attitude analysis that was performed in Subsection 6.2.2. where the attitudes of *E* are the same as those used here, as shown in Table 6.2, and *E* has the same Total Relational Replies, as shown in Table 6.3.

In Subsection 9.4, a brownfield redevelopment conflict is analyzed using GMCR and attitudes analysis in both the standard form and the matrix forms introduced and defined in this chapter.

9.4 Applying the Attitudes Methodology to a Brownfield Conflict

In brownfield redevelopments, there are a number of crucial conflicts, or negotiations, which must be addressed by potential developers in order to properly complete the redeveloping process. In fact, Bernath Walker et al. (2010) outline a series of three stages which must be gone through during any brownfield redevelopment process (Figure 9.1).

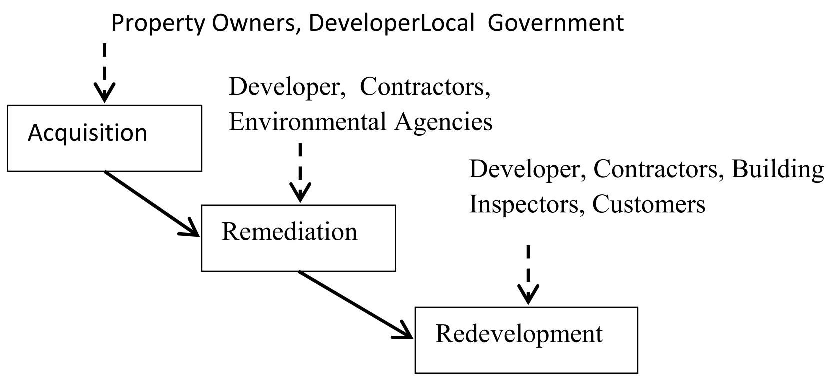


Figure 9.1 Brownfield Redevelopment Process

Of these, one of the most important is the acquisition negotiation in which the developer purchases the property from the property owner, such as the previous industrial land user or some other owner.

Below, in Table 9.4, the conflict is shown in option form. In the very left column is a list of the three DMs: the Property Owner, the Developer and the City Government. Each of these DMs has options, found in the 2nd column from the left. The property owner has the option to 'Sell High' or 'Sell Low', meaning that they can sell the property above market value or at market value. The City Government has the option to offer incentives to the Developer to encourage them to purchase the property; the Developer can chose whether or not purchase the property. To the right of each of these options is a set of 'Y's and 'N's. Each column of 'Y's and 'N's represents a state where each option is chosen (Y) or not (N). The state ID at the bottom, which is used to represent the given state is a decimalized form of the entries above it. For example state 5 is given that ID number as $2^0(1) + 2^1(0) + 2^2(1) + 2^3(0) = 5$.

Table 9.4: Acquisition Conflict in Option Form

DMs	Options												
Property Owner	Sell High	N	Y	N	N	Y	N	N	Y	N	N	Y	N
	Sell Low	N	N	Y	N	N	Y	N	N	Y	N	N	Y
City Gov't	Incentive	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
Developer	Buy	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
State ID		0	1	2	4	5	6	8	9	10	12	13	14

Next, in order to perform a meaningful analysis, it is necessary to construct preferences that represent the desires of the DMs under conflict. For example, the Property Owner strongly prefers to sell the property for the highest price and that the Developer buys it, over all other states. Thus states 9 and 13 are equally preferred to each other and more preferred to all other states in the conflict. This is reflected in the Property Owner's preference vector seen in the 3rd row of Table 9.4. Below each state is the possible unilateral improvement that the given DM may make from the state. For example, as $R_{CG}^{+}(14) = 10$, a 10 is written below state 14 in CG's preference vector. Following this a static analysis of the conflict can be performed. Below, in Table 9.4, is the tableau form of the conflict. Please note that all the DMs names are shortened, such that Property Owner becomes PO, City Government CG and Developer D.

Table 9.5: Tableau form of Static Analysis

	x	x	E	x	x	x	x	x	x	x	x	x
	r	r	r	r	u	u	u	u	u	u	u	u
PO	(13	9)	(1	5)	(0	4	8	12)	(2	6	10)	14
					1	5	9	13	1	5	9	13
									0	4	8	12
	r	s	r	u	r	r	r	r	u	u	u	u
CG	10	14	9	13	(0	1	2	8)	(4	5	6	12)
		10		9					0	1	2	8
	r	s	r	r	u	r	r	r	r	r	u	u
D	14	6	10	(0	2	4	8	12)	5	1	13	9
		14			10						5	1

In the tableau form each of the states are tested for stability using the definitions for Nash and Sequential stability given Definitions 4 and 5, respectively. For example, state 14 is SEQ stable for CG as follows: $R_{CG}^{+}(14) = 10$, $R_{N\text{-}CG}^{+}(10) = \{8, 9, 1\}$ and as $14 >_{CG} \{8, 9, 1\}$ state 14 is thus SEQ stable for CG. When looking at likely outcomes, there is only one equilibrium state, state 1. At state 1, PO offers to sell the property at a high price, CG offers no incentives and D does not buy the property. From the standpoint of CG and D this is not a successful negotiation outcome. Thus, it is in the interest of both parties to see how they might best negotiate to a better outcome for the developer and greater community. This could also be expressed in a simplified matrix form. For example, PO's preferences could be expressed using a preference matrix as follows:

Table 9.6: POs Preference Matrix

$P_{PO}^{+}=$

	0	1	2	4	5	6	8	9	10	12	13	14
0	0	1	0	0	1	0	0	1	0	0	1	0
1	0	0	0	0	0	0	0	1	0	0	1	0
2	1	1	0	1	1	0	1	1	0	1	1	0
4	0	1	0	0	1	0	0	1	0	0	1	0
5	0	0	0	0	0	0	0	1	0	0	1	0
6	1	1	0	1	1	0	1	1	0	1	1	0
8	0	1	0	0	1	0	0	1	0	0	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	1	1	0	1	1	0	1	1	0	1	1	0
12	0	1	0	0	1	0	0	1	0	0	1	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	1	1	1	1	1	1	1	1	1	1	1	0

What is interesting about PO's preference matrix, shown in Table 9.6, is that many of the rows are repeated due to the multitude of equally preferred states. For example, the row corresponding to state 12 is the same as the row corresponding to state 0 as these states are equally preferred.

Next, by doing an appropriate element-by-element multiplication, it is possible to determine the unilateral improvement matrix for PO. First, it is necessary to examine J_{PO}, which is as follows:

Table 9.7: POs UM Matrix

J_{PO}=

	0	1	2	4	5	6	8	9	10	12	13	14
0	0	1	1	0	0	0	0	0	0	0	0	0
1	1	0	1	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	1	1	0	0	0	0	0	0
5	0	0	0	1	0	1	0	0	0	0	0	0
6	0	0	0	1	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	1	0	0	0
9	0	0	0	0	0	0	1	0	1	0	0	0
10	0	0	0	0	0	0	1	1	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1	1
13	0	0	0	0	0	0	0	0	0	1	0	1
14	0	0	0	0	0	0	0	0	0	1	1	0

The element by element multiplication gives rise to the new unilateral improvement matrix, shown in Table 9.8 below, and as discussed in Definition 45.

Table 9.8: POs UI Matrix

J_{PO}^{+}=

	0	1	2	4	5	6	8	9	10	12	13	14
0	0	1	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	1	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	1	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	1	1	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	1	1	0

Briefly examining the unilateral improvement matrix Nash stable states can be readily observed. For example, as the row corresponding to state 1 is composed entirely of 0 entries, state 1 is Nash stable, by Definition 46. To calculate sequential stability, we refer to Definition 52, which states: $M_i^{SEQ} = J_i^+ \cdot \left\lfloor E - sign\left(M_{N-i}^+ \cdot \left(P_i^{-,=}\right)^T\right)\right\rfloor$ whereby a state $s \in S$ is SEQ stable for *i* *iff* $M_i^{SEQ}(s,s) = 0$. To verify this for PO, let us generate $M_{N\text{-}PO}^+ \bullet (P_{PO}^{-,=})^T$ the sanction matrix.

Table 9.9: POs Less Preferred States Matrix

$P_{PO}^{-,=} = E - P_{PO}^+ =$

	0	1	2	4	5	6	8	9	10	12	13	14
0	0	0	1	1	0	1	1	0	1	1	0	1
1	1	0	1	1	1	1	1	0	1	1	0	1
2	0	0	0	0	0	1	0	0	1	0	0	1
4	1	0	1	0	0	1	1	0	1	1	0	1
5	1	1	1	1	0	1	1	0	1	1	0	1
6	0	0	1	0	0	0	0	0	1	0	0	1
8	1	0	1	1	0	1	0	0	1	1	0	1
9	1	1	1	1	1	1	1	0	1	1	1	1
10	0	0	1	0	0	1	0	0	0	0	0	1
12	1	0	1	1	0	1	1	0	1	0	0	1
13	1	1	1	1	1	1	1	1	1	1	0	1
14	0	0	0	0	0	0	0	0	0	0	0	0

Multiplying the transpose of this matrix with the unilateral improvement matrix of the set N – PO, shown below in Table 9.10 and applying the 'sign' function defined earlier to the product leads to the creation of the sanction matrix shown in Table 9.11.

Table 9.10 : N-POs Coalition UI Matrix

$M_{N\text{-}PO}^{+} =$

	0	1	2	4	5	6	8	9	10	12	13	14
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	1	0	0	0
4	1	0	0	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0	0	0	0
6	0	0	1	0	0	0	0	0	1	0	0	1
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	1	0	0	0	0	0
13	0	1	0	0	1	0	0	1	0	0	0	0
14	0	0	0	0	0	0	0	0	1	0	0	0

Having created this unilateral improvement matrix, it is now possible to determine the sanction matrix by multiplying $M_{N\text{-}PO}^{+} \bullet (P_{PO}^{-,=})^{T}$ and applying the sign function defined above.

Table 9.11: POs Sanction Matrix

$\text{sign}[M_{N\text{-}PO}^{+} \bullet (P_{PO}^{-,=})^{T}] =$

	0	1	2	4	5	6	8	9	10	12	13	14
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
4	0	1	0	1	1	0	1	1	0	1	1	0
5	0	0	0	0	1	0	0	1	0	0	1	0
6	1	1	1	1	1	1	1	1	1	1	1	1
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	1	0	0	1	0	0	1	0
10	0	0	0	0	0	0	0	0	0	0	0	0
12	1	1	0	1	1	0	0	1	0	1	1	0
13	0	1	0	0	1	0	0	1	0	0	1	0
14	1	1	1	1	1	1	1	1	0	1	1	0

When this matrix is subtracted from the E matrix, which as was noted earlier is filled entirely with '1' entries and then multiplied by J_{PO}^{+}, the result will be a matrix which will have 0s in all the diagonal entries that correspond to sequentially stable states. This works as when the sanctioning matrix is subtracted from E zeroes will be left where possible sanctions are. Thus if PO's unilateral improvements are sanctioned from state *s* the s^{th} row of the unilateral improvement matrix multiplied with the s^{rh} column of E minus the sanction matrix should give a 0 if the state is SEQ sanctioned. If one compares the results in the MSeq matrix of Table 9.12 below with the stability analysis of Table 9.4, it can be seen that indeed the diagonals with 0 entries correspond to the states that are SEQ stable for PO.

Table 9.12 : POs SEQ Stability Matrix

$M_{PO}^{SEQ} =$

	0	1	2	4	5	6	8	9	10	12	13	14
0	1	1	1	1	1	1	1	1	1	1	1	1
1	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	2	2	2	2	2	2	2	2	2	2
4	1	0	1	1	0	1	1	0	1	1	0	1
5	0	0	0	0	0	0	0	0	0	0	0	0
6	1	0	2	1	0	2	1	0	2	1	0	2
8	1	0	1	1	0	1	1	0	1	1	0	1
9	0	0	0	0	0	0	0	0	0	0	0	0
10	2	1	2	2	1	2	2	1	2	2	1	2
12	1	0	1	1	0	1	1	0	1	1	0	1
13	0	0	0	0	0	0	0	0	0	0	0	0
14	1	0	2	1	0	2	1	0	2	1	0	2

Having observed how solution concepts can be applied both logically and using matrices, we will now apply attitudes to our conflict and use simple matrix operations to confirm our results.

9.4.1 Attitudes in a Brownfield Conflict

As can be seen in the original analysis in the previous subsection, there is only one conflict outcome, which occurs where PO attempts to sell the property above market value, CG offers no incentives and D does not purchase the property. Although PO may not be overly concerned with this outcome CG may be concerned. Indeed at it is CG's primary concern to get the property sold it is possible that CG will look for ways to behave against his short term interests in order to move the conflict past this state. In Table 9.13, a simple set of attitudes is suggested for each of the 3 DMs in the conflict. Here it can be seen that CG acts in a devoting way towards D to entice him to purchase the property.

Table 9.13: New attitudes for a Brownfield Acquisition Conflict

	PO	CG	D
PO	+	0	0
CG	0	0	+
D	0	0	+

Next, using this attitude information and the tableau form in Table 9.5, it is possible to generate a new tableau analysis, as shown in Table 9.14. Here CG now takes moves that favour D without thinking about his own short-term gains, whilst the other two DMs carry on with the same movements they had previously. Again, below each state for PO and D the available UIs from the state are shown. Now, however, for CG, the TRRs are shown instead of the UIs.

Table 9.14: Tableau form of Attitudes Analysis

	x	x	x	E	x	x	x	x	x	x	x	x
	r	r	r	r	u	u	u	u	u	u	u	u
PO	(13	9)	(1	5)	(0	4	8	12)	(2	6	10)	14
					1	5	9	13	1	5	9	13
									0	4	8	12
	rs	rr	u	rr	rr	u	rs	rr	rr	rr	rr	rr
CG	10	14	9	13	(0	1	2	8)	(4	5	6	12)
	14		13			5	6					
	r	s	r	r	s	r	r	r	r	r	u	u
D	14	6	10	(0	2	4	8	12)	5	1	13	9
		14			10						5	1

If one wished to analyze how CG's movements and state stabilities were to be calculated using the matrix definitions given previously, it would be wise to start by forming the Total Relational Preference matrix from what is known about CG's attitudes and the preferences of the

DMs in the conflict using Definitions 53, 54 and 55. From Definition 53, the Attitude matrix is as follows, in Table 9.15.

Table 9.15: Attitudes Matrix for all DMs

		PO	CG	D
	PO	1	0	0
Att =	CG	0	0	1
	D	0	0	1

From Definition 54, $RP^{CG,D} = P_D^+$, $RP^{Cg,PO}$=$RP^{CG,CG}$=[0] and thus $TRP^{CG} = P_D^{+,}$ by Definition 55 and thus it can be written as follows in Table 9.15.

Table 9.16: CGs TRP Matrix

		0	1	2	4	5	6	8	9	10	12	13	14
	0	0	0	0	0	0	1	0	0	1	0	0	1
	1	1	0	1	1	1	1	1	0	1	1	0	1
	2	0	0	0	0	0	1	0	0	1	0	0	1
	4	0	0	0	0	0	1	0	0	1	0	0	1
	5	1	0	1	1	0	1	1	0	1	1	0	1
	6	0	0	0	0	0	0	0	0	0	0	0	1
TRP^{CG} =	8	0	0	0	0	0	1	0	0	1	0	0	1
	9	1	1	1	1	1	1	1	0	1	1	1	1
	10	0	0	0	0	0	1	0	0	0	0	0	1
	12	0	0	0	0	0	1	0	0	1	0	0	1
	13	1	1	1	1	1	1	1	0	1	1	0	1
	14	0	0	0	0	0	0	0	0	0	0	0	0

In the same way as was done in the previous subsection, an element by element multiplication of the preference matrix, in this case P_{CG}^{R+}, is done with the unilateral movement matrix, in this case J_{CG}, to get the unilateral improvement matrix, in this case referred to as P_{CG}^{R+}.

Table 9.17: CGs TRR Matrix

$P_{CG}^{RT}=$

	0	1	2	4	5	6	8	9	10	12	13	14
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	1	0	0	0	0	0	0	0
2	0	0	0	0	0	1	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	1	0
10	0	0	0	0	0	0	0	0	0	0	0	1
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0

As can be seen immediately upon observing P_{CG}^{RT}, the vast majority of the entries are indeed 0's. Each entry that has a row entirely of 0s is thus an RNash state, according to Definition 19.1. This leaves four states that need to be seriously examined for RSEQ stability, for which Definition 22.1 will be adhered to: P_{CG}^{R+} whereby a state $s \in S$ is RSEQ stable for *i iff* $M_i^{RSEQ-}(s,s) = 0$.

To do so, the M_{N-CG}^{+} matrix in Table 9.18 must be formed from the combination of TRRs of all of the DMs in the conflict, besides CG. Here, it makes sense to form the matrix without concerning ourselves with attitudes as both DMs in the set N-CG are behaving according to rational attitudes. With this in mind the M_{N-CG}^{+} matrix is found below.

Table 9.18 : N-CGs Coalition TRR Matrix

$M_{N\text{-}CG}^{+}$ =

	0	1	2	4	5	6	8	9	10	12	13	14
0	0	1	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	1	1	1	0	0	0
4	0	0	0	0	1	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	1	1	0	0	0	0	0	0	1
8	0	1	0	0	0	0	0	1	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0
10	0	1	0	0	0	0	1	1	0	0	0	0
12	0	0	0	0	1	0	0	0	0	0	1	0
13	0	0	0	0	1	0	0	0	0	0	0	0
14	0	0	0	0	1	0	0	0	0	1	1	0

As can be seen above in Table 9.18, there are many more non-zero entries in $M_{N\text{-}CG}^{+}$ than there were in $M_{N\text{-}PO}^{+}$. This difference in entries is a function of the greater number of options available to PO. Applying Theorem 4 means that $M_{N\text{-}PO}^{+}$ must be multiplied by $(TRP^{CG})^{T}$ in order to form the sanction matrix. Subtracting the resulting matrix from the E (all ones) matrix and multiplying by the TRR^{CG} matrix will give results for RSEQ stability.

Table 9.19: CGs RSEQ Stability Matrix

$M_{RSEQ}^{CG} =$

	0	1	2	4	5	6	8	9	10	12	13	14
0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0
10	0	1	0	0	0	0	1	1	0	0	0	0
12	0	0	0	0	1	0	0	0	0	0	1	0
13	0	0	0	0	1	0	0	0	0	0	0	0
14	0	0	0	0	1	0	0	0	0	1	1	0

Examining M_{RSEQ}^{CG} it can be seen that the state stabilities correspond from the matrix form shown here and the tableau form in Table 9.19. For example, state 1 is not RSEQ stable as seen in Table 9.6, and corresponding to this M_{RSEQ}^{CG} (1,1) ≠ 0. In the tableau form the calculation works that by Definition 22 the state is RSEQ stable because: $TRR_{CG}(1) = 5$, $TRR_{N\text{-}CG}(5) = \{5\}$. As the only move that the sanctioning players can make is to the state itself, CG's Total Relational Reply is unsanctioned and thus, state 1 is unstable.

The attitudes methodology shows how the actions of the City Government, based on their willingness to behave in the interests of the developer through the offering of incentives, moves the conflict from a deadlock, to a state where the property changes hands. The new matrix methodology allows us to compute this outcome within the context of a programming environment, using simple mathematical operations that can be easily encoded.

9.5 Summary

The application of attitudes to GMCR is shown to be an effective methodology for examining complex systems problems between multiple DMs. Specifically, exploring how attitudes work allows an analyst to see how, with a different approach, new conflict resolutions can be reached. Xu et al. (2007, 2009) have neatly extended GMCR past its logical set theory framework into a new matrix formulation that allows the calculations to be determined using a number of simple matrix operations. In parallel to this development, this chapter illustrates the resiliency of a matrix technique for attitudes that will allow for easier implementation in a programming environment and, further, for more precise and efficient calculation of state stabilities.

Chapter 10

Conclusions

10.1 Overview

The attitudes methodology within the Graph Model for Conflict Resolution (GMCR), is significantly expanded in this thesis to allow for greater strategic insights into conflicts. Specifically, the following theoretical developments, also indicated on the right side of Figure 1.1, are presented in this thesis:

- The attitudes framework is formally examined and connected to the preference structure in GMCR, through the proof of Theorems 1 through 4 (Chapter 6).
- Original definitions for Dominating Attitudes were carefully crafted, whereby attitudes of different strength are considered, and were applied to a brownfield conflict (Chapter 7).
- A COalitions and ATtitudes method was formally defined to consider the strategic repercussions of attitudes within coalitions (Chapter 8).
- The attitudes methodology was equivalently expressed in matrix form, through the proof of Theorems 5 through 8, which allows matrix operations to be used to determine state stabilities and equilibria within a Decision Support System (Chapter 9).

The implementation of the extensions to attitudes within GMCR represents a significant contribution to the theory of strategic conflict analysis. Specifically, with dominating attitudes a new flexibility has been introduced to the attitudes methodology, whilst the COAT methodology given in Chapter 8, allows one to consider the importance of attitudes in group decision making. The matrix attitude method shown in Chapter 9, allows for the possibility of encoding this attitude framework within a new GMCR DSS to replace GMCR II. The relationship between attitudes and preferences shown in Chapter 6, gives even greater impetus to adopt attitudes within game theoretic models.

To demonstrate how the foregoing theoretical advancements can be conveniently applied in practice and to test and refine the new methodologies, the following range of novel applications are given in the thesis.

- Generic Sustainable Development Conflict is used to show how GMCR works (Chapters 2 and 3).
- Expanded Sustainable Development Conflict is used a common application to illustrate all of the new ideas in attitude analysis (Chapters 6 through 9).
- International greenhouse gas negotiations is strategically analyzed using GMCR and attitudes (Chapter 5).
- Kitchener brownfield conflicts involving acquisition and redevelopment were modelled and analyzed using the new theoretical developments in attitudes. These brownfield applications were developed with input from local government and industry (Chapters 6 through 9).

The development and application of strategic conflict analysis tools focused on decision maker`s attitudes represents a stark contrast to the economic and environmental decision tools used throughout the field of brownfield redevelopment and in the analysis of international environmental agreements. As with the application of attitudes within GMCR to brownfield and environmental management problems within this thesis, previous applications of the graph model to environmental conflicts such as the Elmira groundwater conflict (Fraser and Hipel, 1984) and the Garrison Diversion Unit (Fang, et al., 1993) have proven successful in providing insights into why certain outcomes have occurred in this important subset of systems problems. The application of the graph model to the area of brownfield redevelopment projects illustrates the importance of the relationship between the developer and the local government; the application of attitudes to the sustainability conflict illustrates the important role that government agencies play. When attitudes are positive, such that information is shared between DMs or when coalitions are formed so that actions can be made in conjunction with each coalition member, developers and local governments are able to reach positive win-win outcomes that satisfy the developers, local government and residents of the city. When the government acts in a way that is positive towards the activists, it is possible to pressure industry to behave sustainably.

10.2 Future Research

Conflict analysis methodologies are, and will continue to be, an important area of research in the future. Problems such as the effective management of the brownfields, the creation of binding international environmental agreements and the management of environmental legacies are only increasing in number. All of these conflicts involve multiple DMs having disparate values and backgrounds who must find ways to come to an amicable agreement. To this end, there will be a need for systems tools to help governments, developers and citizens to arrive at effective and conscientious decisions with respect to the environment.

The formal modeling of these various extensions of attitudes within GMCR provides decision analysts with a number of strong systems tools to determine how a DM may act under conflict given a desire to behave in ways other than just self-improvement with no concern for other DMs. Understanding how conflict outcomes change due to the attitudes DMs hold for each other, provides powerful strategic insights. Future improvements to the attitudes methodology include an adaptation of fuzzy sets, to create fuzzy attitudes for handling uncertainty. Additionally, a combination of attitudes, coalitions and hypergames could be used to simultaneously model conflicts containing all these characteristics. These extensions provide further flexibility to improve the usefulness of the attitudes framework. Using the matrix definitions, a new encoded decision support system can be developed for environmental decision makers and analysts. These various expansions and improvements of the previously developed methodologies can be applied to challenging applications, such as the complex negotiation of new greenhouse gas emissions treaties or the cost-effective and environmentally responsible development of brownfield properties.

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