# The Conflict Analysis Group

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## 1. Mission

The Conflict Analysis Group, founded in 1976, is based in the Department of Systems Design Engineering at the University of Waterloo in Waterloo, Ontario. The main goal of the Conflict Analysis Group is to develop and implement formal methodologies for systematically studying decision situations involving multiple participants, each of whom may have multiple objectives. Many conflict analysis techniques have been developed for modeling and analyzing different strategic disputes arising in the real world. The graph model for conflict resolution, described in more detail below, has been utilized by the Conflict Analysis Group to investigate disputes in environmental management, international trade, peace-keeping, labor-management negotiations, and elsewhere. By employing formal procedures for better understanding a dispute and communicating with one another, parties involved in a conflict may cooperatively reach a win/win resolution. On the other hand, formal methods can help a participant to prepare for the moves and countermoves of any strategic interaction.

## 2. Activities

In addition to the authors of this article, other researchers involved with the Conflict Analysis Group include Dr. Mitali De of the School of Business and Economics at Wilfrid Laurier University and Dr. Niall Fraser of St. Clements, Ontario. Professor Jim Radford was also associated with the Group for many years. Group members have close ties with other research organizations such as the Integrated Management for Disaster Risk Division of the Disaster Prevention Research Institute at Kyoto University, Japan, headed by Professor Norio Okada. Members of the Group regularly participate in international conferences and publish research results in journals sponsored by professional organizations such as the Systems, Man and Cybernetics (SMC) Society of the Institute of Electrical and Electronics Engineers (IEEE), American Water Resources Association (AWRA), Institute for Operations Research and Management Science (INFORMS), and Canadian Operational Research Society (CORS).

Master's and Doctoral students who carry out research with one or more members of the Conflict Analysis Group usually register in the Department of Systems Design Engineering. They

utilize the Group's resources for meetings with research advisors to chart research directions and discuss research problems. Prospective graduate students interested in leading-edge research in conflict analysis are welcome to contact Group members or visit the Group's web site, <http://workbench.uwaterloo.ca/cag/>. During the past two decades, about a dozen Ph.D. students and thirty Master's students have successfully completed theses in areas related to conflict resolution and strategic decision making. All of these students succeeded in obtaining good positions in industry, universities, and government organizations.

The main activities of the members of the Conflict Analysis Group are to execute research with their graduate students and colleagues and to disseminate their research findings through scholarly publications and conference presentations. Group members are also actively involved in other research-related undertakings, including providing consulting services, completing contract research, hosting short courses, and presenting special research seminars. Each fall, the Conflict Analysis course SYDE 533 is taught as a 4th year and Master's level course in the Department of Systems Design Engineering. When requested, a Ph.D. course on conflict analysis and decision making is also offered. In 1992 and 1993, two international conferences on topics of conflict resolution and environmental management were organized by Group members and held at the University of Waterloo. For the past eight years, the Group has organized special sessions on conflict resolution and risk assessment at the annual meetings of the IEEE SMC Society. It organized Group Decision and Negotiation sessions at the INFORMS/CORS 1998 Spring Meeting in Montreal. Finally, they also serve as Associate Editors on a range of international journals including *IEEE Transactions on Systems, Man and Cybernetics* and *Group Decision and Negotiation*, and in the past have edited special issues for journals on various topics in decision making.

## 3. Research Themes

The specific research topics of the Conflict Analysis Group can be categorized within the three main themes, as follows:

(a)    Development of new conflict resolution methodologies and improvement of existing techniques;
(b)    Design and implementation of decision support systems for conflict resolution; and
(c)    Application of conflict resolution methodologies and software to significant real world problems.

Research topics falling under theme (a) include theoretical and practical extensions of the graph model for conflict resolution, coalition analysis, game theoretic models for enforcement of environmental laws and regulations, and multiple criteria decision analysis for environmental management. Under theme (b), the major focus is the development of the decision support system GMCR II that permits both practitioners and researchers to apply the graph model for conflict resolution to a wide range of strategic conflicts. Under theme (c), the main application areas to which GMCR II and other decision technologies are applied are bargaining and negotiation in environmental management, water resources management, and international trade.

## 4.  The Graph Model for Conflict Resolution

### 4.1 *Historical Development*

The "jewel in the crown" of Conflict Analysis Group research results is the theoretical and practical development of the graph model for conflict resolution and the development of the decision support system GMCR II to permit convenient implementation of this flexible and comprehensive conflict resolution methodology. The theoretical foundations of the graph model, formulated over a three year period, appeared in *Automatica* in 1987 [Kilgour et al., 1987]. After six more years of research and the publication of research findings in journals and conference proceedings, the book

*Interactive Decision Making*: *The Graph Model for Conflict Resolution* was published by John Wiley & Sons, New York [Fang et al., 1993]. The first journal paper describing the decision support system GMCR II appeared in *Applied Mathematics and Computation* in 1997 [Hipel et al., 1997]; further developments are contained in a number of conference papers [Fang et al., 1997; Kilgour et al., 1996; Peng et al., 1997], and future publications on GMCR II and its applications are planned.

The graph model for conflict resolution constitutes a significant expansion and reformulation of conflict analysis [Fraser and Hipel, 1984], which in turn is an extension of metagame analysis [Howard, 1971]. Other methods for describing and analyzing human conflict include drama theory [Howard, 1994], which gives a role to emotions in conflict resolution, hypergame analysis [Bennett, 1980; Wang et al., 1988], which attempts to take misperceptions into account, and the theory of moves [Brams, 1996]. These approaches to understanding strategic decision making can be considered as belonging to a branch of game theory that is quite distinct from traditional methods based on the classical work of von Neumann and Morgenstern [1944]. Hipel et al. [1993a] furnish an overview of the use of game theory and related models in engineering decision making, and Hipel et al. [1999b] explain how the graph model for conflict resolution and other operational research tools for refining and selecting courses of action can solve problems in a systems engineering context [Sage, 1992].

## 4.2 *Example*: *Analysis of the Elmira Groundwater Contamination Dispute*

To gain some appreciation for how the graph model methodology is applied in practice, consider its analysis of a nasty groundwater contamination conflict. Elmira, a town of 7,500 residents located in an agricultural region of southwestern Ontario, draws its municipal water from an underground aquifer. In late 1989, the Ontario Ministry of the Environment (MoE) discovered that the aquifer was contaminated by a carcinogen, N-nitroso demethylamine (NDMA). Suspicion fell on the Elmira pesticide and rubber products plant of Uniroyal Chemical Ltd. (Uniroyal), which had a history of environmental problems, and was associated with NDMA-producing processes. MoE issued a Control Order under the *Environmental Protection Act of Ontario,* requiring that Uniroyal implement a long-term collection and treatment system, undertake studies to assess the condition of the site, and carry out any necessary cleanup under Ministry supervision. Uniroyal immediately exercised its right to appeal. Meanwhile, various interest groups formed and attempted to influence the process through lobbying and other means. Of particular note was the role of the Regional Municipality of Waterloo and the Township of Woolwich (Local Government), which took common positions in the dispute and, encouraged by the Ministry, hired independent consultants and obtained extensive legal advice at substantial cost.

Negotiations involving MoE, Uniroyal, and Local Government began in mid-1991. MoE's objective was to carry out its mandate as efficiently as possible; Uniroyal wanted the Control Order modified or rescinded; Local Government wanted to protect its citizens and its industrial base. This difficult conflict was studied first by Hipel et al. [1993b] and Kilgour et al. [1994]. Later, Hipel et al. [1999a] modeled and analyzed it using the decision support system GMCR II, completed early in 1999 [Fang et al.,1999; Peng, 1999].

The left-hand column of Table 1 lists the three main decision makers as well as the options under the control of each decision maker. Notice that MoE controls the option to modify the Control Order to make it more acceptable to Uniroyal (called Modify in Table 1). Uniroyal can lengthen the appeal process (Delay), accept the current Control Order (Accept), or abandon its Elmira operations (Abandon). Finally, Local Government can insist that the original Control Order be applied (Insist).

## Table 1

Moving from the status quo (state 1) via the transitional noncooperative equilibrium (state 5) to the final cooperative equilibrium (state 8) in the Elmira groundwater contamination dispute.

| Decision Makers and Options | Status Quo | Noncooperative Equilibrium | | Cooperative Equilibrium |
|---|---|---|---|---|
| MoE | | | | |
|     1. Modify | N | N | ➜ | Y |
| Uniroyal | | | | |
|     2. Delay | Y | Y | ➜ | N |
|     3. Accept | N | N | ➜ | Y |
|     4. Abandon | N | N | | N |
| Local Government | | | | |
|     5. Insist | N ➜ | Y | | Y |
| | | | | |
| State Number | 1 | 5 | | 8 |

Each of the nine feasible states is a possible scenario of this simple model, and is represented by a column of Y's and N's. A Y indicates that Yes, the option opposite the Y is selected by the decision maker controlling it, while an N means No, the option is not taken. For example, state 8, the far right column in Table 1, is the scenario where MoE modifies the Control Order (selects option 1) and Uniroyal accepts this modification (chooses option 3), while Local Government continues to support the original Control Order (selecting option 5).

Reading from left to right, Table 1 traces the evolution of the Elmira conflict from the status quo state, 1, to the final equilibrium, 8. The arrows indicate the option changes that caused the model to move from one state to the next. Historically, the status quo state in mid-1991 was state 1 in which Uniroyal's appeal is extending the negotiation process. Local Government shifted quickly to support the original Control Order, resulting in state 5 for a protracted interval of time. In fact, both state 5 and state 8 are equilibria according to every solution concept in the broad range included in GMCR II, that is, according to all the human behavior patterns that can be described by GMCR II.

Stability analyses determine the best strategic possibilities for a decision maker when all decision makers make their individual choices within the social constraints of a dispute. A natural extension is to question whether it is possible for two or more decision makers to form a coalition in order to cooperatively reach even better outcomes for themselves. For the Elmira Conflict, this was certainly the case. On October 7, 1991, MoE and Uniroyal dramatically announced an agreement on a modified version of the original Control Order, thus moving the conflict from the noncooperative equilibrium, state 5, to the cooperative equilibrium, state 8, which is displayed as the right column in Table 1. Of course, state 8 is also a noncooperative equilibrium; here it is referred to as the cooperative equilibrium because it can be reached from state 5 only by coordinated actions by both Uniroyal and Local Government.

The joint or cooperative move by MoE and Uniroyal from state 5 to 8 is referred to as an equilibrium jump. In GMCR II, a user can request a coalition analysis on the existing equilibria to investigate coalitional stability. Coalition analysis identifies states that are equilibria on an

individual basis but not coalitionally stable, such as state 5 in the Elmira Conflict model. Theoretical descriptions of this new form of conflict analysis are provided by Peng [1999] and Kilgour et al. [1996].

### 4.3 *Important Features of GMCR II*

The design of the graph model for conflict analysis and its practical implementation via GMCR II [Fang et al., 1999; Hipel et al., 1997] offer practitioners and researchers alike many key advantages for the systematic study of real world conflict. Some of these attractive features are listed below.

(a)    The option form of the Elmira conflict model shown in Table 1 contains three decision makers and five options. No theoretical limit to the number of decision makers or the number of options is inherent in the graph model or its implementation in option form.

(b)    In practice, GMCR II can handle a range of sizes of conflict model. Because each option can either be selected or not taken, a model with $k$ options has at most $2^k$ states. One should keep in mind that the user provides GMCR II with the decision makers and their options only. GMCR II then automatically generates all feasible states after infeasible and equivalent option combinations are indicated by the user [Fang et al., 1997]. Currently, GMCR II can handle models with up to 32 options.

(c)    The graph model allows for irreversible moves by decision makers, and GMCR II can keep track of them. For example, if Uniroyal selects the option Delay in the Elmira model (Table 1), it cannot take this move back later, because time is irreversible. The theory of the graph model for conflict resolution is based on a finite directed graph for each decision maker in which vertices represent feasible states and arcs represent state transitions controlled by the decision maker. GMCR II makes use of the option form to facilitate the entry of irreversibility information.

(d)    To calibrate a conflict model, one must specify preference information for every decision maker. The graph model is designed to require only ordinal preference information (i.e. rankings of the states, with ties permitted), not cardinal information (e.g. utilities). GMCR II includes three methodologies for conveniently eliciting a decision maker's relative preferences [Peng et al., 1997]. One method is Option Weighting, in which weights are assigned to options, and then total weights for states are used to determine an ordering. A second technique is Option Prioritizing, based upon a prioritized set of logical statements about options. Finally, manual ranking of the states, called Fine Tuning or Direct Ranking, is useful as an adjunct to one of the other procedures for large models. The flexibility of GMCR II in preference elicitation greatly simplifies this process. While GMCR II assumes preference transitivity, the graph model can in theory handle intransitive preferences [Fang et al., 1993, Ch. 8].

(e)    After a conflict model has been entered, GMCR II carries out an exhaustive stability analysis. To represent the wide range of human behavior under conditions of conflict, a range of solution concepts or stability definitions has been defined to represent different styles or patterns of conflict decision making. Each stability definition is a particular set of assumptions about the consequences of a unilateral move. If it is not advantageous for a given decision maker to depart unilaterally from a state according to a given solution concept, then that state is deemed to be stable. A state that is stable for all decision makers constitutes an equilibrium or compromise solution. GMCR II analyzes each state for stability according to the solution concepts of Nash stability, general metarationality, symmetric metarationality, sequential stability, limited move stability and nonmyopic stability. Fang et al. [1993] define each of these solution concepts within the graph model paradigm and provide further discussion and references.

(f)    As explained for the Elmira conflict, GMCR II finds all noncooperative equilibria (states 5 and 8 in Table 1).  As well, the coalition analysis feature indicates equilibria (like state 5 in Table 1) that are unstable for a coalition (in this case, MoE plus Uniroyal), and the consequences of their joint action (state 8).

(g)    GMCR II can execute extensive sensitivity analyses, finding answers to "What if?" questions.  For instance, it is often important to know whether slight preference changes for a particular decision maker can significantly affect overall equilibrium results.

## 5. Future Opportunities

The members of the Conflict Analysis Group believe that the demand will increase for a broader range of useful conflict resolution methodologies, to address a wider spectrum of real world conflict situations.  Indeed, business leaders are scrambling to understand the complex competitive dynamics of the international marketplace to maintain or expand market shares.  Political leaders are struggling to comprehend social and cultural differences, to utilize them for positive purposes and avoid their harmful, cruel, or unproductive manifestations that are so clearly visible in many regions of the world.  Environmentalists, industrialists, government leaders and other concerned citizens are striving to find a proper balance between economic development and environmental integrity in an attempt to approach the ideal goal of sustainable development.  An overriding objective of members of the Conflict Analysis Group is to assist decision makers in the real world to bring about fair, equitable, positive, and lasting solutions to strategic conflicts by developing appropriate systems methodologies for use in conflict resolution.

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