Negotiation Support System with Third Party Intervention

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.

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Abstract

A flexible methodology is developed to specify how a desired outcome can be reached in a given conflict by determining the preference structures required for the decision makers to find it stable. The objective of this methodology is to provide informed collective negotiation support. This new methodology is generated by reverse engineering some Graph Model for Conflict Resolution (GMCR) procedures and is therefore called "Inverse GMCR". The essence of Inverse GMCR is to determine whether and how a strategic conflict can be ideally resolved, which may inform the mediators of strategies to achieve this resolution.

Formal definitions and mathematical representations for the new Inverse GMCR methodology are formulated in this thesis. The four basic graph model stability definitions, Nash stability (R), general metarationality (GMR), symmetric metarationality (SMR), and sequential stability (SEQ) are redefined for Inverse GMCR as *Nash IPS*, *GMR IPS*, *SMR IPS*, and *SEQ IPS*, respectively where *IPS* stands for *Inverse Preference Structure*. Pattern recognition and inverse calculations are used to generate strategies that permit mediators to negotiate a desired resolution. Mediation, or third party intervention, is strengthened by utilizing the insightful information provided by the Inverse GMCR methodology and the negotiation support system.

An in-depth strategic investigation and analysis of a complex water conflict in the Middle East is carried out to test and refine the algorithms developed here. This conflict occurred along the Euphrates River and had three key time points when the conflict escalated to the brink of a full scale war, in 1975, 1990, and 1998. A comprehensive analysis of

the conflict is undertaken, including bilateral and trilateral negotiations both before and after mediation.

Based on the new Inverse GMCR and existing algorithms, an advanced decision support system (DSS) is designed, built, and illustrated using real world conflicts. The new DSS, called GMCR+, is capable of handling a wide variety of decision problems involving two or more decision makers (DMs). Given the DMs, the options or courses of action available to each of them, and each DM's relative preferences over the scenarios or states that could occur, GMCR+ can calculate stability and equilibrium results according to a range of solution concepts that explain human behavior under conflict. Then the inverse component of the DSS, GMCR+, can determine the preference rankings of DMs that produce stable states and equilibria as specified by the user. Other features incorporated into GMCR+ include coalition analysis, graph and tree diagram visualization, narrative reporting of results, and a tracing feature that shows how the conflict could evolve from a status quo state to a desirable equilibrium or other specified outcome. The system GMCR+ has a modular design in order to facilitate the addition of further advances.

The overarching purpose of this research is to provide a simple and intuitive methodology to better understand and resolve actual conflicts. The GMCR+ DSS was developed in order to implement the Inverse GMCR methodology in the context of the standard graph model functions and in a practical way. Analysis and investigation of real world examples demonstrate the applicability of the methodology in various domains.

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Dedication

This thesis is dedicated to my parents

Dr. Lamya Baharith & Dr. Abdulraheem Kinsara

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Acronyms

DM	Decision Maker
GMCR	The Graph Model for Conflict Resolution
DSS	Decision Support System
GDSS	Group Decision Support System
SODA	Strategic Options Development and Analysis
GMCA	Graph Model for Conflict Analysis (or GMCR I); The first generation DSS for GMCR
GMCR II	The second generation DSS for GMCR
GMCR+	The third generation DSS for GMCR
GUI	Graphical User Interface
R	Nash Stability (sometimes called Rationality)
SEQ	Sequential Stability
GMR	General Metarationality
SMR	Symmetric Metarationality
UM	Unilateral Move
UI	Unilateral Improvement
UAR	United Arab Republic
GAP	"Güneydogu Anadolu Projesi" Is a project that includes 22 dams and 19 hydropower installations on the Euphrates-Tigris
PKK	Kurdish Workers Party
IPS	Inverse Preference Structure
US	United States
USSR	Union of the Soviet Socialist Republics
MRBM	Medium-Range Ballistic Nuclear Missiles
IRBM	Intermediate-Range Ballistic Nuclear Missiles
ICBM	Intercontinental Ballistic Missile
UR	Uniroyal Chemical Ltd
MoE	Ministry of Environment
LG	Local residents, the Regional Municipality of Waterloo, and the Township of Woolwich
NDMA	N-nitroso dimethylamine (carcinogen chemical)
CO	Control Order

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Chapter 1

Introduction

A dispute arises when two or more individuals or groups have conflicting interests, which may arise in the context of economic relations, international trade, environmental management, interpersonal relationships, and elsewhere. For society to be sustainable, stakeholders holding scarce resources or competitors in industrial development must reach appropriate compromises. When several parties are involved, each with an interest in the outcome of the conflict, decision makers (DMs) must select options under their control that determine an outcome. Although each DM has some power over the outcome, no single DM has full control. Moreover, when deadlock is reached in negotiations, a third party may be needed to intervene in order to reach a just resolution.

Because conflict is so pervasive in society, a strategic conflict resolution and analysis methodology may be employed to determine appropriate strategies. Earlier methodologies for modeling and analyzing conflict include metagame analysis (Howard, 1971, 1987), conflict analysis (Fraser and Hipel, 1984), drama theory (Howard, 1994a,b), and hypergame analysis of misperceptions (Bennett, 1980; Wang et al., 1988). The flexibility of the Graph Model for Conflict Resolution (GMCR) constitutes an improvement over earlier methodologies for the systematic resolution of real-world strategic conflicts (Kilgour and Hipel, 2005). Standard GMCR application involves two main stages, modeling and analysis, which will be outlined in Chapter 3 (Hipel et al., 1990). The modeling stage includes determining the DMs, possible options, possible outcomes, and DMs' preferences. In the analysis stage, the possible equilibria or outcomes of the conflict are determined. Practical application of conflict resolution methodologies can require cumbersome data analysis and iteration, which warrants the employment of a computerized decision support system (DSS) to expedite calculation of strategic results for interpretation by analysts. This DSS, for instance, could be used by a mediator to determine how disputants can reach a win/win resolution.

1.1 Research Motivation

Conflicts are the most costly and dangerous of all social processes (Bercovitch and Gartner, 2009). Conflict analysis algorithms can provide forecasting information according to the conflict parameters. However, values of these parameters may be subjective or change unexpectedly, resulting in a different outcome than the one initially predicted (Bristow et al., 2012; Sebenius, 1992; Rangaswamy and Shell, 1997). The development of an approach to model negotiations with and without third party intervention in conflicts will address the most crucial element of international relations, which is conflict, and the most influential component of a conflict, which is negotiation (Bercovitch and Gartner, 2006, 2009). The framework of standard GMCR can be used to predict the likely outcomes of a strategic conflict. However, understanding how a specific outcome can be reached within a negotiation is a challenge that is not addressed in the standard GMCR methodology.

A survey of the literature, which will be presented in Chapter 2, reveals the need for a comprehensive approach to model and analyze conflicts in order to determine strategies that can achieve a desired resolution. Many existing studies on negotiation and mediation address specific conflicts or sets of conflicts but end up using regression analysis, which may be unreliable and difficult to apply.

A number of water conflicts involving a third party in the Middle East have been recently investigated. The case studies emphasize the effects of third party intervention in bringing about a resolution (Hipel et al., 2014). The standard GMCR was used to model and analyze the conflicts before and after third party intervention. The applications provided the motivation to seek a more comprehensive approach to formally model negotiation and third party intervention within the framework of GMCR and to develop a software to visualize the model and allow negotiators and mediators to analyze options that result in an optimal resolution.

1.2 Research Objectives

This research provides a methodology that can generate scenarios regarding the likely evolution of a conflict. Furthermore, the tool can allow an analyst to specify a desired resolution and understand all scenarios that can achieve or avoid that specific resolution. There are two main objectives of this research: the first is to develop a negotiation modeling approach to assist in conflict resolution; the second is to develop a comprehensive DSS to allow practical application of different modeling methodologies related to GMCR, including the new negotiation model.

The specific goals of this research and their intended results are outlined as follows:

1. Reverse engineer the pre-existing GMCR to develop a new approach called "Inverse GMCR":
   - To allow negotiators to understand how a desired resolution can be achieved and suggest relevant strategies to the DMs.
   - To overcome the documented challenges in modeling conflicts in standard GMCR such as determining preference ranking (Hipel, 2011).
   - To require minimal information to model conflicts.
2. Propose new stability definitions for "Inverse GMCR":
   - To permit formal and systematic modeling of negotiation problems.
   - To allow the new methodology to be efficiently programmed.
3. Develop a comprehensive DSS with user-friendly advanced features:
   - To ease application of the methodology by both professionals and researchers.
   - To overcome limitations of previous DSSs.

- To provide analysts with insightful information using graphs, tables, and narrative results.
- To present interactive post-analysis tools such as equilibrium categorization, coalition analysis, and status quo analysis.
- To accommodate future advancements of GMCR by having a modular design.

4. Apply the methodology to diverse real-world problems:

   - To illustrate the value of “Inverse GMCR” in a variety of application domains.
   - To validate and verify the new DSS using documented real-world applications.

1.3 Thesis Organization

The following diagram in Figure 1.1 illustrates the organization of this thesis with key points of each chapter. Chapters 1 - 4 describe the problem statement that this research is solving. Chapter 1 discusses the motivation and main objectives of this research. The existing literature on negotiation, third party intervention, and previous DSS is reviewed in Chapter 2. Chapter 3 is a review of the existing GMCR methodology while Chapter 4 illustrates the challenges of the existing GMCR methodology through a real world international conflict.

Chapter 5 provides the solution model, which is the Inverse GMCR approach. In Chapter 6, the new DSS is described along with two case studies to illustrate its capabilities. The main contributions with directions for future research are provided in Chapter 7.

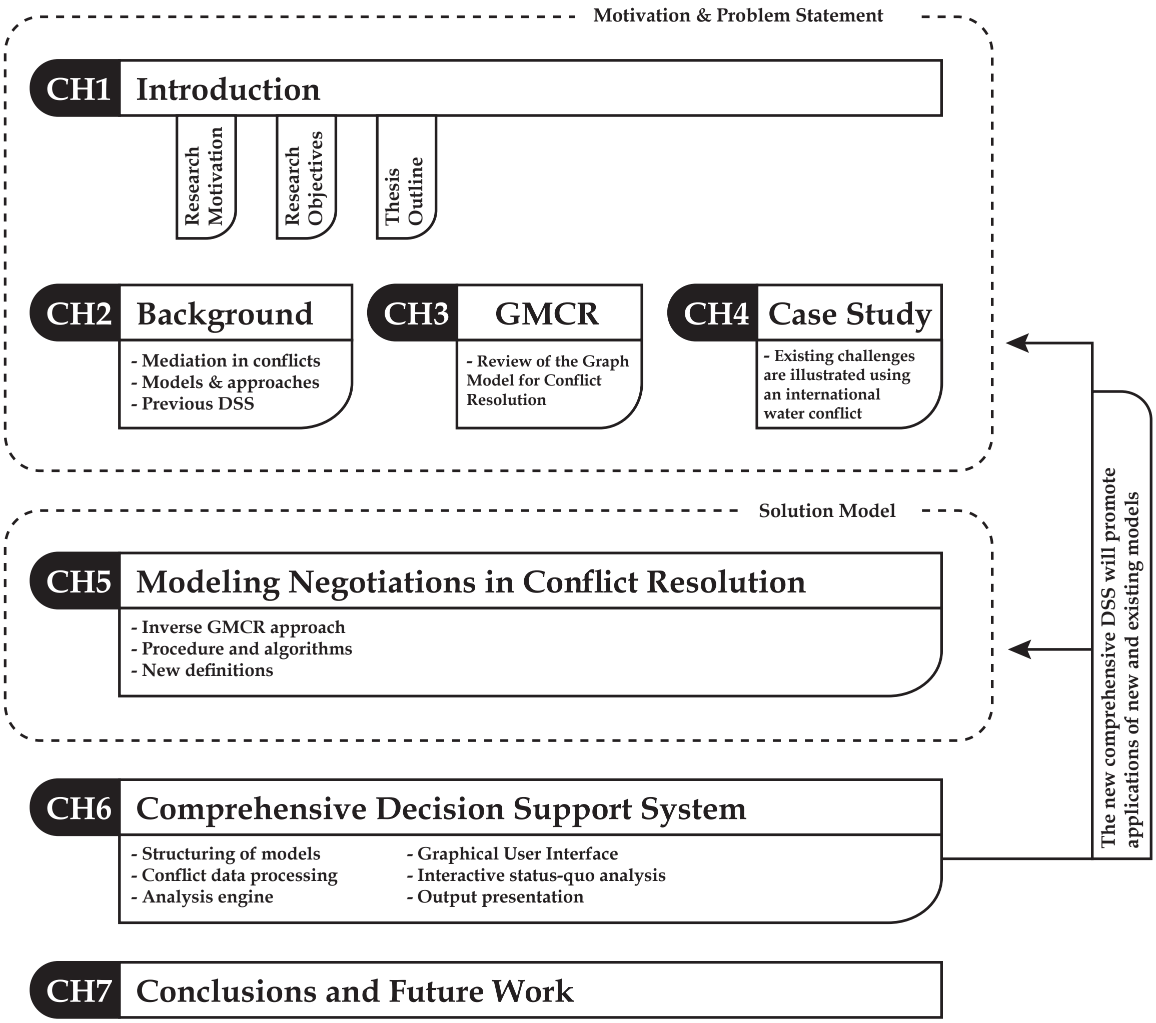


Figure 1.1: Thesis Organization

Chapter 2

Background and Literature Review

2.1 Introduction

Conflict resolution is not about eliminating conflicts, but rather accepting them and recognizing formal or informal activities undertaken by the DMs or mediators, in order to limit and reduce potential violence (Bercovitch and Jackson, 2009). The goal is to achieve an understanding and agreement to dictate resource allocation and future dealings with the opponents. Mediation is likely to happen in high intensity and complex conflicts. These conflicts rarely lead to a resolution without compromise on the part of one or more DMs involved. Therefore, agreements between DMs likely cover a limited segment of the issues in dispute and are short-lived (Bercovitch and Gartner, 2006).

2.2 Negotiation, Third Party Intervention, and Mediation

The negotiation process can be defined as "the interaction that occurs between the parties before the outcome" (Thompson, 1990). Among all methods of international conflict resolution, negotiation is frequently exercised first (Bercovitch and Jackson, 2009). It is a diplomatic solution that aims to reach an agreement without the use of violence and through joint decision-making by the DMs in a conflict. It is a tool that requires voluntary involvement by the DMs and provides an equal platform for the DMs to agree, disagree, or modify the ultimate resolution of the conflict. This can possibly lead to deadlocks and stalling in the process without outside intervention (Bercovitch and Jackson, 2009).

In a conflict situation, when other methods have failed at terminating the conflict, third party intervention is proposed due to the imminent need for resolution (Bercovitch and Gartner, 2009). Mediation is a form of peaceful third party intervention for joint decision-making where the mediator has some control over the process and outcome, but the ultimate power to make decisions rests with the parties directly involved (Moore, 1986). It entails the disputants seeking assistance or accepting help from a person, group, state, or an organization to influence their behavior, without the need for physical force or the need for legal intervention (Bercovitch and Rubin, 1992).

2.2.1 Characteristics of Negotiation and Mediation

There are five key characteristics in a negotiation situation as outlined by Thompson (1990):

1. DMs admit to having conflicting objectives.
2. Communication among DMs can be considered.
3. DMs are willing to reach a compromised resolution.
4. Intermediate solutions and counter proposals can be discussed.
5. The final outcome has to be approved by all DMs involved.

On the other hand, mediation is one of the most important methods used in international conflict resolution. Third party mediation is usually employed in the following situation as outlined by Bercovitch and Jackson (2009) :

1. Complex conflicts with no imminent resolution.
2. DMs are unable to resolve the conflict on their own.
3. Social and political costs are mounting.
4. DMs demonstrate willingness for diplomacy and cooperation.

2.2.2 Negotiation vs. Mediation

Table 2.1 derived from Michael Greig and Diehl (2006) outlines the differences between negotiation and mediation. Moreover, the authors state that outcomes are more likely to be achieved by mediation through third party intervention followed by mediation initiated by the DMs, and finally by negotiation. Whereas diplomacy is more accepted within the negotiation process as opposed to mediation as depicted in Figure 2.1.

Table 2.1: Comparison between Negotiation versus Mediation

Negotiation	Mediation
Direct contact between DMs	May not involve direct contact
DMs have greater faith in diplomacy	DMs may be pressured into a diplomatic solution
Initiated by DMs	Initiated by DMs or third party intervention
Greater commitment to resolution	DMs do not have to be fully invested in the process with the option to withdraw anytime
Higher domestic costs (e.g. possible ultimate failure of process, sign of weakness in front of opponent, can be labeled as traitors)	DMs can justify diplomacy more easily with the presence of a third party

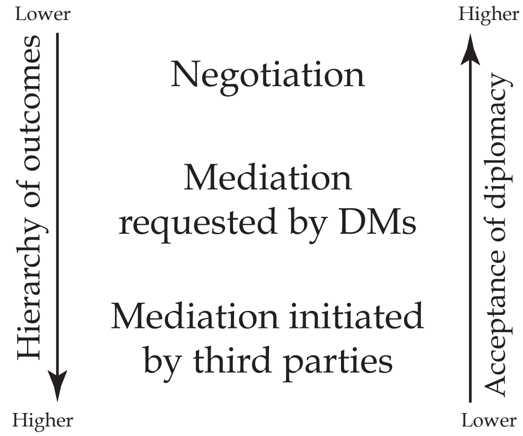


Figure 2.1: Hierarchy of Outcomes and Acceptance of Diplomacy in Negotiation versus Different Mediations

2.2.3 Third Party Roles

A third party can assume different roles in a conflict. Sakamoto et al. (2005) suggested three roles a third party can undertake in a conflict. These roles are commonly assumed when the mediator is not an actual party in the conflict, but is motivated to bring about a more preferred resolution. The suggested three roles are arbitrator, coordinator, and donor. The authors explain each role within a conflict. A third party is an arbitrator if it has the power to restrict or force a DM to accept a certain resolution. If a third party can alter DMs' preferences, then it is either a coordinator or a donor. The difference between the last two roles depends on the time of influence of the third party. A coordinator influences the DM to change preferences immediately, while a donor works on the long term (Sakamoto et al., 2005). On the other hand, Raiffa (1982) classifies third parties as facilitators, mediators, arbitrators, or rule manipulators. Another study suggests mediators can be individuals, regional organizations, states, or international institutions (Bercovitch and Schneider, 2000; Bercovitch and Gartner, 2006). The latter study surveyed 2,354 international conflicts involving mediation since 1945 in order to analyze them and assess various general hypotheses. Table 2.2 summarizes their dataset. Some of their hypotheses will be outlined in Section 2.3.3 of this thesis.

Table 2.2: Dataset Summary (Adopted from Bercovitch and Gartner (2006))

Category	Frequency	Percent (within category)
Mediators		
Individual	106	4.50
Regional	362	15.38
International	792	33.64
State	1,094	46.47
Strategies		
Communications	1,235	52.46
Procedural	434	18.44
Directive	685	29.10
Mediation History		
None	137	5.82
Offered Only	129	5.48
Fail	1,182	50.21
Ceasefire	228	9.69
Partial Settlement	579	24.60
Full Settlement	99	4.21
Outcome		
Failure	1,310	55.65
Ceasefire	234	9.94
Partial Settlement	657	27.91
Full Settlement	153	6.50
Total	2,354	

2.2.4 Factors Influencing the Outcome of Third Party Intervention

The literature is full of issues and factors affecting third party intervention. For example, factors affecting the process of intervention is that a mediator can act formally or informally, be invited to the conflict or not, intervene independently or on behalf of an organization, have interest in the outcome or in the process of intervention, be inclined toward one party or the other, and be consultative or directive in the intervention (Lewicki et al., 1992). Furthermore, mediation history can also have an effect on a new intervention attempt (Bercovitch and Gartner, 2006). A study by Carnevale and De Dreu (2005) addresses the element of time. They found that time pressure affects the mediator to be aggressive in intervening and to use pressuring tactics. Other studies on the effectiveness of third party intervention suggest factors that influence the success of specific situations. For instance, if an uninvited third party intervenes, Murray (1983) specifies three important factors for mediation efficiency: dispute maturity, disputants' relationship, and intervention timing. Other issues raised by different researchers include culture, power asymmetries, conflict ripeness, number of third parties, third party authority, bias, and consistency (Fisher, 2001).

Another aspect of mediation is strategy. The range of strategies a mediator can undertake is immense. Regan (1996) suggests three basic strategies of intervention within intrastate conflicts: military, economic, or mixed. Young (1972) discusses four intermediary functions: informational, tactical, supervisory, and re-conceptualization. In another study on successful mediation, Bercovitch et al. (1991) outline different strategies that can be adopted by a third party: conciliation-facilitation, procedural, directive, substantive, and supervisory. The authors explain each of these strategies and assess their impact based on a range of historical conflicts. While these studies emphasize specific strategies, other approaches provide a more generic context, referred to as intervention styles. For instance, Bartunek et al. (1975) organize intervention techniques into two broad styles: content form and process form. Another wide classification is that of Touval and Zartman, who categorize all intervention approaches as communication, formulation, or manipulation strategies (Bercovitch and Wells, 1993). Bercovitch and Gartner (2006) suggest that all strategies can be grouped into communication, procedural, or directive strategies.

2.3 Models and Approaches

Early research in negotiation used primarily artificial environments, lab experiments, scenarios, and sociological methods such as interviews and questionnaires (Martinovski, 2010). Novel trends called for authentic data obtained through face-to-face recordings, e-negotiations, bargaining, task management etc. This allowed adequate analysis such as discourse analyses, activity-based-communication analysis, and conversation analysis.

On the other hand, various early approaches to mediation included purely scholarly studies, reflections of mediators, policy implications, and proposals for academics to act as third-parties in mediations (Bercovitch and Jackson, 2009). Third party intervention in conflicts has been widely investigated from different perspectives. Most of the research lies within the areas of international relations and political sciences. These studies address issues regarding mediation including methods of intervention (Fisher, 2001), strategies for intervention (Prein, 1987), and conditions for successful intervention (Regan, 1996). Other approaches to conflict resolution previously ignored also include: Track II diplomacy (Aggestam, 2002), problem-solving workshops (Kelman, 1992; Burton, 1972), peace-building and conflict prevention measures (Doyle and Sambanis, 2000; Hartzell et al., 2001). These new approaches involve many unofficial mediators and can be used ad hoc (Bercovitch and Jackson, 2009).

2.3.1 Conflict Types

Conflicts can be classified in a wide variety of ways. In the world of mediation and third party intervention, the differentiation between intrastate and interstate conflicts is usually clear. A study by Regan (1996) focuses on success conditions for third party interventions in intrastate conflicts. Another classification by Bercovitch and Gartner (2006) differentiates between high intensity conflicts and low intensity conflicts. Another conflict category is the cause, which can be ethnic, religious, or ideological (Regan, 1996). The size of the conflict, or the number of parties involved provides another means for classification (Jehn, 1997).

Of the many approaches to study third party intervention, three are prominent in the literature (Bercovitch and Gartner, 2009) :

1. Individual case studies: these lines of research analyze and explore specific conflicts in detail. Although this kind of analysis provides significant insights about a particular conflict, it may lack the ability to be generalized and accommodate other conflicts.

2. Experimental approaches: these approaches are laboratory experiments where variables are controlled by researchers in an artificial setting (Rubin, 1980; Carnevale and De Dreu, 2005)

3. Large scale systematic studies: these studies analyze data representing many conflicts and use criteria to identify factors and relationships affecting the conflicts and their outcomes. It gives a more generalized understanding of conflict management.

2.3.2 Negotiation Approaches

Thompson (1990) classifies the theories and approaches of negotiation into these categories: individual differences, motivations, and cognitive models. Two models that depict the individual differences approach are the direct-effect models and contingency models. Dual-Concern model is an example of the motivations approach. Finally, information processing theory is the basis of the cognitive approach.

Negotiation began to be conducted electronically with the advent of internet as a communication tool (Kilgour and Eden, 2010). This allowed regulation and monitoring of the negotiation for analysis. Various negotiation models were developed from fields of engineering, communication research, management science, and psychology. The various methods to analyze negotiation processes rely on different interactions between DMs. There are quantitative as well as qualitative approaches for providing group negotiation support (Ackermann and Eden, 2010). The quantitative approaches include GMCR (Fang et al., 1993), Game Theory (Von Neumann and Morgenstern, 1944), and others that view negotiation within a game theory framework (Bennett et al., 1997; Bennett, 1980). On the other hand, the qualitative approaches seek out "Getting to Yes" (Fisher et al., 1987) and "Building Agreement" (Fisher and Shapiro, 2007) with emphasis on 'reaching agreements' and 'changing thinking' instead of mathematically optimum solutions.

2.3.3 Mediation and Third Party Modeling

Many studies in the literature tackle third party intervention in the context of a specific historical conflict or set of conflicts such as the work by Regan (1996); Bercovitch et al. (1991); Dixon (1996). For instance, the research by Regan (1996) on success conditions for third party interventions focuses only on intrastate conflicts and analyzes the conflicts that occurred during the period between 1944 to 1994 (Table 2.3). The author suggests a regression model based on the dataset he gathered as illustrated in Fig 2.2. The author emphasizes three intrastate conflict types: ethnic, religious, and ideological. Moreover, the regression model took into account other factors affecting the intervention such as the number of causalities, intervention type, and intervention target.

Results of Logit Regression on the Success or Failure of Intervention

Variable	*Estimated Coefficient*	SE	T-*Ratio*
Conflict type	–.40	.34	–1.17
Casualties	$-.70 \times 10^{-6}$	$.13 \times 10^{-5}$	–.54
Type of intervention	1.26	.59	2.13
Target of intervention	–.12	.03	–3.36
Major Power × Type	–.07	.02	–2.91
Major Power × Target	.12	.03	3.25
Constant	.89	.54	1.63
Log likelihood (0) = –117.71			
Log likelihood function = –107.95			
Likelihood ratio test = 19.50 with 6 *df*			

	Predicted Outcomes	
Actual Outcomes	*Success*	*Failure*
Success	11	7
Failure	48	124

NOTE: Number of correct predictions = 135; percentage of correct predictions = 71%.

Figure 2.2: A snapshot of the regression model by Regan (1996) with the results applied to the study dataset

Although most third party modeling based on historical conflicts uses regression analysis (Regan, 1996; Dixon, 1996), game theory based models are also used to formally model third party intervention based on particular conflicts such as the research by Carment and James (1996); Hipel et al. (2014). One of the challenges in the application of game theory based models is the uncertainty of preference, which has been addressed in research initiatives such as preference uncertainty (Li et al., 2004a) and fuzzy preferences (Bashar et al., 2012). The “Protracted Conflict Crisis model” was developed to support the notion that mediation is most likely to occur in crises during intense international events (Brecher and James, 1988). In addition, Fisher (2001) and Lewicki et al. (1992) discuss different conceptual and descriptive models for third party intervention. Lastly, a standard conflict model of third party intervention is suggested by Siqueira (2003).

Table 2.3: A dataset segment of the Intrastate Conflicts used in Regan's study (Table adopted from Regan (1996))

Conflict	*Type*	*Dates*	*Casualties*	*Interventions*	*Type of Intervention*	*Target of Intervention*	*Success*
Republic of Vietnam	Ideological	1960-1965	300,000	U.S.	Mixed	Government	No
				DRV Vietnam	Military	Opposition	No
Zairian Civil War	Ethnic	1960-1965	300,000	Belgium	Military	Opposition	No
				United Nations	Mixed	Government	Yes
				Algeria	Military	Opposition	No
				Egypt	Military	Opposition	No
				Belgium	Mixed	Government	Yes
Ogaden Conflict I	Ethnic	1960-1964	300	Somalia	Military	Government	No
Laos I	Ideological	1960-1962	30,000	U.S.	Mixed	Opposition	Yes
				U.S.S.R.	Military	Opposition	Yes
				RVN Vietnam	Military	Opposition	Yes
Iraq (Kurdish Rebellion)	Ethnic	1961-1966	5,000	Syria	Military	Government	No
Eritrean War	Ethnic	1962-1991	45,000	Cuba	Military	Opposition	No
				U.S.S.R.	Military	Opposition	No
				U.S.	Mixed	Government	No
				Cuba	Military	Government	No
				U.S.S.R.	Mixed	Government	No
				Sudan	Military	Opposition	No
Arab Republic of Yemen	Ideological	1962-1964	100,000	Egypt	Military	Government	Yes
				Saudi Arabia	Mixed	Opposition	No
				Jordan	Mixed	Opposition	No
Laos II	Ideological	1963-1973	18,000	U.S.	Mixed	Government	No
				DRV Vietnam	Economic	Opposition	No
				France	Military	Government	No
Sudanese Civil War	Religious	1963-1972	200,000	Belgium	Military	Government	No
Cyprus	Ethnic	1963-1964	3,000	U.K.	Military	Neutral	No
				Greece	Military	Government	No
				Turkey	Military	Opposition	No
				United Nations	Military	Neutral	Yes
Chad Civil War I	Ethnic	1965-1972	1,500	France	Military	Government	No
				Libya	Military	Opposition	No
Dominican Revolt	Ideological	1965	1,000	U.S.	Military	Government	Yes
				Honduras	Military	Government	Yes
Thai Communist Insurgency	Ideological	1965-1985	10,000	U.S.	Mixed	Government	No
				China	Military	Opposition	No
				Malaysia	Military	Government	No
Guatemalan Communist Insurgency I	Ideological	1966-1972	45,500	U.S.	Mixed	Government	No
Congo, Kisanguni Mutiny	Ideological	1967	20,000	U.S.	Military	Government	Yes
				Belgium	Mixed	Opposition	No
Burmese Communist Insurgency I	Ideological	1968-1980	1,500	China	Military	Opposition	No
Oman, Dhofar Rebellion	Ethnic	1970-1975	2,000	U.K.	Military	Government	Yes
				Iran	Military	Government	Yes
				Jordan	Military	Government	Yes
				YPR Yemen	Military	Opposition	No
Cambodia	Ideological	1970-1975	150,000	RVN Vietnam	Military	Government	No
				U.S.	Military	Government	No
				DRV Vietnam	Military	Opposition	Yes
Northern Ireland	Religious	1968-1994	3,000	Libya	Military	Opposition	No

A study by Sakamoto et al. (2005) illustrates an approach to incorporate third party intervention in conflict modeling using GMCR. The research suggests three roles a third party can undertake (explained in Section 2.2.3 of this thesis) and developed a conflict management procedure for them. Fig 2.3 below illustrates the authors' conflict management approach with the intervention of a third party.

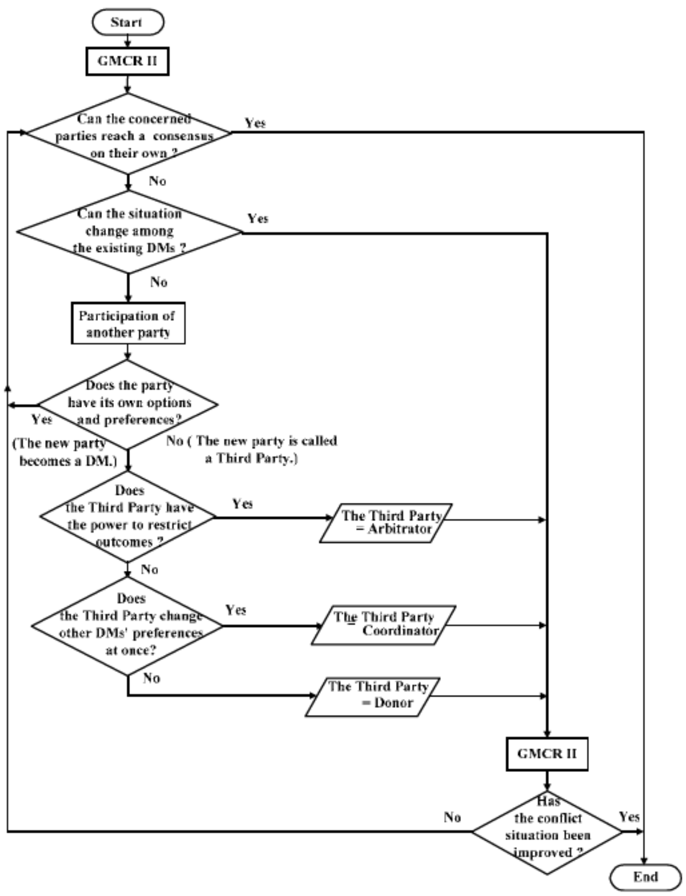


Figure 2.3: Chart developed by Sakamoto et al. (2005) to illustrate conflict management with a third party

A comprehensive study by Bercovitch and Gartner (2006) investigates in depth the success factors of third party intervention. The authors focus on mediators' identities, strategies, and mediation history to predict the outcome of mediation. According to the authors, mediators can be classified according to four categories: individuals, states, regional organizations, and international institutions. After discussing each category, the authors claim that in low intensity conflicts, state and regional mediators are more likely to be successful. However, they are less likely to be successful in high intensity conflicts. International mediators are likely to be effective in high intensity conflicts and individuals are unlikely to be successful in all conflict types. On the other hand, the authors suggest that mediation strategies include communication-facilitation, procedural, and directive strategies. Similarly, the authors make some hypotheses after explaining each of the strategies. They claim that directive strategies are most likely to be successful in high intensity conflicts but not in low intensity conflicts. Procedural strategies are mostly successful in low intensity conflicts. Tables 2.4 and 2.5 summarize the research hypotheses in the study.

Table 2.4: Mediator type and likelihood to be successful

Conflict Type	**Identity**			
	Individuals	***States***	***Regional Organizations***	***International Institutions***
High Intesity	Unlikely	Less likely	Less likely	Likely
Low Intensity	Unlikely	Likely	Likely	Likely

Table 2.5: Mediator strategy and likelihood to be successful

Conflict Type	**Strategy**		
	Directive	***Procedural***	***Communication-Facilitation***
High Intesity	Likely	Unlikely	Passive
Low Intensity	Unlikely	Likely	Passive

2.4 Previous Decision Support Systems for Conflict Resolution

DSS for group negotiations, referred to as GDSS, have been used for over 30 years for various reasons such as providing anonymity (Jessup and Tansik, 1991; Valacich et al., 1992), increasing group productivity (Valacich and Jessup, 1993), visual interactive modeling (Ackermann and Eden, 2001), and enabling collaborative working (Agres et al., 2005; Briggs et al., 2003). In recent times, there are trends in the collaboration engineering arena (De Vreede et al., 2003; Vreede and de Bruijn, 1999; Van Herik and Vreede, 2000) to focus GDSS application in negotiations between DMs to reach a desired resolution (Ackermann and Eden, 2010). Information systems for negotiation modeling require characterization of social interactions with its goal of reaching a desired resolution. Previous information systems neglected the need for third party modeling (Etezadi-Amoli, 2010). The first, and best known computer supported GDSS was “Group Systems” (Dennis et al., 1988; Nunamaker et al., 1991). “Meeting Works” is another GDSS based on a decision analysis framework (Lewis, 1993). A third GDSS focusing on negotiation is called “Group Explorer” which is based on the Strategic Options Development and Analysis (SODA) methodology (Ackermann and Eden, 2001).

In general terms, a DSS is defined as “a computer-based system that aids the process of decision making” (Finlay, 1994). A DSS has to be user-oriented by allowing the DM to understand and formalize preferences while being problem-oriented by defining the problem structure, searching for a resolution, and conducting sensitivity analysis (Kersten and Lai, 2010). Since the introduction of strategic conflict models, there have been various attempts at DSS softwares to assist researchers in carrying out conflict analysis. For example, CONAN (Howard, 1990) and INTERACT (Bennett et al., 1994) are systems based on Howard’s “metagame analysis” (Howard, 1987) and DecisionMaker (Fraser and Hipel, 1980, 1989) and SPANNS (Meister and Fraser, 1994) are founded on Fraser and Hipel’s “conflict analysis” (Fraser and Hipel, 1984). Graph Model for Conflict Analysis (GMCA or sometimes called GMCR I) (Kilgour et al., 1990) and GMCR II (Hipel et al., 1999; Peng, 1999) are the only DSS tailored to implement GMCR.

Application of the standard GMCR proved the need for software assistance, as solving even small models by hand could be cumbersome and inaccurate (Kilgour et al., 2001). GMCA (or GMCR I) was very useful in assisting researchers to utilize GMCR algorithms, despite the fact that it lacked graphical user interface (GUI) (Kilgour et al., 1996). GMCA was written in the C language and had an engine that calculated stability for different solution concepts. However, it could only analyze 100 states for multi-participant conflict models. In 1999, Peng developed GMCR II, an upgraded version of GMCA, that featured the first GUI (Peng, 1999). While using the same engine as GMCA, GMCR II's engine was based on a logical representation of GMCR, making it less efficient to compute results. The software encountered issues that sometimes caused it to crash or display error messages. Although it possessed a user-friendly input system, GMCR II lacked important features especially in output interpretation such as drawing graphs, narrating results, and performing status quo analysis. There have been no significant upgrades to this system although many new concepts and advances have been introduced to GMCR.

2.5 Third Party Intervention in the Literature: Strengths and Weaknesses

According to the aforementioned literature review, Table 2.6 outlines the main strengths and drawbacks of the current literature on third party intervention.

Table 2.6: Strengths and Weaknesses

Strengths	***Weaknesses***
Methods and strategies for intervention are investigated	Research and studies are fragmented and isolated over several disciplines
Conditions for successful intervention are discussed	There is no consensus on ideal roles or strategies for third party intervention
Qualitative approaches are found within the field of political science	Very few quantitative approaches are available
Many historical conflicts are analyzed using regression models	A generic methodology to model and analyze third party intervention is needed
DSS are available to assist researchers in conflict analysis	Information systems have neglected the need for third party modeling

2.6 Chapter Summary

This chapter introduces existing literature on negotiation and mediation methodologies as well as previous DSS to model and analyze conflicts. The difference between negotiation, third party intervention, and mediation is highlighted. The following are key points of this chapter:

1. Conflicts over ethnic, religious, or ideological problems have plagued DMs for centuries. The ultimate goal is to achieve peaceful conflict resolution without violence (Bercovitch and Jackson, 2009).

2. Negotiation and mediation are functionally equivalent. However, negotiation is a softer process involving more diplomacy as opposed to mediation in general (Michael Greig and Diehl, 2006).

3. Negotiation between the DMs within a conflict, whether self-initiated or through outside intervention, allows a formal mediator to have some control in navigating the course of the conflict (Moore, 1986).

4. Third party intervention constitutes a vital element in conflicts; however, most research on third party intervention is done in relative isolation and research on third party roles is fragmented due to many factors including discipline (Lewicki et al., 1992).

5. An external mediator can assume different roles such as an arbitrator, coordinator, or a donor (Sakamoto et al., 2005).

6. The eventual success or failure of a third party intervention depends on various factors such as the mediator's impartiality, the DMs' willingness to compromise in the conflict, time pressure, and mediation history (Lewicki et al., 1992).

7. The dominant modeling method in the area of mediation and third party intervention is regression analysis of historical conflicts.

8. There are three basic strategies of third party intervention in intrastate conflicts, namely: military, economic, and mixed (Regan, 1996) while Bercovitch and Gartner (2006) class all strategies as communication, procedural, and directive.

9. There are qualitative approaches to negotiation support that focus on 'reaching agreements' and 'changing thinking', while quantitative approaches include Game Theory (Von Neumann and Morgenstern, 1944) and GMCR (Fang et al., 1993).

10. Although DSSs have been in use for over 30 years, previous systems did not address the need for mediation modeling (Jessup and Tansik, 1991; Etezadi-Amoli, 2010).

11. GMCR I and GMCR II are the only DSSs based on GMCR by Fang et al. (1993) but were last updated in 1999. They lacked robustness, missed important developments and features, indicating the immediate need for a new comprehensive DSS.

Chapter 3

The Graph Model for Conflict Resolution (GMCR)

The game theory mentioned in "Theory of Games and Economics" as first published in 1944 forms the foundation of a number of tools to model conflicts (Von Neumann and Morgenstern, 2007). These tools allow analysts to effectively determine the best way to approach conflicts in order to model and analyze them. Major innovative work has since been done such as the development of "metagames" (Howard, 1971) and "drama theory" (Howard, 1994a). Metagames introduced a new flexible model within the theoretical approaches for games allowing practical applications to real-world scenarios (Fraser et al., 1983). Howard (1971) introduced new solution concepts that determine whether a state is stable for a DM by labeling states as either rational, general metarational, symmetric metarational, or unstable. These new solution concepts allowed for detailed analyses based on more accurate information of human behavior. The new feature of these solution concepts was the assumption that in a conflict, a DM is only aware of his own relative preference of a state with respect to another state, that is, whether a state is more preferred, equally preferred or less preferred compared to another state (Fraser et al., 1983).

In 1984, the metagame analysis was extended by Fraser and Hipel (1979, 1984) by pioneering sequential stability and simultaneous sanctioning as well as the tableau form to perform stability calculations. The role of sequential sanctioning is to consider the possibility that a DM is aware of another DM's preferences and therefore allow reliable solutions in which a DM will not harm himself in the process of imposing a sanction. In 1993, Fang, Hipel and Kilgour developed GMCR, which is a graph based model comprising of sets of arcs that represent potential moves between vertices, which represent different conflict states or outcomes.

GMCR is a tool to strategically analyze moves and counter moves by DMs in a conflict in order to predict the most likely outcome. GMCR possesses a realistic design for investigating conflicts. The advantages of using GMCR as a framework include simplicity and flexibility of its approach while maintaining robustness and practicality in predicting outcomes (Kilgour et al., 1987; Fang et al., 1989, 1993; Inohara, 2011). Moreover, many developments have been introduced to the original GMCR framework (Kilgour and Hipel, 2005). For example: coalition analysis (Inohara and Hipel, 2008b,a), preference uncertainty (Li et al., 2004a) , fuzzy preferences (Bashar et al., 2012; Hipel et al., 2011) , and attitudes (Walker et al., 2008). The GMCR has been developed and expanded since the mid-1980s (Kilgour and Hipel, 2005) when Kilgour, Hipel, and Fang introduced the idea in

Kilgour et al. (1987). The most comprehensive representation is introduced by the authors in Fang et al. (1993).

3.1 Procedure

The basic procedure of GMCR begins with examining a real-world conflict and involves two main stages: modeling and analysis. In the modeling stage, the user identifies the conflict parameters which include:

- DMs.
- Options available for each DM.
- Feasible states (i.e. remaining states after removing infeasible states such as mutually exclusive situations).
- Allowable transitions.
- Relative preferences.

The first step in the modeling stage of GMCR is to determine the DMs who have an interest and can directly influence the outcome of the conflict. The next step is to determine the set of feasible states by considering the options, or actions available, to each DM. A state is defined as a combination of options selected by the DMs. All possible states, which are composed of all possible combinations of options, may contain infeasible states. These infeasible states are removed to determine the set of feasible states that will actually be considered for analysis. Then, allowable state transitions determine possible moves for each DM among the feasible states by sealing all other DMs' options. Finally, preference relations between feasible states are identified for each DM. These relations can be derived from the conflict history or through information gathered from DMs.

After identifying the conflict parameters, the user analyzes the conflict from each DM's perspective to determine the likely final outcome. This stage includes:

- Determining individual stability (i.e. for each DM).
- Overall equilibria.
- Sensitivity analysis.

The first step in the analysis stage is to investigate the stability of each feasible state under different solution concepts for each DM. Four main solution concepts, or stability definitions, are used within GMCR: Nash stability (R) (Nash et al., 1950; Nash, 1951), general metarationality (GMR) (Howard, 1971), symmetric metarationality (SMR) (Howard, 1971), and sequential stability (SEQ) (Fraser and Hipel, 1984). Simultaneous stability (SIM) examines the strategic impact of two or more DMs moving together at the same time from a given state as such combination of moves can result in a new unexpected outcome (Fraser and Hipel, 1984). These models reflect different human behavior when dealing with strategic risks and foresight. For example, Nash stability only looks one move ahead while SEQ, GMR and SMR look two or three steps ahead. Furthermore, Nash stability ignores risks posed by other DMs, while SEQ accepts some risks, and SMR and

GMR are conservative and avoid risks. An equilibrium is defined as a state that is stable for all DMs under a particular stability definition.

The following diagram in Figure 3.1 illustrates the standard GMCR procedure (The diagram is adapted from Fang et al. (1993)).

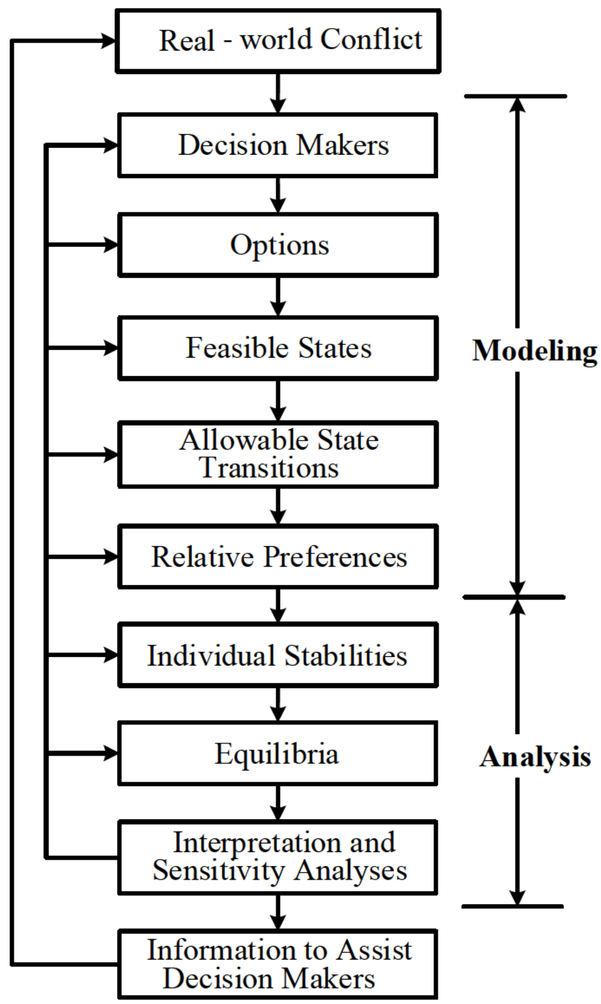


Figure 3.1: The basic procedure of GMCR in a real world conflict (adapted from Fang et al. (1993))

3.2 Notation and Definitions of GMCR

The graph model of a real-world conflict is formally defined as a set of DMs, states, directed graphs to indicate the possible movements between states for each DM, and preference relations over states by each DM. These parameters can be mathematically represented as follows:

Definition 3.2.1. Let $N = \{1, 2, \ldots, n\}$ represent the set of DMs, for each DM $i \in N$, the set O_i is i's options or strategy set and $S = \{s_1, s_2, ..., s_m\}$ represent the set of feasible states.

The set of possible states in a conflict is represented by the expression 2^α where α is the total number of options in a conflict. Some of the possible states may be infeasible such as mutually exclusive options, at least one type of options, or dependent options. In a conflict model, a set of feasible states is defined after removing all infeasible states.

Definition 3.2.2. Let $S = \{s_1, s_2, ..., s_m\}$ represent the set of feasible states in a conflict. For each DM $i \in N$, a set of directed graphs $D_i = (S, A_i)$ can be used to model the conflict.

$A_i \subseteq S \times S$ represent the moves controlled by DM i, so that for $s_a, s_b \in S$, $(s_s, s_b) \in A_i$ if and only if DM i can cause the conflict to move (directly) from state s_a to state s_b. The feasible states of a conflict are represented by vertices in the graph model. In each graph, an arc A_i exists between states s_a and $s_b \in S$ if DM i can move unilaterally in one step between the two states. It is called a *directed* graph because the arc has an orientation which can be one way (irreversible move) or two ways (reversible move).

GMCR uses unilateral improvement lists to determine states' stability by examining moves and counter moves by DMs. Therefore, it is required to identify all states that are directly reachable in one step for each DM from a particular state.

Definition 3.2.3. (Reachable List) Let $i \in N$ and $s \in S$. The *reachable list* for DM i from state $s \in S$ is defined as:

$$R_i(s) = \{s_a \in S \quad : \quad (s, s_a) \in A_i\}$$

The move in one step by DM i from a state s to a state in the reachable list $\{s_a \in S\}$ is called a unilateral move (UM).

The preference information of DM i is a binary relation $\{\succ_i, \sim_i\}$ over S, where $s_a \succ_i s_b$ means that DM i prefers s_a to s_b and $s_a \sim_i s_b$ means that DM i is indifferent between states s_a and s_b. The binary relation $\{\succ_i, \sim_i\}$ is considered complete.

Definition 3.2.4. (Unilateral Improvement List) Let $i \in N$ and $s \in S$. The *unilateral improvement list* for DM i from state $s \in S$ is defined as:

$$R_i^+(s) = \{s_a \in R_i(s) \quad : \quad s_a \succ_i s\}.$$

The move in one step by DM i from a state s to a state in the unilateral improvement list $\{s_a \in S\}$ is called a unilateral improvement (UI).

Definitions 3.2.3 and 3.2.4 are applicable in a two-DM model. However, to calculate the stability in an n-DM model where $n > 2$, *coalition* unilateral improvements are required.

A *coalition* is denoted by $H \subseteq N$, where H is any set of DMs and $n > 2$. The coalition H is non-empty if $|H| > 0$, and is non-trivial if $|H| \geq 2$. A coalition with $|H| = 1$ is trivial since it is equivalent to a single DM. Assuming $H \subseteq N$ is non-trivial, let $R_H(s) \subseteq S$ denote the set of all reachable states from $s \in S$ through a legal sequence. A sequence of states is *legal* if the states are linked by UMs by members of the coalition. A DM in H may move more than once in a *legal* sequence, but not twice consecutively. The set of all last DMs who can to move from state s to s_1 in legal sequences is denoted by $\Omega_H(s, s_1)$. The reachable list by a coalition is defined as follows:

Definition 3.2.5. (Reachable List for a Coalition) Let $s \in S$ and $H \subseteq N$, $|H| \geq 2$. The subset $R_H(s) \subseteq S$ is defined inductively as follows:

1. If $j \in H$ and $s_1 \in R_j(s)$, then $s_1 \in R_H(s)$ and $j \in \Omega_H(s, s_1)$;

2. If $s_1 \in R_H(s)$, $j \in H$, $s_2 \in R_j(s_1)$, and $\Omega_H(s, s_1) \neq \{j\}$, then $s_2 \in R_H(s)$ and $j \in \Omega_H(s, s_2)$.

The set $R_H(s)$ is called the *reachable list* from s for the coalition H, and any member of $R_H(s)$ is called a *unilateral move* from s by the coalition H.

Note that, in Definition 3.2.5, the induction stops as soon as no new state (s_2) can be added to $R_H(s)$ and $|\Omega_H(s, s_1)|$ cannot be increased for any $s_1 \in R_H(s)$.

For a general n-DM ($n > 2$) graph model, a legal sequence of UIs for a coalition can be defined similarly in order to identify the list of coalition UIs.

Definition 3.2.6. (Unilateral Improvement by a Coalition) Let $s \in S$ and $H \subseteq N$, $|H| \geq 2$. A *unilateral improvement* (UI) from s by the coalition H is the subset $R_H^+(s) \subseteq S$ defined inductively as follows:

1. If $j \in H$ and $s_1 \in R_j^+(s)$, then $s_1 \in R_H^+(s)$ and $j \in \Omega_H^+(s, s_1)$, where $\Omega_H^+(s, s_1)$ represents the set of all last DMs in legal sequences from s to s_1;

2. If $s_1 \in R_H^+(s)$, $j \in H$, $s_2 \in R_j^+(s_1)$, and $\Omega_H^+(s, s_1) \neq \{j\}$, then $s_2 \in R_H^+(s)$ and $j \in \Omega_H^+(s, s_2)$.

The induction in Definition 3.2.6 stops as soon as no new state (s_2) can be added to $R_H^+(s)$, and $|\Omega_H^+(s, s_1)|$ cannot be increased for any $s_1 \in R_H^+(s)$.

3.3 Stability Definitions and Solution Concepts

The main goal of the graph model for conflict resolution is to predict the stability of each state for each DM. There are four basic solution concepts according to which a state can be assessed for stability: Nash stability (sometimes called rationality), sequential stability (SEQ), general metarationality (GMR), and symmetric metarationality (SMR).

The solution concepts describe how a DM is motivated to make moves and counter moves. These concepts (or behavior patterns) determine whether a specific state will be terminal or a DM will be motivated to deviate to another state. Different DMs may have different behavior patterns based on different factors. These factors include risk, foresight, and available information. Behavioral characteristics according to the different solution concepts are given in Table 3.1 below.

Definition 3.3.1. (Nash Stability) Let $i \in N$ and $s \in S$. State s is *Nash stable* for DM i *iff* $R_i^+(s) = \phi$.

Definition 3.3.2. (Sequential Stability) Let $i \in N$ and $s \in S$. State $s \in S$ is *sequentially stable* (SEQ) for DM i *iff* for every $s_1 \in R_i^+(s)$ there exists at least one $s_2 \in R_{N-i}^+(s_1)$ such that $s_2 \precsim_i s$.

Definition 3.3.3. (General Metarationality) Let $i \in N$ and $s \in S$. State $s \in S$ is *general metarational* (GMR) for DM i *iff* for every $s_1 \in R_i^+(s)$ there exists an $s_2 \in R_{N-i}(s_1)$ such that $s_2 \precsim_i s$.

Definition 3.3.4. (Symmetric Metarationality) Let $i, k \in N$ and $s \in S$. State $s \in S$ is *symmetric metarational* (SMR) for DM i *iff* for every $s_1 \in R_i^+(s)$ there exists an $s_2 \in R_{N-i}(s_1)$ such that $s_2 \precsim_i s$ and $s_3 \precsim_i s$ for all $s_3 \in R_k(s_2)$.

Table 3.1: Behavioral characteristics describing different solution concepts

<table>
<tr><th>Solution Concepts</th><th>Stability Descriptions</th><th>Foresight</th><th>Knowledge of Preferences</th><th>Disimprovement</th><th>Strategic Risk</th></tr>
<tr><td>Nash stability (R)</td><td>Focal DM (decision maker) cannot move unilaterally to a more preferred state.</td><td>Low</td><td>Own</td><td>Never</td><td>Ignores risk</td></tr>
<tr><td>General Metarational (GMR)</td><td>All focal DM's unilateral improvements are sanctioned by subsequent unilateral moves by others</td><td>Medium</td><td>Own</td><td>By opponents</td><td rowspan="2">Avoids risk; conservative</td></tr>
<tr><td>Symmetric Metarational (SMR)</td><td>All focal DM's unilateral improvements are sanctioned, even after response by the focal DM.</td><td>Medium</td><td>Own</td><td>By opponents</td></tr>
<tr><td>Sequential Stability (SEQ)</td><td>All focal DM's unilateral improvements are sanctioned by subsequent unilateral improvements by others.</td><td>Medium</td><td>All</td><td>Never</td><td>Takes some risks; satisfices</td></tr>
</table>

Definition 3.3.5. (Equilibrium) Let $i \in N$ and $s \in S$. State $s \in S$ is called *equilibrium* (E) *iff* state s is stable for every DM.

Sometimes the graph model for conflict resolution is referred to as a 3-tuple or triplet $G = \langle N, S, (\succ_i, \sim_i)_{i \in N} \rangle$ where $N = \{1, \ldots, n\}$ is the list of DMs, $S = \{1, \ldots, m\}$ is the set of feasible states, and $(\succ_i, \sim_i)$ is the binary relation DM i has on S. Consequently, $Nash(G) = \{\ s \in S\ :\ s\ \text{ is a Nash Equilibrium of } G\}$. More explicitly,

$$Nash(N, S, (\succ_i, \sim_i)_{i \in N}) = \{\ s \in S\ :\ s \text{ is Nash stable for all } i \in N \text{ in } \langle N, S, (\succ_i, \sim_i)_{i \in N} \rangle\}$$

and similarly for SEQ, GMR, and SMR.

3.4 Follow-Up Analysis

To take the basic analysis further, a number of follow-up analyses may be undertaken to test the reliability of the predicted outcomes and whether they are achievable from the status quo or not.

Since many conflict parameters are subjective, it may be essential to perform sensitivity analysis in order to determine the robustness of the conflict model. Sensitivity analysis also points out how different parameters can influence the stability results. The most common type of sensitivity analysis is the change of preferences since they are the most difficult parameters to obtain and determine. Other sensitivity analysis types include:

- Adding or combining DMs.

- Change of options (adding, removing, or modifying).
- Changing moves reversibility.
- Coalition analysis.
- Modeling misunderstandings (hypergames).
- Examining other patterns of human behavior.

Every real world conflict has a starting point from which the conflict evolves. This point or state is called *status quo* (Fang et al., 1993). Depending on the status quo, a potential equilibrium may or may not be reached. Li et al. (2004b, 2005) developed algorithms and formal definitions to inspect the attainability of a potential resolution (*equilibrium*) from a particular state (*status quo*).

3.5 Chapter Summary

This chapter outlines the GMCR procedure, formal definitions, and mathematical representations to prepare for the introduction of the Inverse GMCR. Key highlights of this chapter include:

1. GMCR was developed to understand, model, and analyze conflicts in a practical way with minimal requirements as existing methods were cumbersome and often failed to provide useful analyses and insights (Kilgour and Hipel, 2005).

2. GMCR was greatly expanded since the mid-1980s, and different extensions were introduced.

3. The reason behind the rapid development of GMCR is that its framework is simple and its approach is flexible yet robust in predicting outcomes (Fang et al., 1993, 1989).

4. The two stages of GMCR include modeling to identify conflict parameters, and analysis based on stability definitions to calculate equilibria and the likely final outcome.

5. Nash stability (R), general metarationality (GMR), symmetric metarationality (SMR), and sequential stability (SEQ) are referred to as the basic *solution concepts* or *stability definitions*. They are behavior models that determines whether a specific state is terminal across all DMs, or whether a DM will be motivated to deviate to a different state, usually by a unilateral improvement (UI).

6. Basic GMCR analysis is usually supplemented with follow-up analyses such as sensitivity analysis to validate the robustness of the conflict model.

Chapter 4 provides a comprehensive analysis using GMCR for a real-world water conflict with an introduction of third party intervention.

Chapter 4

Strategic Investigations of Water Conflicts in the Middle East

The arid nature of the Middle East environment causes continuously escalating conflicts among the countries of the region. Conflicts arise as water resources dwindle due to increased industrial and agricultural projects and population growth. The main renewable sources of freshwater in the region are rivers. Like all water resources, they are replenished by their hydrological cycle, with renewal rates varying from days to centuries. The rate of renewal for Middle Eastern rivers is decreasing due to population growth and the increasingly arid conditions of the region. At 2,700 km, the Euphrates is the longest and arguably most important river in the Middle East (Southwest Asia) (Kolars and Mitchell, 1991). The Euphrates originates in eastern Anatolia in Turkey and flows through Syria and finally Iraq, where it joins the Tigris River. Conflicts regarding the river became serious during the 1960s, when Turkey began building dams on the Euphrates to generate electricity and increase the availability of irrigation water in Southeast Turkey (Akanda et al., 2007). As a result of external mediation, war was narrowly avoided twice, in 1975 and 1998 (Akanda et al., 2007).

Water conflicts have been widely investigated during the last decade (Dinar, 2004) and different approaches have been used to model them (Madani, 2010). For instance, the Waiahole Water Project conflict, in the American state of Hawaii, has been modeled and analyzed using GMCR (Gopalakrishnan et al., 2005), and a status quo analysis of the Flathead River conflict involving the United States and Canada was examined using the same methodology (Li et al., 2004c). Other modeling approaches used to study water conflicts include Alternative Dispute Resolution (ADR) (Wolf, 2000), Shared Vision Modeling (Lund and Palmer, 1997), and Adjusted Winner (AW) mechanism (Massoud, 2000).

The aim of this chapter is to examine in depth the main conflicts that have occurred in the past along the Euphrates and to model them using the GMCR methodology (Kilgour et al., 1987; Fang et al., 1993) as implemented by the decision support system, GMCR II (Hipel et al., 1997; Fang et al., 2003a,b). Time periods of interest for this analysis are 1975, 1990, and 1998, when the conflict escalated to the near outbreak of a full scale war. Accordingly, the historical background underlying the disputes at these three points in time are described in the next section. Subsequently, modeling and stability analyses are carried out for these three conflicts, followed by a summary of strategic insights that are garnered. The contents of this chapter are based on a published paper which was originally presented as a keynote address at the International Meeting on Group Decision and Negotiation held in Recife, Brazil, from May 20th to 24th, 2012 (Hipel et al., 2014).

4.1 Background

As explained in the next three subsections, the interconnected conflicts of 1975, 1990, and 1998 took place dynamically over time. Therefore, systematically investigating these disputes together enhances the appropriateness of the analyses and furnishes more meaningful insights.

4.1.1 The conflict in 1975

In 1966, Turkey started the construction of the Keban Dam, which is a hydroelectric dam on the Euphrates River (Fig 4.1). After the construction was finished in 1974, Turkey started the filling of the Keban Reservoir. During the flooding, Turkey maintained a 450 m^3/s discharge of the Euphrates to the two downstream countries consisting of Syria and Iraq. This rate was agreed upon by both countries through the United States Agency for International Development (USAID), which was financing the project (Inan, 2000). However, Syria also started filling the lake behind its newly constructed Thawra Dam. Simultaneously, the area was hit by a significant drought (Kalpakian, 2004). As a result, the flow of the Euphrates River entering Iraq was reduced to a trickle. Iraq accused Syria of this reduction and of endangering the lives of three million Iraqi farmers dependent on river irrigation water (Morris, 1997). Iraq complained that the flow had dropped from the normal 920 m^3/sec to an unacceptable 197 m^3/sec (Priscoli and Wolf, 2009). Iraq requested an intervention by the Arab League; however, Syria argued that it was receiving less water from Turkey as well and refused to cooperate. As the tension increased, Syria closed its airspace to all Iraqi aircraft, suspended Syrian flights to Baghdad, and transferred troops from the Israeli border to the Iraqi frontier by May 1975 (Morris, 1997). Iraq also sent its troops to the shared border and threatened to bomb Syria's dam.

Before the conflict could escalate any further, Saudi Arabia and the Soviet Union intervened - only mediation on the part of Saudi Arabia was able to alleviate the situation (Priscoli and Wolf, 2009). On June 3, 1975, an agreement between Iraq and Syria, with the mediation of Saudi Arabia, averted the impending war. The agreement stipulated that Syria is to release extra amounts of water to Iraq (Akanda et al., 2007): specifically, 58% of what Syria receives from the Euphrates is to be released to Iraq (Priscoli and Wolf, 2009). In addition to resolving the conflict, Saudi Arabia contributed to a basin fund that would finance irrigation reform and other methods to reduce unmet demands (Akanda et al., 2007).

4.1.2 The Conflict in 1990

In 1977, Turkey announced plans for the largest water resources project in South-Eastern Anatolia, referred to as "Güneydogu Anadolu Projesi", commonly known as the "GAP Project", which includes 22 dams and 19 hydropower installations on the Euphrates-Tigris (Frenken et al., 2009). The incentive for this project, apart from the steadily increased

Figure 4.1: The Euphrates River along with the dams constructed on it (The New York Times, 2009)

water demand, was to promote Turkey's internal stability. Turkey has been continually preoccupied with the rebellion movement of the Kurdish Workers Party (PKK), which is struggling to create a Kurdish state in South Eastern Turkey (Güner, 1998). The construction of the GAP project scattered the Kurdish rebels and the PKK denounced the GAP project as harmful to Kurds and their villages. GAP irrigation projects transformed the geography of the area and obstructed the free movement of the PKK. The PKK had targeted the GAP project with sabotage and kidnapping of engineers in order to stop the development. Aside from weakening the PKK movement, the GAP project also provided extra jobs for resident Kurds, thereby promoting internal stability. It also helped in stemming the flow of immigrants from this region to the already over-crowded cities.

On the other hand, both Syria and Iraq demonstrated their distrust and rejection of the GAP project. When Turkey requested funding from the World Bank for a second dam after the Keban Dam, Syria and Iraq raised many objections to urge the World Bank to withhold the funding, although the Bank and Turkey concluded that the downstream requirements could be satisfied (Akanda et al., 2007). During the conflict between Turkey and PKK, Syria supported the PKK by granting their leader refugee status and provided him with shelter. Moreover, Syria allowed PKK to have military bases in the Beqaa Valley, a region in eastern Lebanon under Syria's control (Güner, 1998). Syrian support of the PKK was potentially intended for the reduction, or at least the interruption, of the GAP project (Güner, 1998). In 1987, Turkey guaranteed a minimum water flow of 500 m^3/s and Syria, in return, promised to cooperate in security matters. A few months later, Turkey complained about terrorist activities and accused Syria of supporting them (Güner, 1998). Turkey allegedly hinted at a cut in the flow of Euphrates water to Syria over Syrian support for Kurdish terrorists (Starr, 1991). In January 1990, Turkey completely stopped the flow of the Euphrates. The official justification for the interruption was to fill the lake behind the Ataturk Dam and the interruption was intended to be only for one month (Darwish, 1994). Behind the scenes, this interruption was an indirect threat to Syria for its continued support of the PKK. Turkey did not care about Iraq's reaction as Syria and Iraq were bitter enemies; however, Turkey's actions united both Iraq and Syria against it. Once Turkey halted the flow of the Euphrates, both countries, Syria and Iraq, boycotted companies involved in the GAP project. Furthermore, military leaders from both nations drew up plans for armed retaliation against Turkey (Darwish, 1994). After three weeks, water was released in the Euphrates River, even though the interruption was intended to last a whole month.

4.1.3 The Conflict in 1998

After the joint coalition between Syria and Iraq in 1990, Turkey decided not to use the Euphrates as a weapon in order to avoid Iraq's intervention. However, Syria's continuous support for the PKK was affecting Turkey's stability and depleting its resources. Despite bilateral security agreements between Syria and Turkey in 1992 and 1993, Turkey continued to accuse Syria of supporting the PKK, while Syria insisted that it forced the PKK to move its bases from Syrian territory in conformity with the bilateral agreements between itself and Turkey (Güner, 1998). In 1993, the Turkish Prime Minister declared that if Syria did not ban PKK from its country, there could be no solution to the water problem. The issue was raised again in the trilateral summit of 1994 between the Foreign Ministers of Turkey, Syria, and Iraq with no improvements. Moreover, in 1995, Turkey organized military operations in northern Iraq against PKK members who fled to Syria, thus confirming Turkish suspicions. Finally, in 1998, Turkey charged Syria with support of the PKK and harboring its leader, perhaps providing refuge to the leader in Damascus. Turkey escalated the situation and threatened to invade Syria. Egypt intervened and the Egyptian President, Hosni Mubarak, secured Syria's pledge to stop supporting the PKK (Akanda et al., 2007). On account of the intervention of Egypt and in order to avert an invasion by Turkey, the Syrian government agreed to ban PKK from Syria by signing the Adana Agreement on October 20, 1998 (Priscoli and Wolf, 2009). Finally, Table 4.1 provides the historical evolution of the most notable events related to the Euphrates conflicts.

Table 4.1: Notable events related to conflicts along the Euphrates River

Dates	Events
Early 1970s	Rebellious Kurdish Workers Party (PKK) was formed. Syria supported this party.
Late 1974	The filling of Keban and Thawra dams started.
Early 1975	Iraq complained about the flows in the Euphrates dropping from the normal 920 m^3/sec to an “intolerable” 197 m^3/sec. Iraq requested that the Arab League intervene. However, Syria said it was receiving less than average flow and dropped out of the Arab League. Both countries amassed their troops on the shared borders and the situation escalated.
June 3, 1975	Intervention and mediation efforts by Saudi Arabia are at last successful and war was averted. Agreement details were not announced.
1977	Turkey announced plans for the "GAP Project", which includes 22 dams and 19 hydropower installations on the Euphrates-Tigris Rivers.
1987	Turkey guaranteed a minimum water flow of 500 m^3/s and Syria, in return, promised to cooperate in security matters. A few months later, Turkey complained about terrorist activities and accused Syria of supporting them.
January, 1990	The filling of the Ataturk Dam by Turkey started, shutting off completely the flow to the Euphrates River. Even though the interruption was intended to be for only one month, Syria and Iraq boycotted companies involved in the GAP project. Moreover, military leaders from both nations drew up plans for armed retaliation against Turkey. After three weeks, Turkey released water to the Euphrates River.
1992 1994	Bilateral security agreements between Syria and Turkey were discussed, with little success. Turkey continued to accuse Syria of supporting the PKK. In 1993, the Turkish Prime Minister declared that if Syria did not ban PKK from its country, there could be no solution to the water problem.
1995	Turkey organized military operations in northern Iraq against PKK members who fled to Syria, thus confirming Turkish suspicions.
August, 1998	Turkey threatened full military action and invasion against Syria for continuing to support PKK rebels.
October, 1998	With the mediation of Egypt, the Adana Agreement, obligating the Syrian government to ban PKK, was signed by Turkey and Syria.

4.2 Conflict Analysis of the 1975 Dispute

The DMs and options for the 1975 conflict are given in Table 4.2. Notice that Syria has an option regarding the release of the water plus an option of escalating the situation. Iraq has the single option of attacking Syria. Since both Saudi Arabia and the Soviet Union have similar preferences and reasons for getting involved, they are considered as a single DM labeled as "Third Party". The Third Party has a single option of acting or not. Table 4.2 describes the options for each DM. Each option is labeled with a number and can be either taken (Y for yes) or not (N for no). For example, option 3, which is entitled Attack, is the situation in which Iraq can use military action to force Syria to release water into the Euphrates. Undertaking this option, as indicated by Y for yes, means using force, while not taking this option, N for no, indicates accepting the situation and allowing Syria to fill the Thawra Dam without escalation.

Table 4.2: DMs, options and descriptions for the 1975 conflict

DM	Option	Choice	Description
Syria	1.Release Water	**Y**	Syria agrees to halt the filling of Thawra Dam and let the Euphrates flow into Iraq
		N	Syria continues to fill its dam
	2.Escalate	**Y**	This could be done by cutting relations with Iraq, sending troops to the shared border, closing the air space to Iraqi aircraft, or any combination of these actions
		N	Syria does not undertake any of the escalating options
Iraq	3.Attack	**Y**	This includes bombing of the dam and going to war with Syria
		N	Iraq does not act and accepts the situation
Third Party	4.Act	**Y**	This includes mediation and reconciliation between the two countries and monetary support
		N	Do not intervene

To emphasize the effect of the third party, this conflict will be analyzed without and with the intervention of the third party. The sets of possible states are given in Tables 4.3 and 4.4, respectively. Notice that there is one infeasible situation in which Syria both releases the water and escalates the situation at the same time (mutually exclusive options). Taking this into account results in the removal of two states in the model without the intervention of the third party and the removal of four states in the model with the participation of the third party.

Table 4.3: DMs, options and states for the 1975 conflict without the third party

DM	Option	States					
Syria	1.Release Water	**N**	**Y**	**N**	**N**	**Y**	**N**
	2.Escalate	**N**	**N**	**Y**	**N**	**N**	**Y**
Iraq	3.Attack	**N**	**N**	**N**	**Y**	**Y**	**Y**
Label		1	2	3	4	5	6

Table 4.4: DMs, options and states for the 1975 conflict with the third party

DM	Option	States											
Syria	1.Release Water	N	Y	N	N	Y	N	N	Y	N	N	Y	N
	2.Escalate	N	N	Y	N	N	Y	N	N	Y	N	N	Y
Iraq	3.Attack	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
Third Party	4.Act	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
Label		1	2	3	4	5	6	7	8	9	10	11	12

Figures 4.2 and 4.3 show the integrated Graph Models of the conflict both without and with the participation of the third party, respectively. The numbers in the nodes refer to the state numbers as indicated in Tables 4.3 and 4.4. The lines with arrows between the nodes are moves that can be carried out by the indicated DM in one step.

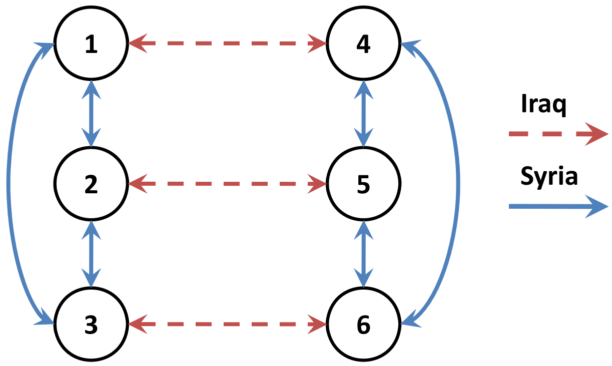


Figure 4.2: Integrated Graph Model of the 1975 conflict without the third party

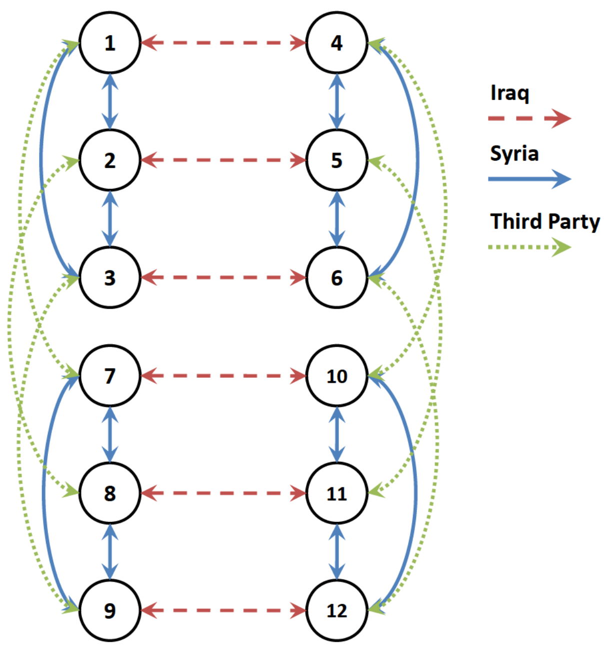


Figure 4.3: Integrated Graph Model of the 1975 conflict with the third party

Table 4.5 presents the preference prioritization information for each DM in the 1975 conflict without the participation of the third party, from most important at the top to least important at the bottom for each DM. The statements presented herein are a sample of how the ranking of states is constructed. This information is used to order the states from most to least preferred by the DM. Assuming transitivity for the preferences, Table 4.6 presents the ranking of states from most to least preferred for both Syria and Iraq using option prioritization (Hipel et al., 1997; Fang et al., 2003a,b). For example, State 1, which is the status quo, is the best state to be in for Syria. State 5, in which Syria releases the Euphrates and Iraq attacks at the same time, is considered the worst possible state for Syria.

Table 4.5: Preference prioritization information for the 1975 conflict without the third party

DM	P#	Preference Information (From most to least important)	Further Explanation
Syria	**1**	Remain at the status quo	Syria continues filling its dam and Iraq accepts the situation without any escalation or intervention
	2	Escalate the situation if Iraq decides to attack	Syria next prefers going to war with Iraq if it is attacked, which is more preferred than releasing water
Iraq	**1**	Syria releases more flow of the Euphrates River	Iraq most prefers the situation in which Syria stops filling its dam without any escalation
	2	Execute an attack if Syria does not release more water	Iraq's interest in water far outweighs the consequence of going to war

Table 4.6: Ranking of states for the DMs in the 1975 conflict without the third party

DM	States					
Syria	1	3	6	2	4	5
Iraq	2	4	6	1	5	3
	Most Preferred				*Least Preferred*	

The third party could be viewed as an actual DM if it has its own options and preferences. However, if the party is not an actual stakeholder in the conflict but is motivated to bring about a more preferred equilibrium, then it can be categorized as Arbitrator, Coordinator, or Donor (Sakamoto et al., 2005). If the party has the influence to change other DMs' preferences or options, then the party is called a Donor. On the other hand, if the party has the power to exclude some states, then it is considered to be an Arbitrator. In this conflict, the third party, Saudi Arabia, is clearly a Donor as it contributed to financing the basin development and both DMs, Syria and Iraq, want to please Saudi Arabia. Therefore, DMs' preferences, especially on the part of Syria, are changed. Table 4.7 presents the preference prioritization information for each DM in the 1975 conflict with the participation of the third party from most to least preferred. Table 4.8 gives the preference rankings for Syria, Iraq, and the third party from most to least preferred.

Table 4.7: Preference prioritization information for the 1975 conflict with the third party

DM	P#	Preference Information (From most to least important)	Explanation
Syria	**1**	Remain at the status quo	Syria continues filling its dam and Iraq accepts the situation without any escalation or intervention
	2	Release the flow of the Euphrates if and only if Iraq does not attack and with the mediation of a third party	This is the new preference information after the intervention of the Third Party
	3	Escalate the situation if Iraq decides to attack	Syria's least preferred situation is to go to war with Iraq
Iraq	**1**	Syria releases the flow of the Euphrates	Iraq's most preferred situation is that Syria stops the filling of its dam without any escalation and with or without an intervention
	2	Strike an attack if Syria does not release more water	Iraq's interest in water far outweighs the consequence of going to war
Third Party	**1**	Acts and influences Syria to release the flow of the Euphrates	The mediator's interest is to promote peace in the region and reduce harm for everyone

Table 4.8: Ranking of states for the DMs in the 1975 conflict with the third party

DM	States											
Syria	1	3	8	9	2	7	12	6	10	4	11	5
Iraq	8	2	6	12	4	10	7	5	11	1	9	3
Third Party	8	2	1	7	9	3	4	10	6	12	5	11
		Most Preferred									*Least Preferred*	

The objective of the analysis is to determine the equilibrium states, which are the states from which no DM is motivated to move and, therefore, the conflict will probably end at that particular state. To determine the equilibrium states we use stability definitions (or solution concepts), which describe human behavior and patterns based on moves and counter moves. Equilibria are states that are stable for all DMs. After inputting the foregoing information into GMCR II, equilibrium results are obtained for both Syria and Iraq without the third party (Table 4.9) and with the third party (Table 4.10). In Tables 4.9 and 4.10, the left column gives the different stability definitions while the remaining columns present the stability calculation results for each solution concept corresponding to the state. Nash and Sequential Stability (SEQ) are considered the strongest stability definitions. General Metarationality (GMR) and Symmetric Metarationality (SMR) are not considered as strong stability definitions since DMs are permitted to harm themselves during the process of sanctioning. Fang et al. (1989) discuss the relationships among the different solution concepts.

Table 4.9: Equilibrium results for the 1975 conflict without the third party

Solution Concepts	**States**	**1**	**2**	**3**	**4**	**5**	**6**
R (Nash)							✓
GMR		✓					✓
SMR		✓					✓
SEQ							✓

Table 4.10: Equilibrium results for the 1975 conflict with the third party

Solution Concepts	**States**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
R (Nash)							✓		✓				
GMR			✓				✓	✓	✓				✓
SMR			✓				✓	✓	✓				✓
SEQ							✓		✓				

It is clear from the aforementioned analysis that when the third party does not participate (Table 4.9), the strongest equilibrium is state 6 which means that both Syria and Iraq go to war. That is what nearly happened as both countries amassed their troops on their shared border. The status quo, State 1, is a very weak equilibrium and the unilateral improvement by Iraq will most likely be taken; that is, Iraq will move to state 4 in which it will attack. In contrast, with the intervention of the third party, a new equilibrium is introduced: State 8 in which Syria releases water and no escalation or attack from Iraq occurs. Referring to the ranking of states in Tables 4.6 and 4.8 as well as the integrated graphs in Figures 4.2 and 4.3, one can easily view the unilateral moves and improvements for each DM. A unilateral move is any possible move controlled by that particular DM, whereas a unilateral improvement necessitates that this move is also a movement to a more preferred state. The analysis of the conflict demonstrates how each DM's preferences may have an impact on the overall conflict. Table 4.11 provides the actual historical evolution of the conflict when moving from the status quo on the left via several intermediate states to the final equilibrium on the right. One can clearly see how both Syria and Iraq almost went to war until the third party intervened. It is clear that the actual historical evolution of the conflict is consistent with the earlier analysis.

Table 4.11: Historical evolution of the 1975 conflict

DM	**Option**	**Status Quo**		Intermediary states		**Equilibrium**
Syria	Release Water	N	N	N	N →	Y
	Escalate	N	N →	Y	Y →	N
Iraq	Attack	N →	Y	Y	Y →	N
Third Party	Act	N	N	N →	Y	Y
Label		1	4	6	12	8

4.3 Strategic Study of the 1990 Conflict

4.3.1 Modeling and analysis

The DMs and options for the 1990 conflict are given in Table 4.12. Turkey has two options: escalate the dispute with Syria and/or decrease the flow of the Euphrates. Syria possesses the two options of stopping its support for the PKK or escalating the situation. Iraq controls the single option of escalating the situation against Turkey.

Table 4.12: DMs, options and description for the 1990 conflict

DM	Option	Choice	Description
Turkey (T)	Escalate	**Y**	This includes an attack on Syria, massing the troops on the shared border with Syria
		N	Do not escalate
	Euphrates Cutoff/ Reduction	**Y**	This includes stopping or reducing the flow of the Euphrates to Syria and further to Iraq
		N	Turkey will allow the river to flow
Syria (S)	Stop PKK Support	**Y**	This includes banning of the PKK in Syria and the extradition of PKK leader to Turkey
		N	Syria continues to support PKK rebels
	Escalate	**Y**	This includes attacks on Turkey and its development projects
		N	Not escalating the situation
Iraq (I)	Escalate	**Y**	Iraq will join Syria against Turkey
		N	Iraq will accept the situation and do nothing

The set of possible feasible states is given in Table 4.13. Notice that the number of mathematically possible states equals $2^5 = 32$ since there are 5 options each of which can be taken or not. However, Syria cannot both ban PKK and escalate at the same time (mutually exclusive options) and there is no point for Iraq to escalate if Turkey does not cut the water and Syria does not escalate. Removing the foregoing infeasible situations leads to a total of 20 feasible states or scenarios.

Table 4.13: DMs, options and states for the 1990 conflict

DM	**Option**																				
T	Escalate	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
	Cut Euphrates	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	Y	Y
S	Ban PKK	N	N	N	N	Y	Y	Y	Y	N	N	N	N	N	N	Y	Y	N	N	N	N
	Escalate	N	N	N	N	N	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y
I	Escalate	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Label		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**

This conflict is now analyzed using a regular analysis and an in-depth coalition analysis based on the procedure described by Kilgour et al. (2001) and Inohara and Hipel (2008b,a). Figure 4.4 illustrates the possible moves by Turkey. Figure 4.5 shows the Integrated Graph Model of the conflict and possible moves by each of Syria and Iraq unilaterally. Figure 4.6 displays the Coalition Graph Model of the conflict for both DMs, Syria and Iraq. Coalition improvements are denoted in this graph by a filled-in circle while coalition moves are denoted by a normal arrow. For example, from state 18 (top right corner) in Figure 4.6, there is a coalition move to states 2 and 10. However, the coalition move to state 10 is a coalition improvement by both Syria and Iraq.

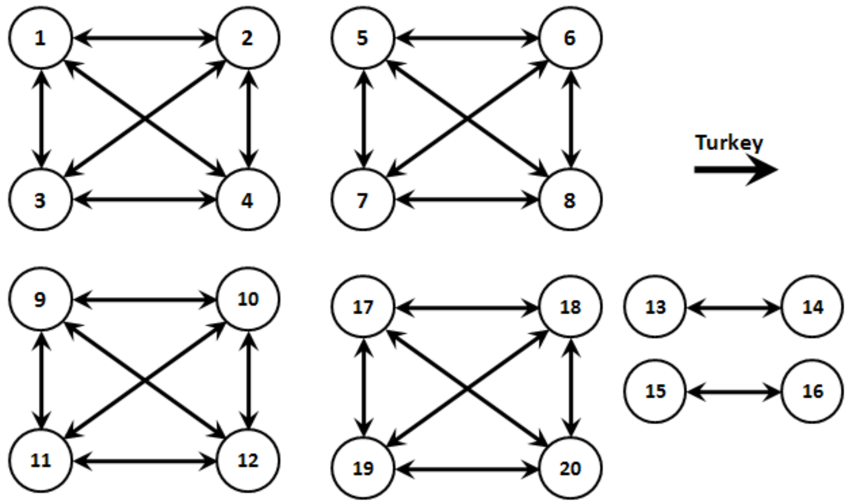


Figure 4.4: Graph Model of the 1990 conflict for movements by Turkey

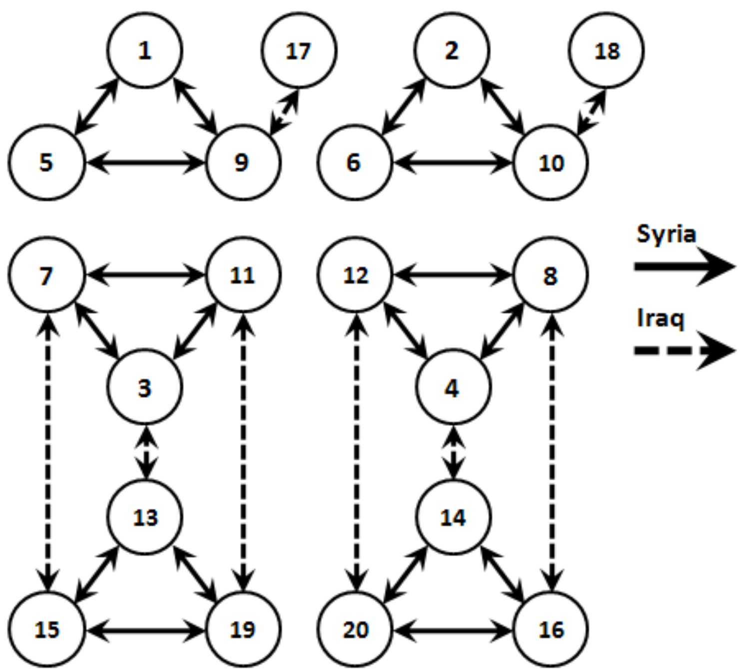


Figure 4.5: Integrated Graph Model of the 1990 conflict for both Syria and Iraq

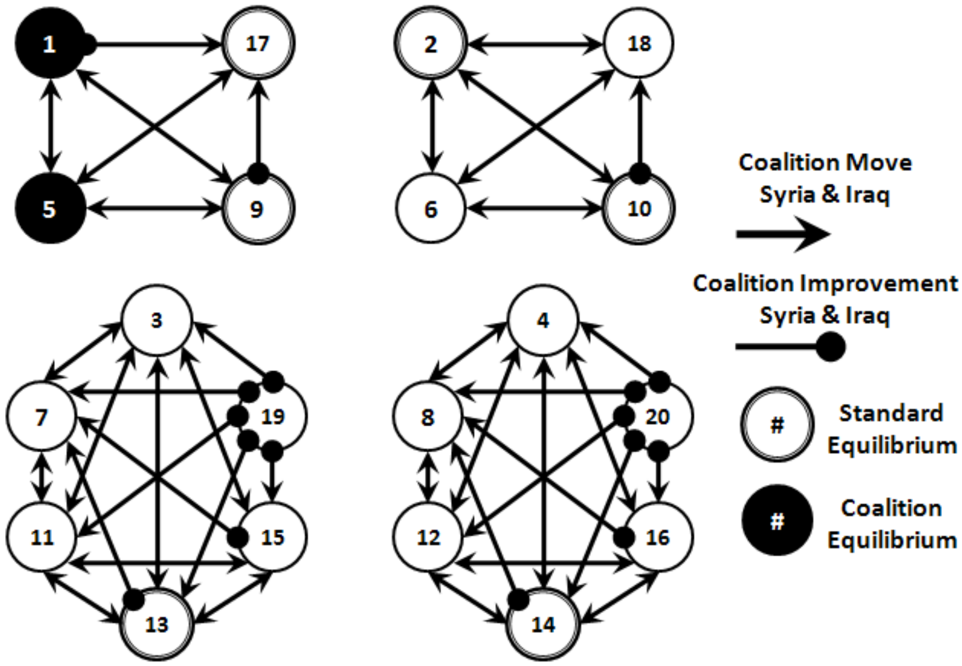


Figure 4.6: Coalition Graph Model of the 1990 conflict for a coalition of Syria and Iraq

Table 4.14 presents the preference prioritization information for each DM of the 1990 conflict without the participation of the third party from most to least important. Table 4.15 presents the ranking of states for all DMs in the conflict from most to least preferred. Equally preferred states are denoted by a bar above them. Table 4.16 displays the equilibria results for each of the states after inputting the foregoing information into GMCR II.

Table 4.14: Preference prioritization information for 1990 conflict

DM	P#	Preference Information (From most to least important)	Explanation
T	1	Syria stops its support for PKK, and reduce the flow of the Euphrates to continue its development projects	
	2	Release the flow of the Euphrates if and only if Syria stops its support for PKK	Turkey does not want to escalate the situation with Syria if the latter banned the PKK
	3	Stop the flow of the Euphrates and escalate the situation against Syria if the latter continues to support PKK and harbor its leader	Turkey's least preferred situation is to go to war. The even worse situation is if both Syria and Iraq escalate at the same time
S	1	Syria continues to support the PKK and Turkey allows the Euphrates to flow	
	2	Both Syria and Iraq escalate if Turkey stops the flow or attacks	
	3	Stop supporting PKK if and only if Turkey allows the Euphrates to flow and Iraq does not join in escalating	
I	1	Turkey allows the Euphrates to flow	
	2	Escalate if Turkey stops the flow	

Table 4.15: Preference vector for DMs in the 1990 conflict

DM	States																			
T	7	8	5	6	3	4	1	2	11	12	15	9	10	16	13	14	17	19	20	18
S	1	9	17	5	19	20	10	18	2	3	11	13	4	14	12	6	15	16	8	7
I	1	2	6	5	10	9	19	20	15	16	14	13	18	17	4	7	8	11	12	3
	Most Preferred																			*Least Preferred*

Table 4.16: Equilibria results for the 1990 conflict

Solution Concepts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
R (Nash)																				
GMR	✓	✓			✓				✓	✓			✓	✓			✓			
SMR	✓	✓			✓				✓	✓										
SEQ	✓				✓				✓				✓	✓			✓			

4.3.2 In-depth coalition analysis

In this subsection, a detailed coalition analysis is undertaken. The procedure for carrying out this analysis is adapted from Kilgour et al. (2001) and Inohara and Hipel (2008b,a). The main steps of the procedure are now outlined briefly, while the detailed procedure can be found in the referenced articles. The first step is to construct the reachable lists $R_H(s)$ of all possible coalitions. This is illustrated in Table 4.17. For simplicity and to save space, Turkey, Syria, and Iraq are abbreviated as T, S, and I, respectively. Similarly, the coalition between Turkey and Syria is abbreviated as TS, and so on. Next, one constructs the coalition improvement lists, denoted by $R_H^{(++)}(s)$, of possible coalitions. Table 4.18 provides the results of this step.

Table 4.17: Reachable lists $R_H(s)$ for the 1990 conflict

s/h	T	S	I	TS	TI	SI	TSI
1	{2,3,4}	{5,9}	∅	{2,3,4,5,6,7,8,9,10,11,12}	{2,3,4,13,14}	{5,9,17}	{2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20}
2	{1,3,4}	{6,10}	∅	{1,3,4,5,6,7,8,9,10,11,12}	{1,3,4,13,14}	{6,10,18}	{1,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20}
3	{1,2,4}	{7,11}	{13}	{1,2,4,5,6,7,8,9,10,11,12}	{1,2,4,13,14}	{7,11,13,15,19}	{1,2,3,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20}
4	{1,2,3}	{8,12}	{14}	{1,2,3,5,6,7,8,9,10,11,12}	{1,2,3,13,14}	{8,12,14,16,20}	{1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20}
5	{6,7,8}	{1,9}	∅	{1,2,3,4,6,7,8,9,10,11,12}	{6,7,8,15,16}	{1,9,17}	{1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20}
6	{5,7,8}	{2,10}	∅	{1,2,3,4,5,7,8,9,10,11,12}	{5,7,8,15,16}	{2,10,18}	{1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18,19,20}
7	{5,6,8}	{3,11}	{15}	{1,2,3,4,5,6,8,9,10,11,12}	{5,6,8,15,16}	{3,11,13,15,19}	{1,2,3,4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20}
8	{5,6,7}	{4,12}	{16}	{1,2,3,4,5,6,7,9,10,11,12}	{5,6,7,15,16}	{4,12,14,16,20}	{1,2,3,4,5,6,7,8,10,11,12,13,14,15,16,17,18,19,20}
9	{10,11,12}	{1,5}	{17}	{1,2,3,4,5,6,7,8,10,11,12}	{10,11,12,17,18,19,20}	{1,5,17}	{1,2,3,4,5,6,7,8,9,11,12,13,14,15,16,17,18,19,20}
10	{9,11,12}	{2,6}	{18}	{1,2,3,4,5,6,7,8,9,11,12}	{9,11,12,17,18,19,20}	{2,6,18}	{1,2,3,4,5,6,7,8,9,10,12,13,14,15,16,17,18,19,20}
11	{9,10,12}	{3,7}	{19}	{1,2,3,4,5,6,7,8,9,10,12}	{9,10,12,17,18,19,20}	{3,7,13,15,19}	{1,2,3,4,5,6,7,8,9,10,11,13,14,15,16,17,18,19,20}
12	{9,10,11}	{4,8}	{20}	{1,2,3,4,5,6,7,8,9,10,11}	{9,10,11,17,18,19,20}	{4,8,14,16,20}	{1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19,20}
13	{14}	{15,19}	{3}	{14,15,16,17,18,19,20}	{1,2,3,4,14}	{3,7,11,15,19}	{1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18,19,20}
14	{13}	{16,20}	{4}	{13,15,16,17,18,19,20}	{1,2,3,4,13}	{4,8,12,16,20}	{1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18,19,20}
15	{16}	{13,19}	{7}	{13,14,16,17,18,19,20}	{5,6,7,8,16}	{3,7,11,13,19}	{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19,20}
16	{15}	{14,20}	{8}	{13,14,15,17,18,19,20}	{5,6,7,8,15}	{4,8,12,14,20}	{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,18,19,20}
17	{18,19,20}	∅	{9}	{13,14,15,16,18,19,20}	{9,10,11,12,18,19,20}	{1,5,9}	{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,19,20}
18	{17,19,20}	∅	{10}	{13,14,15,16,17,19,20}	{9,10,11,12,17,19,20}	{2,6,10}	{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,19,20}
19	{17,18,20}	{13,15}	{11}	{13,14,15,16,17,18,20}	{9,10,11,12,17,18,20}	{3,7,11,13,15}	{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,20}
20	{17,18,19}	{14,16}	{12}	{13,14,15,16,17,18,19}	{9,10,11,12,17,18,19}	{4,8,12,14,16}	{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19}

Table 4.18: Coalition improvement lists $R_H^{(++)}(s)$ for the 1990 conflict

s/H	T	S	I	TS	TI	SI	TSI
1	{3,4}	Ø	Ø	Ø	Ø	Ø	Ø
2	{1,3,4}	{10}	Ø	{1,5}	Ø	Ø	Ø
3	Ø	Ø	{13}	{5}	Ø	{19}	{5}
4	{3}	Ø	{14}	{3,5}	Ø	{20}	{5}
5	{7,8}	{1,9}	Ø	Ø	Ø	Ø	Ø
6	{5,7,8}	{2,10}	Ø	{5}	Ø	Ø	Ø
7	Ø	{3,11}	{15}	Ø	Ø	{13,15,19}	Ø
8	{7}	{4,12}	{16}	Ø	Ø	{14,16,20}	Ø
9	{11,12}	{1}	Ø	{1}	Ø	Ø	Ø
10	{9,11,12}	Ø	Ø	{1,5,9}	Ø	Ø	Ø
11	Ø	{3}	{19}	{1,2,3,5}	Ø	{19}	{1,2,5}
12	11	Ø	{20}	{1,2,3,5}	Ø	{20}	{1,2,5}
13	Ø	{19}	Ø	Ø	{1,2}	{19}	{1,2,5,9,10}
14	{13}	{20}	Ø	Ø	{1,2}	{20}	{1,2,5,1,0}
15	Ø	{13,19}	Ø	Ø	{6}	{19}	{1,2,5,6}
16	{15}	{14,20}	Ø	{15}	{5,6}	{20}	{1,2,5,6,9,10}
17	Ø	Ø	{9}	Ø	{9,10}	{1,9}	{1,9}
18	{17,19,20}	Ø	{10}	{17,19,20}	{9,10,19 20}	{10}	{159,10,1920}
19	{17}	Ø	Ø	{17}	{9,10}	Ø	{1,5,9}
20	{17,19}	Ø	Ø	{17,19}	{9,10,19}	Ø	{15,919}

The third step is to construct the stability tableau. Table 4.19 illustrates the construction of the table. The fourth step is to calculate the stability of each state for each DM according to the solution concepts with respect to the various coalitions. Notice that improvements written alone without squiggly parentheses (i.e.{ }) indicate unilateral improvements by that DM. Improvements written to the left of squiggly parentheses mean that these improvements are carried out with the coalition given within the squiggly parentheses. For example, from state 9, Turkey has a unilateral improvement to states 11 and 12. Turkey also has a coalition improvement from state 9 to 1 if it formed a coalition with Syria in this case and so on.

Finally, to determine the coalition equilibrium according to a specific solution concept, the state under consideration should be stable for all of the DMs. In Table 4.19 the conflict is examined according to both CNash (i.e. Coalition Nash Stability) and CSEQ (i.e. Coalition Sequential Stability). The coalition stability is a generalization of the individual stability. Other solution concepts can be assessed as well. However, as this conflict is fairly large and contains 20 states, the analysis is limited to these two solution concepts.

Table 4.19: Stability analysis tableau for coalition sequential stability for the 1990 conflict

Overall Coalition Stability	x	x	E	x	x	x	E	x	x	x	x	x	x	x	x	x	x	x	x	x
DM Stability	r	s	s	s	u	u	s	u	u	u	u	u	u	u	u	u	u	u	u	u
Turkey	7	8	5	6	3	4	1	2	11	12	15	9	10	16	13	14	17	19	20	18
		7	7 8	5 7 8	5{TS}	3 3{TS} 5{TS}	3 4	1 3 4 1{TS} 5{TS}	1{TS} 2{TS} 3{TS} 5{TS} 1{TSI} 2{TSI} 5{TSI}	11 1{TS} 2{TS} 3{TS} 5{TS} 1{TSI} 2{TSI} 5{TSI}	6{TI} 1{TSI} 2{TSI} 5{TSI} 6{TSI}	11 12 1{TS}	9 11 12 1{TS} 5{TS} 9{TS}	15 15{TS} 1{TSI} 2{TSI} 5{TSI} 6{TSI} 9{TSI} 10{TSI}	1{TI} 2{TI} 1{TSI} 2{TSI} 5{TSI} 9{TSI} 10{TSI}	13 1{TI} 2{TI} 1{TSI} 2{TSI} 5{TSI} 10{TSI}	9{TI} 10{TI} 1{TSI} 9{TSI}	17 17{TS} 9{TI} 10{TI} 1{TSI} 9{TSI}	17 19 17{TS} 19{TS} 9{TI} 10{TI} 19{TI} 1{TSI} 5{TSI} 9{TSI} 19{TSI}	17 19 20 17{TS} 19{TS} 20{TS} 9{TI} 10{TI} 19{TI} 20{TI} 1{TSI} 5{TSI} 9{TSI} 10{TSI} 19{TSI} 20{TSI}
DM Stability	r	u	u	s	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u	u
Syria	1	9	17	5	19	20	10	18	2	3	11	13	4	14	12	6	15	16	8	7
		1 1{TS}	1{SI} 9{SI} 1{TSI} 9{TSI}	1 9	17{TS} 1{TSI} 5{TSI} 9{TSI}	17{TS} 19{TS} 1{TSI} 5{TSI} 9{TSI} 19{TSI}	1{TS} 5{TS} 9{TS}	17{TS} 19{TS} 20{TS} 10{SI} 1{TSI} 5{TSI} 9{TSI} 10{TSI} 19{TSI} 20{TSI}	10 1{TS} 5{TS}	5{TS} 19{SI} 5{TSI}	3 1{TS} 2{TS} 3{TS} 5{TS} 19{SI} 1{TSI} 2{TSI} 5{TSI}	19 19{SI} 1{TSI} 2{TSI} 5{TSI} 9{TSI} 10{TSI}	3{TS} 5{TS} 20{SI} 5{TSI}	20 20{SI} 1{TSI} 2{TSI} 5{TSI} 10{TSI}	1{TS} 2{TS} 3{TS} 5{TS} 20{SI} 1{TSI} 2{TSI} 5{TSI}	2 10 5{TS}	13 19 19{SI} 1{TSI} 2{TSI} 5{TSI} 6{TSI}	14 20 15{TS} 20{SI} 1{TSI} 2{TSI} 5{TSI} 6{TSI} 9{TSI} 10{TSI}	4 12 14{SI} 16{SI} 20{SI}	3 11 13{SI} 15{SI} 19{SI}
DM Stability	r	r	r	r	r	r	u	u	u	u	u	u	u	u	u	u	u	u	u	u
Iraq	1	2	6	5	10	9	19	20	15	16	14	13	18	17	4	7	8	11	12	3
							9{TI} 10{TI} 1{TSI} 5{TSI} 9{TSI}	9{TI} 10{TI} 19{TI} 1{TSI} 5{TSI} 9{TSI} 19{TSI}	6{TI} 19{SI} 1{TSI} 2{TSI} 5{TSI} 6{TSI}	5{TI} 6{TI} 20{SI} 1{TSI} 2{TSI} 5{TSI} 6{TSI} 9{TSI} 10{TSI}	1{TI} 2{TI} 20{SI} 1{TSI} 2{TSI} 5{TSI} 10{TSI}	1{TI} 2{TI} 19{SI} 1{TSI} 2{TSI} 5{TSI} 9{TSI} 10{TSI}	10 9{TI} 10{TI} 19{TI} 20{TI} 10{SI} 1{TSI} 5{TSI} 9{TSI} 10{TSI} 19{TSI} 20{TSI}	9 9{TI} 10{TI} 1{SI} 9{SI} 1{TSI} 9{TSI}	14 20{SI} 5{TSI}	15 13{SI} 15{SI} 19{SI}	16 14{SI} 16{SI} 20{SI}	19 19{SI} 1{TSI} 2{TSI} 5{TSI}	20 20{SI} 1{TSI} 2{TSI} 5{TSI}	13 19{SI} 5{TSI}

4.3.3 Insights on the 1990 conflict

Although no rational (Nash) coalition stability is present in this conflict, states 1 and 5 are sequentially stable by coalition sanctioning and, therefore, one can confidently state that the conflict will end up at one of these two states. Historically, the conflict concluded at state 1, as will be described in the evolution of the conflict.

The construction of the different types of Graph Models in Figures 4.4, 4.5, and 4.6 give a very clear understanding of the conflict and how it can evolve by unilateral moves by each DM as well as by a coalition. This forms a framework to communicate the conflict to stakeholders. Moreover, different moves and counter-moves can be easily assessed and compared especially in a complicated conflict like this one. From the analysis given in Table 4.16, one can see that there is no rational Nash stable state. However, three states have fairly strong equilibria by sequential sanctioning and symmetric metarationality: states 1, 5, and 9. These states represent the status quo, banning PKK, and escalating the situation unilaterally by Syria, respectively. An examination of these results eliminates the possibility of forming a coalition, which happened historically, and none of these equilibria includes escalation by Iraq.

After performing the in-depth coalition analysis, no new equilibrium jump is introduced but coalition moves can be spotted and taken into account. The lesson learned from this conflict is that one should account for coalition moves and improvements. The historical evolution of the conflict, illustrated in Table 4.20, shows how Turkey's action formed a coalition between the bitter enemies, Syria and Iraq, forcing Turkey to revert to the status quo equilibrium. Furthermore, in complicated conflicts like this one, one must be very careful to choose the right preference information as the conflict resolutions can be highly sensitive to preferences. This is especially true when many political factors are considered.

Table 4.20: Historical evolution of the 1990 conflict

DM	Option	Status Quo	← The conflict lasted only 3 weeks →			Final Equilibrium
T	Escalate	N	N	N	N	N
	Reduce Euphrates	N →	Y	Y →	N	N
S	Ban PKK	N	N	N	N	N
	Escalate	N	N →	Y	Y →	N
I	Escalate	N	N →	Y	Y →	N
Label		1	3	19	17	1

4.4 Strategic Investigation of the 1998 Controversy

The DMs and options for the 1998 conflict are given in Table 4.21. Turkey has two options: escalate the situation against Syria or carry out a full invasion. Syria has two options of stopping its support for the PKK or escalating the situation. The third party, Egypt, has a single option of acting or not.

Table 4.21: DMs, options and descriptions for the 1998 conflict

DM	Option	Choice	Description
Turkey	Escalate	Y	This includes threatening Syria, and massing the troops on the shared border with Syria
		N	Do not escalate
	Invade	Y	This includes an invasion of Syria and the declaration of war
		N	Do not attack
Syria	Stop PKK Support	Y	This includes banning of the PKK in Syria and the extradition of PKK leader to Turkey
		N	Syria continues to support PKK rebels
	Escalate	Y	This includes attacks on Turkey and its development projects
		N	Do not escalate
Third Party	Act	Y	This includes mediation and reconciliation between the two countries of Turkey and Syria.
		N	Do not intervene

The set of feasible states is provided in Table 4.22. Note that there is one infeasible situation in which Syria can both ban PKK and escalate at the same time (mutually exclusive options). Also notice that state 9 is an indistinguishable state if Turkey decides to invade Syria, since a full scale war will occur and the game will end. Because the third party played an Arbitrator role in this conflict, the situation in which it acts and Syria does not ban the PKK, is removed. The remaining possible states or scenarios are provided in Table 4.22. Figure 4.7 shows the Integrated Graph Model of the conflict.

Table 4.22: DMs, options and states for the 1998 conflict with the third party

DM	**Option**	**States**								
Turkey	Escalate	N	Y	N	Y	N	Y	N	Y	--
	Invasion	N	N	N	N	N	N	N	N	**Y**
Syria	Ban PKK	N	N	Y	Y	N	N	Y	Y	--
	Escalate	N	N	N	N	Y	Y	N	N	--
Third Party	Act	N	N	N	N	N	N	Y	Y	--
Label		1	2	3	4	5	6	7	8	9

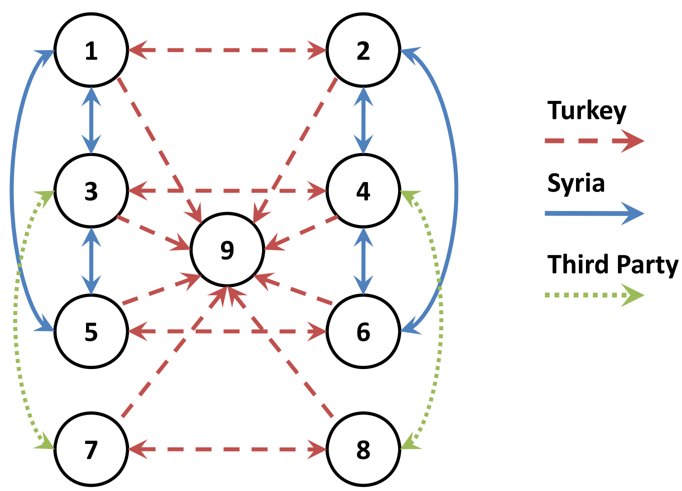


Figure 4.7: Integrated Graph Model of the 1998 conflict with the third party

In this situation, the third party acts as an Arbitrator, since the party has the power to exclude some states (Sakamoto et al., 2005). In this conflict, the third party, Egypt, restricted Syria's move of not banning the PKK if it intervened. Egypt brings to the table legitimacy and extensive experience gained through experience with the conflicts along the Nile basin (Akanda et al., 2007). Syria was united with Egypt under the United Arab Republic (UAR) before Syria declared independence from the UAR in the 1970s. UAR was mostly led by the Egyptian President, Gamal Abdel Nasser. These factors combined allow Egypt to have a say in Syria's politics. Table 4.23 presents the preference prioritization information for each DM in the 1998 conflict from most to least preferred. Table 4.24 indicated the ranking of states for Turkey, Syria, and the third party from most to least preferred. Table 4.25 outlines the analysis results after inputting the foregoing information into GMCR II.

Table 4.23: Preference prioritization information for the 1998 conflict with the third party

DM	P#	Preference Information (From most to least preferred)	Further Explanation or Comments
Turkey	**1**	Syria stops its support for PKK	
	2	Escalate the situation if Syria does not ban PKK	
	3	Invade Syria if and only if Syria does not ban PKK	Turkey's least preferred situation is remaining at the status quo
Syria	**1**	Remain at the status quo	Syria continues to support the PKK and Turkey does not escalate (However, this move is restricted by the Third Party's intervention)
	2	Turkey does not invade	Syria's least preferred situation is an invasion by Turkey
	3	Escalate if Turkey escalates	
Third Party	**1**	Syria stops its support of PKK and Turkey does not invade Syria	Third Party is against the support of the rebellious PKK and wants to bring peace to the area

Table 4.24: Ranking of states for DMs in the 1998 conflict with the third party

DM	**States**								
Turkey	3	7	8	4	6	9	2	1	5
Syria	1	5	7	6	2	3	8	4	9
Third Party	7	3	8	4	1	2	5	6	9
	Most Preferred							*Least Preferred*	

Table 4.25: Equilibrium results for the 1998 conflict with the third party

Solution Concepts	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
R (Nash)						✓	✓		✓
GMR			✓	✓		✓	✓	✓	✓
SMR			✓	✓		✓	✓	✓	✓
SEQ						✓	✓		✓

This conflict study shows that Turkey played a more important role than Syria and did not have to use water as a weapon. Moreover, Turkey's superior military power puts it at an advantage, which allowed it to threaten Syria with an invasion, thereby bringing the game to an end. The strongest equilibrium states are 6 and 9 (Table 4.25) in which both Syria and Turkey escalate the situation and Turkey invades eventually if the third party does not act. However, with the mediation of the third party, a new equilibrium came about: state 7 in which the third party acts and Syria bans the PKK. As will be explained in Section 4.5, Syria has been put in a Pareto-inferior situation as it had to give up other things in addition to banning the PKK. The notion of classifying the role of the third party into Arbitrator, Coordinator, and Donor can determine, in advance, how a third party can influence and bring about a potential resolution to the conflict. Table 4.26 shows the actual historical evolution of the 1998 conflict.

Table 4.26: Historical evolution of the 1998 conflict

DM	Option	Status Quo						Final Equilibrium
Turkey	Escalate	N	→	Y		Y	→	N
	Invasion	N		N		N		N
Syria	Ban PKK	N		N		N	→	Y
	Escalate	N		N	→	Y	→	N
Third Party	Act	N		N		N	→	Y
Label		1		2		6		7

4.5 Fundamental Insights of Conflicts along the Euphrates

The analyses provided in this chapter confirm similar conclusions drawn by Priscoli and Wolf (2009) in their studies of Middle East water conflicts. Firstly, unilateral development of water resources without the coordination and cooperation of other countries sharing the same water recourse may create conflict. Secondly, if one riparian country holds the geographical and military power, unbiased agreements are difficult to achieve. For example, Turkey is upstream and most of the water originates in its territory. Moreover, it has the most advanced military power (Priscoli and Wolf, 2009), giving it the upper hand in negotiations. As a consequence, Syria ended up in a Pareto-inferior situation because it did not ban the PKK earlier in the conflict which led to the signing of the Adana Agreement. The terms of the agreement include more things Syria has to give up in addition to banning PKK. For instance, Syria accepted Turkish rule over Hatay province, a long disputed land between the two countries. Syria publicly recognized Hatay as a Turkish territory after the Adana agreement, thereby losing two of its playing cards. The third lesson that can be garnered from the case in this chapter is the vital role of third party intervention in resolving conflicts.

For the analysis part, the presented conflicts, especially the conflicts in both 1990 and 1998, can be seen as a single evolving conflict. This can serve as a base for methodology development. In addition, a more in-depth analysis could be carried out by mixing various approaches to conflict analysis. For instance, one can carry out hypergame analysis and coalition analysis at the same time for the 1990 conflict.

It is clear that the conflict along the Euphrates River is indeed a complex one. Bipartite and tripartite negotiations continue with mixed success. However, no solid agreement to date has been reached. This chapter forms a strong motivation to develop a negotiation methodology to carry out an in-depth analysis of third party intervention in complex conflicts.

Chapter 5

Modeling Negotiations in Conflict Resolution Using Inverse GMCR

Although having a tool such as GMCR to predict and assess equilibria is important, real life conflicts require more than that. Studies show that 70 percent of all international conflicts since 1945 have involved third party intervention (Bercovitch and Gartner, 2006). These interventions strive to change the course of the conflict and ultimately reach a more desired resolution. The available models, including the standard GMCR, only predict the likely outcomes of the conflict. The many extensions of GMCR developed over the years aim to improve how GMCR predicts these outcomes. Another downside of the standard GMCR is the difficulty and subjectivity of obtaining preference rankings for DMs in the conflict. Hipel (2011) states that "the most difficult hurdle to overcome in calibrating a decision model is to obtain accurate preference information". Many GMCR extensions to enrich the preference ranking procedure have been developed, such as strength of preference (Hamouda et al., 2004, 2006), preference uncertainty (Li et al., 2004a), and fuzzy preferences (Bashar et al., 2012; Hipel et al., 2011).

In order to address the aforementioned shortcomings, an Inverse GMCR is developed here. A main feature of this methodology is that it does not require preference information to model the conflict. This methodology can be utilized in many different ways. For instance, an intervener can use it to understand how to influence one or more of the disputants in a conflict. On the other hand, one of the disputants can utilize it to his or her advantage by understanding how competing parties could behave in order to achieve a desired resolution.

In addition to its use as a negotiation tool, Inverse GMCR also can determine a more reliable prediction based on minimal preference ranking information. In standard GMCR modeling, an analyst is usually confident about the most and least preferred states. The dilemma usually arises with preference rankings between these two ends. Having a methodology such as Inverse GMCR allows for exploration of all possible scenarios for unknown preference ranking ranges. The contents of this chapter are based on a journal paper written by Kinsara et al. (2014c).

5.1 Overview and Objective of Inverse GMCR

GMCR forms an ideal framework to model and analyze conflicts; however, there are challenges to its applicability, especially in estimating the relative preferences of DMs involved in the conflict as mentioned earlier. In order to address this problem, Inverse GMCR allows the analyst to determine how a desired resolution to the conflict can arise by generating all possible relative preferences that achieve it.

The premise of Inverse GMCR is that the mediator needs a negotiation tool to influence the DMs. To be valuable, this tool should contain information about what motivates each party to undertake the selection of options leading to the resolution desired by the mediator. Therefore, mediators can focus their resources and strategies to guide the parties toward preferences that lead to this resolution. This tool is not just useful to third parties; DMs may be able to take advantage of it to influence their opponent(s).

In contrast, the current GMCR methodology informs the user only about the possible resolution of a conflict based on the input preferences. Inverse GMCR explains how this resolution can be reached. The main objectives of Inverse GMCR are the following:

- Allow a third party to determine a desired resolution and understand how to achieve it.
- Produce strategic information that will help mediators to influence the DMs involved in the conflict.
- Give a range of preference rankings that measures the robustness of the conflict resolution.

Table 5.1: Comparison between standard GMCR and Inverse GMCR

	Standard GMCR (Prediction Tool)	Inverse GMCR (Negotiation Tool)
Purpose	Predict possible resolution through determining equilibria	Understand how a specific resolution can be achieved by generating scenarios
Preference Requirements	Full information is required	Minimal information or No information at all
Analysis type	Static stability analysis	Dynamic analysis
Output	Equilibrium results	Scenarios and set of possible preference patterns
Sensitivity Analysis	Must be performed independently	Is inherent

5.1.1 Comparison between Standard and Inverse GMCR

The standard GMCR framework forms the foundation for Inverse GMCR. However, the two methodologies differ in their requirements and outputs. Standard GMCR requires complete preference ranking information, that is usually not easy to obtain. Moreover, standard GMCR produces only equilibrium results based on static stability analysis as mentioned earlier. On the other hand, Inverse GMCR introduces a modeling approach that does not require any preference information but can make use of any available preference information to speed and refine the results. Also, Inverse GMCR analysis is dynamic, as it produces possible scenarios for a desired resolution to be achieved. To summarize, Inverse GMCR utilizes the standard GMCR procedure to form a negotiation tool instead of a prediction tool. Table 5.1 illustrates the main differences between standard GMCR and Inverse GMCR.

5.2 Procedure and Implementation

The main difference between Inverse GMCR and the standard GMCR procedure is in the order of steps. Figure 3.1 illustrates the current procedure for applying GMCR in the real world. A modified version, shown in Figure 5.1, illustrates how to apply Inverse GMCR. The original procedure requires the following inputs for the conflict to be analyzed (Fang et al., 1989, 1993):

- Decision makers (DMs).
- Options for each DM.
- Infeasible states (such as mutually exclusive situations).
- Allowable transitions.
- Relative preferences.

On the other hand, Inverse GMCR does not require the ranking of states for all DMs. Its requirements are:

- Decision makers (DMs).
- Options for each DM.
- Infeasible states (such as mutually exclusive situations).
- Allowable transitions.

- *Desired resolution.*

The result will be a list of possible state rankings that will make the desired resolution stable under the selected stability definition.

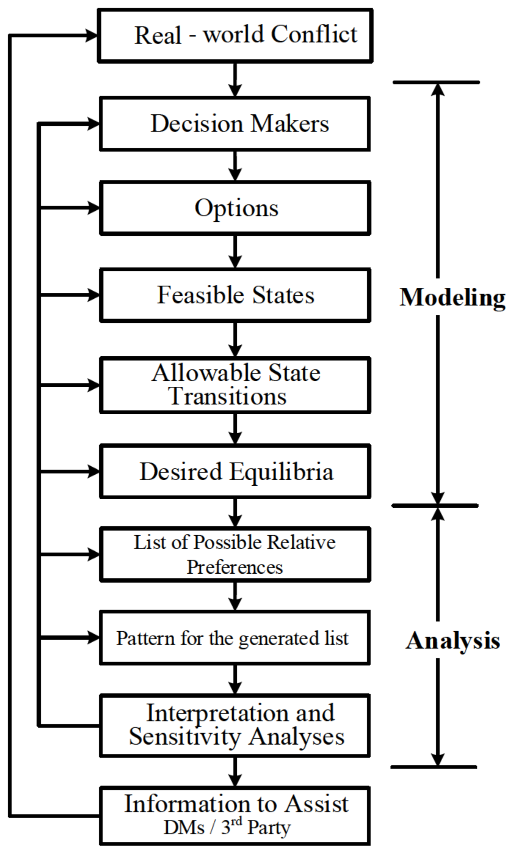


Figure 5.1: Inverse GMCR procedure in a real world conflict (modified from (Fang et al., 1993))

In order to formally define *Inverse GMCR*, one needs to furnish some definitions and notation. First, we show how a DM's preferences can be represented using an ordinal payoff vector.

Definition 5.2.1. The ordinal payoff vector of DM i, denoted by P_i, is

$$p^i = P_i = (p_1^i, p_2^i, \ldots, p_m^i), \quad P_i \in \mathbb{R}^m$$

If $s_a, s_b \in S$, then DM i prefers s_a to s_b or is indifferent ($s_a \succsim_i s_b$) *iff* $p_a^i \geq p_b^i$. An equivalent notation is $P_i(s_j) = p_j^i$ so that $s_a \succsim_i s_b$ *iff* $P_i(s_a) \geq P_i(s_b)$.

For example, if $P_i = (5, 0, 6, 2, 6)$ then the ordinal payoff value for DM i for state 1 is equal to 5. Thus, $P_i(s_1) = 5, P_i(s_2) = 0, P_i(s_3) = 6, P_i(s_4) = 2$, and $P_i(s_5) = 6$. Because preferences are assumed to be transitive, the payoff vector can be translated into a preference profile. A preference ranking for DM i is a list of feasible states ordered from most to least preferred for DM i, where ties are allowed. In the previous example, the preference ranking for DM i would be $PR_i = s_3 \sim s_5 \succ s_1 \succ s_4 \succ s_2$.

Note that the same preference ranking can be represented by many different ordinal payoff vectors. Two such ordinal payoff vectors are called *equivalent*.

Definition 5.2.2. If $p^i \in \mathbb{R}^m$ is an ordinal payoff vector for DM $i \in N$, then $(p^1, p^2, \ldots, p^n) \in \mathbb{R}^{mn}$ is a preference profile.

In the graph model, analysis means finding all equilibria given a preference profile. In Inverse GMCR, the problem is to find all preference profiles under which a given state is an equilibrium with respect to a selected stability definition. After the introduction of preference profiles, a graph model can be denoted $G = \langle N, S, P \rangle$ where N is the list of DMs $N = \{1, \ldots, n\}$, S is the set of feasible states $S = \{s_1, s_2, ..., s_m\}$, and P is the preference profile $P \in \mathbb{R}^{mn}$.

The *inverse problem* for a desired equilibrium state $s_E \in S$ is to find all $p \in \mathbb{R}^{mn}$ such that state s_E is stable for all DMs if the preference profile is p. The list of preference profiles is organized into an *Inverse Preference Structure (IPS).*

Inverse Nash problem for s_E: Find all $p \in \mathbb{R}^{mn}$ such that $s_E \in Nash(G)$ where $G = \langle N, S, P \rangle$.

Inverse SEQ problem for s_E: Find $p \in \mathbb{R}^{mn}$ such that $s_E \in SEQ(G)$ where $G = \langle N, S, P \rangle$.

Inverse GMR problem for s_E: Find $p \in \mathbb{R}^{mn}$ such that $s_E \in GMR(G)$ where $G = \langle N, S, P \rangle$.

Inverse SMR problem for s_E: Find $p \in \mathbb{R}^{mn}$ such that $s_E \in SMR(G)$ where $G = \langle N, S, P \rangle$.

A more formal definition according to each solution concept will follow.

5.2.1 Inverse Nash Equilibrium

Definition 5.2.3. State s_E is a Nash equilibrium *iff* $P_i(s) \leq P_i(s_E)$ for all $i \in N$ and all $s \in R_i(s_E)$.

Thus, Inverse GMCR should produce all preference profiles that make the desired state s_E a Nash equilibrium. For illustration, Inverse GMCR list according to preference profiles (or payoff vectors), denoted by $IPS(s_E)$, is shown in Fig 5.2. Note that each of the T rows is a preference profile, a combination of ordinal payoff vectors, that will make state s_E stable for all DMs. The possible number of profiles is denoted by T.

$$IPS(s_E) = \left\{ \begin{array}{cccc} [{}^1p_1^1, {}^1p_2^1, \ldots, {}^1p_m^1] & [{}^1p_1^2, {}^1p_2^2, \ldots, {}^1p_m^2] & \ldots & [{}^1p_1^n, {}^1p_2^n, \ldots, {}^1p_m^n] \\ [{}^2p_1^1, {}^2p_2^1, \ldots, {}^2p_m^1] & [{}^2p_1^2, {}^2p_2^2, \ldots, {}^2p_m^2] & \ldots & [{}^2p_1^n, {}^2p_2^n, \ldots, {}^2p_m^n] \\ \vdots & \vdots & \ddots & \vdots \\ [{}^Tp_1^1, {}^Tp_2^1, \ldots, {}^Tp_m^1] & [{}^Tp_1^2, {}^Tp_2^2, \ldots, {}^Tp_m^2] & \ldots & [{}^Tp_1^n, {}^Tp_2^n, \ldots, {}^Tp_m^n] \end{array} \right\}$$

Figure 5.2: Representation of the inverse preference structure list for state s_E

Note that ${}^hp_j^i$ is player i's ordinal payoff for state j in profile h.

Definition 5.2.4. A *Nash* $IPS(s_E)$ is a list of preference profiles, $p \in \mathbb{R}^{mn}$, where in each profile, for all $i \in N$, all $q \in R_i^+(s_E)$ satisfies $P_i(q) \leq P_i(s_E)$.

5.2.2 Inverse SEQ Equilibrium

Definition 5.2.5. An *SEQ* $IPS(s_E)$ is a list of preference profiles, $p \in \mathbb{R}^{mn}$, such that for each state $q \in R_i^+(s_E)$ in the preference profile, there exists at least one state $k \in R_{N-i}^+(q)$ satisfying $P_i(k) \leq P_i(s_E)$ for all $i \in N$.

In other words, the combination of payoff vectors must ensure that for each UI a DM can take, there exists at least one sanction that will put the original player in a less preferred state. Please note that the notation $N - i$ means all DMs other than i.

5.2.3 Inverse GMR Equilibrium

Definition 5.2.6. A *GMR* $IPS(s_E)$ is a list of preference profiles, $p \in \mathbb{R}^{mn}$, such that for each state $q \in R_i^+(s_E)$ in the preference profile, there exists at least one state $k \in R_{N-i}(q)$ satisfying $P_i(k) \leq P_i(s_E)$ for all $i \in N$.

5.2.4 Inverse SMR Equilibrium

Definition 5.2.7. An *SMR* $IPS(s_E)$ is a list of preference profiles, $p \in \mathbb{R}^{mn}$, such that for each state $q \in R_i^+(s_E)$ in the preference profile, there exists at least one state $k \in R_{N-i}(q)$ satisfying $P_i(k) \leq P_i(s_E)$ and all $h \in R_i(k)$ satisfy $P_i(h) \leq P_i(s_E)$ for all $i \in N$.

5.2.5 Approaches to Implementation

In order to implement Inverse GMCR, two approaches were investigated. The first was the brute-force method. As the name suggests, this technique exhaustively tests each possible preference profile for each DM against the desired equilibrium. Since the number of possible preference rankings is fairly large, a decision support system was designed to implement this concept. The number of iterations required for a model, assuming strict ordinal preferences, is given by $(m!)^n$ where m is the number of feasible states and n is the number of DMs. Any combination of preference rankings for all DMs (i.e. preference profile) that achieves the desired equilibrium will be saved in a list. The list can be used to derive tactics to influence the course of the conflict. Although generating an extensive list and deriving insights were possible for small models, a more efficient and comprehensive approach is obviously desirable. Therefore, a second approach was designed after observing the patterns produced by the brute-force method. It was clear that results followed certain rules which can be defined more formally, as outlined in the aforementioned sections. Pseudo-codes for both algorithms are provided in the next section.

5.2.6 Algorithms

Brute-Force Method

In order carry out the brute-force calculations, two algorithms were used. Algorithm 5.1 is utilized to generate all possible preference profiles for the conflict model and then filter the profiles that make a desired state a Nash equilibrium. As mentioned in Section 5.2.5, there will be $(m!)^n$ preference profiles where m is the number of feasible states and n is the number of DMs. In order to test each profile for Nash equilibrium, the *MBL-N* function, illustrated in Algorithm 5.2, is called. It generates a list of states that must be less preferred than the desired equilibrium state, S_E, for each DM. Then, if any state in the *MBL-N* list has a higher ordinal payoff than S_E in a given preference profile, the program will reject that preference profile. All other profiles satisfy the Nash criteria, and are stored in the IPS matrix. The steps involved in generating the IPS matrix are outlined as follows:

Step 1: Obtain DMs (N), feasible states (F), and desired equilibrium (S_E).

Step 2: Generate all possible combinations of preference profiles ($PList$).

Step 3: Create an empty matrix (IPS).

Step 4: Call the function (*MBL-N(S_E)*) to generate the list of states that must be less preferred than S_E.

Step 5: Check each preference profile h in $PList$. If the end of the list is reached, stop and go to Step 8.

Step 6: Check each state j in (*MBL-N(S_E)*) whether it is more preferred for any DM i in N. If yes, then disregard the current preference profile and check next profile. Otherwise go to Step 7.

Step 7: Add the current preference profile to the IPS matrix.

Step 8: Return the IPS matrix.

The steps involved in generating the MBL-N list are outlined as follows:

Step 1: Obtain the reachability matrix for each DM *dm.R*.

Step 2: Create an empty matrix (*MBL-N*).

Step 3: For each DM add the list of reachable states from S_E for that DM to $MBL-N$.

Step 4: Return the (*MBL-N*) list.

Algorithm 5.1 Generate a Nash IPS for State S_E

```
F ← Feasible States
N ← DMs
S_E ← Desired Equilibrium
PList ← All possible combinations of preference profiles
IPS ← [ ]
Call MBL-N(S_E)
for each prefrence profile h in PList do
    isEquilibrium ← True
    for each DM i in N do
        for each state j in MBL-N(S_E) do
            if ^h p^i_j > ^h p^i_E then
                isEquilibrium ← False
            end if
        end for
    end for
    if isEquilibrium=True then
        IPS ← IPS + h
    end if
end for
return IPS
```

Algorithm 5.2 Generate MBL-N(S_E)

Require: dm.R ← Reachability Matrix $F \times F$ for each DM
  function MBL-N(S_E)
    MBL-N ← [ ]
    for each DM i in N **do**
      MBL-N ← MBL-N + i.R(S_E)
    end for
  return MBL-N
  end function

Improved Method

It was clear that generating all possible preference profiles and testing them one-by-one are both time and memory intensive, and not feasible for larger models. A conflict model with only five states and two DMs will have $(5!)^2 = 14,400$ permutations. Adding one more state produces $(6!)^2 = 518,400$ permutations, making computational complexity undesirably high, as explained later in Section 6.9.2. However, after observing the patterns of multiple examples using the brute-force method, an improved method involving the specification of rules making a desired state an equilibrium was developed. Algorithm 5.3 illustrates the process of generating rules that make a desired state, S_E, a Nash equilibrium.

Algorithm 5.3 Generate Nash Inverse Rules for State S_E

  F ← Feasible States
  N ← DMs
  S_E ← Desired Equilibrium
  Call MBL-N(S_E)
  for each DM i in N **do**
    PRINT State S_E must be more preferred than all $S_j \in i$.R(S_E)
  end for

Suppose in a graph model with 2 DMs and 6 states, the brute-force method (worst case) involves $(6!)^2 = 518,400$ comparisons and may produce a list of up to 86,400 to make a desired state a Nash equilibrium. However, the improved method involves only four steps and produces only two statements explaining the same results. Refer to Section 5.3 for the Syria-Iraq conflict as an example.

Similar algorithms have been developed for other solution concepts and produce similar gains in computational time and memory requirements. The improved algorithms were all implemented in GMCR+ as will be explained in Chapter 6.

5.3 Application

The water conflict between Syria and Iraq in 1975 is explained in Section 4.1.1. In order to illustrate the Inverse GMCR, this conflict will be re-investigated.

5.3.1 Standard GMCR Results

The standard GMCR analysis for this conflict is provided in detail in Section 4.2. As mentioned earlier in this research, standard GMCR requires preference information (or ranking of states). Since this model is fairly small, it is not difficult to derive the preference information from the conflict background, although it remains subjective. The ranking of states for this conflict is shown in Table 4.6. Running the standard GMCR analysis predicts the most likely outcome in terms of equilibria based on the input preferences. Table 4.9 shows the equilibrium results according to different behavior patterns. Nash and Sequential Stability (SEQ) are the strongest stability definitions, meaning that DMs are not motivated to deviate from a particular state if the conflict reaches it. General Metarationality (GMR) and Symmetric Metarationality (SMR) are not as strong. More formal definitions and the relationships among the different stability definitions are mentioned earlier and can be found in Fang et al. (1989).

The objective of the standard GMCR analysis is to determine the equilibrium states, the states from which no DM is motivated to move. Therefore, once an equilibrium is attained, the conflict will probably end there. As mentioned in the historical background, the conflict reached state 6 in which both Syria and Iraq go to war, a strong equilibrium as shown in Table 4.9.

The standard GMCR methodology lacks the ability to determine a more desired resolution and explain how it can be achieved. This example also illustrates the subjectivity in determining the ranking of states.

5.3.2 Inverse GMCR Results

The goal of any intervention is to bring about a better resolution for all parties to the conflict. Inverse GMCR acts as a negotiation tool allowing the analyst to determine a more desirable resolution. In this particular case, a more desired resolution would be state 2 in which both Syria and Iraq stop escalating and water is released to Iraq. The objective of Inverse GMCR is to provide mediators with strategic information in order to help them focus their efforts effectively and efficiently. Here, the mediation aims to influence Syria to release water and stop escalating. Using Inverse GMCR, state 2 is chosen as a desired equilibrium and the decision support system was used to run the analysis. The findings indicate that 420 possible preference profiles can achieve the desired resolution. After analyzing these results, two meaningful patterns were identified that lead the conflict to the desired equilibrium:

1. **Nash Stability:** if and only if Syria prefers state 2 to states 1 and 3 *(240 profiles)*.
2. **Sequential Stability:** *(180 profiles)*.
   (a) if Iraq prefers state 4 to state 1, then Syria must have state 4 less preferred than 2.
   (b) or if Iraq prefers state 6 to state 3, then Syria must have state 6 less preferred than 2.

In other words, state 2 will be the resolution to the conflict if and only if (1) Syria prefers not to escalate or (2) being attacked by Iraq is less preferred for Syria. Having this strategic information could be vital to the mediators as they focus their efforts at influencing Syria to change its preference ranking. Consequently, the final outcome of the conflict would change.

The diagram in Figure 5.3 illustrates the inverse status quo tree in which state 2 is clearly reachable from state 6. Usually, when all moves in a conflict are reversible, states can be reachable using all DMs level. However, this tool becomes very valuable when irreversible moves are introduced to a conflict.

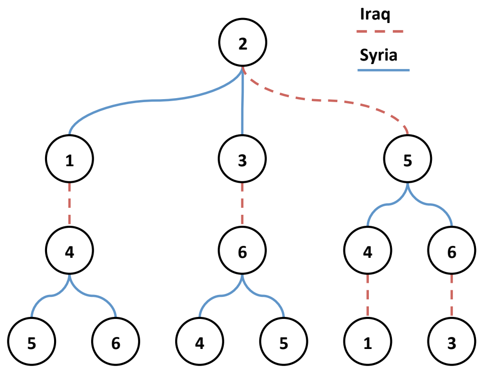


Figure 5.3: Inverse Status Quo Diagram for the Syria-Iraq conflict

5.3.3 Insights for the Syria-Iraq Conflict

The historical evolution of the conflict is illustrated in Table 5.2. Note that state numbers with an asterisk (*) indicate mediation. In Inverse GMCR context, Iraq as a DM or a third party mediator can influence Syria in two ways:

- Making the escalation option for Syria less preferred.
- Making the attack option by Iraq disastrous for Syria.

In this conflict, Saudi Arabia mediated the conflict by contributing to a basin fund that would finance irrigation reform (Akanda et al., 2007). Therefore, escalation by Syria became less preferred as it risked losing this fund, in addition to other factors related to international pressure and war costs.

Table 5.2: Historical evolution of the Syria-Iraq conflict

DM	Option	Status Quo	Intermediary States				Equilibrium
Syria	Release Water	N	N	N	N	→	Y
	Escalate	N	N →	Y	Y	→	N
Iraq	Attack	N →	Y	Y	Y	→	N
Third Party	Act	N	N	N →	Y		Y
Label		1	4	6	6*		2*

This conflict emphasizes how third party intervention can change the course of the conflict and bring about a better resolution. The strategy of intervention is as important as the intervention itself if not more. Therefore, a tool to provide insights on how to achieve a desired resolution is valuable. Inverse GMCR is a strategic tool that utilizes GMCR as a negotiation tool rather than as a prediction tool. Moreover, its information requirements are minimal.

5.4 Chapter Summary

This chapter contains the main contribution of this research. The standard GMCR and other conflict models can be used only to predict the likely outcome of a conflict. Inverse GMCR, on the other hand, utilizes GMCR as a negotiation tool rather than a prediction tool. The framework, algorithms, and formal definitions of Inverse GMCR are outlined and applied to the conflict discussed in Chapter 4. The main highlights of this chapter are summarized below:

1. Unlike standard GMCR, Inverse GMCR does not require DMs' preference information, thus allowing it to help analysts in modeling conflicts with minimal information. Table 5.1 compares standard and Inverse GMCR.

2. The standard GMCR methodology informs the user only about the possible resolutions of a conflict based on the input preferences. In contrast, Inverse GMCR explains how a desired resolution can be reached.

3. In order to simplify the definitions for Inverse GMCR, DMs' ordinal payoff vectors are organized into a new notation called the *preference profile*. The product of Inverse GMCR is referred to as the *Inverse Preference Structure (IPS)*. Mathematical representations and formal definitions for both preference profiles and the IPS are formulated.

4. The four basic graph model stability definitions, *Nash*, *GMR*, *SMR*, and *SEQ* are redefined for Inverse GMCR as *Nash IPS*, *GMR IPS*, *SMR IPS*, and *SEQ IPS*, respectively.

Chapter 6

Comprehensive Decision Support System

The introduction of the inverse approach makes the need for a DSS obvious. Solving problems by hand is possible but tiresome, time consuming, and error-prone. First, a code to test each preference profile was developed. This is called the brute-force method and the matrix approach to GMCR allows for faster processing (Xu et al., 2007; Xu, 2009). The last DSS, GMCR II, was developed by Peng back in 1999 (Peng, 1999). Until recently, no significant update was made to GMCR II, even though the program had issues that sometimes caused it to crash or display error messages. A project to combine both the logical and matrix approaches into a more robust and flexible decision support system was initiated by Oskar Petersons and Rami Kinsara under the supervision of Prof. Keith Hipel and Prof. D. Marc Kilgour. The objective of this system is to overcome the limitations in the previous version and also add new extensions and capabilities that it did not support. A main objective of the new system is to include the Inverse GMCR methodology. Two important features of the software are the ability to narrate output results and draw graph models.

6.1 Framework of the Decision Support System GMCR+

DSSs are meant to facilitate the application of theoretical methodologies and definitions, especially for non-specialized practitioners and researchers. A modern DSS is defined as "an interactive, flexible, and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making. It utilizes data, provides an easy-to-use interface, and allows for the DM's own insights" (Turban, 1995). Therefore, GMCR+ is built with a human-centric framework to allow intuitive manipulation and interaction of conflict models.

The overall structure of GMCR+ is illustrated in Figure 6.1. The main visible component is the friendly GUI where all interactions between the user and the system take place. This structure ensures robustness of the back end and makes it easy to track any errors as each module is completely independent of other modules. Also, this structure allows the system to be universal and workable on any platform (Mac, Windows, or Linux). Finally, the modular design of the GMCR+ system provides the flexibility of adding new advancements in the form of modules to the DSS.

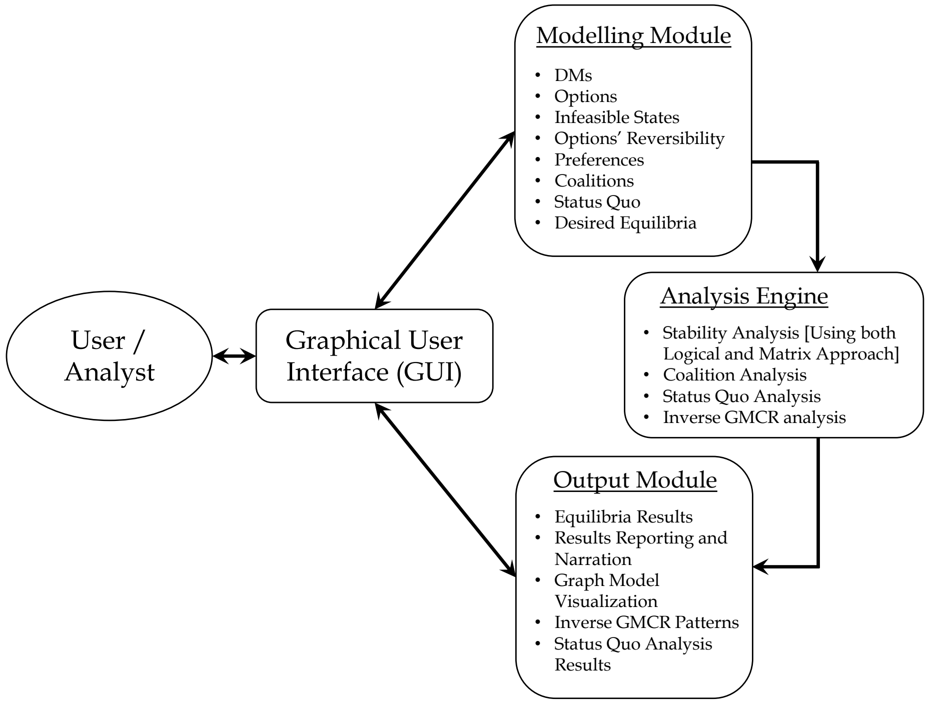


Figure 6.1: GMCR+ Structure

The following list describes three main situations where the methodology depicted in Figure 6.1 can be used:

- A tool for analysis and simulation for a DM or a DM's agent in a conflict: As a decision aid, GMCR+ can be used to evaluate outcomes of a conflict as various strategic initiatives are implemented.

- A tool for communication and analysis in mediation: To attain a win-win resolution, a mediator can use GMCR+ to analyze possible consequences of small changes in positions made by DMs in addition to utilizing the novel Inverse GMCR.

- A tool for analysis for a third-party analyst: For example, a government may wish to determine the strategic effectiveness of another government's policy, although it is not itself directly involved.

The GMCR is a distinctive systems engineering process for systematically studying a diverse range of disputes. Published literature documents case studies of applying GMCR to real-world conflicts in a variety of different fields, including brownfields (polluted industrial or military land) (Hipel et al., 2010; Yousefi et al., 2010b), construction management (Kassab et al., 2010; Yousefi et al., 2010a), aquaculture (Noakes et al., 2003, 2005), bulk water exports (Obeidi et al., 2002; Hipel et al., 2008), First Nations (Obeidi et al., 2006), international trade (Hipel and Walker, 2011), military and peace support (Kilgour et al., 1998), sustainable development (Ghanbarpour and Hipel, 2009; Hipel and Walker, 2011), and water resources management (Hipel, 1992; Hipel and McLeod, 1994; Gopalakrishnan et al., 2005; Nandalal and Hipel, 2007; Madani and Hipel, 2011). This flexible methodology is applied to the Cuban Missile Crisis in Section 6.7 to demonstrate how easy it is to apply this well-designed DSS technology in practice and to point out its many benefits for users.

6.2 Conflict Specification

One of the GMCR+ project's central goals is the creation of a simple and flexible system to model conflicts in an electronic format. In pursuit of this goal, identifying the parameters of the conflict and making logical connections between them is required. Since the DSS is programmed using an object oriented language, the conflict parameters will be referred to as objects. Figure 6.2 illustrates the top-level specifications (i.e. objects) of the conflict model as implemented in GMCR+. In the following subsections, each object is explained and its properties are illustrated.

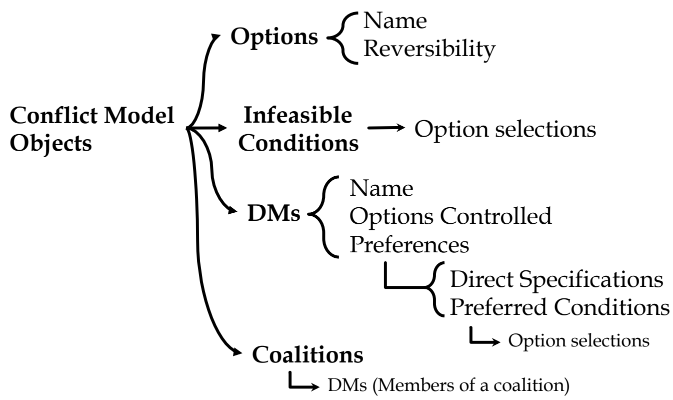


Figure 6.2: Conflict Specifications Hierarchy in GMCR+

Typically, DMs are identified before options, as demonstrated in the standard GMCR procedure shown in Figure 3.1. However, options will be discussed as the root of the conflict model, which better reflects the structure of GMCR+.

6.2.1 Option Objects

Each option within a conflict is represented by an object. This object contains all of the defining attributes as follows:

Option Name

A simple identifier that is readable to humans which is used while modeling the conflict and when displaying results.

Reversibility

An option may be On or Off (selected or not). An option is reversible if it is permissible to move back and forth between the two option selections. An option is irreversible if it is permissible to move in only one of these directions.

A list containing all of the options within a conflict is part of the top-level specification of that conflict. References to the option objects contained within that master list appear in three instances:

- DM objects (to allow a DM to have control over an option)
- Infeasible conditions (making a condition dependent on option selections)
- Preferred conditions (within a DM's preferences)

The last two instances will be clarified in the following subsection.

6.2.2 Condition Objects

A group of option selections is called a condition. For example, consider a model of five options. The complete set of states where no option selection is made could be represented as "- - - - -". A pattern in which the second option is chosen and the fourth option is not chosen is described as "- Y - N -". Conditions of this form are used in the two aforementioned instances: determining infeasible states and specifying preferences using preference prioritization.

6.2.3 Infeasible Conditions

A conflict's infeasible states are described through a list of conditions mentioned earlier. All states for which one or more of the infeasible conditions is true are removed from the model before analysis is carried out. Specifying the infeasible states in a conflict through the use of infeasible conditions allows a large number of related infeasible states to be described more easily.

6.2.4 DM Objects

Each DM within a conflict is represented by an object. This object contains all of the defining attributes of the DM as follows:

DM Name

A simple identifier that is readable to humans which is used while modeling the conflict and when displaying results.

Options Controlled

A list of references to options (contained in the top level specifications) that a DM controls. Each option is controlled by one and only one DM.

Preferences

This refers to the ordering of conflict states from most preferred to least preferred for each DM. This information can be inputted using direct specification or using preference prioritization conditions. GMCR+ represents preferences by assigning payoff values to each state for each DM. A higher payoff value indicates a greater preference for that state by that DM. A user can directly specify preferences by providing a list of all states, ordered from most preferred to least preferred. Equally preferred states can be indicated by grouping them together with brackets and the DSS will then assign payoffs accordingly.

Another way to specify preferences is a qualitative tool utilizing the preference prioritization method, which uses preferred conditions. When using preference prioritization to assign payoffs, preferred conditions are specified for each DM. These conditions are ordered from the most preferred conditions to the least preferred conditions. Weights are assigned to each of the conditions, and a state's payoff is calculated by summing the weights of all conditions it satisfies.

6.2.5 Coalitions Objects

A coalition is formed through the grouping of two or more DMs. A coalition of DMs has control over all options controlled by any member of the coalition. A move is only preferred for a coalition if it is preferred by all of the coalition's members. The defining property of a coalition is the list of DMs (i.e. members). A DM may only belong to one coalition, and a DM may not act independently while part of a coalition.

6.3 Conflict Data Processing

In this section, algorithms and pseudocodes for how GMCR+ processes the aforementioned conflict specifications are outlined.

6.3.1 Removing Infeasible States

Infeasible states must be removed from a conflict before useful analysis can be performed. Since infeasible states are represented through conditions, the list of feasible states can be obtained through a subtraction process.

A condition with no option selection specified (i.e. all possible options can be either taken or not) is referred to as a "null condition". A null condition includes the complete set of mathematically possible states (given by the expression 2^{α} where α is the number of options in a conflict model). The list of feasible states in a conflict model can be expressed as a set of conditions. Starting with the null condition, the list of conditions that describe the feasible states of a game can be obtained through Algorithm 6.4. Please note that Algorithm 6.5 is called within Algorithm 6.4. The results provided by the use of these algorithms is the set of feasible states for the conflict, referred to as F.

6.3.2 Preference Prioritization

Preference prioritization is the process by which a ranked list of preferred conditions can be translated into payoff values for each state according to each DM. In order to perform the preference prioritization, the first step is to establish a weight for each preferred condition.

Algorithm 6.4 Calculate Feasible States

```
F ← null condition
G ← Set of infeasible conditions
W ← φ
for each condition g in G do
    for each condition f in F do
        X ← SUBTRACT(f, g)
        W ← W ∪ X
    end for
    F ← W
    W ← φ
end for
```

Algorithm 6.5 Calculate $X - Y$

```
function SUBTRACT(x,y)
    if X ∩ Y = φ then
return X
    end if
    W ← φ
    Z ← X
    for each option i do
        if Y[i] == '−' then
            CONTINUE
        end if
        if Z[i] == '−' then
            A ← Z
            A[i] ← NOT Y[i]
            W ← W ∪ A
            Z[i] ← Y[i]
        end if
    end for
return W
end function
```

Given a user-provided list of conditions, P, ordered from most to least important, payoff values can be assigned according to the following procedure:

- Algorithm 6.6 outlines the method used to weigh the conditions in GMCR+. Each condition is given a weight of $2^{|P|-i}$, where $|P|$ is the length of the user provided list of conditions, and i is the position of the condition on the list.
- After all the conditions have been weighted, all feasible states within the conflict model are then scored against these conditions as outlined in Algorithm 6.7. The payoff for a state according to each DM is the sum of the weights of all conditions that are satisfied by the state.

As each DM has a unique set of preferred conditions, which will yield unique payoff values for each state, this procedure must be performed for every DM.

Algorithm 6.6 Weight Preferred Conditions

```
P = User-Provided list of Preferred Conditions
for each condition p in P and index i in |P| do ▷ |P| is the length of the user provided list
    p.weight ← 2^(|P|−i)                        ▷ p.weight is the weight of the condition p
end for
```

6.3.3 Direct Ranking Handling

An alternative method for specifying preferences is through direct specification. Direct specification is the manual ordering of states from the most preferred to least preferred state for each DM. The user-entered preference rankings are converted to payoff values using Algorithm 6.8.

Algorithm 6.7 Score States

F = List of Feasible States
P = User-Provided list of Preferred Conditions
for state f in F **do**
    f.payoff$\leftarrow 0$
    for condition p in P **do**
        if f satisfies p **then**
            f.payoff$\leftarrow$ f.payoff+p.weight
        end if
    end for
end for

Algorithm 6.8 Convert Preference Ranking to Payoff Values

$R \leftarrow$ User-entered preference ranking
for each state number r in R and index i in $|R|$ **do**
    r.payoff$\leftarrow |R| - i$
end for

6.3.4 Reachability Matrix

The reachability matrix contains information central to all analysis capabilities of the GMCR+ system. For each DM, an $|F| \times |F|$ reachability matrix is constructed, where $|F|$ is the number of feasible states in the conflict model. If state j is reachable from state i by a DM, then entry $[i, j]$ of the reachability matrix for that DM is assigned the payoff of state j for that DM. If state j is not reachable from state i by a DM, then the $[i, j]$ entry is undefined. Figure 6.3 is an example for a 3-state model where a DM has a move from state s_1 to state s_2 that has a payoff of 3. On the other hand, a move from state s_2 to state s_3 has a payoff of -5. There is no possible move from state s_3 to state s_1, but a move from state s_1 to state s_3 has a payoff of 1 and the move is irreversible.

$$\begin{array}{c} \\ s_1 \\ s_2 \\ s_3 \end{array} \begin{array}{c} \begin{array}{ccc} s_1 & s_2 & s_3 \end{array} \\ \begin{bmatrix} & 3 & 1 \\ -3 & & -5 \\ & 5 & \end{bmatrix} \end{array}$$

Figure 6.3: Reachability Matrix Example

Using this format allows both reachability and payoff information to be co-located and used in different GMCR+ procedures and analyses.

6.3.5 Inverse Status Quo Analysis

Every real world conflict has a starting point from which the conflict evolves. This point or state is called *status quo* (Fang et al., 1993). Depending on the status quo, a potential equilibrium may or may not be reached.

Li et al. developed algorithms and formal definitions to inspect the attainability of a potential resolution (*equilibrium*) from a certain state (*status quo*) (Li et al., 2004b, 2005). An inverse approach to determine the required starting points in order to attain a desired equilibria is achieved by tracking the evolution of the conflict backward from a desired equilibrium to the status quo states. This feature is illustrated in Sections 6.6.1 and 6.6.2.

6.4 Analysis Engines

There are four independent "solvers" within GMCR+: the logical solver, the matrix solver, the inverse solver, and the goal seeker. GMCR+ utilizes both logical and matrix approaches to determine and calculate the stability of states. This allows the system to extract insightful information while being fast and efficient in analyzing conflict models.

The Logical Solution Engine in GMCR+ calculates the stability of each state for every DM according to the four solution concepts introduced in Section 3.3: Nash, SEQ, GMR, and SMR. Overall conflict equilibria can be determined based on individual stabilities. Moreover, the engine can generate a narration of the stability for any given state and DM. This insightful narration provides a clear picture of what sanctioning moves or unilateral improvements (UIs) are directly responsible for the stability or instability of a state.

In addition to the Logical Solution Engine, the back end of the system utilizes the Matrix Approach by Xu et al. (2007); Xu (2009). The advantage of using the Matrix Approach is the increased computational speed due to the efficiency of computers when dealing with matrices versus logical loops. However, if the user demands insights for a specific state, then the logical approach is utilized to provide the narration.

An 'inverse solver' subsystem to utilize the above engines is implemented to incorporate Inverse GMCR. Inverse GMCR is a new extension to the original GMCR (Kinsara et al., 2012, 2013a,b) in which GMCR is utilized as a negotiation tool rather than a prediction tool as explained in Chapter 5. Through the application of the stability concept definitions and analysis of the reachability matrix, it is possible to generate a list of conditions that must be satisfied by the DMs' preferences to lead to an equilibrium at a given state. The engine can produce a list of the conditions that must be satisfied to produce an equilibrium under any of the basic stability concepts: Nash, SEQ, GMR, and SMR. Moreover, the engine can utilize the definitions discussed in Section 5.2 to produce patterns for the generated list.

Finally, the 'Goal Seeking' solution engine is an adaptation of the inverse solution engine. It allows the user to specify a variety of different states that are desired either to be "stable" or "unstable". The engine uses the definitions of the stability concepts to determine the conditions that must be satisfied for all of these defined "goals" of stability or instability to be achieved. It also allows the user to interactively browse through the tree of moves below a selected "status quo".

6.5 Graphical User Interface

The GUI for GMCR+ was created in python, using the *tkinter* user interface package. The basic interface, shown in Figure 6.4, includes a large navigation bar at the top of the screen. This bar displays each of the logical steps in the modeling of a conflict, and allows the user to easily move between them. At the top left of the screen, the user can find standard utility buttons to load, save, and create new conflict models. The remainder of the screen is used to display and edit information related to the active step of the modeling process. To the right edge of the screen, a column provides a quick reference about the current step of the modeling process and how to use the interface.

6.5.1 Decision Makers and Options

This is the first step in conflict modeling where the user or analyst defines the DMs and their options in the conflict. The full list of DMs in the conflict is shown to the left of

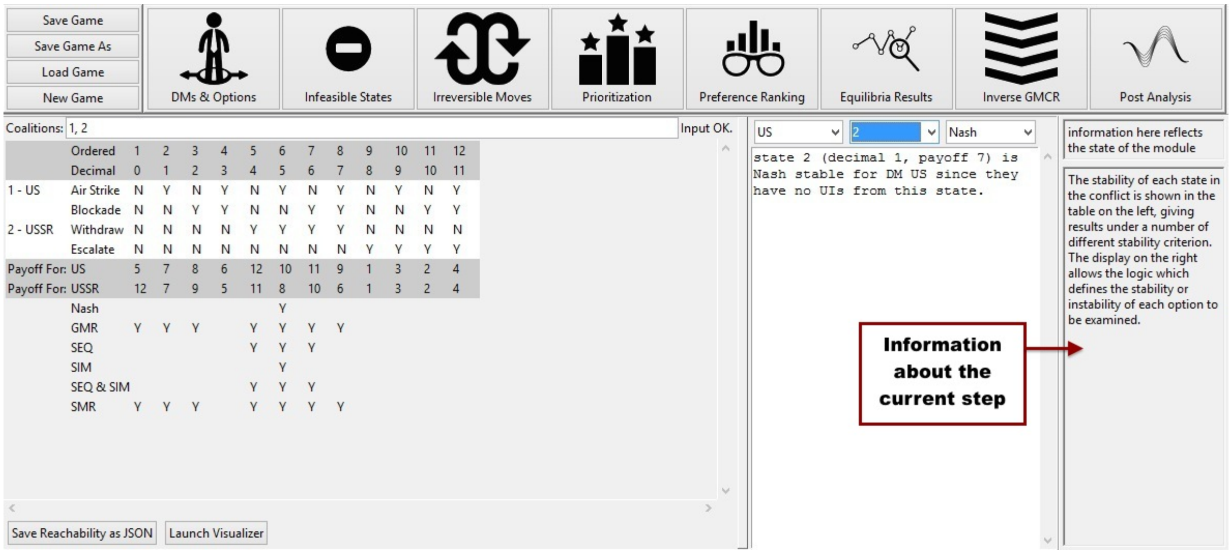


Figure 6.4: GUI for GMCR+

the screen as shown in Figure 6.5. Clicking on a DM's name will select it, displaying the DM's associated options in a list to the right. While a DM or option is selected, it can be deleted, or its name can be modified. Buttons at the bottom of the screen allow the order of DMs and options to be changed, and new DMs or options to be added to the conflict. The information panel at the right edge of the screen displays the number of defined DMs, options, and the total number of states that would be in the game if no infeasible states were removed.

6.5.2 Infeasible States

After defining DMs and options, the program will generate a list of all possible states. There are usually infeasible states that must be removed as explained earlier in Sections

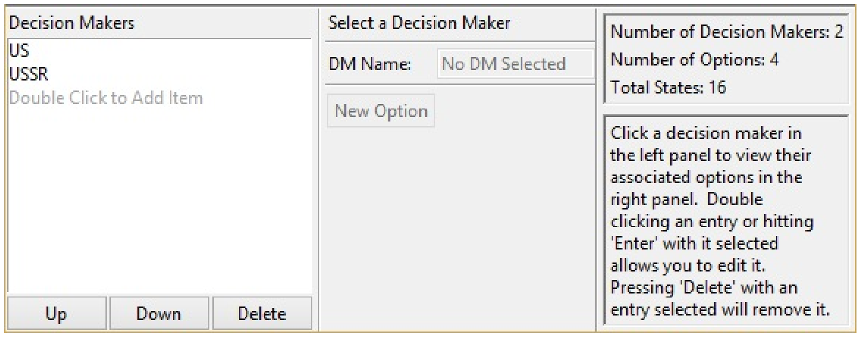


Figure 6.5: DMs and Options Screen

6.2.3 and 6.3.1. The infeasible states screen (Figure 6.6) allows the user to create conditions specifying infeasible states to be removed.

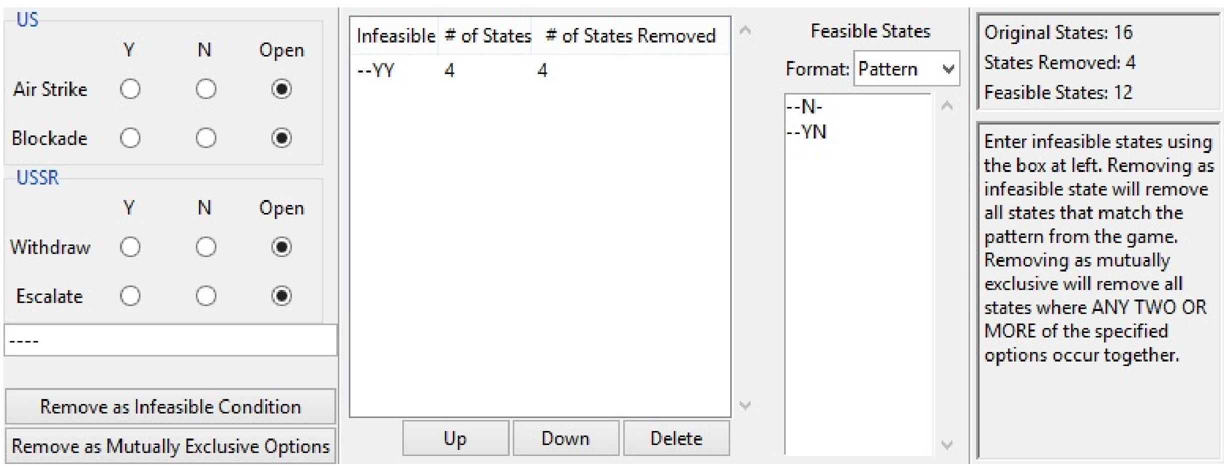


Figure 6.6: Infeasible States Screen

The panel to the left contains a set of toggle buttons where option selections can be made to specify an infeasible condition. Clicking "remove as infeasible condition" will remove all states satisfying this condition from the conflict and display the infeasible condition along with the number of removed states in the middle of the screen. Clicking "remove as mutually exclusive options" generates a list of conditions prohibiting any states where two or more of the chosen option selections are taken. For example, consider a person with three options: eat, sleep, and breathe. A person can't eat and sleep at the same time. Moreover, a person can't eat or sleep without also breathing. Table 6.1 outlines all possible states combinations for this example. Four states are infeasible in this example: 2, 3, 4, and 8. In order to remove them, an analyst would have to input at least three conditions manually:

- Eat and sleep
- Eat and not breathe
- Sleep and not breathe

However, using the mutually exclusive button, an analyst can generate this list of conditions by selecting Eat, Sleep, and not Breathe and clicking on "remove as mutually exclusive options".

Table 6.1: Example for mutually exclusive options

	1	2	3	4	5	6	7	8
Eat		☑		☑		☑		☑
Sleep			☑	☑			☑	☑
Breathe					☑	☑	☑	☑
Feasible	Yes	No	No	No	Yes	Yes	Yes	No

The feasible states are displayed on the right of the infeasible conditions panel as shown in Figure 6.6. The set of feasible states can be displayed either as a list of feasible conditions, as a full list of feasible states in YN format, or as ordered and decimal state numbers. On the right edge of the screen, an information panel displays the original number of states in the conflict, the number of states removed, and the number of feasible states remaining. Below that is a brief set of instructions for using the interface.

6.5.3 Irreversible Moves

In this step, an analyst can define the reversibility of each option. By default, all options in the conflict are displayed with a two-headed arrow pointing between 'Y' and 'N' denoting that all moves are reversible. Clicking the arrow toggles the direction of reversibility. In this way, the user or analyst can leave the option as reversible, or define the direction of irreversibility. All moves in Figure 6.7 are reversible except that of Air Strike.

Figure 6.7: Irreversible Moves Screen

6.5.4 Preferences

Preferences for DMs can be specified through preferred conditions or through direct ranking of states as mentioned previously in Sections 6.3.2 and 6.3.3. The preferred conditions method allows the analyst to define preference prioritization conditions to make the ranking of states easier and more intuitive. Direct ranking allows the analyst to fine tune the results from prioritization or assumes the analyst is certain about the ranking of states for each DM.

Prioritization

As explained earlier in Section 6.2.2, a condition is a set of option selections describing a group of states. By specifying conditions that are preferred by a DM and ordering these conditions by importance, a ranking of states can be generated using the methodology described in Section 6.3.2.

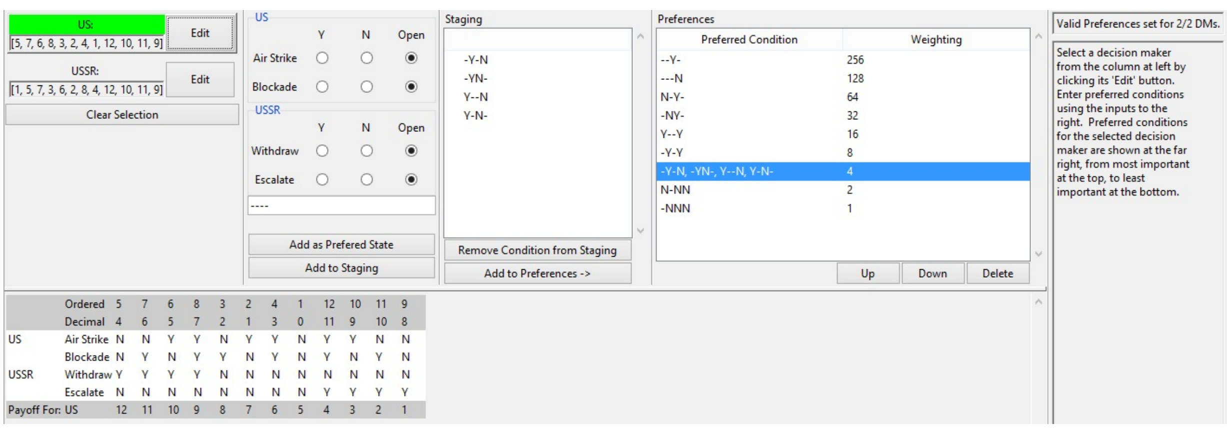


Figure 6.8: Preference Prioritization Screen

The panel to the left of the screen in Figure 6.8 is a table with all DMs and their corresponding preference rankings. Clicking on any DM will change its color to green and allow the preferences for that DM to be modified. A user can click "Done" to clear the DM selection. The panel in the middle includes toggle buttons for all DMs and their options. In order to add a preferred condition, a user will make option selections and can either add them directly as a preferred condition or move them to a staging area where multiple conditions can be added together with equal weight. The right panel of the screen displays the preferred conditions for the selected DM and the weights associated with those conditions.

A large table displaying the conflict in option form occupies the bottom of the screen in Figure 6.8. The states are ordered according to their ranking for the active DM. The table also displays the payoff value of each state according to the active DM. If no DM is selected, the states are ordered based on state number and payoff values for all DMs are shown.

Preference Ranking

A user may wish to fine-tune the ranking of states after performing preference prioritization or simply entering preference information directly. At the top of the screen in Figure 6.9 is a large button which allows a user to enable manual preference ranking. This is accomplished by modifying the preference rankings shown for the DMs in the fields below. States are listed using their ordered numbers, and equally preferred states can be indicated by enclosing them in square brackets. In the middle of the screen, a large text box displays feedback on the validity of the entered preference rankings. Each preference ranking must contain each state once and only once to be considered valid. At the bottom of the screen, an option form table for the conflict is shown, similar to that on the Preference Prioritization screen. If the user wishes to revert changes to preferences made on the Preference Ranking screen, they can return to the Preference Prioritization screen, and click the large button that appears at the top of the screen.

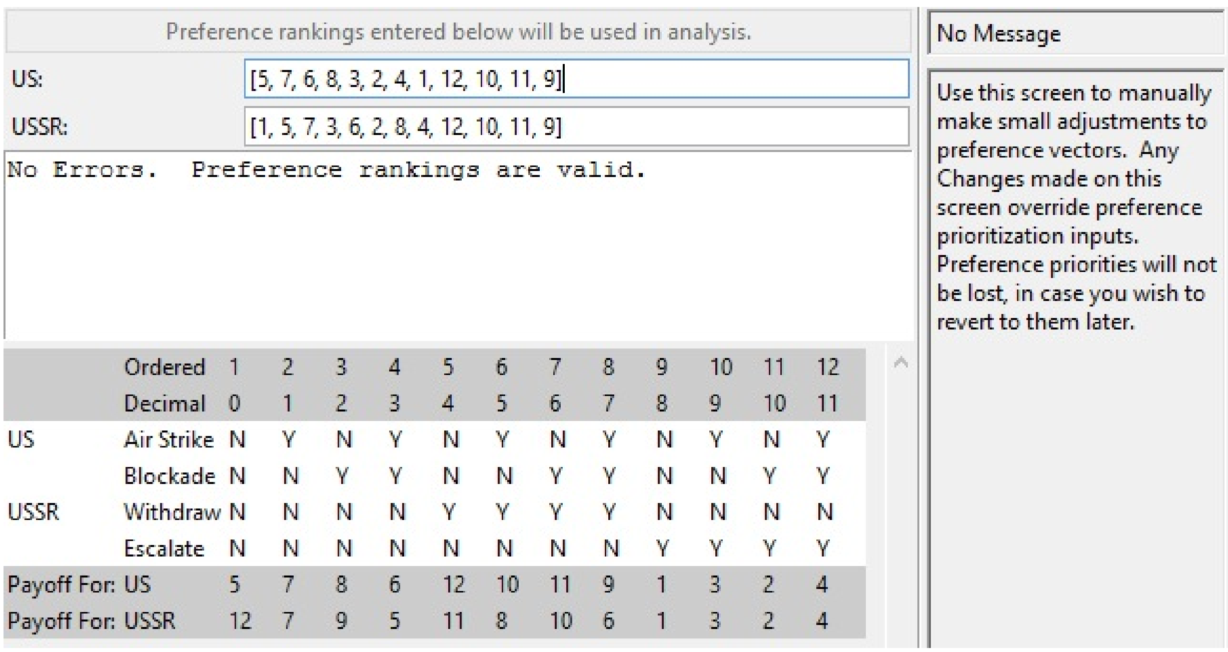


Figure 6.9: Preference Ranking Screen

6.5.5 Equilibrium Results

Figure 6.4 illustrates the Equilibria Results screen. The top of the screen shows the results of equilibria calculations for all states and solution concepts in an option form table for the conflict model similar to that on the preferences screens. Moreover, an analyst can examine the equilibria for coalitions by merging possible coalitions in square brackets to the top of the screen. To the right of the screen is the analysis narration panel, which allows an analyst to check for individual stability by selecting a DM, state, and solution concept and the process used to determine that individual stability or instability is explained. At the bottom of this screen, an option to launch a visualizer is available which is explained in Section 6.6.

6.5.6 Inverse GMCR

This screen deals with one of the novel additions to GMCR as mentioned in the introduction and in Section 6.4. The screen contains a control panel to the left as seen in Figure 6.10. This control panel allows the analyst to specify a desired equilibrium state. Furthermore, an analyst can select a preference variance range for each DM and then perform the Inverse GMCR calculations. Required conditions for stability are explained to the right for each solution concept. Long form results can be displayed on the bottom by selecting to display all permutations in the control panel and can be filtered by the solution concepts check boxes. This is a useful addition allowing analysts to perform extensive sensitivity analysis on preferences.

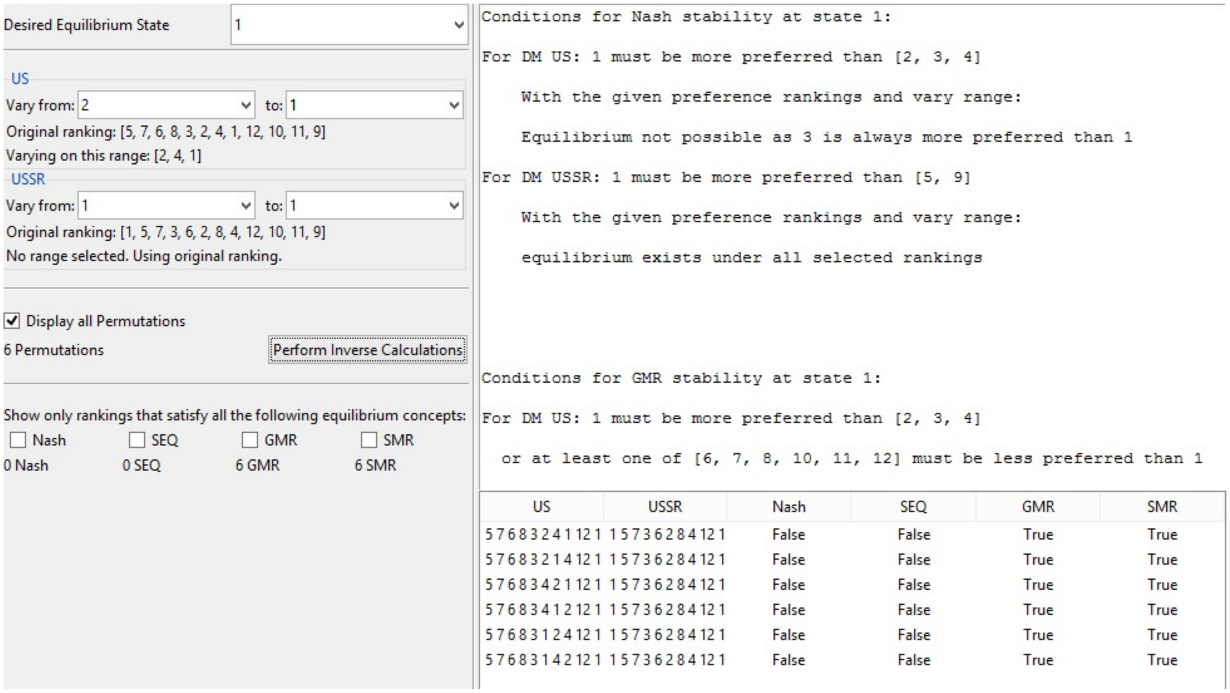


Figure 6.10: Inverse GMCR Screen

6.6 Presentation of Results and Post Analysis Tools

Web technologies present a wide array of opportunities for easily creating and distributing visualizations of information. The complexities of a conflict's graph model are often most easily understood when presented in a visual form, and so the following tools were created to accompany GMCR+, facilitating presentation and allowing deeper analysis.

6.6.1 Graphical Representation

Within the equilibria results screen described in Section 6.5.5 is a button to launch a visualizer. Clicking this button will launch a web application within the GMCR+ system allowing the analyst to see the actual graph of the conflict model as shown in Figure 6.11. The default view is a tree diagram illustrating a status quo analysis diagram. The top of the tree denotes the status quo and the branches are the possible unilateral moves from that state by each DM. Lines are color and dash coded for each DM. Hovering the mouse on any state shades all states within the tree.

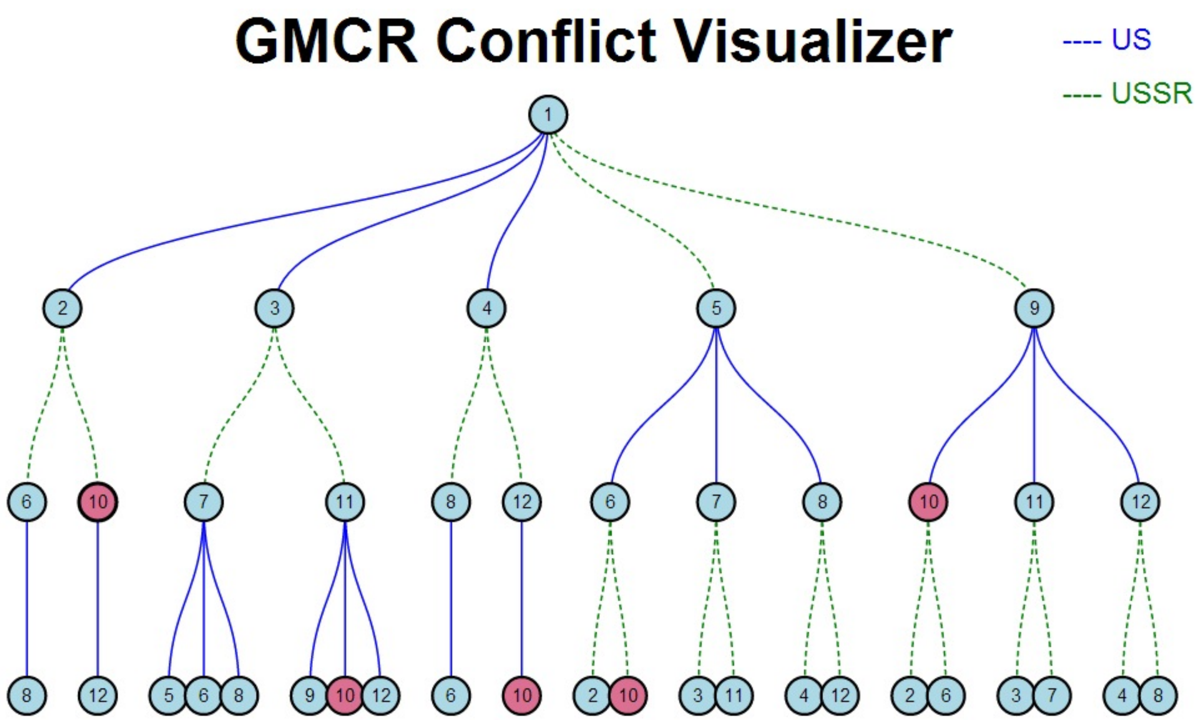


Figure 6.11: Conflict Model Tree Diagram

Hovering the mouse at the bottom of the screen displays an option form table for the conflict model. Hovering the mouse along the left of the screen shows the display options panel as shown in Figure 6.12. This panel allows an analyst to change the display method between a tree and a graph diagram. Furthermore, multiple options such as selecting a specific DM, showing UIs only, and specifying the tree depth can be adjusted.

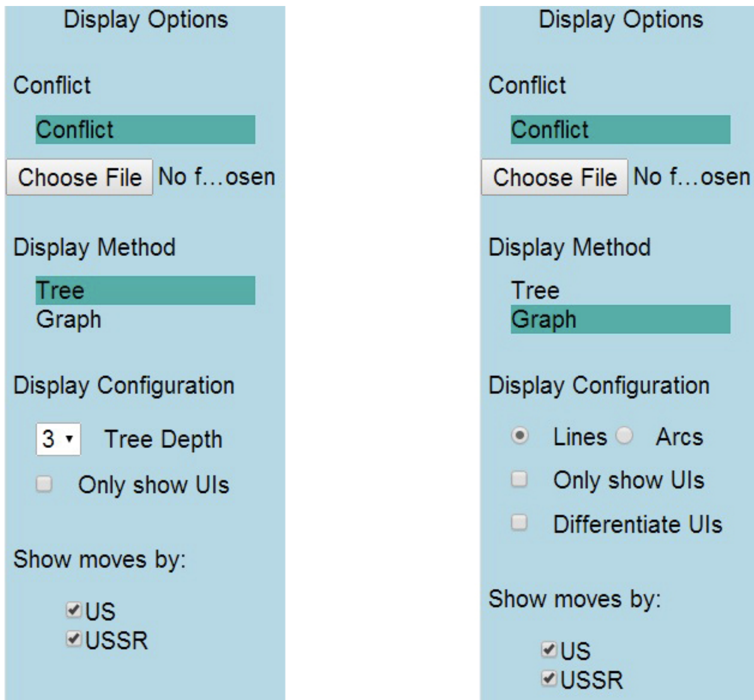


Figure 6.12: Display Options Panel for Tree and Graph Diagrams

Switching to the graph diagram mode will show the actual graph model for the conflict at hand as shown in Figure 6.13

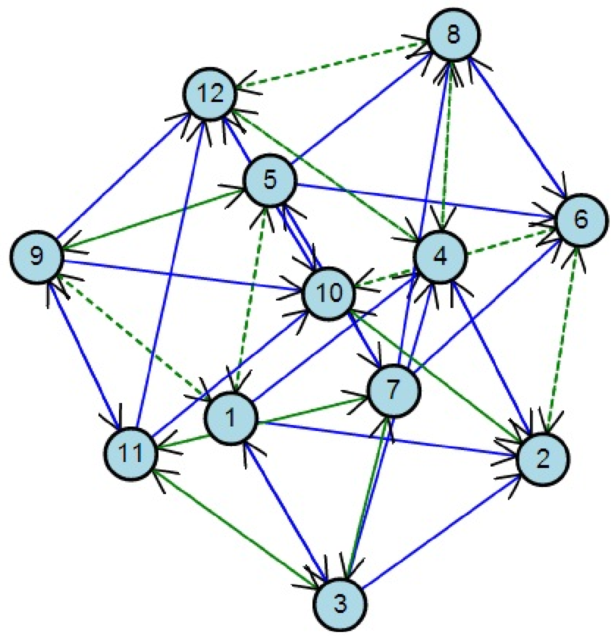


Figure 6.13: Conflict Model Graph Diagram

6.6.2 Post Analysis

This is the last screen in the GMCR+ system as illustrated in Figure 6.14. In this screen an analyst can specify coalitions within the control panel on the left of the screen, similar to the equilibria results screen mentioned in Section 6.5.5. In addition, this screen has two main submodules described in the following subsections.

Status Quo Analysis

In the control panel, an analyst can choose a specific state to act as a status quo for the conflict and carry out the analysis from it. The middle panel will automatically show the

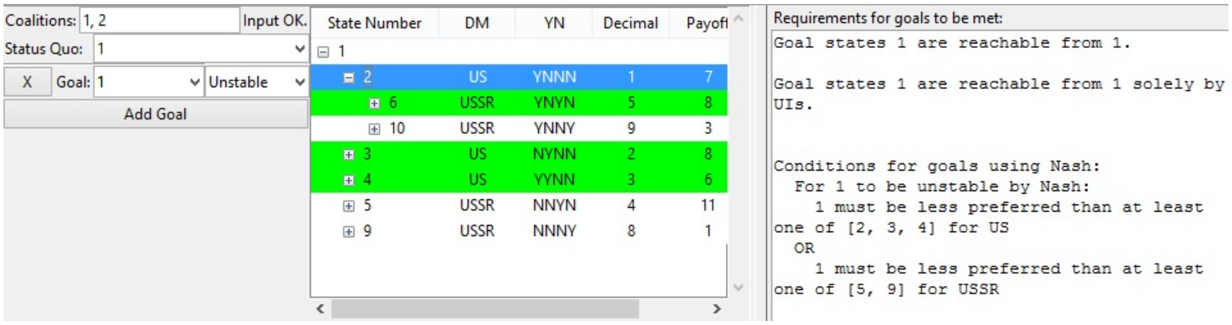


Figure 6.14: Post Analysis Screen

selected state as the top of the tree with a '+' sign to expand the branch. Clicking the '+' sign expands the branch into reachable states and UIs are shaded green. This feature allows the analyst to know if a possible equilibrium is reachable from the status quo and whether it is reachable solely by UIs. This information is also given in the narration panel to the right of the screen.

Goal Technique

This tool is an extensive version of the Inverse GMCR mentioned in Section 6.5.6. An analyst can experiment with different scenarios by setting particular states to be stable while avoiding other states. Whether these choices are possible or not is explained in the right panel and how they can be achieved if possible is narrated as well.

6.7 Case Study 1: Cuban Missile Crisis

In order to illustrate the capabilities of GMCR+, an international political conflict is summarized and then analyzed using GMCR+.

6.7.1 Background

The Cuban Missile Crisis between the United States (US) and the Union of the Soviet Socialist Republics (USSR) in October 1962 is used to demonstrate the capabilities of the DSS GMCR+ (**??**Fraser and Hipel, 1984; Hipel, 2011). The crisis was the closest that the USSR and US came to nuclear conflict, but it was averted due to the restraint and intelligence of the DMs on both sides. After Fidel Castro overthrew the Batista regime in 1959, there was impounding of American property in Cuba, which caused the US to sponsor the Bay of Pigs invasion in April 1961. This was a failed attempt at destroying the perceived military threat, following which the US vowed not to commit any further military invasions of Cuba. In October 1962, US intelligence discovered several USSR missile construction sites including medium-range and intermediate-range ballistic nuclear missiles (MRBMs and IRBMs) on Cuban soil, thus beginning the Cuban Missile Crisis. US President Kennedy summoned the Executive Committee of the National Security Council to advise and consider options to resolve the crisis. The options put forward by the various political and military decision makers included an air strike to destroy the missiles, a naval blockade of USSR military ships to Cuba, and, more passively, a stern warning to Cuba and USSR. On the other hand, the USSR DM Premier Nikita Kruschev had to consider the options of withdrawing missiles from Cuba or escalating the crisis by attacking US naval blockades, bombing in-range US targets from Cuba, and initiating an Intercontinental Ballistic Missile (ICBM) attack on the US. The options chosen by both DMs demonstrate an effort to promote the diplomatic channel, as the US chose to blockade USSR military supplies to Cuba while the USSR chose to withdraw the nuclear missiles. On November

20, 1962, with the end of the US naval blockade of Cuba, the Cuban Missile Crisis was finally over.

6.7.2 Modeling the Cuban Missile Crisis

DMs and Options

There are 2 main DMs in the Cuban Missile Crisis, the US and the USSR, as seen in the left-hand column of Table 6.2. Cuba is not modeled as a DM since it does not control any options over the US or the USSR and is not significant to the conflict. The DMs control two options each; the US controls the option of 1) conducting an air strike (Air Strike) on Cuba and 2) applying a naval blockade of USSR military ships to Cuba (Blockade). The USSR controls the option of 1) withdrawing missiles from Cuba (Withdraw) and 2) escalating the crisis (Escalate). The same modeling is applied for the crisis studied by Fraser and Hipel (Fraser and Hipel, 1984) using conflict analysis. Throughout the chapter, all screen-shots were taken for this specific conflict. Defining DMs and options is done in the first screen as shown in Figure 6.5.

Infeasible states and Irreversible Moves

Through the various combinations of all options for both DMs, there are a total of 16 possible states; however, 4 states are infeasible where a DM chooses contradictory options. For example, there are no states where the USSR chooses both to Withdraw and to Escalate. Figure 6.6 shows how this step can be implemented in GMCR+. The result is 12 feasible states as shown in the 12 columns of Table 6.2, with 'Y' denoting 'yes' indicating an option is taken and 'N' denoting 'No' indicating an option is not taken. Notice that at state 7, the US chooses not to conduct an air strike but instead applies a naval blockade to Cuba. Also in state 7, the USSR chooses the option of withdrawing missiles and not escalating the crisis. Historically, this was the actual resolution to the crisis (i.e. the final equilibrium of the conflict). For feasible states, a DM can choose to cause a unilateral transition between states by changing the option choice except if the option is irreversible like the option of an Air Strike by the US as illustrated in Figure 6.7.

Table 6.2: DMs, Options and Stated for the Cuban Missile Crisis

DMs and options	States											
	1	2	3	4	5	6	7	8	9	10	11	12
US												
1. Air Strike	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
2. Blockade	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y
USSR												
3. Withdraw	N	N	N	N	Y	Y	Y	Y	N	N	N	N
4. Escalate	N	N	N	N	N	N	N	N	Y	Y	Y	Y

Preferences

In order to rank states for a DM, one can directly rank the states using pairwise comparisons of feasible states. However, this process can be inaccurate and lengthy. Hence, an efficient process is necessary.

Table 6.3 demonstrates preference statements for the US in the Cuban Missile Crisis.

These preference statements are used to rank the states based on the algorithms described in Section 6.3.2. For example, the preference statement with the highest ranking, statement #1, means that the US would most prefer the USSR to just withdraw their missiles from Cuba. The seventh US preference statement means that the US prefers an air strike or a blockade if the USSR does not withdraw and does not escalate. Figure 6.8 shows how to input these statements into GMCR+. Through algorithms in GMCR+, the preference statements are automatically converted to states rankings.

Table 6.3: US Preference Statements

P#	Preference Statements (From most to least important)	GMCR+ Implementation (Using friendly toggle buttons)
1	USSR to withdraw missiles from Cuba	– – Y –
2	USSR not to escalate	– – – N
3	US doesn't air strike and USSR withdraw missiles	N – Y –
4	US doesn't carry a blockade and USSR withdraw missiles	– N Y –
5	US air strike and USSR escalates	Y – – Y
6	US carry a blockade and USSR escalates	– Y – Y
7	US air strike or carry a blockade if USSR doesn't withdraw & escalates	– Y – N / – Y N – / Y – – N / Y – N –
8	US doesn't air strike if USSR doesn't withdraw & escalates	N – N N
9	US doesn't carry a blockade if USSR doesn't withdraw & escalates	– N N N

Equilibria Results and Insights

The equilibria results screen depicted in Figure 6.4 shows that states 5, 6, and 7 are the strongest equilibria for this conflict model. State 7 was historically the final resolution of the conflict. Launching the visualizer at the bottom of the screen reveals both tree diagram and the graph model of the conflict depicted in Figures 6.11 and 6.13. Note that solid lines indicate the US while dashed lines indicate the USSR.

Using the post analysis screen, one can see that state 7 is reachable from the status quo state 1 and is reachable solely by UIs. Furthermore, the analyst may wish to carry out some sensitivity analysis using the Inverse GMCR screen as shown in Figure 6.10.

6.8 Case Study 2: The Elmira Conflict

6.8.1 Background

In late 1989, a controversy surfaced in the small town of Elmira, located north of the cities of Kitchener and Waterloo in southwestern Ontario, Canada. With a population of about 12,000 residents, Elmira is known for its agriculture and various industries, including a pesticide and rubber manufacturer, Uniroyal Chemical Ltd (UR). The municipal water supply of the town was formerly obtained from an underground aquifer, until the Ontario Ministry of Environment (MoE) uncovered that this fresh water supply was polluted with a carcinogen chemical, N-nitroso dimethylamine or NDMA.

Local residents, the Regional Municipality of Waterloo, and the Township of Woolwich (LG) collectively suspected UR to have caused the pollution, citing a long history of environmental problems and NDMA being a by-product of their manufacturing. Subsequently, the MoE issued a Control Order (CO) under the *Environment Protection Act of Ontario*, which required UR to, among other things, execute the necessary cleanup under the supervision of the MoE. Soon after, as per the *Environment Protection Act*, UR exercised its right to appeal the CO which allowed a hearing to decide whether the CO should be enforced, a modified version be proposed, or whether it should be dismissed.

The MoE encouraged the LG to take a position in the dispute and hire independent consultants for legal and technical advice, which cost substantial sums of money. As negotiations were underway, in August 1991, K.W. Hipel, D.M. Kilgour, and L. Fang conducted the first conflict study of the Elmira dispute with Domain Expert Murray Haight (Inohara and Hipel, 2008a). The conflict modeling and analysis assessed how the three DMs could negotiate a resolution with their independent goals to a) honor the CO for the MoE, b) modify or fully lift the CO for UR, and c) protect the health of the citizens and save its economic base for the LG.

This work is founded upon two paper written by Kinsara et al. (2014a,b).

6.8.2 Modeling and Analysis Using Standard GMCR

The graph model for this conflict was established by Hipel et al. (1993) containing three DMs: MoE, UR, and LG. MoE can control a single option of modifying the CO, making it more acceptable to UR (Modify). UR has three options: to delay the appeal process (Delay), to accept the CO whether modified or not (Accept), or to abandon the Elmira operations (Abandon). LG has one option of insisting the original CO be applied (Insist). Table 6.4 outlines the DMs, their options, and the 12 feasible states for the conflict. In the table, 'Y' denotes 'Yes' meaning that option in the corresponding row is taken while

'N' denotes 'No' indicating that the option is not taken. States 5,6,11, and 12 are shaded indicating that UR abandons its operations in Elmira and thus ending the conflict.

Table 6.4: DMs, Options, and States for the Elmira Conflict

DM	**State #**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
MoE	Modify	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
UR	Delay	Y	Y	N	N	N	N	Y	Y	N	N	N	N
	Accept	N	N	Y	Y	N	N	N	N	Y	Y	N	N
	Abandon	N	N	N	N	Y	Y	N	N	N	N	Y	Y
LG	Insist	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y

According to the aforementioned background, the analysts derived the preference rankings represented in Table 6.5 (Hipel et al., 1993). The preferences are ordered from the most preferred states on the left to the least preferred states on the right. Equally preferred states are shaded. Consequently, the standard GMCR produced the equilibria results outlined in Table 6.6.

Table 6.5: Preferences from Most to Least Preferred States for the Elmira Conflict

DM	Most Preferred										Least Preferred
MoE	9	3	4	10	7	1	2	8	5	6	11	12
UR	1	4	10	7	5	6	11	12	2	3	9	8
LG	9	3	7	1	10	8	4	2	5	6	11	12

Table 6.6: Equilibria Results for the Elmira Conflict

State #	1	2	3	4	5	6	7	8	9	10	11	12
Nash					✓	✓	✓			✓	✓	✓
SEQ					✓	✓	✓			✓	✓	✓
GMR	✓			✓	✓	✓	✓			✓	✓	✓
SMR	✓			✓	✓	✓	✓			✓	✓	✓

Finally, the evolution of the Elmira conflict is illustrated in Table 6.7. While the original analysis suggested that the conflict would be deadlocked in equilibrium state 7, on October 7, 1991, MoE and UR announced an agreement to modify the CO, making state 10 the final equilibrium (Inohara and Hipel, 2008a). With the lack of unilateral improvements by MoE and UR from state 7 to state 10, the authors then investigated a novel area of coalition analysis within GMCR to explain the equilibrium jump from state 7 to state 10. A new insight and explanation is provided to the dramatic resolution using Inverse GMCR.

Table 6.7: The Evolution of the Elmira Conflict

DM	State #	1		7		10
MoE	Modify	N		N	→	Y
UR	Delay	Y		Y	→	N
	Accept	N		N	→	Y
	Abandon	N		N		N
LG	Insist	N	→	Y		Y

6.8.3 Analysis Using Inverse GMCR

The aforementioned background and discussion clearly suggest that state 7 is not a desired resolution to the conflict. Although what happened initially was in agreement with the original analysis suggesting the conflict will be deadlocked in equilibrium state 7, it can be anticipated that it is infeasible for UR to delay forever. Since standard GMCR deals only with static analysis, it was not easy to foresee how the conflict can evolve. However, from the perspective of Inverse GMCR, the analyst can understand how specific situations may evolve. Using the goals feature of the new *GMCR+*, analyst can set state 10 to be an equilibrium, and state 7 to be unstable.

Integrated graph models are illustrated in Figures 6.15 and 6.16. Each state is represented by a circled number. Each line represents a move by a specific DM. For example, LG has a move from state 1 to state 7 and vice-versa. The move from state 1 to state 7 by LG is a UI because there are double arrows pointing to state 7.

UIs are distinguished by thick lines. Figure 6.15 depicts the original integrated graph model of the Elmira conflict. As seen, there are no possible UIs from state 7, making it a deadlock equilibrium. On the other hand, Figure 6.16 depicts a modified integrated graph after using Inverse GMCR goals. State 7 now has a new UI from state 7 to state 8 by MoE, breaking it from the original equilibrium.

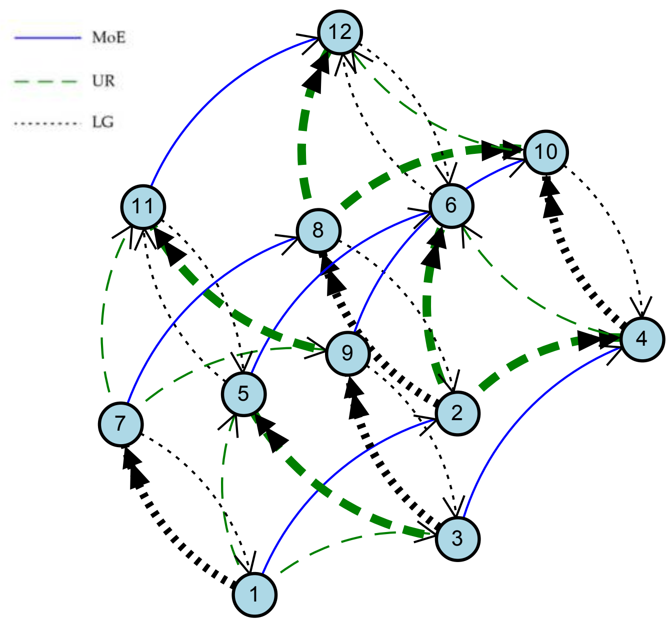


Figure 6.15: Integrated Graph Model of the Elmira Conflict (Original Model)

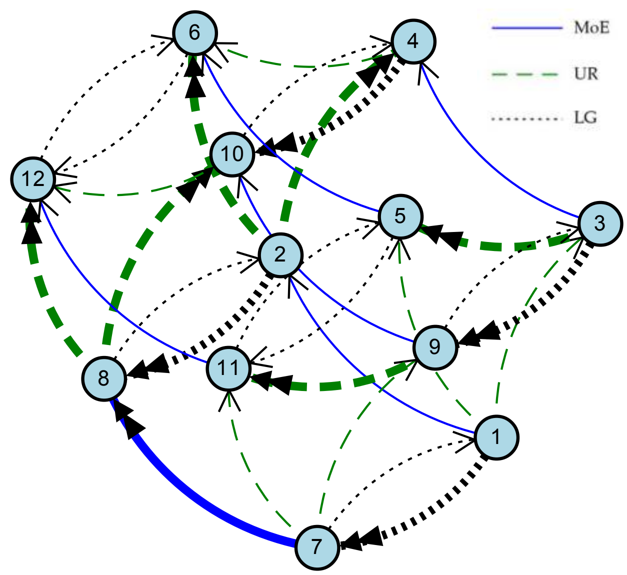


Figure 6.16: Integrated Graph Model of the Elmira Conflict (New Model)

Although state 7 can be made unstable using coalitions, as was later investigated, generating all scenarios including coalitions gives better understanding to the conflict. Coalition analysis shows that both MoE and UR have to cooperate to make an equilibrium jump to a mutually preferred state. However, Inverse GMCR explanation allows each DM to make UIs without having to cooperate. Although it is not clear how the agreement on October of 1991 was achieved, it is very possible that negotiation between MoE and UR in which MoE suggested its modification to the CO in order for UR to accept it. Inverse GMCR proves to be a very valuable negotiation tool that provides analyst and mediators with vital information to reach a desired resolution. Table 6.8 illustrates the evolution of the conflict as explained by Inverse GMCR.

Understanding the dynamics is a vital element in conflict modeling and analysis. Inverse GMCR is a valuable negotiation tool that explains how a state can or cannot be achieved. The Elmira dispute is a suitable environmental conflict that illustrates the advantage of using a variety of conflict modeling approaches, standard GMCR, coalition analysis, and Inverse GMCR, to achieve a sustainable equilibrium. Applying these approaches provides deeper insights and comprehensive understanding about the conflict at hand.

Table 6.8: The Evolution of the Elmira Conflict Using Invese GMCR

DM	**State #**	**1**		**7**		**8**		**10**
MoE	Modify	N		N	→	Y		Y
UR	Delay	Y		Y		Y	→	N
	Accept	N		N		N	→	Y
	Abandon	N		N		N		N
LG	Insist	N	→	Y		Y		Y

6.9 Summary of Features

A summary of GMCR+ features with a comparison of different DSSs tailored for GMCR is illustrated in Table 6.9. It is evident that GMCR+ is richer than all of its predecessors and superior in performance.

Table 6.9: Comparison of different DSSs capabilities

		GMCR I (or GMCA)	GMCR II	GMCR+
Overall Capabilities	Year of Development	1990	1999	2014
	Environment	Windows	Windows	Universal (Windows, Mac, Linux)
	Programming Language	C Language	C Language	Python and JavaScript
	Results	Plain Text	Table	Various reporting styles (Graphs, tables, and insightful text)
	Maximum # of States	200 for two-player models and 100 for multi-player models	600	Unlimited
	Solution Concepts	Nash, GMR, SMR, SEQ	Nash, GMR, SMR, SEQ	Nash, GMR, SMR, SEQ, SIM
	User Friendly (System-User Interaction)	✘ (Requires ASCII input file in a required format)	✓	✓
Input Capabilities	Option Form	✘	✓	✓
	Preferences Prioritization Input	✘	✓	✓
	Graphical User Interface	✘	✓	✓
	Infeasible States Removal	✘	✓	✓
	Handles Reversibility	✘	✓	✓
	Handles Intransitive Preferences	✘	✘	✓
Output Capabilities	Stability Explanation	✘	✘	✓
	Categorization of Equilibria	✘	✘	✓
	Interactive Status Quo Analysis	✘	✘	✓
	Graph Drawing	✘	✘	✓
	Interactive Graphs	✘	✘	✓
	Advanced Coalition Analysis	✘	✘	✓
Inverse GMCR	Inverse GMCR Capability	✘	✘	✓
	Post Analysis Capabilities	✘	✘	✓
	Scenario/Strategy Suggestion	✘	✘	✓
Design	Modular Design (Expandable to add new advancements)	✘	✘	✓

6.9.1 Overall review

In summary, three essential elements constitute the GMCR+ DSS: the structure of the model (conflict specifications), conflict data processors, and display components (GUI).

The conflict specification is built on a structured set of objects (options, DMs, conditions, etc.) with defined properties and interactions that exist within a conflict model as outlined in Section 6.2.

The "conflict data processors" as explained in Sections 6.3 and 6.4 constitute the solution engines. GMCR+ has 4 distinct and independent "solvers": the logical solver, the matrix solver, the inverse solver, and the goal seeker.

The GUI is the component which the user actually interacts with. The purpose of the GUI is to control the flow of all parts of the program. It is organized into screens, of which there are eight so far (more can be easily added). Each of these screens is composed of a series of smaller elements that display and/or control some elements of either the conflict model or one of the solution engines. These elements are reusable on multiple screens, as appropriate. When a user launches the program, the basic parts of the user interface are constructed, then an empty conflict model is formulated. GMCR+ then initializes all the parts of the interface that are meant to contain and/or control conflict information by building those elements and giving them references to the part of the conflict model they are meant to represent. When a user interacts with a part of the interface, it sends a message to the conflict model and the requested change is executed. This change is then reflected in all other elements of the interface that hold references to that part of the conflict model.

When a user navigates to one of the result screens (Equilibria Results, Inverse GMCR, or Post Analysis), GMCR+ creates an instance of one of the solvers, giving it a reference to the current conflict model. The solver does the work of interpreting the conflict model and generating results. The interface elements of the screen (some of which communicate with the conflict model, some with the solver, while others communicate to both) display the results generated. Moreover, GMCR+ allows the user to request additional analysis from the solver, the results of which are returned to the appropriate user interface element.

Figure 6.17 illustrates the different elements of GMCR+ and their interactions. Moreover, the figure depicts the modular design of GMCR+ and how new extensions can be integrated.

6.9.2 Complexity

Algorithms are commonly measured for computational complexity in order to determine time and memory requirements as a function of the input, and are commonly expressed using the O-notation (Papadimitriou, 2003). Complexity class is based on the mathematical logic required. Complex computations are classified as *Non-deterministic Polynomial-time hard* or *NP-hard* which is "at least as hard as the hardest problems in NP". (Bovet et al., 1994). Less complex operations are classified as polynomial. The primary operation in GMCR+ is a simple comparison, which has a complexity of $O(m)$, where m refers to the number of feasible states in the conflict model. However, the comparison operation is performed on the reachability matrix which has a size of $m \times m$. Therefore, initializing the

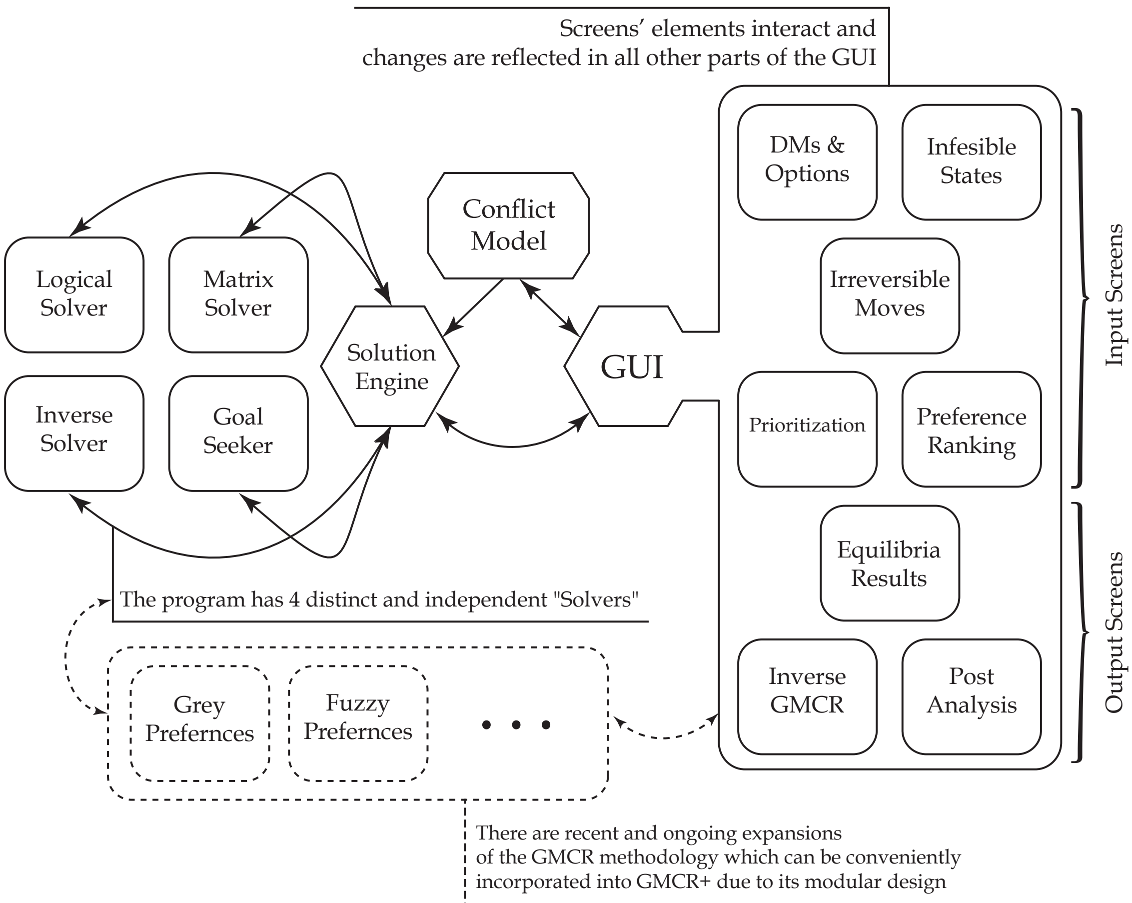


Figure 6.17: Elements of GMCR+ and their interactions

matrix has a complexity of $O(m^2)$. Using the improved method of Peng (1999), populating the reachability matrix has a worst-case complexity of $O(2^{2m/n})$ where n denotes the number of DMs. This level of complexity was achieved in GMCR II by limiting the scope of the search to only possible moves among states controlled by each DM instead of looping through all feasible states (Peng, 1999).

The number of permutations for calculating Inverse GMCR using brute-force is given by $(m!)^n$ as mentioned in Section 5.2.5, making the complexity of this implementation $O(m!)$. This can harm the system performance especially when large models are used. However, the improved approach based on the definitions stated in Section 5.2 reduces the complexity to less than $O(m^2)$.

Memory issues may arise as the core of any conflict model within GMCR+ is based on a dense reachability matrix. The full reachability matrix with size $m \times m$ is created in memory. The observed limit is around 20,000 states using a computer with 4GB of RAM, and reflects the memory required to hold the reachability matrix. Most real-world models in the literature contain fewer than 1,000 states, making GMCR+ sufficient. Moving to dynamically generated reachabilities could eliminate this constraint for conflicts having more than 20,000 states, and might be an important future project .

6.10 Chapter Summary

The framework, modules, and algorithms used within the newly developed DSS, GMCR+, are presented in this chapter. GMCR+ allows the analyst to be accurate, efficient, and insightful in modeling and analyzing strategic conflicts. The presentation and visualization components of GMCR+ provide a superior platform for communicating conflict dynamics and results. Strategic insights are derived from the rich, easy-to-manipulate post-analysis tools within the system. Finally, flexibility and modularity make the system adaptable and open for future theoretical developments in the field of conflict resolution and the graph model. Key highlights of the GMCR+ system include the following:

1. GMCR+ is a comprehensive DSS that has been built from scratch to overcome previous DSS limitations and provide additional features.

2. GMCR+ uses Python and Javascript programming languages, allowing it to be a universal software.

3. All features from GMCR II are included in GMCR+, in addition to many new features including:

    (a) Stability explanation

    (b) Categorization of equilibria

    (c) Interactive graphs and status quo analysis

    (d) Advanced coalition analysis

    (e) Post analysis capabilities

4. GMCR+ includes Inverse GMCR capabilities to facilitate negotiation modeling, in addition to other post analysis features.

5. GMCR+ has four distinct and independent "solvers": the logical solver, the matrix solver, the inverse solver, and the goal seeker.

6. The modular design of GMCR+ facilitates the addition of new graph model algorithms.

Chapter 7

Conclusions and Future Work

Complicated strategic conflicts require deep analysis for understanding and for drawing strategic insights. In a complex conflict, a definitive prediction is highly unlikely, as predictions tend to be inaccurate, especially in a dynamic world. Inverse GMCR provides strategic information and generates important scenarios that can aid analysts, mediators, or disputants to make wise decisions to achieve more desired resolutions. It is evident that decision support is vital in resolving modern strategic conflicts especially when thousands of scenarios must be examined and countless computations performed. The development of *GMCR+* facilitates numerous insights into a conflict, including scenario generation, graph model drawing, status quo analysis, and coalition analysis, to name a few. Coupling a strategic methodology like Inverse GMCR with a powerful DSS like *GMCR+* results in a practical framework that is widely accessible to researchers and can be applied to many modern strategic conflicts.

The application of standard GMCR methodology is limited by the requirement of an accurate preference ranking for all DMs involved in a conflict. Despite various attempts to simplify preference input, there is no appropriate methodology to solve and avoid the preference requirement. The methodology presented in this thesis has resolved this predicament. Inverse GMCR does not require preference ranking input in the modeling stage. In fact, the results of Inverse GMCR include the preference structure required to achieve or avoid a specific outcome.

7.1 Research Contributions

The main contributions of this research are summarized in the following points:

1. Negotiation and third party intervention are formally modeled by the development of the Inverse GMCR framework.

2. New stability definitions are crafted for Inverse GMCR and mathematical representations are formulated.

    (a) The new concepts of preference profiles and preference structures are introduced. Formal mathematical representations for both concepts are provided.

    (b) The four basic solution concepts from standard GMCR: *Nash*, *GMR*, *SMR*, and *SEQ* are redefined for Inverse GMCR as *Nash IPS*, *GMR IPS*, *SMR IPS*, and *SEQ IPS*, respectively.

3. A comprehensive DSS with advanced reporting features, GMCR+, is designed, built, and illustrated in Chapter 6.

    (a) GMCR+ was built from scratch to handle standard GMCR analysis as the root of its analysis engine. It has all the relevant capabilities of its predecessor, GMCR II, with additional features and functionality including:

        i. Intransitive preference handling.

        ii. Individual stability explanation.

        iii. Categorization of equilibria by option selection and sorting feature.

        iv. Interactive graphs with UI differentiation.

        v. Multi-level tree diagrams with interactive status quo analysis.

        vi. Advanced coalition analysis with graphing feature.

        vii. Post-analysis and goal-seeking capabilities.

    (b) Conflict specification within GMCR+ branches into objects and attributes. The root of any conflict model is the option object(s). Other objects within GMCR+ include condition objects, DM objects, and coalition objects. Each object contains all of the defining attributes.

    (c) Data processing and algorithms used within GMCR+ are discussed and illustrated using pseudocodes and examples.

    (d) GMCR+ has four analysis engines, referred to as 'solvers', that address different types of problems. The logical solver is derived from the basic definitions of the standard GMCR methodology. The matrix solver is a computational enhancement to the logical solver proposed by Xu et al. (2007). The inverse solver and the goal seeker are both based on the new Inverse GMCR methodology given in this research.

4. The methodology introduced and the new DSS, GMCR+, were applied to a wide range of real world conflicts including a complex water conflict along the Euphrates River in the Middle East, an environmental conflict in Elmira, Ontario, Canada, and the international Cuban Missile Crisis.

7.2 Future Work

Reverse engineering the GMCR methodology for simple preferences using Inverse GMCR is the first step towards negotiation modeling within the framework of GMCR. Many recent and ongoing expansions within the GMCR structure may be integrated with the new Inverse GMCR methodology. Research opportunities that can be considered for future studies are as follows:

1. Research on preference approaches within the framework of GMCR can be incorporated into the new Inverse GMCR methodology. These approaches include the research on strength of preferences (Hamouda et al., 2004, 2006), preferences uncertainty (Li et al., 2004a), fuzzy preferences (Bashar et al., 2012; Hipel et al., 2011) and grey-based preferences (Kuang et al., 2013).

2. Determining a target equilibrium state could be a challenging task, especially in

complex conflicts. A methodology to advise mediators on possibilities for a target state may be an important project.

3. In the standard graph model, multiple equilibria may cause uncertainty. Coalition analysis (Kilgour et al., 2001) can be used to reduce the number of possible equilibria. Status-quo analysis (Li et al., 2004b) may show that an equilibrium is unreachable, in theory or in practice. Additional research is needed to integrate these methodologies within Inverse GMCR.

4. Research on misperceptions (Wang et al., 1988; Fraser et al., 1990) can be investigated and possibly incorporated into the standard GMCR. Further research could integrate misperceptions with Inverse GMCR.

5. Various third party roles and strategies are investigated and presented in Chapter 2 of this thesis. A methodology is needed to advise a mediator on the best role and strategy to undertake in any particular conflict situation.

6. There are recent and ongoing expansions of the GMCR methodology which can be conveniently incorporated into GMCR+ due to its modular design. A research project to incorporate these advancements would enhance the GMCR+ system. These expansions include:

    - Strength of preference (Hamouda et al., 2004, 2006).
    - Uncertain preferences (Li et al., 2004a).
    - Fuzzy preferences (Bashar et al., 2012; Hipel et al., 2011).

- Grey-Based preferences (Kuang et al., 2013).
- Policy stability (Zeng et al., 2004).
- Attitudes (Walker et al., 2008).
- Hypergames (Bennett, 1980; Wang et al., 1988).

7. GMCR+ uses a dense reachability matrix, which is created in memory. This creates a memory restriction limiting the models that can be analyzed by the available RAM. Moving to dynamically generated reachabilities could eliminate this restriction to analyze larger conflict models.

8. Although GMCR+ can theoretically handle intransitive preferences, there has not been an adequate way to represent them graphically in the user interface (GUI). Therefore, the design of a suitable representation for intransitive preferences may be an important future project.

APPENDICES

Appendix A

Complete User's Manual for GMCR+

A Simple Guide to

GMCR+

by Rami Kinsara

Contents

A Simple Guide to GMCR+[1]

By Rami A. Kinsara

Last Updated: October 15, 2014

[1] Holders of GMCR+ copyright are Rami A. Kinsara, Oskar Petersons, Keith W. Hipel, and D. Marc Kilgour

This document is intended as a short and simple guide to using GMCR+. Although GMCR+ was built to be intuitive and user-friendly, this guide aims at maximizing the benefits from this advanced decision support system. The approach in designing this guide is to be succinct by maximizing illustrations and avoiding unnecessary details. Since Microsoft Windows® is the most common operating system, it will be used for explanation purposes. However, the illustrations shown can be navigated on other operating systems as well.

1 *Installation*

You can download GMCR+ from its official website. Simply navigate to the URL: `http://www.gmcrplus.com` and click *Download* on the main page. After downloading the installation package, simply double click the installation file. You will face a typical installation welcome screen where you can modify the default installation path. Clicking next will install GMCR+ and you are all done.

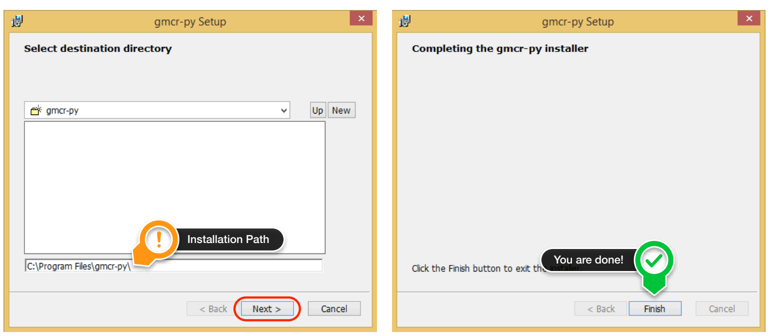


Figure 1: Installation Wizard Windows. *Notice that this process requires only two simple clicks*

After installation is completed, you will find a shortcut icon on your desktop as shown in Figure 2.

Figure 2: You will find a link to GMCR+ on your desktop

2 *Starting GMCR+ and the Main Screen*

Double clicking the GMCR+ icon (Figure 2) will start GMCR+ and a new conflict model is loaded as shown in Figure 3.

Figure 3: Main GMCR+ Screen.

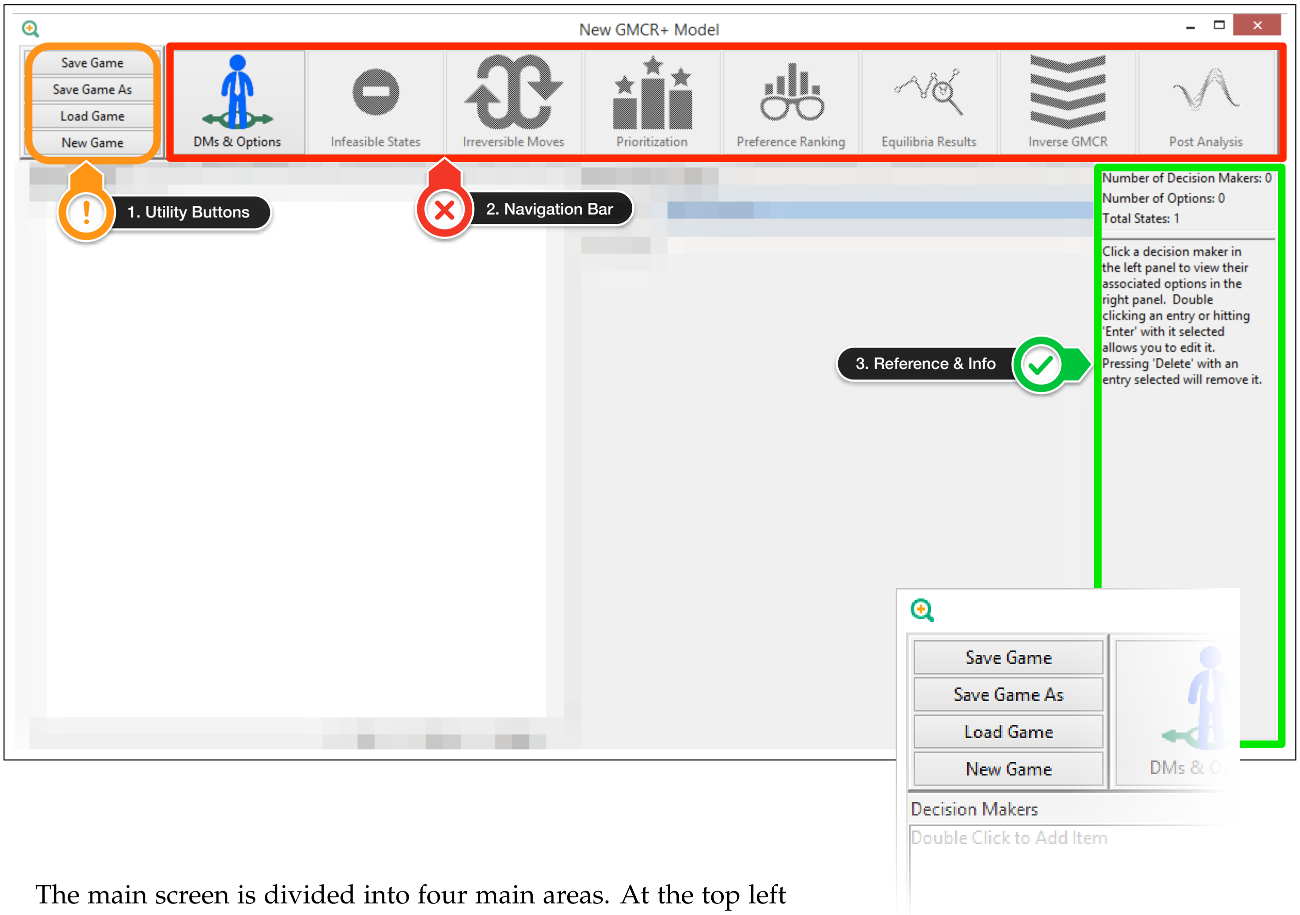


Figure 4: Standard Utility Buttons.

The main screen is divided into four main areas. At the top left of the screen, the user can find standard utility buttons to load, save, and create new conflict models (Figure 4). The top of the screen contains a large navigation bar (Figure 5). This bar displays each of the logical steps in the modeling of a conflict, and allows the user to easily move between them. The active stage button is colored while the other buttons are dimmed.

Figure 5: Main Navigation Bar. *Notice that each modeling step is referred to as button in the main navigation bar*

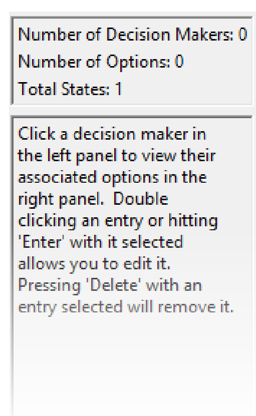


Figure 6: Quick Reference and Info Area.

Along the right edge of the screen, a column provides a quick reference about how to use the interface for the current stage of the modeling process (Figure 6). The remainder of the screen is used to display and edit information related to the active stage of the modeling process.

3 Modeling Conflicts with GMCR+

For the sake of making this guide practical, an actual conflict will be analyzed in the process of explaining the functions of GMCR+. The conflict that took place in 1975 between Syria and Iraq over the Euphrates River will be analyzed. For a detailed historical background and analysis for this conflict and other related conflicts along the Euphrates, please refer to the work done by Hipel et al. [2].

[2] Keith W Hipel, D Marc Kilgour, and Rami A Kinsara. Strategic investigations of water conflicts in the middle east. *Group Decision and Negotiation*, 23(3): 355–376, 2014

3.1 Inputting DMs and Options

Make sure you are located in the *DMs & Options* screen by clicking on its button (Figure 7). The DMs and options for the Syria-Iraq conflict are given in Table 1.

Table 1: DMs, options and descriptions for the Syria-Iraq conflict. *For when an option is taken (Y for yes) or not selected (N for no)*

DM	Option		Description
Syria	1. Release Water	**Y**	Syria agrees to halt the filling of Thawra Dam and let the Euphrates flow into Iraq
		N	Syria continues to fill its dam
	2. Escalate	**Y**	This could be done by cutting relations with Iraq, sending troops to the shared border, closing the air space to Iraqi aircraft, or any combination of these actions
		N	Syria does not undertake any of the escalating options
Iraq	3. Attack	**Y**	This includes bombing of the dam and going to war with Syria
		N	Iraq does not act and accepts the situation

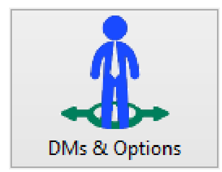
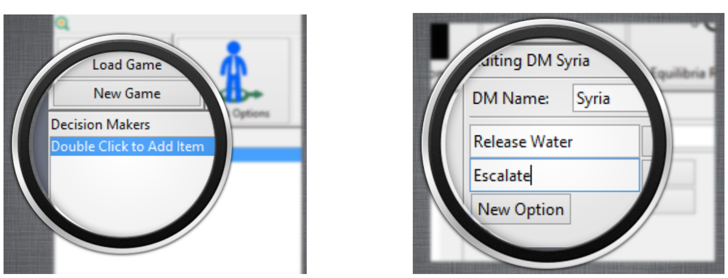


Figure 7: DMs & Options Button.

Start adding Syria as a DM by double clicking on *"Double Click to Add an Item"* at the left of the screen (Figure 8a). Once you double click, the middle screen becomes active and you can type the DM's name (Figure 8b). *New Option* button allows you to add options to the active DM. As you can see, the two options of Release Water and Escalate for Syria have been added. Do the same for DM Iraq.



(a) (b)

Figure 8: (a) Adding DMs. (b) Editing DM's Name and Adding Options.

After inputting all DMs and options, you can see the full list of DMs in the conflict to the left of the screen. Clicking on a DM's name will select it and display the DM's associated options in a list to the right. While a DM or option is selected, it can be deleted, or its name can be modified. Buttons at the bottom of the screen allow the order of DMs to be changed or a DM deleted (Figure 9). The information panel at the right edge of the screen displays the number of DMs already defined, the options, and the total number of states that would be in the game if no infeasible states were removed.

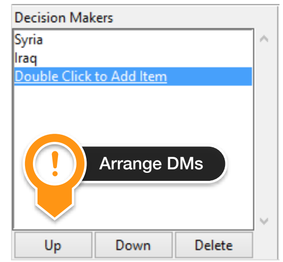


Figure 9: Buttons for Arranging and Deleting DMs.

3.2 *Removing Infeasible States*

After defining DMs and options, GMCR+ will generate a list of all possible states. There are usually infeasible states that must be removed from the conflict model. In order to do that, navigate to the *Infeasible States* screen (Figure 10).

Figure 10: Infeasible States Button.

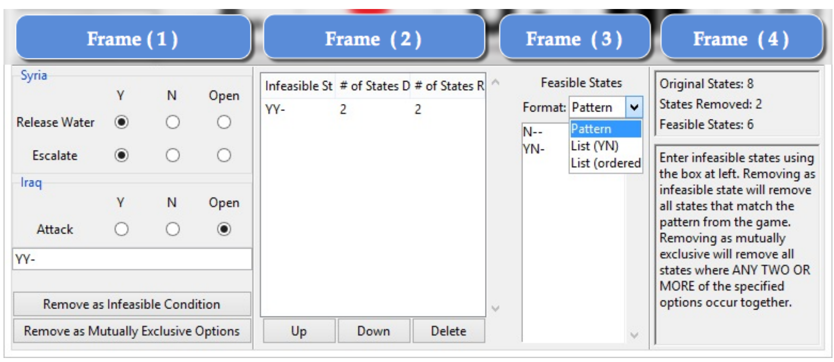


Figure 11: Infeasible States Removal Screen.

The panel to the left (Frame 1 in Figure 11) contains a set of toggle buttons where option selections can be made to specify an infeasible condition. Clicking *"Remove as Infeasible Condition"* will remove all states satisfying this condition from the conflict model and display the infeasible condition along with the number of removed states in the middle of the screen (Frame 2 in Figure 11). Clicking *"Remove as Mutually Exclusive Options"* generates a list of conditions prohibiting any states where two or more of the chosen option selections are taken. In the Syria-Iraq conflict, there is one infeasible situation in which Syria both releases the water and escalates the situation at the same time (mutually exclusive options). Inputting this pattern generates two infeasible conditions as shown in Figure 11. The remaining feasible states can be viewed in different formats as illustrated in Frame 3 of Figure 11. The set of feasible states can be displayed either as a list of feasible conditions, as a full list of feasible states in YN format, or as ordered and decimal state numbers. Finally, Frame 4 of Figure 11 is an informational panel displaying the original number of states in the conflict, the number of states removed, and the number of feasible states remaining. Below is a brief set of instructions for using the *Infeasible States* screen.

3.3 *Specifying Irreversible Moves*

In order to specify the reversibility of options, navigate to the *Irreversible Moves* screen (Figure 12).

By default, all options in the conflict are displayed with a two-headed arrow pointing between 'Y' and 'N' denoting that all moves are reversible (Figure 13). Clicking the arrow toggles the direction of reversibility. This way, the user or analyst can leave the option as reversible, or define the direction of irreversibility. For the case of Syria-Iraq conflict, all moves are assumed to be reversible.

Figure 12: Irreversible Moves Button.

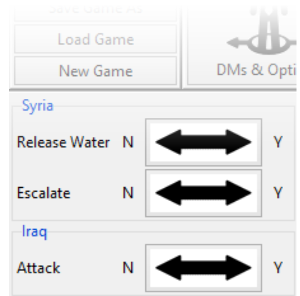


Figure 13: Irreversible Moves Screen.

3.4 *Inputting Preferences Using Option Prioritization*

Preferences for DMs can be specified through preferred conditions or through direct ranking of states. The preferred conditions method allows you to define preference prioritization conditions to make the ranking of states easier and more intuitive. Direct ranking, on the other hand, allows you to fine tune the results from prioritization or assumes that you are certain about the ranking of states for each DM. In order to input preferences using prioritization, navigate to the *Prioritization* screen (Figure 14).

Table 2: Preference Prioritization Information for the Syria-Iraq Conflict.

DM	P#	Preference Information (From most to least important)	Further Explanation
Syria	1	Remain at the status quo	Syria continues filling its dam and Iraq accepts the situation without any escalation or intervention
	2	Escalate the situation if Iraq decides to attack	Syria next prefers going to war with Iraq if it is attacked, which is more preferred than releasing water
Iraq	1	Syria releases more flow of the Euphrates River	Iraq most prefers the situation in which Syria stops filling its dam without any escalation
	2	Execute an attack if Syria does not release more water	Iraq's interest in water far outweighs the consequence of going to war

The panel to the left of the *Prioritization* screen contains all DMs and their corresponding preference rankings as shown in Frame 1 of Figure 15 is a table with all . Clicking *Edit* next to any DM will change its color to green and allow the preferences for that DM to be modified. A user can click *"Done"* to clear the DM selection. Frame 2 of Figure 15 includes toggle buttons for all DMs and their options. In order to add a preferred condition, simply make option selections (current toggle selection is shown in 'YN' format at the bottom bar *Balloon A* of Frame 2). Then, you can either add them directly as a preferred condition (Frame 4) or move them to a staging area (Frame 3) where multiple conditions can be added together with

Figure 14: Prioritization Button.

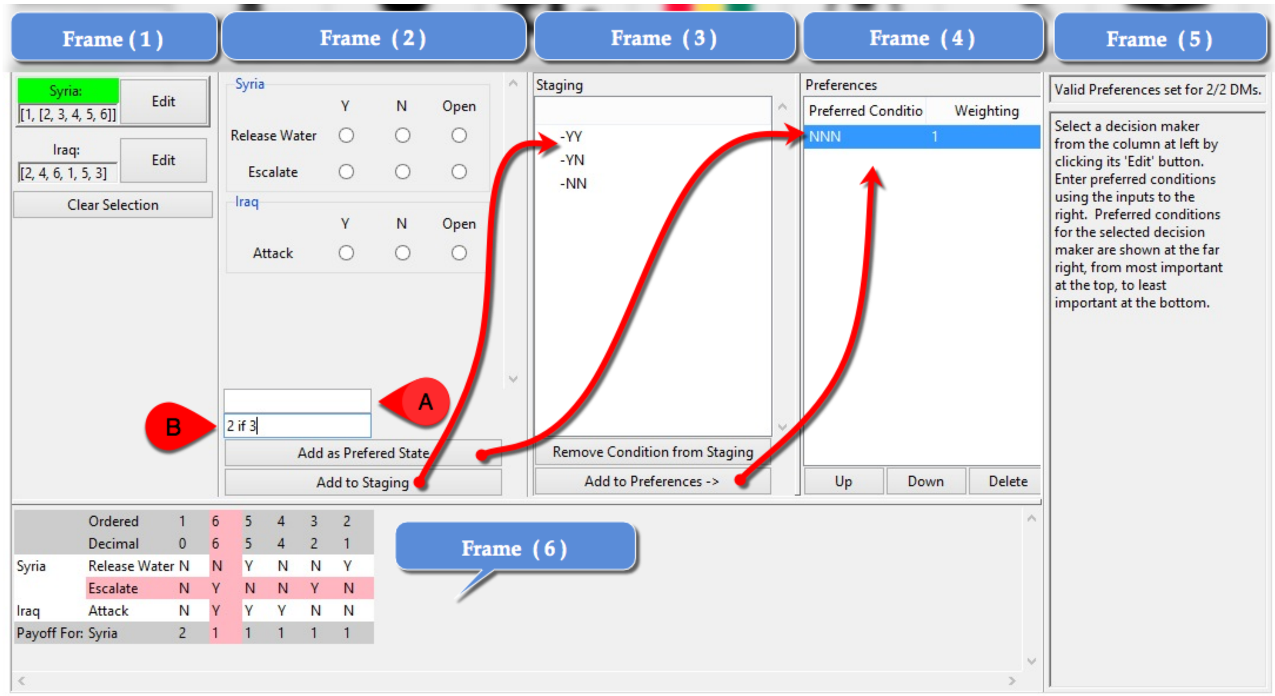


Figure 15: Prioritization Screen.

equal weight. Moreover, you can add conditions using logical statements via the input bar at the bottom of Frame 2 as shown in Balloon B. *IF* and *IFF* logical statements are allowed to speed the preferences input process. Simply type *if* or *iff* between the option numbers (positive for Y) and (negative for N), see below.

Table 2 presents the preference prioritization information for each DM in the Syria-Iraq conflict. The first preference statement for Syria is to remain at the status quo. Therefore, you should choose 'N' across all options to indicate the status quo, then you simply click *"Add as Preferred State"*. The second statement for Syria is to *Escalate* if DM Iraq *Attack*s. This information is entered using the logical statement input bar by typing "`2 if 3`" then you can add it directly as a preferred state. Suppose the statement was *Don't release water if Iraq attacks*, then the logical statement would be "`-1 if 3`" and so on. If the syntax entered is invalid, you will receive an error message next to the input bar.

Frame 4 of Figure 15 displays the preferred conditions for the selected DM and the weights associated with those conditions. Frame 5 displays a prompt ensuring preferences are valid and below that is a quick reference guide for using the *Prioritization* screen. Finally, a large table displaying the conflict in option form occupies the bottom of the screen as shown in Frame 6 of Figure 15. A pink indicator follows the mouse to highlight the selected row and column. The states are ordered according to their ranking for the active DM. The table also displays the ordinal payoff value of each state according to the active DM. If no DM is selected, the states are ordered based on state number and payoff values for all DMs will be shown.

3.5 *Inputting Preferences Using Preference Ranking*

Figure 16: Preference Ranking Button.

In order to fine tune or input preferences information directly, navigate to the *Preference Ranking* screen (Figure 16). At the top of Frame 1 in Figure 17 is a large button entitled *"Press to enable manual preference ranking changes"* which allows you to enable the screen when clicked. Then you can start modifying the preference rankings shown for the DMs in the fields below (Balloon (B) of Frame 1 in Figure 17). States are listed using their ordered numbers, and equally preferred states can be indicated by enclosing them in square brackets. In the middle of the screen (Balloon C of Frame 1), a large text box displays feedback on the validity of the entered preference rankings. Each preference ranking must contain each state once and only once to be considered valid. At the bottom of the screen (Balloon D of Frame 1), an option form table for the conflict is shown, similar to that on the *Preference Prioritization* screen. If you wish to revert to the preferences of the *Preference Prioritization* screen, you can return to the *Preference Prioritization* screen and click the large button that appears at the top of the screen.

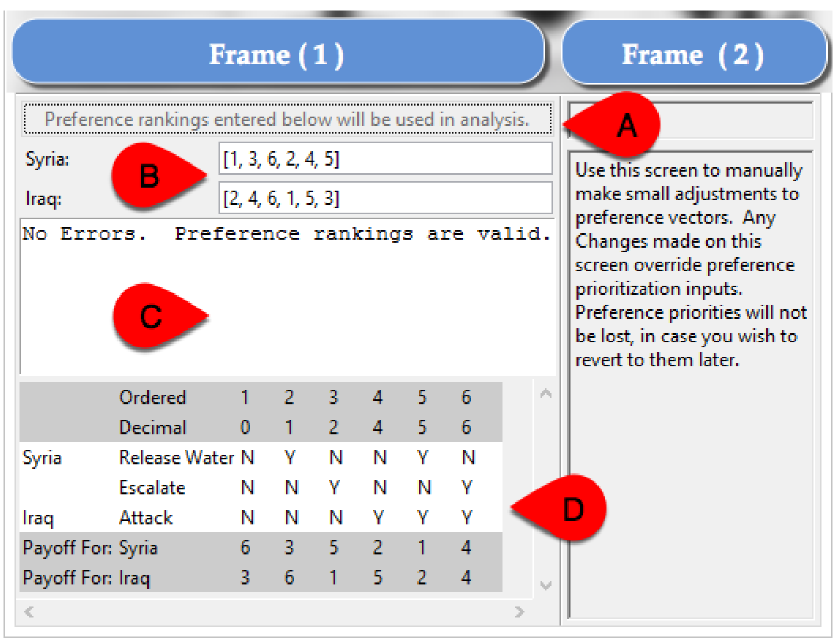


Figure 17: Preference Ranking Screen.

DM	States					
Syria	1	3	6	2	4	5
Iraq	2	4	6	1	5	3
	Most Preferred				*Least Preferred*	

Table 3: Ranking of States for the DMs in the Syria-Iraq Conflict.

Table 3 presents the ranking of states for the Syria-Iraq conflict from most to least preferred for both DMs. This information can be easily entered into the input bars corresponding to each DM. For Syria enter `[1, 3, 6, 2, 4, 5]` and for Iraq enter `[2, 4, 6, 1, 5, 3]`.

At this point, make sure you have saved the conflict model using the standard save button (Figure 4). Now that you have a graph model, we will guide you through the analysis functionality of GMCR+ in the next section.

4 *Analyzing Conflicts with GMCR+*

In this section, the different analyses and output representation capabilities of GMCR+ are illustrated.

4.1 *Equilibria Results and Visualizer*

In order to display equilibria results, navigate to the *Equilibria Results* screen (Figure 18). The top of Frame 1 in Figure 19 shows the option form table for the conflict. Below that you can see equilibria calculation results for all states and solution concepts. You can filter the results, which is handy in large conflicts, using the toggle buttons (Balloon B of Frame 1). Results can also be ordered according to each DM's preferences. You examine the equilibria for coalitions by merging possible coalitions in square brackets in the bar to the top of the screen (Balloon A of Frame 1). Frame 2 of Figure 19 is the narration panel, which allows you to check for individual stability by selecting a DM, state, and solution concept; then the process used to determine that individual stability or instability is explained. At the bottom of Frame 1 (Balloon C), the option to launch a visualizer will draw the graphs in a separate screen.

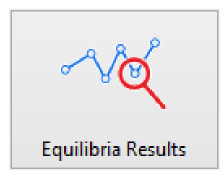


Figure 18: Equilibria Results Button.

Notice that Figure 19 shows equilibria results for the Syria-Iraq conflict and the results are sorted according to Syria's preferences. Click on "*Launch Visualizer*" to launch a web application within the GMCR+ system allowing you to see the actual graph of the conflict model as shown in Figure 20. The default view is a status quo analysis tree diagram. The top of the tree denotes the status quo and the

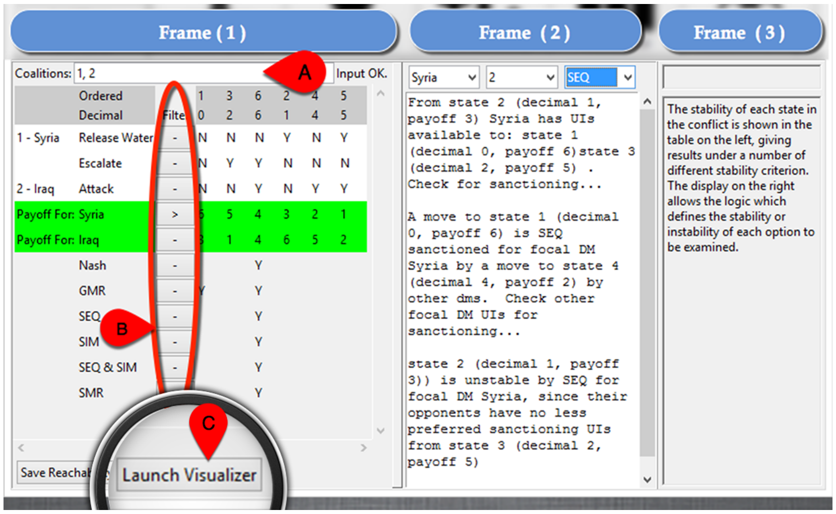


Figure 19: Equilibria Results Screen. *Note that* ***Nash*** *stands for Nash stability,* ***GMR*** *for general metarationality,* ***SMR*** *for symmetric metarationality, and* ***SEQ*** *for sequential stability. Simultaneous stability (****SIM****) examines the strategic impact of two or more DMs moving together at the same time from a given state*

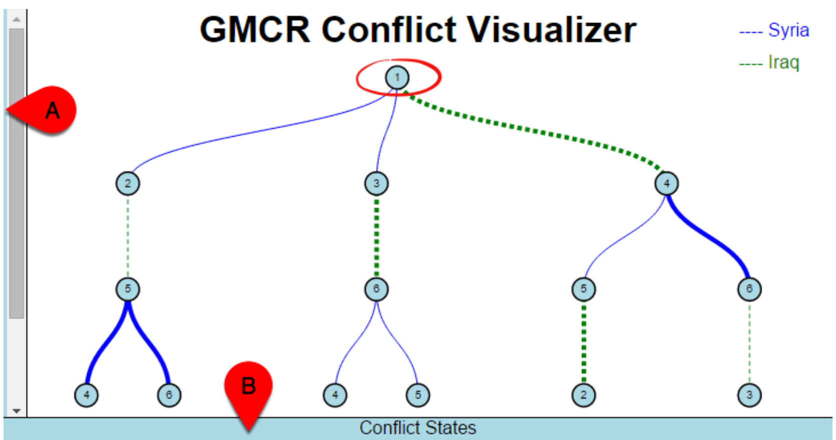


Figure 20: Default Visualizer Screen. *Notice that it is the tree diagram*

branches are the possible unilateral moves from that state by each DM. Lines are color- and dash-coded for each DM. Hovering the mouse on any state shades all circles with that state within the tree. Hovering the mouse at the bottom of the screen (Balloon B of Figure 20) displays an option form table for the conflict model. Hovering the mouse to the left of the screen (Balloon A of Figure 20) shows the display options panel as shown in Figure 21. This panel allows you to change the display method between a tree and a graph diagram (See A in Figure 21). Switching to the graph diagram mode will show the actual graph model for the conflict at hand as shown in Figure 22. In the *Display Options* panel, Differentiating or showing UIs only can be achieved from the *Display Configuration* area as shown in Balloons B and C of Figure 21. Other configurations include adjusting the tree depth and the shape of connections in the graph diagram. The options shown in the area of Balloon D in Figure 21 allow you to select a specific DM(s) to see individual graphs instead of integrated ones.

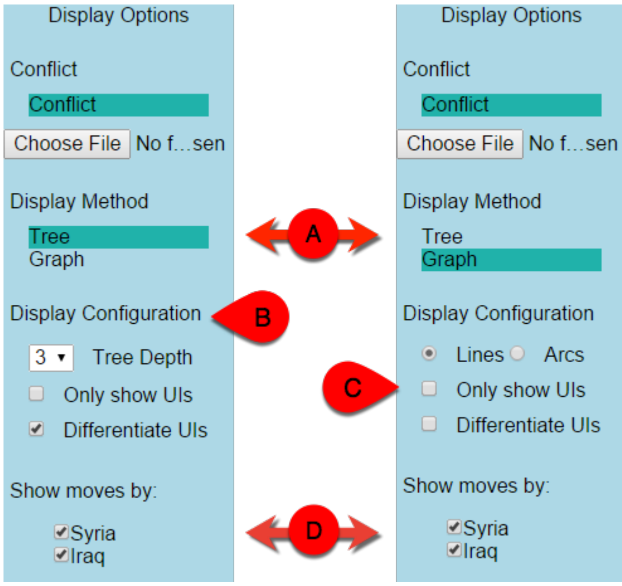


Figure 21: Display Options Panel for Tree and Graph Diagrams

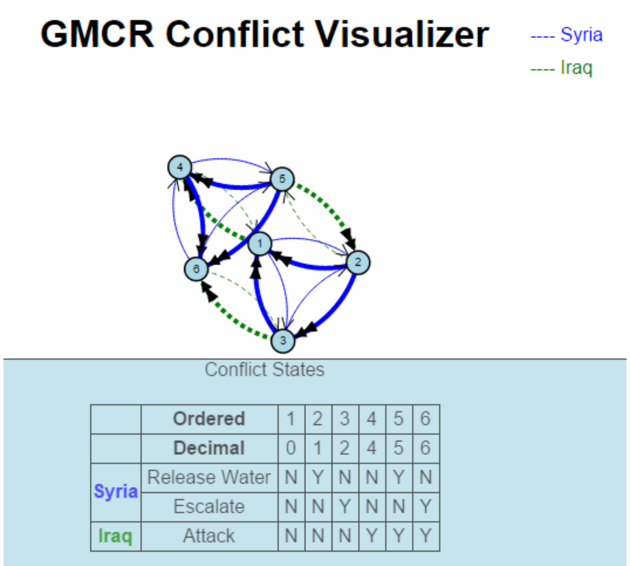


Figure 22: Conflict Model Graph Diagram

4.2 *Inverse GMCR*

In order to perform Inverse GMCR analysis, navigate to the *Inverse GMCR* screen (Figure 23). Frame 1 of Figure 24 contains the control panel. This control panel allows you to specify a desired equilibrium state (Balloon A). Furthermore, you can select a preference variance range for each DM and then perform the Inverse GMCR calculations

Figure 23: Inverse GMCR Button.

(Balloon B). Frame 2 explains the conditions required to achieve the desired stability according to each solution concept. Long form results can be displayed on the bottom of Frame 2 by selecting to display all permutations in the control panel (Balloon C) and can be filtered by the solution concepts check boxes (Balloon D). This is a useful addition allowing you to perform extensive sensitivity analysis on preferences.

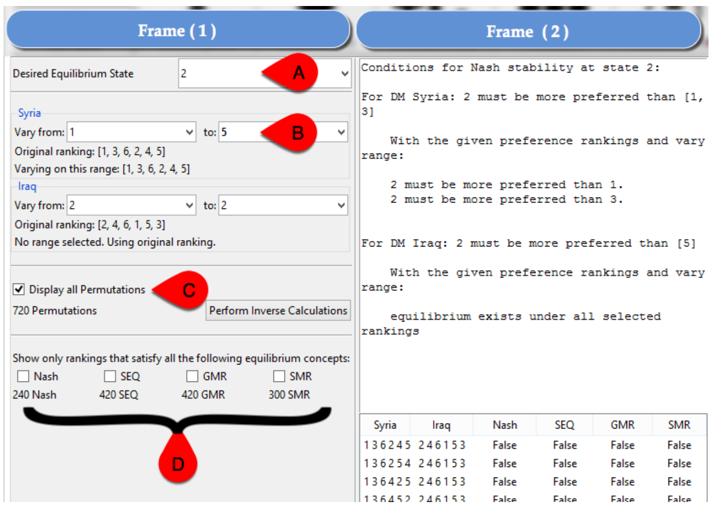


Figure 24: Inverse GMCR Screen.

For the Syria-Iraq conflict, a more desired resolution would be state 2 in which both Syria and Iraq stop escalating and water is released to Iraq. Choose state 2 as a desired equilibrium, make sure you specify the variation range for Syria then click on *"Perform Inverse Calculations"*. You will see that 240 and 420 possible preference profiles can achieve the desired resolution according to Nash and SEQ solution concepts, respectively. In Frame 2 of Figure 24, you can see the explanation as follows:

1. **Nash Stability:** if and only if Syria prefers state 2 to states 1 and 3.
2. **Sequential Stability:** if and only if Syria prefers state 2 to states 1 and 3. *OR*
   (a) if Iraq prefers state 4 to state 1, then Syria must have state 4 less preferred than 2.
   (b) or if Iraq prefers state 6 to state 3, then Syria must have state 6 less preferred than 2.

4.3 *Post Analysis*

To carry out more advanced post analysis functions, navigate to the *Post Analysis* screen (Figure 25). In this screen you can specify coali-

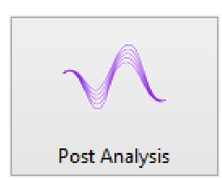


Figure 25: Post Analysis Button.

tions within the control panel (Balloon A in Frame 1 of Figure 26) similar to the way illustrated in the *Equilibria Results* screen mentioned in Section 4.1. In addition, you can choose a specific state to act as a status quo for the conflict and carry out the analysis from it. Frame 2 will automatically show the selected state as the top of the tree with a '+' sign to expand the branch at Frame 2 in Figure 26. Clicking the '+' sign expands the branch into reachable states and UIs are shaded green. This feature allows you to know if a possible equilibrium is reachable from the status quo and whether it is reachable solely by UIs. This information is also given in the narration panel to the right of the screen (Frame 3).

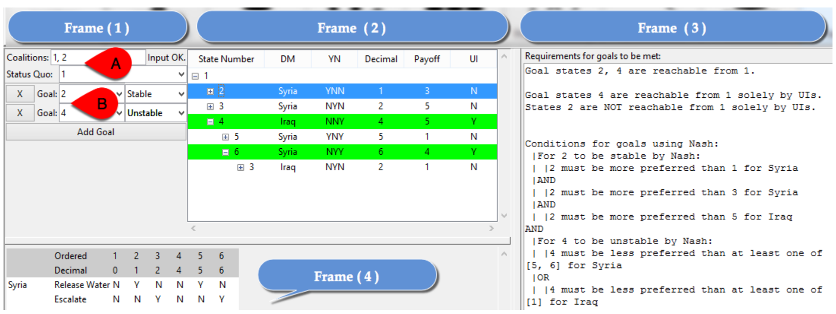


Figure 26: Post Analysis Screen.

The tool highlighted in Balloon B of Frame 1 in Figure 26 is called the *Goal Seeker*, which is an extensive version of the *Inverse GMCR*. You can experiment with different scenarios by setting particular states to be stable while setting other states to be unstable. Whether these choices are possible or not is explained in Frame 3 and how they can be achieved if possible is narrated as well. Frame 4 contains the conflict table in option form for your convenience.

5 *Highlights of GMCR+ Capabilities through Examples*

In this section, you will learn about distinct GMCR+ features through various built-in examples. GMCR+ comes with ready-made examples that are accessible from the standard utility button *"Load Game"* as shown in Figure 27. The file extension for all games modeled with GMCR+ is `.gmcr`. Built-in examples include:

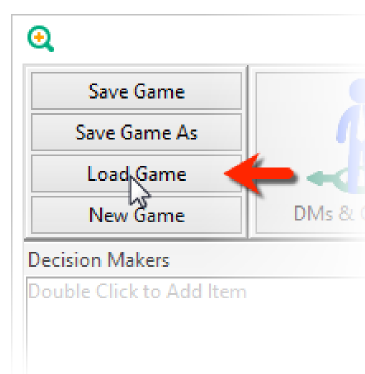


Figure 27: Load Utility Buttons.

- Prisoners' Dilemma (`Prisoners.gmcr`).
- The Cuban Missile Crisis (`Cuban.gmcr`).
- The Elmira conflict (`Elmira.gmcr`).
- The Garrison Diversion Unit (GDU) (`Garrison.gmcr`).
- The Syria-Iraq conflict (used earlier in this guide) (`SyriaIraq.gmcr`).

5.1 *Equilibria Filtering*

Load the GDU model by clicking on *"Load Game"* and opening `(Garrison.gmcr)` file. Navigate to the *Equilibria Results* screen (Figure 18). The filtering feature mentioned briefly in Section 4.1 is a very handy tool for large conflicts such as the GDU conflict [3]. This conflict has 23 feasible states, which may be challenging to keep track of. But using the filtering feature, it is easy to navigate through the relevant states. Assume that you are interested only in states in which *U.S. Support* does not proceed to complete full GDU and that are at least *GMR* stable. You can achieve this by clicking the toggle button in front of each option (Ballon A in Figure 28). You can then sort the results according to *U.S. Support* from most to least preferred by clicking in front of its payoff (Ballon B in Figure 28).

[3] Keith W. Hipel and Niall M. Fraser. Metagame analysis of the garrison conflict. *Water Resources Research*, 16(4): 629–637, 1980. ISSN 1944-7973

	Ordered		2	8	11	15	13	17	19	21
	Decimal	Filter	36	58	74	90	84	148	154	276
1 - US Support	Full	N	N	N	N	N	N	N	N	N
	Reduced	-	N	Y	Y	Y	N	N	Y	N
	Appease	-	Y	N	N	N	Y	Y	N	Y
2 - US Opposition	Legal Challenge	-	N	Y	Y	Y	N	N	Y	N
3 - Canadian Opposit	Treaty Challenge	-	N	Y	N	Y	Y	Y	Y	Y
4 - IJC	Full	-	Y	Y	N	N	N	N	N	N
	Reduced	-	N	N	Y	Y	Y	N	N	N
	Lonetree	-	N	N	N	N	N	Y	Y	N
	Suspend	-	N	N	N	N	N	N	N	Y
Payoff For:	US Support	>	21	18	15	14	12	10	7	6
Payoff For:	US Opposition	-	23	19	20	21	23	23	22	23
Payoff For:	Canadian Opposition	-	15	12	19	17	16	20	21	22
Payoff For:	IJC	-	23	23	23	23	23	23	23	23
	Nash	-	Y		Y			Y		Y
	GMR	Y	Y	Y	Y	Y	Y	Y	Y	Y
	SEQ	-	Y		Y			Y		Y
	SIM	-	Y		Y			Y		Y
	SEQ & SIM	-	Y		Y			Y		Y
	SMR	-	Y	Y	Y	Y	Y	Y	Y	Y

Figure 28: GDU Equilibria Filtering.

5.2 *Coalitions*

The Elmira conflict [4] is an environmental case that demonstrates the power of *Coalitions*. Load the Elmira model by clicking on *"Load Game"* and opening `(Elmira.gmcr)` file. Navigate to the *Equilibria Results* screen (Figure 18). As you can see in Figure 29, state 7 is an equilibrium, indicating that the conflict will be deadlocked at this

[4] Rami A. Kinsara, D. Marc Kilgour, and Keith W. Hipel. The inverse approach to conflict resolution in environmental management. *Group Decision and Negotiation*, pages 224–231, June 2014

state. However, if a coalition is formed, the situation will change. Modify the coalitions bar to be `Coalitions:[1,2],3` indicating a coalition between *MoE* and *Uniroyal* instead of the original unilateral game with `Coalitions:1,2,3` (Balloon A in Figure 30).

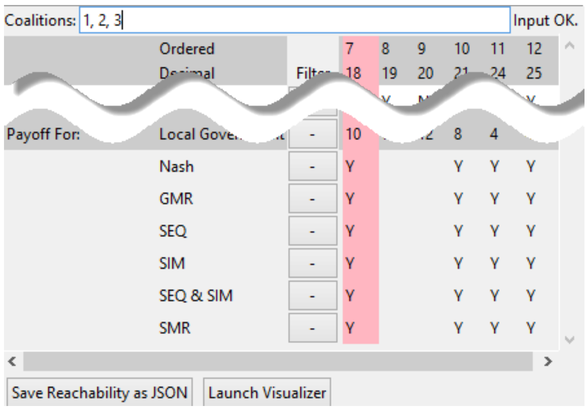


Figure 29: Original Elmira Equilibria.

Notice that members of the coalition are enclosed between square brackets. If the format is incorrect, you will see a prompt `Invalid Syntax` or `Missing DMs` in Balloon B of Figure 30. As you can see, state 7 is no longer an equilibrium. The following section highlights the significance of this information with the use of interactive status quo analysis.

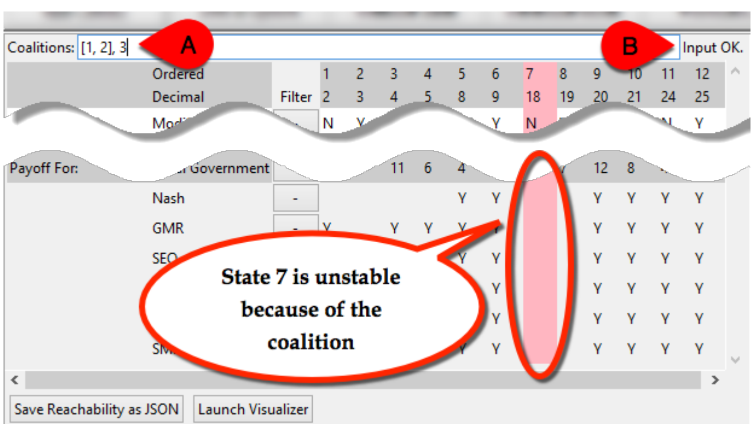


Figure 30: Elmira Equilibria with Coalition.

5.3 *Interactive Status Quo Analysis*

GMCR+ system is equipped with two different interfaces to carry out status quo analysis. Following up with the aforementioned Elmira conflict; while you are in the *Equilibria Results* screen (Figure 30), click on *"Launch Visualizer"*. A web application will start loading the tree diagram of the conflict as depicted in Figure 31. Notice that, since the model has defined coalitions, the tree diagram treats the coalition as an individual *Entity* represented by a single line (Figure 31 has the coalition marked with a solid blue line). If you checked the *Differentiate UIs* box within the *Display Configuration* on the left, you can see bold lines indicating UIs. From the status quo, state 1, the *Local Government* has a UI to state 7, from which the coalition, *MoE* and *Uniroyal*, has a UI to state 10. Prior to the coalition, there were no possible moves from state 7 to state 10.

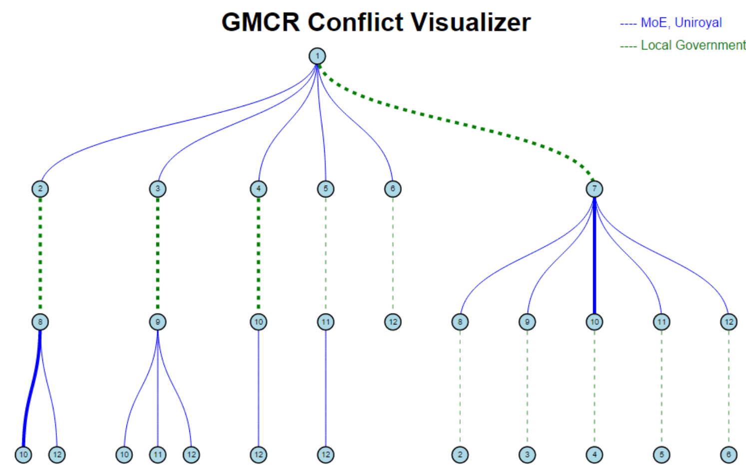
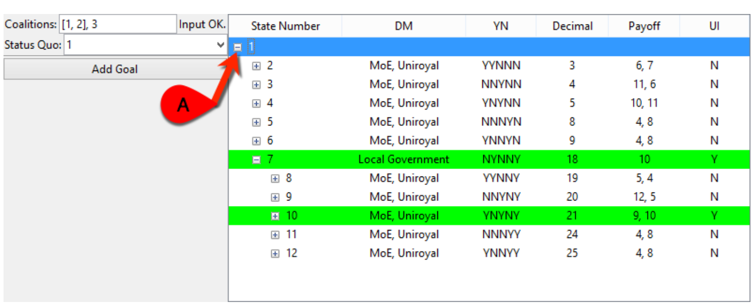


Figure 31: Elmira Tree Diagram with Coalition.

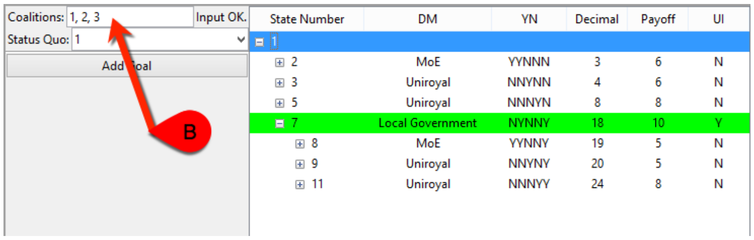
Another way of conducting status quo analysis is by navigating to the *Post Analysis* screen (Figure 25). Click on the (+) sign as shown by Balloon A in Figure 32 to expand the tree from the status quo, which in this example is state 1. As you can see, there is only one UI available, which is by the *Local Government* highlighted in *green*. Expanding this node reveals the five possible moves from state 7, of which only one is a UI that can be carried out by the coalition (*MoE* and *Uniroyal*).



State Number	DM	YN	Decimal	Payoff	UI
1					
2	MoE, Uniroyal	YYNNN	3	6, 7	N
3	MoE, Uniroyal	NNYNN	4	11, 6	N
4	MoE, Uniroyal	YNYNN	5	10, 11	N
5	MoE, Uniroyal	NNNYN	8	4, 8	N
6	MoE, Uniroyal	YNNYN	9	4, 8	N
7	Local Government	NYNNY	18	10	Y
8	MoE, Uniroyal	YYNNY	19	5, 4	N
9	MoE, Uniroyal	NNYNY	20	12, 5	N
10	MoE, Uniroyal	YNYNY	21	9, 10	Y
11	MoE, Uniroyal	NNNYY	24	4, 8	N
12	MoE, Uniroyal	YNNYY	25	4, 8	N

Figure 32: Elmira Status Quo Analysis with Coalition.

Try removing the coalition by simply removing the square brackets from the *coalition bar* as shown by Balloon B in Figure 33. Expanding the status quo tree reveals that only one UI to state 7 is available and no moves can be made to state 10 by any DM unilaterally.



State Number	DM	YN	Decimal	Payoff	UI
1					
2	MoE	YYNNN	3	6	N
3	Uniroyal	NNYNN	4	6	N
5	Uniroyal	NNNYN	8	8	N
7	Local Government	NYNNY	18	10	Y
8	MoE	YYNNY	19	5	N
9	Uniroyal	NNYNY	20	5	N
11	Uniroyal	NNNYY	24	8	N

Figure 33: Elmira Status Quo Analysis without Coalition.

6 *Visualizer and JSON Files*

An advanced feature of GMCR+ is the ability to export the *Java Script Object Notation* (JSON) file of the conflict. A JSON file contains the conflict description including DMs, options, coalitions, reachability matrix, and ordinal payoffs. This file can be easily imported into GMCR+ visualizer. Say you want to share or communicate a conflict model, simply navigate to the *Equilibria Results* screen (Figure 18) and click on *Save Reachability as JSON* (Figure 34). You can then import the conflict model into any computer (even if it does not have GMCR+ installed) by opening your web browser and navigating to the URL: `http://gmcr.rkinsara.com`. Once you open this URL, you will see a *GMCR Conflict Visualizer* web application with a default tree diagram of the *Prisoners' Dilemma* game. Hovering the mouse to the left of the screen (Balloon A of Figure 36) will reveal the *Display Options* panel where you can click the *Choose File* button to import the JSON file as shown in Figure 35.

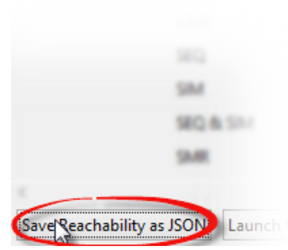


Figure 34: Exporting a Conflict Model as JSON.

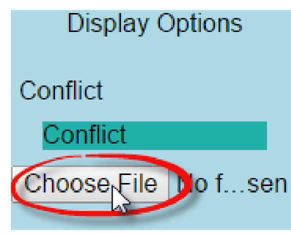


Figure 35: Importing a Conflict Model into the Visualizer.

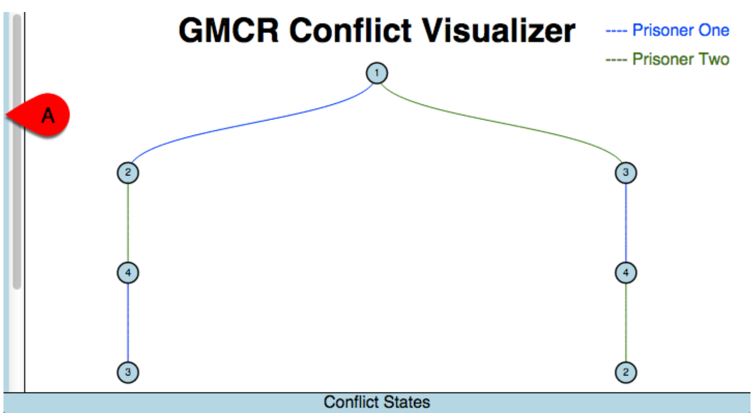


Figure 36: GMCR+ Visualizer Web Application .

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