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STRATEGIC DECISION MAKING FOR IMPROVED ENVIRONMENTAL SECURITY: COALITIONS AND ATTITUDES

Sean BERNATH WALKER [1] **Keith W. HIPEL** [2] **Takehiro INOHARA** [3]

[1] *Department of Systems Design Engineering, University of Waterloo, Waterloo, Ontario, Canada*
sgwalker@uwaterloo.ca (✉)

[2] *Department of Systems Design Engineering, University of Waterloo, Waterloo, Ontario, Canada*
kwhipel@uwaterloo.ca

[3] *Department of Decision and Value Science, Tokyo Institute of Technology, Tokyo, Japan*
inohara.t.aa@m.titech.ac.jp

Abstract

The utilization of decision support systems which are flexible enough to handle information about cooperative behavior and stakeholder attitudes are useful for analyzing complex social conflicts. One such conflict which arose from the redevelopment of a private brownfield property in Kitchener, Ontario, Canada is examined using such a decision support tool. Specifically, a formal model referred to as COAT which allows for the examination of conflicts with both coalition and attitude properties is rigorously defined and then implemented within the framework of the Graph Model for Conflict Resolution in order that insights may be gained on how the decision makers can reach win-win resolutions.

Keywords: Graph model for conflict resolution, attitudes, coalitions, COAT, decision support system, conflict

1. Introduction

Conflict, for better or for worse, is an intrinsic part of the human experience. In all walks of life and in all aspects of our professional lives, conflicts arise. Mainly, these conflicts result from the interaction of different stakeholders who have different goals. As conflicts involve multiple parties attempting to satisfy multiple objectives, it can often be difficult to determine the most appropriate course of action a decision maker should take. In order to explain how decision makers interact under conflict, the Graph Model for Conflict Resolution (GMCR) can be used to analyze the strategic moves and countermoves made by decision makers. Further, extensions of GMCR that model how decision makers form coalitions under conflict and how these coalitions can create moves that lead to better conflict outcomes have also been developed. Attitudes, an important element of conflict behavior, have also been formally defined within the Graph Model to provide a better understanding of conflicts.

Within Section 2 the Graph Model for Conflict Resolution is defined formally. In Section 3 these definitions are expanded to encompass the possible movements of coalitions of decision makers, while in Section 4 definitions pertaining to the behavior of stakeholders with different attitudes are given. In Section 5 the solution concepts defined in Sections 2 through 4 are combined to form solution concepts which account for coalitions and their attitudes. In Section 6, a brownfield redevelopment in Kitchener, Ontario, Canada is examined using the conflict resolution tools discussed in Sections 2 through 5.

2. Graph Model for Conflict Resolution

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

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

- $\succ_i$ is asymmetric; hence, for all $s, t \in S$. $s \succ_i t$ and $t \succ_i s$ cannot hold true simultaneously.
- $\sim_i$ is reflexive; therefore, for any $s \in S$, $s \sim_i s$.
- $\sim_i$ is symmetric; hence, for any $s, t \in S$ if $s \sim_i t$ then $t \sim_i s$.
- ($\succ_i$, $\sim_i$) is complete; therefore, for all s, $t\in S$ one of $s \succ_i t$, $t \succ_i s$ or $s \sim_i t$ is true.

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

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

When assessing the stability of a state for a given DM, it is necessary to examine possible responses by other DMs. In a two-DM model, the opponent is a single DM, while in an n-DM model with $n \geq 2$, two or more opposing DMs coexist within the model. To extend the stability definitions to n-DM models, the definition of countermoves by a group of DMs must be introduced first. Let $H\subseteq N$ be a nonempty subset of all DMs. A unilateral move (UM) by a group of DMs is defined by a *legal sequence* of

UMs, defined below, by individual DMs in the group. In a legal sequence, a DM may move more than once, but not consecutively. Let $R_H(s)$ denote the set of all states that can be reached through any legal sequence of UMs from state s by some or all DMs in H. If $s_1 \in R_H(s)$, let $\Omega_H(s, s_1)$ be the set of all last DMs in legal sequences from s to s_1.

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

Ordinal rankings are an intuitive manner for handling information about DM preferences. In order to adequately describe the three most common preference structures: more preferred, equally preferred and less preferred, sets that define DM preferences for given strategies and options are utilized. The symbol $\varphi_i^{\simeq}(s)$ represents the set of states that are less than or equally preferred by DM i to state s and $\varphi_i^{+}(s)$ represents the set of states preferred by DM i to state s. It is worth noting that neither of these preceding symbols should be confused with φ which stands for the null or empty set and is often used in set notation.

Definition 3 (Unilateral Improvement (UI) list for a DM) For $i \in N$ and $s \in S$, DM i's UI list from state s is the set $\{t \in R_i(s) \mid t \succ_i s\}$, denoted by $R_i^+(s) \subset S$. The UI list is a subset of the reachable list and includes all states which are more preferred than the starting state for DM i. More inductively, UI lists are defined as the intersection of a reachable list as defined in Definition 2 and the set of more preferred states, written as $R_i^+(s) = \varphi_i^+(s) \cap R_i(s)$.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3. Coalition Solution Concepts

Groups of DMs, referred to as coalitions, commonly form under conflict situations. Thus, extending the solution concepts defined in Section 2 to coalition behavior is needed in order to better understand conflicts. The following definitions extend the theory and solution concepts to include this group behavior using the research completed by Inohara & Hipel (2008a, b) and Kilgour et al. (2001).

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

Definition 11 (Coalition less improved state) Let $\varphi_H^{\simeq}(s)$ represent the set of all states that are less preferred to state s or are equally preferred with respect to state s by at least one DM in coalition H, that is, $\{x \in S \mid \exists i \in H, (s \succ_i x \text{ or } s \sim_i x)\}$. The set $\varphi_H^{\simeq}(s)$ thus represents all the states that are not more preferred than s by every member of the coalition H.

**Definition 12 (Coalition Nash stability for a

coalition (CNash)) A state $s \in S$ is coalition Nash stable for coalition $H \in P(N)$, denoted by $s \in S_H^{CNash}$, if and only if $R_H^{++}(s) = \varnothing$ (Kilgour et al. 2001, Hipel & Inohara 2008).

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

Definition 14 (Coalition sequentially stable for a coalition (CSEQ)): A state $s \in S$ is coalition sequentially stable for coalition $H \in P(N)$, denoted by $s \in S_H^{CSEQ}$, if and only if for all $x \in R_H^{++}(s)$, $R_{P(N\backslash H)}^{++}(x) \cap \varphi_H^{\tilde{\simeq}}(s) \neq \varnothing$.

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

Definition 15 (Coalition sequential stability for a DM) For $i \in N$, state $s \in S$ is coalition sequentially stable for DM i, if and only if $s \in S_H^{CSEQ}$ for all $H \in P(N)$ such that $i \in H$.

Definition 16 (Coalition general meta-rationality for a coalition (CGMR)): For $H \in P(N)$, state $s \in S$ is coalition general metarational for coalition H, denoted by $s \in S_H^{CGMR}$, if and only if for all $x \in R_H^{++}(s)$, $R_{P(N\text{-}H)}(x) \cap \varphi_H^{\tilde{\simeq}}(s) \neq \varnothing$.

Definition 17 (Coalition general meta-rationality for a DM): For $i \in N$, state $s \in S$ is coalition general metarational for DM i, if and only if $s \in S_H^{CGMR}$ for all $H \in P(N)$ such that $i \in H$.

Definition 18 (Coalition symmetric meta-rationality for a coalition (CSMR)) For $H \in P(N)$, state $s \in S$ is coalition symmetric metarational for coalition H, denoted by $s \in S_H^{CSMR}$, if and only if for all $x \in R_H^{+}(s)$, there exists $y \in R_{P(N\text{-}H)}(x) \cap \varphi_H^{\tilde{\simeq}}(s)$ such that $z \in \varphi_H^{\tilde{\simeq}}(s)$ for all $z \in R_H(y)$.

Definition 19 (Coalition symmetric meta-rationality for a DM) For $i \in N$, state $s \in S$ is coalition symmetric metarational for DM i, if and only if $s \in S_H^{CSMR}$ for all $H \in P(N)$ such that $i \in H$.

4. Attitudes

A further extension of the theory and solution concepts of Section 2 is the set of relational solution concepts provided by Inohara et al. (2007). In the following section, the concept of DM attitudes is applied to the solution concepts already discussed in order to help analysts better handle the actions of non-rational DMs.

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

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

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

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

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

I_{ij} if $e_{ij} = +$

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

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

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

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

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

$k \in TRR(e)_H(s)$ and $j \in \Omega_{Hs}^{TRR}(k)$,

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

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

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

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

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

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

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

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

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

TRR$(e)_{N\setminus\{i\}}(x) \cap R\varphi^{\tilde{=}}(e)_i(s) \neq \varnothing$.

5. COalitions and ATtitudes (COAT)

This final extension of the theory and solution concepts of GMCR is based both on the extension coalition analysis developed by Inohara & Hipel (2008a, b) and Kilgour et al. (2001) and attitudes developed by Inohara et al. (2007). The following section is an attempt to combine and synthesize this information to create an extension which accounts for both attitudes and group behavior.

Definition 32 (Attitudes of a coalition (e_H)) For a coalition H of size M where $H \subseteq N$, the attitudes of the coalition are a set of M attitude vectors of magnitude N. Thus,

$$e_H = \{e_i, e_j, e_k, e_l, ..., e_z\},$$

where $DMs\, i, j, k, l, ..., z \in H$.

Definition 33 (Coalition relational less preferred states) The symbol $R\varphi^{\tilde{=}}(e)_H(s)$ is an analogue of $\varphi_H^{\tilde{=}}(s)$ given in Definition 12. Specifically, $R\varphi^{\tilde{=}}(e)_i(s)$ is the set of all states that are not relational preferred to state s by at least one DM in coalition H, that is, $\{t\in S \mid \exists\, i\in H, \mathrm{NE}(t\ \mathbf{TRP}(e)_i\ s)\}$.

Note: $s \notin R\varphi^{\tilde{=}}(e)_H(s)$ always holds. $R\varphi^{\tilde{=}}(e)_H(s) = \cup_{i\in H} R\varphi^{\tilde{=}}(e)_i(s)$.

Definition 34 (TRR$^{++}(e)_H(s)$: Relational Coalition improvement list) The relational coalition improvement list of a coalition $H \subset N$ with states $s\in S$, **TRR**$^{++}(e)_H(s)$ is an analogue of the coalition improvement list $R_H^{++}(s)$ given in Definition 11, and is defined as the set $\{t\in R_H(s) \cup \{s\} \mid \forall\, i\in H, t\ \mathbf{TRP}(e)_i\ s\}$.

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

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

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

Definition 35 (TRR$^{++}(e)_{\mathrm{C}}(s)$: Class relational improvement list) For a subclass C of P(N) and $s\in S$, the class relational improvement list of subclass C from state s is defined inductively as the set **TRR**$^{++}(e)_{\mathrm{C}}(s)$ for which $\Omega_{Cs}^{TRR++}(k)$ is the set of last DMs and $C \subset N,\ C \neq \varnothing$ at e for state $s\in S$ such that:

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

$k \in TRR^{++}(e)_C(s)$ and $j \in \Omega_{Cs}^{TRR++}(k)$,

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

$k_1 \in TRR^{++}(e)_j(k)$, then

a) if $\left|\Omega_{Cs}^{TRR++}(k)\right| = 1$ and $j \notin \Omega_{Cs}^{TRR++}(k)$,

then $k_1 \in TRR^{++}(e)_C(s)$ and $j \in \Omega_{Cs}^{TRR++}(k_1)$,

b) if $\left|\Omega_{Cs}^{TRR++}(k)\right| > 1$ then

$k_1 \in TRR^{++}(e)_C(s)$ and $j \in \Omega_{Cs}^{TRR++}(k_1)$.

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

$t \in$ **TRR**$^{++}(e)c(s)$ and $u \in$ **TRR**$^{++}(e)_H(t)$, then $u \in$ **TRR**$^{++}(e)c(s)$.

Definition 36 ($S_H^{CRNash(e)}$: Coalition relational Nash stability (CRNash)): For $H \subseteq N$, $s \in S$, and e, state s is coalition relational Nash stable at e for coalition H, denoted by $s \in S_H^{CRNash(e)}$, if and only if **TRR**$^{++}(e)_H(s) = \{s\}$.

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

Definition 37 ($S_H^{CRSEQ(e)}$: Coalition relational sequential stability (CRSEQ)): For $H \subseteq N$, $s \in S$, and e, state s is coalition relational sequential stable at e for coalition H, denoted by $s \in S_H^{CRSEQ(e)}$, if and only if for all $x \in$ **TRR**$^{++}(e)_H(s)-\{s\}$, **TRR**$^{++}(e)_{P(N-H)}(x) \cap (R\varphi^{\tilde{-}}(e)_H(s) \cup \{s\}) \neq \varnothing$

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

Definition 38 ($S_H^{CRGMR(e)}$: Coalition relational general metarationality (CRGMR)): For $H \subseteq N$, $s \in S$, and e, state s is coalition relational general metarational at e for coalition H, denoted by $s \in S_H^{CRGMR(e)}$, if and only if for all $x \in$ TR**R**$^{++}$**(*e*)$_H$(*s*)**, $\mathbf{R}_{P(N-H)}(x) \cap (R\varphi^{\tilde{-}}(e)_H(s) \cup \{s\}) \neq \varnothing$.

Definition 39 ($S_H^{CRMR(e)}$: Coalition relational symmetric metarationality (CRSMR)): For $H \subseteq N$, $s \in S$, and e, state s is coalition relational symmetric metarational at e for coalition H, denoted by $s \in S_H^{CRSMR(e)}$, if and only if for all $x \in$ **TRR**$^{++}(e)_H(s)-\{s\}$, there exists $y \in R_{P(N-H)}(x) \cap (R\varphi^{\tilde{-}}(e)_H(s) \cup \{s\})$ such that $z \in R\varphi^{\tilde{-}}(e)_H(s) \cup \{s\}$ for all $z \in R_H(y)$.

6. Brownfield Redevelopment Case Study

In this section, a simple conflict over the use of a contaminated plot of land in Kitchener, Ontario, Canada is modeled using the aforementioned GMCR - Section 2 - and the COalitions and ATtitudes extension developed in Sections 3 through 5.

6.1 Background to the Dispute

The Intowns is a condominium development within the Mill-Courtland Woodside Park community which came into being through the collaboration of the City of Kitchener, concerned citizens and the developer, Stirling Bridge Limited. The property itself is a 3.38 ha

Table 1 Original property use conflict in tableau form

Feasible states														
D	1	Full project	N	Y	N	N	Y	N	N	Y	N	N	Y	N
	2	Reduction	N	N	Y	N	N	Y	N	N	Y	N	N	Y
CK	3	Support community	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N
	4	Delay	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
G	5	Protest	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
			1	2	3	4	5	6	7	8	9	10	11	12
			4	5	6	8	9	10	20	21	22	24	25	26

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

6.2 Model Calibration and Initial Analysis

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

From information known about the goals of each of the DMs a ranking of states was determined. To determine these rankings an option prioritization method was employed for all three DMs. These rankings represent the DMs preferences and thus form the basis of the analyses performed in GMCR. Using this option prioritization D's preferences assumed that D wanted to build a full project (1) while CK delays (4) and without protests from G (5). CK's preferences were that the project be at least reduced by D (2), that there be no protests (5) and that if protests did occur that they support N (3 IF 5) and that D sells the property (NOT 1 OR 2). Finally, G prefers that D sells the property (NOT 1 OR 2), and that CK support them (3). Using rules such as these the preference ranking of each DM was developed. Armed with this information, a simple static analysis was undertaken using Nash and Sequential stabilities, given by Definitions 6 and 9 respectively, in

Table 2. From the tableau form of the conflict shown in Table 2, it can be seen that there are equilibria at states 1, 3 and 11. Within the analysis in Table 2, Nash and Sequential stability were implemented to determine the overall state equilibriums. For example, state 5 was found to be unstable for CK. From state 5 CK can move according to $R_{CK}(5) = 9$. In order for a state to be sequentially stable, by Definition 9, either D or G must have a UI from 9 to a state that belongs to the set $\varphi_{CK}^{\approx}(9)$. As $R^{+}_{D}(9) = 7$ and $R^{+}_{G}(9) = \varnothing$, state 7 must be compared to state 5 using CK's preferences. As state 9 is not less preferred to state 5 by CK, i.e. $5 \notin \varphi_{CK}^{\approx}(9)$, CK's unilateral improvement cannot be sanctioned and thus the state is unstable.

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

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

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

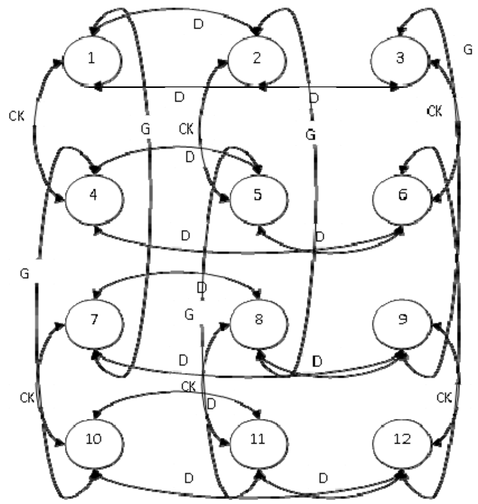

Figure 1 Graph model of the conflict

6.3 Attitudes and Coalitions

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

Table 2 Static analysis of property use conflict

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

Table 3 Reachable lists in original property use conflict

s	1	2	3	4	5	6	7	8	9	10	11	12
$R_d(s)$	2	1	1	5	4	4	8	7	7	11	10	10
	3	3	2	6	6	5	9	9	8	12	12	11
$R_c(s)$	4	5	6	1	2	3	10	11	12	7	8	9
$R_n(s)$	7	8	9	10	11	12	1	2	3	4	5	6
$R_{n\text{-}c}(s)$	4	5	6	1	2	3	1	2	3	1	2	3
	7	8	9	7	8	9	4	5	6	4	5	6
	10	11	12	10	11	12	10	11	12	7	8	9

coalition's constituent DMs. In this subsection, the creation of a coalition with attitudes that aid G in moving the conflict towards a preferred final conflict outcome is described.

Given the option form of the conflict found in Table 1, it is possible to describe the movements of the DMs using reachable lists as laid out in Definition 2. In Table 3, these reachable lists, as well as the reachable list of a coalition of DMs C and G, are given. The first three rows, which represent the unilateral movements of D, CK and G were used in the analysis of the conflict given in Table 2. Each reachable list is derived from the option form of the conflict using Definitions 2 and 4. In order that the new coalition movements are utilized according to the values of G and CK it is necessary to employ the formal model of COalitions and ATtitudes defined in Definitions 32 to 39. To determine the relational moves of G-CK, the attitudes of all three DMs within the conflict are expressed in tabular form with the +, 0 or – representing positive, indifferent or negative attitudes by the row DM towards the column DM, respectively (Definition 20).

As defined in Definition 32, e_H is the set of

DM attitudes for some coalition H. The attitudes shown in Table 4 indicate that both CK and G are indifferent towards CK and D and devoting towards G. Thus, G-CK's attitudes can be written as $e_{G\text{-}CK} = \{ e_G , e_{CK} \} = \{(0, 0, +), (0, 0, +)\}$. With this information defining the attitudes of the coalition, it is possible to determine the TRPs and TRRs for the coalition using Definitions 33 and 34, respectively.

Table 4 Decision maker attitudes in original property use conflict

	D	CK	G
D	+	0	0
CK	0	0	+
G	0	0	+

In order to apply the relational coalition definitions, coalition movements from Table 3 are taken and states that are relationally less preferred are removed, thus satisfying Definition 35. In this particular case, as both CK and G are working to make moves that are beneficial to G according to the attitudes expressed in Table 4; only those moves that are less preferred BY G are removed from the coalition reachable lists to obtain the subsets. The result of the manipulation of the coalition reachable list and DM preferences is shown in Table 5, where the TRR for G-CK has been determined from the coalition movements of G-CK and G's preferences. This determination of G-CK's TRR list comes from Definition 34 which shows that for a coalition H, a state x is $x\text{TRR}_H y$ if $x \in R_H(y)$ and $x\text{TRP}_H y$, from Definition 35. For example, from state 5, $R_H(5) = \{2, 8, 11\}$ and $8\text{TRP}_H 5$, $11\text{TRP}_H 5$. Thus, both states 8 and 11 are TRRs from state 5.

After having determined the relational coalition improvements and movements, it is possible to analyze the conflict for stable and equilibrium states. The tableau form of the conflict in Table 7 shows that there are now only two equilibria at state 1 and state 3 which is Nash stable for D, by Definition 6 and CRNash for G-CK by Definition 36. Definition 36 states that a state x is CRNash for coalition H if $\text{TRR}_H(x) = x$, meaning that the only relational improvement that coalition H can reach is state x itself. For G-CK, $\text{TRR}_{G\text{-}CK}(1) = \{1\}$ and thus the state is CRNash for G-CK. The same proof can be shown for G-CK at state 3 as well. Thus as state 3 is stable for D and G-CK the state is a Coalition Relational Nash equilibrium state.

The introduction of coalition moves with attitudes has introduced new moves and countermoves into the conflict. Now that state 11 is unstable, the coalition G-CK can move past this state to other conflict equilibriums. In Figure 2, the evolution of the conflict from state 11 is shown, illustrating how the application of COAT has illuminated potential moves for G-CK.

Table 5 Coalition total relational replies for G-CK

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

Table 6 Tableau form of property use conflict with attitudes and coalitions

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

Table 7 CRGMR and CRSMR stability for N-CK

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

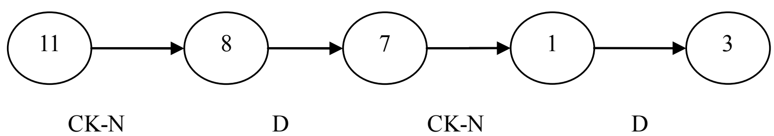

Figure 2 Conflict evolution

In Table 6 there is one state which is a Coalition Relational Nash (CRNash) Equilibrium, state 1, marked "crn". Applying CRNash and Coalition Relational Sequential (CRSEQ) stabilities, there are no relational sanctioned states. To determine if states with coalition TRRs are relationally sanctioned from a given state, Definition 33 is employed. Definition 33 simply states that if a state is not relationally preferred by at least one member of the coalition, it is relationally less preferred. Examining state 7 for CRSEQ stability yields some instability; from state 7 G-CK has a coalition total relational reply to state 1. In response to this movement D can make a unilateral move within the conflict to 3. However as $3 \notin R\varphi_i^{\approx}$ (7), D's unilateral movement does not sanction G-CK and thus, state 7 is not CRSEQ stable for G-CK.

Employing the CRSMR and CRGMR solution concepts as defined in Definitions 38 and 39 can give additional information about the strength or weakness of the stable states in a conflict, as illustrated in Table 7. Within this conflict model the three states that were CRNash stable for G-CK were also CRGMR and CRSMR as well as state 10. State 10 is CRGMR and CRSMR stable for N-CK. At state 10, N-CK has a TRR^{++} to state 1 and a TRR^{++} to state 7. From state 1, D has a unilateral movement to state 2; as state 5 is not relationally more preferred, by Definition 33, it is possible for D to sanction N-CK's move from state 10 to 1. If N-CK moves to state 7, D can make a unilateral movement to state 8, such that $8 \in R\varphi^{\approx}_{G-CK}(10)$. Thus state 10 is CRGMR for G-CK. Additionally, as G-CK cannot escape from either sanction the state is CRSMR. In the first sanction where D moves from state 1 to state 2 CK's possible moves are to states 5, 8 and 11, all of which belong to the set $R\varphi^{\approx}_{G-CK}(10)$. From G-CK's move to state 7 and D's subsequent response to state 8, G-CK has no possible escapes. That is to say that from state 8 G-CK's reachable list is empty ($R_{G\text{-}CK}(8) = \varnothing$).

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

7. Concluding Remarks

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

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References

[1] City of Kitchener. (2005). Reurbanization of 90 Woodside Avenue. August 22, 2005. Available via DIALOG. http://www.

kitchener.ca/woodside.htm. Cited October 10, 2008

[2] Fang, L., Hipel, K.W. & Kilgour, D.M. (1993). Interactive Decision Making: the Graph model for conflict resolution. Wiley, New York, NY

[3] Feick, D. (2007). Inspiring townhome community supports Kitchener's revitalization efforts. Waterloo Region Record, July 7, 2007. Available via DIALOG. http://news.therecord.com/article/212296. Cited August 19, 2008

[4] Fraser N.M. & Hipel, K.W. (1984). Conflict Analysis: Models and Resolutions. North-Holland, New York, NY

[5] Howard, N. (1971). Paradoxes of Reality: Theory of Metagames and Political Behaviour. MIT Press, Cambridge

[6] Inohara, T. & Hipel, K.W. (2008a). Coalition analysis in the graph model for conflict resolution. Accepted for publication

[7] Inohara T. & Hipel, K.W. (2008b). Interrelationships among Noncooperative and Coalition Stability Concepts. Journal of Systems Science and Systems Engineering, 17 (1): 1-29

[8] Inohara, T., Hipel, K.W. & Walker, S. (2007). Conflict analysis approaches for investigating attitudes and misperceptions in the war of 1812. Journal of Systems Science and Systems Engineering, 16 (2): 181-201

[9] Kilgour, D.M., Hipel, K.W., Fang, L. & Peng, X. (2001). Coalition analysis in group decision and support. Group Decision and Negotiation, 10 (2): 159-175

[10] Nash, J.F. (1950). Equilibrium points in *n*-player games. Proceedings National Academy of Sciences, 36 (1): 48-49

[11] Nash, J.F. (1951). Non-cooperative games. Annals of Mathematics, 54 (2): 286-295

[12] Record Staff. (2007). Kitchener brownfield project wins national recognition. Waterloo Region Record, October 26, 2007. Available via DIALOG. http://news.therecord.com/article/261487. Cited September 14, 2008

Sean Bernath Walker is a doctoral student of Systems Design Engineering at the University of Waterloo. He received his BASc in Chemical Engineering and his MASc in Systems Design Engineering both from the University of Waterloo. His current research interests are coalitions, attitudes and their applications to environmental policy and conflict.

Keith W. Hipel is University Professor of Systems Design Engineering at the University of Waterloo, where he is Coordinator of the Conflict Analysis Group. He is Senior Fellow with the Centre for International Governance Innovation and recently completed a two-year term as Vice President of the Academy of Sciences, which is part of the Royal Society of Canada. His major research interests are the development of conflict resolution, multiple objective decision making and time series analysis techniques from a systems design engineering perspective with application to water resources management, hydrology, environmental engineering and sustainable development. He received his Bachelor's and PhD degrees in Civil Engineering from the University of Waterloo in 1970 and 1975, respectively, and his Master's degree in Systems Design from Waterloo in 1972. Dr. Hipel is Fellow of the Royal Society of Canada (FRSC),

Canadian Academy of Engineering (FCAE), Institute of Electrical and Electronics Engineers (FIEEE), International Council on Systems Engineering (FINCOSE), Engineering Institute of Canada (FEIC), and the American Water Resources Association (FAWRA). He is also a recipient of the Norbert Wiener Award from the IEEE Systems, Man and Cybernetics (SMC) Society, and Docteur Honoris Causa from École Centrale de Lille.

Takehiro Inohara received his B.S. (Mathematics, 1992), M.S. (Systems Science, 1994) and PhD (Systems Science, 1997), all from the Tokyo Institute of Technology (Tokyo Tech), Tokyo, Japan. He is currently an Associate Professor in Department of Value and Decision Science (VALDES), Tokyo Tech. His research interests are in the fields of conflict resolution, decision making, consensus building, and social network theory. He is a reviewer of Mathematical Reviews, and the leader of the International Program on Consensus Building (IPCOB) at Tokyo Tech. In 2003, Professor Inohara received "Tokyo Tech Award for Challenging Research" from Tokyo Tech, and in 2005, "The Young Scientist's Prize" from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in Japan.