Group Decision and Negotiation, 5:371–383 (1996)

Negotiation Support Using the Decision Support System GMCR

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Abstract

The Graph Model for Conflict Resolution constitutes a unique and flexible approach to the representation, analysis, and understanding of strategic conflict. This methodology, as implemented in the Decision Support System GMCR, constitutes a useful tool for negotiation support. Because GMCR includes efficient algorithms for calculating the stability of states, it encourages extensive comparisons of the consequences of different models of negotiators' decision making. GMCR also facilitates modifications to the way in which the conflict is represented, encouraging sensitivity and what-if analyses. The applicability of GMCR to negotiations is discussed in general, and in the context of a specific case study in environmental conflict resolution.

Key words: conflict resolution, decision support system, environmental conflict, graph model, negotiation support, negotiations

1. Introduction

Negotiations are common phenomena in virtually every realm of human activity where individuals or interest groups interact with one another. For example, in an attempt to find peaceful solutions to the armed conflict in the former Yugoslav Republic of Boznia-Herzegovina, negotiations have been taking place among representatives of the warring factions, the United Nations, and other organizations. To develop fair trading practices in goods and services, international negotiation occurred within the framework of GATT (General Agreement on Tariffs and Trade) for more than 20 years. Negotiations frequently arise over responsibilities for actions affecting the environment; for example, bargaining over who should treat wastes polluting an underground aquifer is described, formally modeled, and analyzed in section 3 of this article.

To assist decision makers in handling negotiation problems as effectively as possible, formal analytical tools are required. One such tool is the recently developed *Graph Model for Conflict Resolution* (Fang et al. 1993). The purpose of this article is to present the Decision Support System GMCR, a direct implementation of the Graph Model for Conflict Resolution, and to show how it permits practitioners to conveniently apply the graph model to a rich variety of real-world negotiations. GMCR provides a decision maker with the capabilities to systematically study, better understand, and thereby more efficiently execute negotiations. Versions of GMCR for studying conflicts involving two or more decision makers are provided with the book of Fang et al. (1993), where GMCR is described in some detail. To demonstrate how GMCR can be applied in practice, it is employed below to study real-world environmental negotiations. Subsequently, the many insights that can be garnered by employing GMCR are discussed with respect to the environmental conflict, and in general.

2. The decision support system GMCR

The Graph Model for Conflict Resolution (Fang et al. 1993) constitutes a reformulation and extension of both the conflict analysis (Fraser and Hipel 1984) and metagame analysis (Howard 1971) approaches to the systematic study of strategic conflict in real-world disputes. A recent development, related in spirit though not implemented on computer, is the "theory of moves" of Brams (1993). For articles regarding recent developments in conflict analysis, refer to the special issue on conflict analysis of *Information and Decision Technologies* (Vol. 16, Nos. 3 and 4, 1990, pp. 183–371). Further contributions to conflict analysis and resolution are contained in articles published in proceedings for special sessions held at conferences in France (Singh and Travé-Massuyès 1991; IEEE 1993) and the United States (IEEE 1991). A perspective on conflict resolution and game theory techniques in engineering decision making is furnished by Hipel et al. (1993b). Finally, three 1994 issues of *Group Decision and Negotiation* contain many recent articles on conflict analysis methods and systems originally presented at an international conference at the University of Waterloo. In particular, Radford et al. (1994) provide a list of decision support systems that can be employed for studying various aspects of decision making under conditions of conflict.

A decision support system permits a decision technology to be used by practitioners (Sage 1991). The decision support system GMCR is a direct implementation of the Graph Model for Conflict Resolution that can be used to apply the graph model to practical problems. A decision maker or an analyst may enter a new model or retrieve and modify a model developed earlier. All stability criteria consistent with the user's assessment of the likely behavior patterns of the participants are selected. GMCR also invites and assists the user to assess the impact of varying either these behavior patterns (the analysis stage), or the model itself (the modeling stage).

GMCR builds a model of a strategic conflict by storing the following components:

(1) Set of decision makers, N.

(2) State set, $\boldsymbol{K}$. Each state represents a distinguishable condition (or status) of the interaction, except that two states are considered identical unless at least one decision maker has a preference between them.
(3) Reachable lists, $\boldsymbol{S}_i(\cdot)$. For each state $k \in \boldsymbol{K}$ and each decision maker $i \in \boldsymbol{N}$, $\boldsymbol{S}_i(k) \subseteq \boldsymbol{K}$ is the set of states that decision maker i can achieve, unilaterally and in one step, starting from k.
(4) Payoffs, $\mathrm{P}_i(\cdot)$. For each state $k \in \boldsymbol{K}$ and each decision maker $i \in \boldsymbol{N}$, the numerical value of $\mathrm{P}_i(k)$ measures the worth of state k to decision maker i.

GMCR stores reachable lists as linked lists. Payoff functions are ordinal: if $k, k' \in \boldsymbol{K}$, then $\mathrm{P}_i(k) \geq \mathrm{P}_i(k')$ iff decision maker i prefers state k to state k', or is indifferent. Therefore, the values of $\mathrm{P}_i(k)$ can be stored as small positive integers, with the smallest integer value indicating i's least preferred state(s), etc.

In modeling real-world conflicts, the authors have found ordinal preferences to be more than adequate for purposes of analysis and prediction. Cardinal preference information, such as von Neumann–Morgenstern utilities, is usually more difficult to elicit. If the user is a conflict participant, then the user's own cardinal preferences may be available, but the cardinal preferences of others are much more difficult to estimate reliably. The Graph Model for Conflict Resolution Methodology, on which GMCR is based, assumes ordinal preference information only. Because GMCR has proved convenient and useful in applications, no attempt has been made to extend this methodology to utilize cardinal preference information, if any is available. Of course, GMCR can take advantage of the ordinal rankings implied by cardinal preference information.

After obtaining the above information and using it to calibrate a conflict model, GMCR carries out stability analyses using a variety of solution concepts. In a general sense, a state is *stable* for a particular decision maker if it is not advantageous for him or her to move away from the state by unilaterally changing his or her strategy selection. A *solution concept* or *stability criterion* is a precise mathematical definition of how stability is to be calculated and is, therefore, a sociological description of possible human behavior in a conflict situation. But humans can react in different ways in a dispute, so many solution concepts have been defined for modeling the range of human behavior. Table 1 lists the solution concepts that GMCR uses in its stability analyses. For the precise definition of each solution concept, refer to Fang et al. (1993). For convenience, a brief summary of each stability definition is given here.

- A state is *Nash stable* for a decision maker if that decision maker cannot move to a preferred state.
- A state is *general metarational* for a decision maker if all of the decision maker's unilateral improvements are sanctioned by subsequent unilateral moves of others.
- A state is *symmetric metarational* for a decision maker if all of the decision maker's unilateral improvements are still sanctioned, even after a possible response by the original decision maker.
- A state is *sequentially stable* for a decision maker if all of the decision maker's unilateral improvements are sanctioned by subsequent unilateral improvements of others.

Table 1. Solution concepts and human behavior

Solution concepts	Original references	Foresight	Disimprovements
Nash stability (R)	Nash (1950, 1951); von Neumann and Morgenstern (1953)	low	never
General metarationality (GMR)	Howard (1971)	medium	by opponents
Symmetric metarationality (SMR)	Howard (1971)	medium	by opponents
Sequential stability (SEQ)	Fraser and Hipel (1979, 1984)	medium	never
Limited-move stability (L_h)	Kilgour (1985); Kilgour et al. (1987); Zagare (1984); Fang et al. (1989)	variable	strategic
Non-myopic stability (NM)	Brams and Wittman (1981); Kilgour (1984, 1985); Kilgour et al. (1987)	high	strategic

- *Limited-move stability* assumes a fixed number of state transitions; all decision makers are assumed to act optimally.
- *Non-myopic stability* is the limiting case of limited-move stability, as the number of state transitions increases.

A qualitative comparison of solution concepts is furnished in Table 1. The second column provides original references for each solution concept. The last two furnish qualitative characterizations, according to the criteria of foresight and disimprovement. *Foresight* refers to the extent of a decision maker's ability to think about possible moves that could take place in the future. A decision maker with high (or long) foresight thinks many steps (moves and countermoves) ahead when evaluating where the conflict could end up because of an initial unilateral move on his or her part. In Nash stability foresight is low, for example, whereas it is very high for non-myopic stability. A *disimprovement* is a unilateral move by a decision maker to a less preferred state. "Strategic disimprovement" refers to a decision maker's willingness to move (temporarily, of course) to a worse state in anticipation that a more preferred final state will eventually be reached as a result of other decision makers acting in their own interests. "Disimprovements by opponents" indicates that the focal decision maker sees other decision makers as willing to put themselves in worse positions in order to sanction unilateral improvements by the focal decision maker. Finally, the relationship between graph models and extensive games and the meanings of these stability definitions in terms of extensive games are examined in detail in chapter 4 of Fang et al. (1993).

In a stability analysis, GMCR examines every state for stability from every decision maker's point of view. When a state is stable for each decision maker, it constitutes a possible resolution or *equilibrium*. This means that if an equilibrium is reached as the conflict evolves from the initial status quo state via state changes effected by individual decision makers, then the conflict will remain at the equilibrium. During the evolution of a conflict from an unstable status quo position, decision makers may freely take advantage of any available moves, and thereby cause the conflict to move from one state to another. When an equilibrium is eventually reached, the conflict will stay at that state, because no decision maker has an incentive to move away.

GMCR calculates whether each state is stable or unstable (*s/u*) for each decision maker, under each of the stability types or solution concepts listed in Table 1. The results of all these stability analyses are stored in the three-dimensional array illustrated in Figure 1, which originally appeared in Fang et al. (1993, Appendix A, p. 195).

To assist the practitioner in understanding the analytical results, the information contained in the array displayed in Figure 1 can be viewed in various ways, including the following:

- For each decision maker, the *decision maker's plane* (parallel to the STATE/STABILITY-TYPE plane) indicates the stability types or solution concepts (if any) under which each state is stable for that specific decision maker.
- For each stability type, the *stability-type plane* (parallel to the DECISION MAKER/STATE plane) provides a complete analysis of the model according to that stability type.
- For each state, the *state plane* (parallel to the DECISION MAKER/STABILITY-TYPE plane) identifies the decision makers for whom that particular state is stable, under each possible stability type.

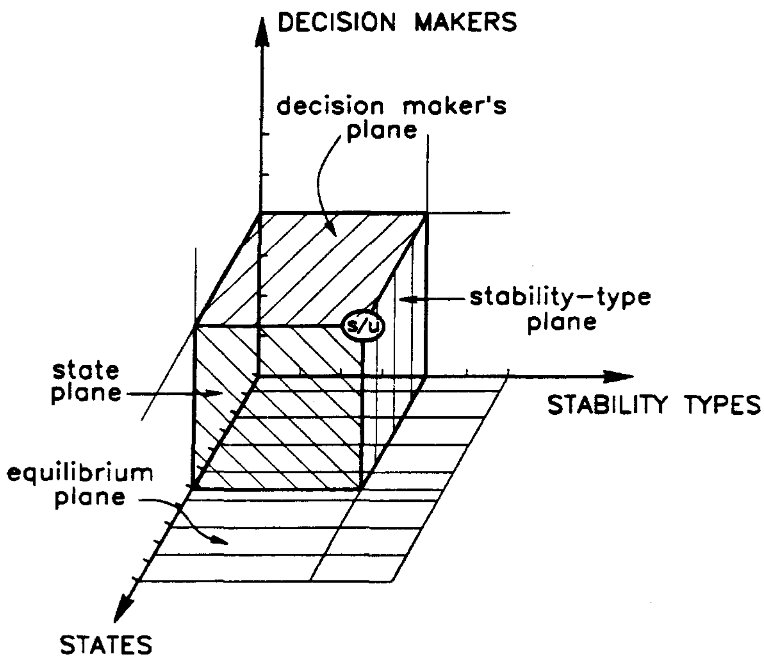

Figure 1. GMCR stability results structure.

- The STABILITY-TYPE/STATE plane itself, referred to as the *equilibrium plane*, contains the projections of stability results for each decision maker (E if s for all decision makers, blank otherwise), indicating all equilibria for each stability type.

There is a variety of ways in which GMCR can be utilized in practice, including:

- *As an analysis tool for a participant in a conflict, or an agent of a participant.* Strategic interactions following the focal participant's actions can be analyzed, and the consequences of certain strategies estimated, in order to improve the participant's position. The participant can use GMCR to make assessments and preparations at different times as the conflict unfolds.
- *As a communication and analysis tool used in mediation.* The mediator can utilize GMCR by using various preference rankings, without revealing (or knowing) which one correctly describes the participants, to estimate possible outcomes. This might identify options that are detrimental, irrelevant, or beneficial to all parties.
- *As an analysis tool used by a third-party analyst.* The analyst can use GMCR to study the evolution of the conflict and to estimate what the preferences must have been to result in the observed outcome. The analyst can also study how the structure of the conflict influenced behavior. Finally, the analyst can learn better ways to structure a future conflict.

3. Case study: Elmira groundwater contamination dispute

3.1. Background

The background to the environmental conflict described in this section is adapted from a conference paper (Hipel et al. 1993a). A detailed history of the Uniroyal dispute is provided by Bergmann-Baker (1991); newspaper articles (Burtt 1991, 1993; Crowley 1991; Crowley and Thompson 1991; Mittelstaedt 1991) constitute useful additional sources.

Elmira, a town with about 7400 residents, is located in the agricultural heartland of southwestern Ontario, Canada, about 15 kilometers north of Kitchener and Waterloo. Among the several industries in the town are a sulfuric acid plant, an aluminum castings operation, a steel foundry, a fertilizer blending and bagging operation, and a pesticide/rubber products manufacturing plant. The latter, operated by Uniroyal Chemical Ltd. (Uniroyal), has a history of environmental problems.

In late 1989, a serious controversy arose when a known carcinogen, N-nitroso dimethylamine or NDMA, was discovered in the underground aquifer beneath the town, and in the municipal water supply drawn from the aquifer. There was some indirect evidence to support the commonly held view that the source of the NDMA pollutant was the Uniroyal plant. Consequently, various interest groups maintained that Uniroyal should be held responsible for cleaning up the contamination and furnishing a safe water supply. Governments and regulatory agencies began negotiating with Uniroyal.

In August 1991, the authors carried out a conflict study of the Uniroyal dispute in order to assess whether and how a negotiated settlement could be reached. At the time of the modeling and analysis, Uniroyal had appealed a Control Order (CO) issued by the Ontario Ministry of the Environment (MoE) that placed several long-term requirements on Uniroyal, including the implementation of a collection and treatment system. Generally, when a CO is issued by MoE as an enforcement instrument under the *Environmental Protection Act* of Ontario, the recipient must comply with its terms. However, under the *Act* the recipient may appeal before the Environmental Appeal Board. When granted, a hearing is convened and the Board decides whether the CO, or a modified version, should be put into effect, or whether it should be rescinded.

3.2. Modeling the Elmira groundwater contamination dispute

The key information required for developing a graph model of a strategic conflict is identification of the decision makers, the states, each decision maker's possible actions (state transitions), and each decision maker's relative preferences. In this subsection, a model of the situation existing in the summer of 1991 is described, while in the next subsection analyses of this model are carried out. The model was originated in Hipel et al. (1993a), with the assistance of a domain expert who provided the information needed to calibrate the model. The authors met with the expert in two sessions, lasting about two hours each, to obtain the necessary modeling information. The model was refined and revised in a conference paper by Kilgour et al. (1994). An extended version is introduced here.

The decision makers and the options they control are given in Table 2. (In general, a decision maker may select none, some, or all of the options it controls.) Brief explanations of the options are provided in the right column in Table 2.

At the hearing of the Environmental Appeal Board, MoE could modify the CO to make it acceptable to Uniroyal, or stand by the CO in the original form. Uniroyal controls four options. It can delay the entire process, accept the CO, attempt to blame another local industry (Nutrite Inc.) and force Local Government to accept some cleanup responsibilities, or abandon its plant. These options are not exclusive, of course, although the option

Table 2. Decision makers and options in the model

Decision makers and options	Interpretations
MoE	Ontario Ministry of the Environment
Modify CO	MoE modifies the control order to make it acceptable to Uniroyal
Uniroyal	Uniroyal Chemicals Ltd.
Delay	Uniroyal lengthens the appeal process
Accept	Uniroyal accepts responsibility
Blame	Uniroyal blames others
Abandon	Uniroyal abandons its Elmira operation
Local Government	Regional Municipality of Waterloo
Support	Local Government supports MoE/agreement

of abandoning the Elmira operation, which would have had a significant negative impact on the economy of the Elmira region, would have superseded Uniroyal's other alternatives. If Uniroyal abandoned its plant in Elmira, any prosecution would take longer and be less effective, as fewer legal penalties and remedies would be available. Finally, Local Government could support the original CO at the hearing and support an agreement if one were reached, or it could give up its active role in the negotiations.

The feasible states in the Uniroyal conflict are listed as columns of Y's and N's in Table 3. A "Y" indicates "yes," the option is taken by the decision maker controlling it, whereas an "N" means "no," the option is not selected. In state 1, for example, MoE does not modify the original CO, Uniroyal delays the appeal process but does not try to blame others, and Local Government has not taken a position on the CO. This state was, in fact, the status quo at the time that the negotiations were modeled in the late summer of 1991. In Table 3, a dash indicates that the entry can be either a Y or an N. For instance, if Uniroyal decides to close down its Elmira facility (state 17 in Table 3), it does not matter what MoE or Local Government does.

The reachable lists for the Uniroyal dispute are given in Table 4. Note, for instance, that Uniroyal can unilaterally move the conflict from state 5 to state 7 by changing from its delay option to its accept option. Likewise, Uniroyal can make the conflict move from state 5 to state 13 by attempting to blame others, to state 15 by partially accepting the responsibility and attempting to blame others, or to state 17 by abandoning its plant. In fact, Uniroyal can unilaterally achieve state 17 from any other state. However, because it cannot easily reopen once it abandons its Elmira operation, Uniroyal cannot move from state 17 back to any other state. Consequently, a move to state 17 is *irreversible*. In fact, one significant advantage of the graph model for conflict resolution is its ability to model irreversible moves accurately and conveniently.

Figure 2 depicts the graph model for movement in the conflict. Each vertex represents one of the states defined in Table 3. Each feasible movement between states is shown as an arc, labeled according to the decision maker controlling the movement. For instance, Uniroyal can move from state 1 to state 9, indicated by the "UR" label on the arc from 1 to 9.

Table 3. States of the model

MoE																	
Modify	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	–
Uniroyal																	
Delay	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	–
Accept	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N
Blame	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N
Abandon	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y
Local Government																	
Support	N	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	–
State Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

Table 4. Reachable lists (S_i) and payoffs (P_i) for each state (k) and decision maker

	MoE		Uniroyal		LG	
k	S_1	P_1	S_2	P_2	S_3	P_3
1	2	8	3, 9, 11, 17	14	5	14
2		3	4, 10, 12, 17	3	6	6
3	4	16	11, 17	5	7	16
4		14	12, 17	13	8	7
5	6	9	7, 13, 15, 17	10	1	15
6		5	8, 14, 16, 17	1	2	12
7	8	17	15, 17	6	3	17
8		12	16, 17	12	4	13
9	10	6	1, 3, 11, 17	15	13	10
10		2	2, 4, 12, 17	4	14	9
11	12	11	3, 17	8	15	11
12		10	4, 17	16	16	8
13	14	7	5, 7, 15, 17	11	9	3
14		4	6, 8, 16, 17	2	10	2
15	16	15	7, 17	7	11	5
16		13	8, 17	17	12	4
17		1		9		1

Besides reachable lists, Table 4 also presents the preference rankings (ordinal payoffs) for each of the three decision makers; a state with a higher payoff is more preferred by a decision maker than one having a lower payoff. As can be seen, state 17, where Uniroyal closes its operation, is least preferred for both the MoE and Local Government. As demonstrated in the analyses of Hipel et al. (1993a) and Kilgour et al. (1994), Uniroyal's payoff for state 17 can be a key factor in determining which equilibria are available.

The purpose of building and analyzing different models of the same negotiation problem is to develop a more complete understanding of different aspects of the problem. For instance, the model of Kilgour et al. (1994) provides a good explanation of the most dramatic event of the Uniroyal negotiations—namely, the agreement between Uniroyal and MoE on October 7, 1991 concerning the obligations of Uniroyal, an agreement which caught Local Government completely by surprise. But that model says little with respect to uniroyal's relations with neighboring industries and municipalities in the Elmira area.

The purposes of the model described above (in Figure 2, and Tables 2, 3, and 4) are to further explore Uniroyal's relationship with its community. Specifically, the agreement reached between Uniroyal and MoE forced Local Government to accept responsibility for some of the cleanup. It was certainly consistent with the view, expressed clearly by Uniroyal during the negotiations, that the municipal government, and other industries, might also have some responsibility for the condition of the Elmira aquifer. The model used here therefore contains a "Blame" option for Uniroyal; when an agreement is reached in the presence of this option, Local Government's incentives to support the agreement are reduced.

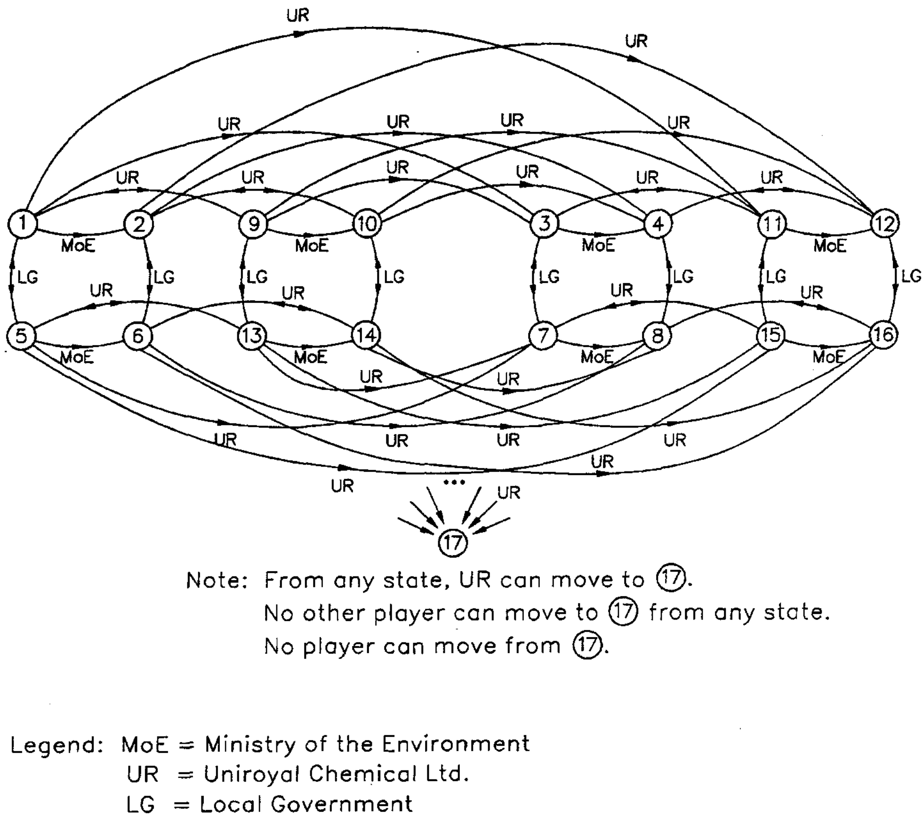

Figure 2. Graphical representation of the unilateral moves in the Elmira conflict.

3.3. Analyses

Table 5 summarizes the results of the analysis of this model using GMCR. This table is taken from GMCR's equilibrium plane and shows that the model has four weak equilibria, at states 1, 5, 13, and 16, and three strong (and long-term) equilibria, at states 9, 12, and 17. The fact that state 17 has strong equilibrium properties should not be surprising, in view of Figure 2, which shows that the conflict can never exit state 17 should it ever arrive there. In interpreting Table 5, it should be kept in mind that the status quo state was state 1, and that the state most closely representing the final outcome is state 12.

Using Figure 2 and Tables 3, 4, and 5, the evolution of the conflict can be traced quite clearly. First Uniroyal executed its unilateral move from state 1 to state 9. State 9 is more preferred than state 1 for Uniroyal, but less preferred for the other decision makers. State 9 is also a strong equilibrium, and it is not surprising (see Tables 5 and 1) that it persisted for a long time. Neither Uniroyal nor MoE could move from state 9 to 12 on its own. Rather, the move from state 9 to state 12 required actions by both Uniroyal and MoE, as

Table 5. Summary of equilibria from GMCR's equilibrium plane

k	Equilibria
1	GMR, SMR
5	GMR
9	R, GMR, SMR, SEQ, L(1), L(2), L(3), L(4), NM
12	R, GMR, SMR, SEQ, L(1), L(2), L(3), L(4), NM
13	GMR, SMR
16	GMR, SMR
17	R, GMR, SMR, SEQ, L(1), L(2), L(3), L(4), NM

shown in Figure 2 and Table 3. While the sequence of these actions is not clear, it is evident that both occurred. Furthermore, the resulting state 12 is preferred to the prior state 9 by both Uniroyal and MoE, so both were motivated to act cooperatively. The cooperation of the one decision maker who preferred to stay at state 9, Local Government, was not required to effect the transition to the final state, 12. Again, state 12 is very stable for both shortsighted and farsighted players, so it is consistent with the model that no further movement occurred after the conflict reached state 12.

From this model, the news for Local Government is all bad. At every strong equilibrium (other than the one at which Uniroyal completely abandons its Elmira operation), Uniroyal selects its "Blame" option; likewise, there are no strong equilibria that include Local Government's "Support" option. The clear conclusion from this model is that strategic factors made it inevitable that Local Government would be left out of any resolution of the Elmira aquifer conflict. This is a particularly ironic finding, because Local Government had been encouraged by MoE to take an active role in the negotiations, and had hired independent consultants and obtained extensive legal advice at substantial cost to itself.

While other models of the strategic aspects of the Elmira negotiations (Kilgour et al. 1994; Hipel et al. 1993a) have found that the participation of the local municipalities contributed positively toward the final resolution, the current model indicates that the municipalities themselves were not well served by the process. This suggests that governments and regulatory authorities will need to organize future environmental negotiations in a different way if the participation of local communities is to be encouraged and rewarded.

4. Conclusions

As exemplified by the case study presented in section 3, the decision support system GMCR provides a practical and useful tool for assisting decision makers involved in negotiations. In fact, GMCR has many distinct advantages in application to practical negotiation problems. First, GMCR's systematic modeling approach provides a vocabulary, and therefore a common *communication medium* with which decision makers and other interested parties can realistically discuss negotiations. Formal representation of information and rigorous analyses lead to a second important benefit of GMCR: *understanding*. Because GMCR facilitates discussion of a negotiation problem and of its analysis, decision makers and analysts can gain a deeper and clearer understanding of the problem and its possible resolutions. Moreover, a better understanding of negotiations ultimately leads to *improved decision making*. These are the primary benefits that the Graph Model for Conflict Resolution and GMCR were designed to provide.

Acknowledgments

The authors thank two anonymous referees for suggestions that helped to improve this article.

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