The Decision Support System GMCR II in Negotiations Over Groundwater Contamination

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Objectives
Illustrate how GMCR II can be applied to a social conflict by applying it to a groundwater contamination dispute in Southern Ontario, Canada.

Explain why two of the disputants formed a coalition to bring about a dramatic resolution to the conflict.

Discuss the role of data and time series analyses of the physical systems aspects of the problem and how it influenced the political decision making surrounding this conflict.

The Duality of Systems Modeling of a Real World Problem

Societal Level
Conflict among stakeholders over who is responsible and who should pay for cleansing the aquifer.

Physical Realm
Mathematical modeling of the dispersion and elimination of the pollution. Statistical and time series analyses of the data.

Water Resources and Environmental Management
Problems and Opportunities

- Span the societal and physical systems realms.
- Are interdisciplinary.
- Require a team of practitioners and researchers from a wide spectrum of disciplines to systematically solve problems in a creative fashion to arrive at solutions that are equitable, sustainable and cost effective.

Accomplishments
Water resources and environmental personnel are pioneers in developing and applying:

- Societal decision analysis models,
- Physical, chemical and biological systems models, and
- Decision support systems (DSSs) for allowing societal and physical systems models to be conveniently used in practice.

Aquifer Contamination
By-products from a local chemical factory contaminate an aquifer supplying a town with fresh water.

Societal Level
Conflict among stakeholders over who is responsible and who should pay for cleansing the aquifer.

Physical Realm
Mathematical modeling of the dispersion and elimination of the pollution. Statistical and time series analyses of the data.
Formal Decision Making Methods

A rich variety of techniques developed in the fields of:

- Operational Research (OR)
- System Engineering (SE)

Operational Research

Focuses on:

- Quantitative methods
- Tactical level of decision making
- Special components of an overall system problem
- Single decision maker situation

Systems Engineering

Another systems science field in which decision analysis models were developed.

Focuses on:

- Quantitative and qualitative methods
- Strategic and tactical levels of decision making
- Integration of technology, institutional perspectives and value judgements
- Entire system including the components and their synergistic connections
- Holistic viewpoint
- Unstructured and complex problems
- Single and multiple decision makers

GMCR II

A flexible and comprehensive Decision Support System which allows the Graph Model for Conflict Resolution methodology to be applied to practical real world problems.

GMCR II Structure

GMCR II

- Developed in the Microsoft Windows Environment using 32-bit windows.
- Follows an objective-oriented approach and is implemented in Microsoft Visual C++ utilizing Microsoft Foundation Classes.
- Adopts the popular Model-View-Controller architecture.
GMCR II

- Dialog boxes are used for input information that calibrates the conflict model.
- Property pages, which form a property sheet occupying the client area of the document window, are used strictly for display.

Genealogy of Formal Conflict Models

Game Theory

Nonquantitative Approaches
- Metagame Analysis
- Conflict Analysis
- Graph Model for Conflict Resolution

Quantitative Procedures
- Normal Form
- Extensive Form
- Cooperative Game Theory

Drama Theory

Applying the Graph Model for Conflict Resolution

Elmira Groundwater Contamination Dispute

- Elmira is a town of 7,500 residents located in Southern Ontario, Canada.
- Municipal water is drawn from an underground aquifer.
- In late 1989, the Ontario Ministry of the Environment (MoE) discovered that the aquifer was contaminated by a carcinogen N-nitrosodimethylamine (NDMA).
- Uniroyal Chemical Ltd. (Uniroyal) operates NDMA-producing processes.
Elmira Groundwater Contamination Dispute

- MoE issued a Control Order to Uniroyal to clean up the contaminants.
- Uniroyal appealed the Control Order.
- Regional Municipality of Waterloo and Woolwich Township (Local Government) hired consultants and obtained legal advice.
- Negotiations involving the three DM’s took place in mid-1991.

Study the negotiations using GMCR II

Conflict Model

- Input Decision Makers (DMs) and Options.
- Specify Infeasible States.
- Indicate Indistinguishable States.
- Specify Allowable State Transitions.
- Elicit Relative Preferences.

Evolution of the Elmira conflict from the status quo, to a transitional non-cooperative equilibrium and to a final cooperative coalition equilibrium.

<table>
<thead>
<tr>
<th>Status Quo</th>
<th>Transitional Non-cooperative Equilibrium</th>
<th>Cooperative Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoE:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Modify</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Uniroyal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Delay</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>3. Accept</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>4. Abandon</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Local Government</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Insist</td>
<td>N</td>
<td>Y</td>
</tr>
</tbody>
</table>

State Number 1 5 8

The DM/option Input Dialog Box

Displaying DMs and Options in the Elmira Conflict Model

GMCR II Structure
Keeping Track of Irreversible Moves

- GMCR II automatically calculates all possible state transitions, if present, from each state for each decision maker.
- Bombing the missile sites in Cuba is irreversible.
- Each decision maker has a finite directed graph in which vertices represent the feasible states and the state transitions are the arcs on the graph connecting the vertices.
- Allowable state transitions in both directions between two states are indicated by two arrowheads in opposite directions.
- An irreversible move is marked by a single arrowhead.
- GMCR II uses a reachable list to keep track of the set of allowable state transitions for a given state and decision maker.

Preference Elicitation

- GMCRIII only requires relative preferences for each decision maker.
- The problem of obtaining cardinal preference information, such as utility values is avoided.
- GMCRIII develops an ordinal ranking of states from most to least preferred and allows for ties.
- The graph theory methodology can handle intransitive preferences.

Preferences

- Would you like to have tea or coffee to drink.
  – Quantitative response: I have a utility value of 1.9673 for coffee and 1.0000 for tea.
  – Human response: I would prefer to drink tea. Thank you.
- Quantitative preferences:
  – Cardinal number is assigned to each state or object (ex. Dollars or utility value).
- Non-quantitative or relative preferences:
  – One state is either more preferred, less preferred or equally preferred to another.

Types of Relative Preferences

- Ordinal
- Strictly ordinal
  - Transitive
- Intransitive
- Unknown
- Greatly more (or less) preferred
MoE most prefers that Uniroyal not abandon its Elmi ra plant.

Next, MoE would like Uniroyal to accept the current Control Order.

MoE then prefers that Uniroyal not delay the appeal process.

MoE would not like to modify the Control Order.

MoE prefers that Local Government insists that the original Control Order be applied (5), if and only if (iff) it does not modify the Control Order (-1) itself.
Analysis and Results

- GMCR II analyzes every state for stability for each DM according to all of the solution concepts in Table 1.

GMCR II CAN DISPLAY

- Individual stability results.
- Equilibria according to the preferences of a given decision maker.
- Customized equilibria after the user specifies the kind of solution concept each decision maker should follow.
- Common features of the equilibria.
- Equilibria which contain specified patterns desired by the user.

Solution Concepts and Behavioral Characteristics

<table>
<thead>
<tr>
<th>Solution Concepts</th>
<th>Stability Descriptions</th>
<th>Foresight</th>
<th>Knowledge of Preferences</th>
<th>Disagreement</th>
<th>Strategic Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nash stability (R)</td>
<td>Focal DM (decision maker) cannot move unilaterally to a more preferred state.</td>
<td>Low</td>
<td>Never</td>
<td>Ignored risk</td>
<td>Medium</td>
</tr>
<tr>
<td>Metarational (GMR)</td>
<td>All focal DM unilateral improvements are sanctioned by subsequent unilateral improvements by others.</td>
<td>Medium</td>
<td>Own</td>
<td>By opponents</td>
<td>Medium</td>
</tr>
<tr>
<td>Metarational (SMR)</td>
<td>All focal DM unilateral improvements are sanctioned even after response by the focal DM.</td>
<td>Medium</td>
<td>Own</td>
<td>By opponents</td>
<td>Medium</td>
</tr>
<tr>
<td>Sequential Stability (SEQ)</td>
<td>All focal DM unilateral improvements are sanctioned by subsequent unilateral improvements by others.</td>
<td>Medium</td>
<td>All</td>
<td>Never</td>
<td>Low</td>
</tr>
<tr>
<td>Limited-move Stability (Ln)</td>
<td>All DMs are assumed to act optimally and the maximum number of state transitions (h) is specified.</td>
<td>Variable</td>
<td>All</td>
<td>Strategic</td>
<td>Non-myopic</td>
</tr>
<tr>
<td>Non-myopic Stability (NM)</td>
<td>Limiting case of limited move stability as the maximum number of state transitions increases to infinity.</td>
<td>High</td>
<td>All</td>
<td>Strategic</td>
<td>Non-myopic</td>
</tr>
</tbody>
</table>

Displaying DMs and Options in the Elmira Conflict Model

Equilibria

- Strong equilibria occur at states 5, 8, and 9.
- Historically, the status quo was state 1 in mid-1991.
- Local Government shifted to supporting the original Control Order, resulting in state 5 for a protracted interval of time.

Display of Equilibrium Results

Coalition Analysis

- MoE and Uniroyal together control the transition from state 5 to 8.
- Both are better off at state 8 than at state 5.

On October 7, 1991, MoE and Uniroyal dramatically announced an agreement on a modified version of the original Control Order, which moved the conflict from the non-cooperative equilibrium at state 5 to the cooperative equilibrium at state 8.

This is called an Equilibrium Jump.
A Tool Box

- Select appropriate societal and physical systems tools to solve a given problem.
- Decision Support systems permit these tools to be conveniently used in practice.

Influences of Physical Systems Modelling as well as Data and Time Series Analyses

- Samples taken at bore holes indicated that NDMA was present in the aquifer underlying Elmira.

- All wells in Elmira are still closed and water continues to be shipped via pipeline from the City of Waterloo to Elmira.

- The Elmira aquifer continues to be cleansed and all NDMA effluents from the Uniroyal plant are treated.
Ongoing Cleansing of Elmira Contamination

Chemtura operates for the Ontario Ministry of Environment:
- shallow aquifer containment and treatment system on the Uniroyal property to prevent discharge of contaminated water from reaching the adjacent creek;
- municipal aquifer property boundary containment and treatment system along the property boundary to stop the most contaminated water from leaving the property; and
- off-site containment and treatment system consisting of wells at 4 locations to prevent further movement of the plume. One of the locations is the former municipal supply wells at the south end of town.

Treatment systems have all been consolidated into one system.

(Information from Eric Hodgins, Manager, Hydrogeology and Source Water, Regional Municipality of Waterloo. February 29, 2012.)

Conclusions

- As illustrated by the Elmira conflict, GMCR II can be conveniently applied to an actual conflict.
- GMCR II can determine non-cooperative equilibria which reflect the best a DM can do on his or her own when a given equilibrium is reached.
- GMCR II can indicate when beneficial coalitions can be formed so that coalition members can achieve even better results.
- Political decisions may partially reflect findings from data analyses and physical systems modelling.

References

Decision Making in Engineering

- Informed Decision Making
- Social and Political Analyses
- Finance and Economics
- Environmental Factors
- Proposal
- Alternative Solutions
- Need for Creative Problem Solving

Strategic Level
- Unstructured Information
- Soft Systems

Tactical Level
- Structured Information
- Hard Systems

Competitive and Cooperative in Conflict Resolution

- Conflict Resolution
- Competition
- Cooperation (Coalition/Group Decision Making)
- Graph Model for Conflict Resolution
- Nonsensical Behavior
- Combination Analysis
- Multiple Criteria Decision Analysis
- Fair Resource Allocation
- Implementation Algorithms
- Decision Support Systems
- Recent Developments

- Identifying opportunities for coalition formation to move to a mutually preferred stable outcome
- Handling emotions and strength of preference
- Tracing the evolution of a conflict to a final outcome
- Taking care of uncertain preference information
- Incorporating policy analysis into a conflict study
- Modeling attitudes and misperceptions
- Determining strategic implications of misperceptions
- Having efficient algorithms for handling large conflicts

Research on the Graph Model for Conflict Resolution