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# Power asymmetry in conflict resolution with application to a water pollution dispute in China

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**Key Points:**
- A unique definition of power asymmetry is provided
- A conflict analysis model considering power asymmetry is established
- A water pollution dispute in China is investigated

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**Abstract** The concept of power asymmetry is incorporated into the framework of the Graph Model for Conflict Resolution (GMCR) and then applied to a water pollution dispute in China in order to show how it can provide strategic insights into courses of action. In a new definition of power asymmetry, one of the decision makers (DMs) in a conflict can influence the preferences of other DMs by taking advantage of additional options reflecting the particular DM's more powerful position. The more powerful DM may have three different kinds of power: direct positive, direct negative, or indirect. It is useful to analyze a model of a conflict without power asymmetry, and then to analyze a power-asymmetric model. As demonstrated by analysis of the water quality controversy that took place at the border separating the Chinese provinces of Jiangsu and Zhejiang, this novel conflict resolution methodology can be readily applied to real-world strategic conflicts to gain an enhanced understanding of the effects of asymmetric power.

## 1. Introduction

With population growth and economic development, water resources crises have become a global phenomenon. Water resources issues arise at the international level (the Nile Basin [*Dinar and Alemu*, 2000; *Wu and Whittington*, 2006; *Elimam et al.*, 2008], the Ganges [*Kilgour and Dinar*, 2001], the Indus River [*Zawahri*, 2008, 2009a], the Zambezi River basin [*Tilmant et al.*, 2010; *Tilmant and Kinzelbach*, 2012; *Giuliani and Castelletti*, 2013], the Caspian Sea [*Madani and Gholizadeh*, 2011; *Madani et al.*, 2014], the Middle East [*Hipel et al.*, 2014], the trans-border Canada-US basins [*Hipel and Fraser*, 1980; *Fraser and Hipel*, 1980; *Ma et al.*, 2011, 2013], and the Aral Sea Basin [*Nandalal and Hipel*, 2007]) and at the regional level (the Maipo River Basin [*Cai et al.*, 2003], Zayandeh-Rud River Basin [*Madani and Mariño*, 2009], the Upper Klamath Basin [*Boehlert and Jaeger*, 2010], California's Sacramento-San Joaquin Delta [*Madani and Lund*, 2011a, 2011b], and water diversions in China [*He et al.*, 2014; *Chu et al.*, 2015]). Generally, water resources conflicts reflect different needs for water quantity or quality or navigation across different stakeholders, and different economic or temporal demands in meeting these needs. Water conflicts are also shaped by history, political leverage, perceptions of need, broader conflicts, and other connected issues. Water resources disputes seriously restrict sustainable development and efficient utilization of limited water resources. On the other hand, based on a study of 261 international rivers, *Wolf* [1998] concludes that water is an agent for peace and cooperation rather than hostile conflicts and war. For instance, although attempts by international corporations to assume control over water supply and treatment, as well as other infrastructure systems, in countries around the globe have caused serious conflict to arise [*Hipel and Obeidi*, 2005], various versions of Public Private Partnerships (PPPs), which take advantage of the private sector for economic efficiency and the public sector for longer-term vision in water management, have been adopted as a compromise approach [*Kassab et al.*, 2011].

Various quantitative and qualitative conflict resolution methods have been developed for water resources management. Among them, a very rich body of analytical techniques deal with treaties, conflict, and cooperation over international rivers [*Gleditsch et al.*, 2006; *Zawahri et al.*, 2010, 2011; *Zawahri and Mitchell*, 2011; *Dinar et al.*, 2011; *Brochmann and Hensel*, 2009, 2011; *Brochmann*, 2012]. For a description of various economic, statistical, and game-theoretical approaches for studying transboundary water conflict and cooperation, see *Dinar and Dinar* [2003] and *Dinar* [2004]. In particular, water resources conflict resolution research has been carried out in a game-theoretic framework because game methods can provide a better understanding of the trade-offs inherent in water resources management, such as sustainability versus efficiency. The objective is to more effectively manage water resources, in strategic and positive ways [*Madani*, 2010; *Madani and Hipel*, 2011].

A water resources system has many attributes including ecology and effects on nature, society, and the economy, so water resources conflicts are highly complex strategic decision problems—multigoal, multistakeholder, multistage, and multilevel. They are usually settled through negotiations. As a simple, flexible, and practical conflict analysis methodology, the Graph Model for Conflict Resolution (GMCR) [*Kilgour et al*., 1987; *Fang et al*., 1993] can model and analyze water resources conflicts well. Specifically, using GMCR the development or evolution of a water resources conflict can be simulated through dynamically tracking the possible moves and countermoves of decision makers (DMs) among different states (outcomes) in the conflict. Then the possible stable states (equilibria or resolutions) of the conflict can be identified, and appropriate strategic guidance can be provided to the DMs in the conflict.

GMCR can solve strategic conflicts in the form of strategic interactions modeled on a directed graph. *Kilgour and Hipel* [2005] characterize a strategic conflict as an interaction of two or more independent DMs, each of whom makes choices that together determine how the state of the conflict evolves, and each of whom has preferences over these possible states (as eventual resolutions). It is clear that strategic conflicts are very common in interactions in all fields, including water resources management. The interest groups in a strategic conflict are modeled as DMs (decision makers), where each DM can unilaterally make choices (also known as strategies or options). The combination of choices of all DMs together determines the state (potential outcome) of the conflict. Generally, DMs' interests and objectives clash, as reflected by their preferences over the states [*Getirana and Malta*, 2010].

Stability in a graph model is based on the idea of moves and countermoves by the DMs. This idea of stability is strategic, and contrasts with that of determining equilibria by maximizing expected utility, even using a minimax concept as is often done in the normal form [*Von Neumann and Morgenstern*, 1944], especially for two-person zerosum games. In a graph model, a DM may choose to move or stay at any initial state; the order of moves is immaterial. Another constraint that may limit the verisimilitude of a normal-form game model is that in a game players' preferences must be represented by real-valued utilities, which open up the possibility of mixed strategies (probabilistic mixtures of actions, as opposed to specific actions). But utilities are notoriously difficult to measure and mixed strategies are often hard to interpret as "advice" [*Kilgour and Hipel*, 2005].

The GMCR method was first put forward by *Kilgour et al.* [1987] based in part on earlier methods [*Fraser and Hipel*, 1979; *Howard*, 1971]. In a 1993 book, *Fang et al*. [1993] explained in detail the GMCR methodology as it existed at the time, included real-world applications, and provided a conflict analysis software system. Later, the Decision Support System GMCR II [*Hipel et al*., 1997; *Fang et al*., 2003a, 2003b] was designed to permit a user to conveniently calibrate a graph model and thereby apply the GMCR methodology to small, medium, and large conflicts.

Many scholars have improved and broadened the basic GMCR approach. For example, uncertain preference [Li et al., 2004a; *Yu et al*., 2015a], multilevel strength of preference [*Hamouda et al*., 2004; *Xu et al*., 2009a], and fuzzy preference [*Hipel et al*., 2011; *Bashar et al*., 2012] were introduced into GMCR to determine the strategic impacts of preference uncertainty. *Obeidi et al*. [2005] showed how emotions can affect the preference ranking while *Inohara et al*. [2007] defined stability concepts that take DMs' attitudes into account. Other extensions of the graph model framework include coalition analysis [*Kilgour et al*., 2001; *Inohara and Hipel*, 2008a, 2008b], sensitivity analysis [*Ma et al*., 2011], status quo analysis [*Li et al*., 2004b], third-party intervention [*Kinsara et al*., 2012], multistage conflict analysis [*Toyota and Kijima*, 2005], and policy stability [*Zeng et al*., 2004, 2007]. Additional studies combine some of the above extensions, such as status quo analysis under uncertain preference [*Li et al*., 2005]. Finally, *Xu et al*. [2009b] provided a matrix method to speed up the analysis of a graph model.

Compared to other formal conflict analysis methodologies such as game theory [*Von Neumann and Morgenstern*, 1944], metagame analysis [*Howard*, 1971], conflict analysis [*Fraser and Hipel*, 1984], and drama theory

[*Howard*, 1999], GMCR [*Kilgour et al*., 1987; *Fang et al*., 1993] holds many advantages. For instance, GMCR can accept models with many DMs and any finite number of actions. It needs only DMs' relative preference information (which may be transitive or intransitive). It can model reversible, irreversible, and common moves (more than one DM can make the same move). It provides a flexible framework to define, characterize, and compare different stability concepts and is easy to apply to real-world conflicts. It provides a good understanding of how DMs should choose and gives strategic advice to both practitioners and researchers [see *Hipel*, 2009a, 2009b; *Kilgour and Eden*, 2010 for summaries]. GMCR has been employed to analyze and resolve various conflicts including water resources and environmental management conflicts [*Li et al*., 2004a, 2004b; *Gopalakrishnan et al*., 2005; *Madani and Hipel*, 2007; *Nandalal and Hipel*, 2007; *Elimam et al*., 2008; *Getirana and Malta*, 2010; *Ma et al*., 2011; *Hipel and Walker*, 2011; *Hipel et al*., 2015; *Yu et al*., 2013, 2015b].

The theories and methods of conflict analysis, first developed in the mid-1980s, have demonstrated the capacity of analyzing the development and internal mechanisms of a conflict. However, the representation of DMs who have special relationships, such as some forms of dependence, is limited. In the real world, these dependencies are usually asymmetric, in which status levels and powers of subjects are different. When a conflict outcome deviates from what a subject with power wants, the power owner may consider using power to achieve a more favorable equilibrium. At the same time, other DMs must pay special attention to the actions of a DM with power.

The influence of asymmetric power has been the focus of many studies in supply chain management [*Hunt and Nevin*, 1974; *Lusch*, 1976; *Gaski*, 1984]. Within the framework of non-cooperative game theory, *De et al*. [1990] put forward a concept of hierarchical power which is similar to asymmetric power. *Zeitoun and Warner* [2006] proposed the framework of hydro-hegemony for analyzing transboundary water conflicts by studying and evaluating riparians' geographical position (upstream/downstream), power (economic/political/military/securitization), and resource exploitation potential (infrastructure/technology capacity). *Zeitoun* [2007, 2008] explained how the asymmetric power relations between the two sides in the Palestinian-Israeli water conflict results in the conflict being contained, but unresolved. In the seventh chapter of the book by *Dinar et al*. [2007], the influence of relative power on international water conflict and cooperation is discussed. The existing literature on the hegemony and asymmetric power relations among riparians over transboundary rivers also include contributions by *Mirumachi and Allan* [2007], *Zeitoun and Mirumachi* [2008], *Dinar* [2009, 2012], *Zeitoun et al*. [2011], and *Warner and Zawahri* [2012].

Despite the prevalence of power asymmetry in conflicts, few scholars have considered the role of asymmetric power in conflict analysis. In particular, power asymmetry is very common in water resources conflicts. For instance, power asymmetry is a dominant natural feature of most river basins, where—in the absence of basin wide markets or regulation—upstream-downstream conflicts are structurally asymmetric. Because water resources conflicts are often complex decision problems, they are often solved by multilateral negotiations, in which DMs can use power (political, military, economic, etc.) to affect the final outcome. Thus, power asymmetry may be fundamental to the understanding and resolution of water resources disputes, yet it is relatively unstudied in the water resources domain.

The objective of this research is to formally incorporate the concept of asymmetric power into the GMCR framework. The underlying motivation was the need to address a challenging water pollution dispute in China in which asymmetric power was a crucial factor. This study is the first attempt to develop the mathematical formulation of power asymmetry within the GMCR framework. This technique can be applied to many conflict resolution issues including water resources management but, to the best of our knowledge, this is the first water resources conflict study in which the asymmetric power has been explicitly considered in the modeling process. In section 2, the basic idea of power in conflicts is described, followed by the presentation in section 3 of a new GMCR approach for formally investigating asymmetric power. The capability of this new method for conveniently and realistically modeling asymmetric power is illustrated using the water pollution dispute that took place along the Maxi Port River where it crosses the boarder of Jiangsu and Zhejiang provinces in section 4. In the final section of the paper, some conclusions are drawn.

## 2. Power in Conflicts

As noted above, the concept of asymmetric power has been developed for the analysis of supply chain conflicts, focusing mainly on the relationships among power, conflict, and channel members' satisfaction. *Hunt* *and Nevin* [1974] found that coercive power (punishment) reduces power receptors' satisfaction (in contrast to power owners), while noncoercive power (rewards) increases power receptors' satisfaction; *Lusch* [1976] claimed that coercive power intensifies conflict, while noncoercive power reduces it; and *Gaski* [1984] proposed that the relationship of coercive or noncoercive power with conflict is closely related to whether the power is exercised or not, respectively.

Within the water resources literature, some scholars have considered the power-asymmetric relations of riparians along transboundary or international rivers, focusing mainly on the influence of the interactions between the hegemonic states and the nonhegemonic states regarding conflict and cooperation. However, researchers have reached different conclusions, for example, on the potential effects of hydro-hegemony on cooperation [*Zawahri et al*., 2011]. Some argue that hegemons can use asymmetric power to achieve coerced cooperation that confines the interest of nonhegemons [*Zeitoun and Warner*, 2006; *Zeitoun et al*., 2011], while others suggest that hegemony can contribute to the public good by bringing about cooperation [*Zawahri and Mitchell*, 2011].

All in all, power difference is an important factor affecting negotiation behavior and results in conflicts. Clearly, power in a conflict is a "double-edged sword." It can create more cooperation among DMs, perhaps preventing or controlling the conflict. Conversely, power can escalate a conflict. Power must be important in conflict analysis—so, before analyzing conflict using the idea of asymmetric power, the concept of power must be defined carefully.

### 2.1. Definition of Power

It is widely agreed among sociologists that power can be essentially defined as the ability to influence others. In order to further illuminate the nature of power, *Emerson* [1962] proposed that the power of A over B is equal to, and based upon, the dependence of B upon A. Actually, these two definitions with different starting points are not mutually exclusive. Combining them, one can define power as the potential or ability of one party in the conflict to control or influence the behavior of another party, and this ability depends on the degree of dependence between the two parties.

### 2.2. Classification of Power

The basic classification of power (coercive, reward, legitimate, referent, and expert) was first proposed by social psychologists *French and Raven* [1959]. Later, this classification was widely adopted in supply chain studies. The five kinds of power sources can be classified from different points of view, such as coercive versus noncoercive power, economic versus noneconomic power, and exercised versus unexercised power [*Gaski*, 1984].

However, in order to make the concept of power useful to analyze general conflicts, not just specific channel conflicts in supply chain management, direct and indirect power are defined in this research according to the effect and cost of use. Direct power refers to power that can directly change or influence the target receptor's behavior, but that usually imposes some costs on the party exercising the power. Direct power can also be divided into direct positive and direct negative power according to whether the power owner is exercising incentive or punitive power on the power receptor. Indirect power is power that might change or influence the receptor's behavior, but is often costless to use. That is, indirect power might make a power receptor behave submissively through changing the target's subjective intention. Direct and indirect powers are different from coercive versus noncoercive power, but are similar to exercised coercive versus exercised noncoercive power.

For instance, the United Nations or countries like the United States sometimes use sanctions to punish other countries. These sanctions can be regarded as direct negative power. Saudi Arabia acted through reconciliation and monetary support to intervene in the conflict between Syria and Iraq [*Kinsara et al*., 2012]; the reconciliation and monetary support can be regarded as indirect power and direct positive power, respectively. In channel studies within supply chain management, coercive and legitimate power are forms of direct negative power, reward is direct positive power, and indirect power includes referent and expert power.

In the Framework of Hydro-hegemony proposed by *Zeitoun and Warner* [2006], most of the water resource control tactics that the powerful state would employ to exert power in riparian circumstances for leadership or dominative outcomes can be classified into direct positive, direct negative, and indirect powers mentioned above. For example, trade incentives, diplomatic recognitions, and military protection are forms of direct positive power; military action, economic sanctions, and political isolation belong to direct negative power; and knowledge construction is an instance of indirect power.

**Table 1.** Power-Asymmetric Conflict Model

| | | $S$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $S^{\neg p}$ | | | | $S^{p}$ | | | | | | | |
| DMs | Options | $s_1$ | $s_2$ | $s_3$ | $s_4$ | $s_5$ | $s_6$ | $s_7$ | $s_8$ | $s_9$ | $s_{10}$ | $s_{11}$ | $s_{12}$ |
| LDM 1 | $o_{11}$ | **Y** | **Y** | N | N | **Y** | **Y** | N | N | **Y** | **Y** | N | N |
| | $o_{12}$ | N | N | **Y** | **Y** | N | N | **Y** | **Y** | N | N | **Y** | **Y** |
| LDM 2 | $o_{21}$ | **Y** | N | **Y** | N | **Y** | N | **Y** | N | **Y** | N | **Y** | N |
| | $o_{22}$ | N | **Y** | N | **Y** | N | **Y** | N | **Y** | N | **Y** | N | **Y** |
| HDM | $o_{31}$ | **Y** | **Y** | **Y** | **Y** | N | N | N | N | N | N | N | N |
| | $o_{32}$ | N | N | N | N | **Y** | **Y** | **Y** | **Y** | N | N | N | N |
| | $o_{33}$ | N | N | N | N | N | N | N | N | **Y** | **Y** | **Y** | **Y** |

Overall, as an involuntary exogenous force on the target, the effect of direct power is obvious. Indirect power mediates a conflict by changing the target's sense of identification or approval of the power owner, so if it works, it may have a long-term influence.

### 2.3. Perception of Power

Power itself influences the conflict only through perception or action. Therefore, the DMs' evaluations of their own and others' potential powers are very important. In general, the greater the power, the stronger the perception of it. Although the perception can more or less reflect the power itself, cognitive bias can easily occur due to the subjectivity of the perception. However, in this paper, it is assumed that all DMs have the correct perception of power, and hence, there are no errors on any side.

## 3. Conflict Modeling Under Power Asymmetry

The conflict analysis methodology provides a feasible approach for modeling, analyzing, and solving conflict problems. Generally, each subject or DM in the model has equal status and can act independently of one another. However, for some conflicts, one DM has more power than others and can control the overall situation by acting as a leader. In this case, many existing conflict analysis methods are no longer suitable. Here the conflict analysis model with power asymmetry is established as follows.

### 3.1. Model Building

The key elements of a conflict graph model generally include the DMs, options (choices or actions), feasible states (scenarios or outcomes), preferences, state transitions, and a set of directed graphs. The purpose of a stability analysis based on a calibrated conflict model is to investigate potential moves and counter-moves among DMs as they jockey for position according to their interests or value systems during the dynamic process of reaching a possible resolution or equilibrium from which no DM has an incentive to deviate.

#### 3.1.1. Decision Makers

DMs refer to the individuals or organizations involved in a given conflict who have the capability to make decisions. Participants whose options and preferences are essentially the same can be regarded as one DM. In the power-asymmetric conflict model considered in this paper, there are two levels in the power structure. The DM with greater power (also known as the higher decision maker (HDM)) is at a higher level or status. Other DMs with less power (the lower decision makers (LDMs)) have lower status. Sometimes, an HDM can influence or change an LDM's behavior or preferences according to the HDM's goals by invoking power. DMs can be represented by the set $N=\{1,\ 2,\ \ldots,\ h,\ i,\ \ldots, n-1,\ n\}$, where DM $h$ is the single HDM.

In the power-asymmetric conflict model defined below, it is assumed that each individual DM tries to satisfy or maximize his own interests or objectives by making strategic decisions based on his own target values and preferences among the possible scenarios in the full knowledge of how the other DMs could possibly react. In addition, all DMs' perceptions of power are considered as being correct. In other words, there is no misunderstanding about power among the DMs.

#### 3.1.2. Power and Options

Power refers to the HDM's ability to change the conflict situation and to influence an LDM's behavior. As mentioned in section 2, an HDM can use two kinds of power: direct and indirect. Direct power falls into two categories: positive and negative. Generally, direct power involves a cost when it is exercised, while indirect

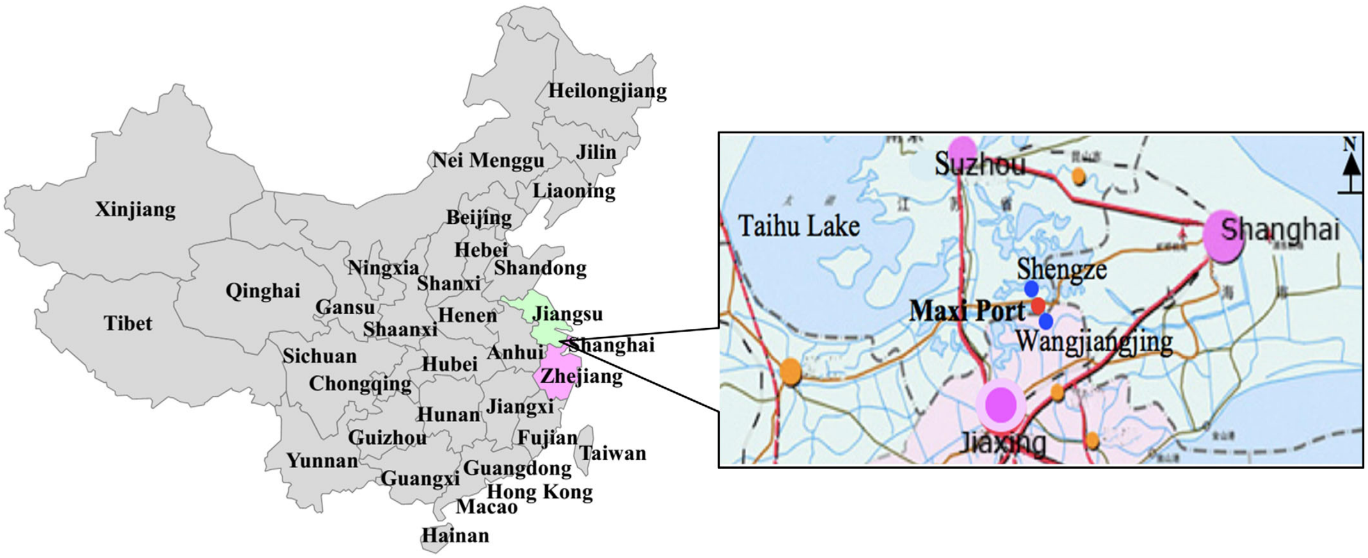


**Figure 1.** Map of the conflict.

power incurs no cost. Direct power directly changes at least one LDM's preference, while indirect power may make one or more LDMs behave submissively.

An effective way to define states is to use option form, which was originally proposed by *Howard* [1971] and has been employed by other authors such as *Fraser and Hipel* [1984] and *Fang et al.* [1993]. Specifically, let $O_i$ denote DM $i$'s set of options, where $o_{ij}$ is DM $i$'s $j^{th}$ option. The set of all options in a conflict is then $O = \cup_{i \in N} O_i$ in which the $i$ index indicates who controls the options. The exercise of power is expressed and reflected through the HDM's power options. An HDM can use power by creating additional power options and thereby changing one or more LDMs' preferences. Assume there are three kinds of separated sets of power options denoted by $O_{d+}$, $O_{d\text{-}}$, and $O_{d0}$, which represent direct positive, direct negative and indirect power, respectively. The HDM's set of all power options is given by $O_h^p = O_{d+} \cup O_{d\text{-}} \cup O_{d0}$. For example, the HDM's "reward," "punish," and "persuade" options, provided later in Table 12 and explained in section 4.3, constitute the direct positive, direct negative, and ineffective indirect power options, respectively. In practice, the direct positive and negative options are usually mutually exclusive since they cannot be used at the same time.

The situation in which HDM interacts with the LDMs using power or force is signaled by the letter $p$, while the situation in which HDM uses no power is indicated by $\neg p$, where "$\neg$" means no. Assume that $O_h^{\neg p} = \{o_{h1}, o_{h2}, \cdots, o_{hj}, \cdots, o_{hm}\}$ is HDM's set of options that do not include power, and $O_h^p = \{o_{h,\ m+1}, o_{h,\ m+2}, \cdots, o_{h,\ m+j}, \cdots, o_{h,\ m+w}\}$ is HDM's set of power options, where $o_{h,\ m+j} \in O_{d+} \cup O_{d\text{-}} \cup O_{d0}$, for which $O_{d+} \cup O_{d\text{-}} \cup O_{d0} \neq \phi$. Notice that $o_{d0} \in O_{d0}$ might belong to $O_h^{\neg p}$, when the HDM's indirect power is ineffective and hence can be regarded as no power. Therefore, the HDM's option set is denoted by $O_h^{\neg p}$ before using power and $O_h = O_h^{\neg p} \cup O_h^p$ when power can be invoked. The sets $O_h^{\neg p}$ and $O_h$ might be the same when no power or only ineffective indirect power is available, but can differ (the number of options in $O_h$ may be greater than in $O_h^{\neg p}$) when direct power is available. The option set of a given LDM, denoted by $O_i$, is the same whether or not HDM uses power, i.e., $O_i^p = \phi$ and $O_i = O_i^{\neg p}$. Therefore, the set of all options in a conflict model when the HDM can employ power is $O = \cup_{i \in N} O_i$.

### 3.1.3. Strategies and Feasible States

When a particular DM decides which of his options to select, a specific strategy is formed. A strategy for DM $i$ is a subset $g_i \subseteq O_i$. Suppose DM $i$ has an option $o_{ij} \in O_i$, and $g$ is an indicator function. If his strategy $g_i$ includes the selection of $o_{ij}$, we say $g(o_{ij}) = \text{Y}$; otherwise, $g(o_{ij}) = \text{N}$. Thus, in the option form [*Howard*, 1971; *Fraser and Hipel*, 1979, 1984] of a conflict model such as that shown in Table 1, one can easily discover the reasons for the "Y"s and "N"s in the table. Take state $s_{11}$ in Table 1 for example: LDM 1's strategy is $g_1 = \{g(o_{11}) = \text{N},\ g(o_{12}) = \text{Y}\}$, LDM 2's strategy is $g_2 = \{g(o_{21}) = \text{Y},\ g(o_{22}) = \text{N}\}$, and HDM's strategy is $g_3 = \{g(o_{31}) = \text{N},\ g(o_{32}) = \text{N},\ g(o_{33}) = \text{Y}\}$.

The set of all subsets of $O_i$ is the power set $2^{O_i}$, so a strategy for DM $i$ is $g_i \in 2^{O_i}$. HDM's strategies with no power options, with power options, and with all options are $g_h^{\neg p} \in 2^{O_h^{\neg p}}$, $g_h^p \in 2^{O_h^p}$, and $g_h \in 2^{O_h}$, respectively. When each DM selects a strategy, a state, representing a specific situation or scenario in the conflict, is

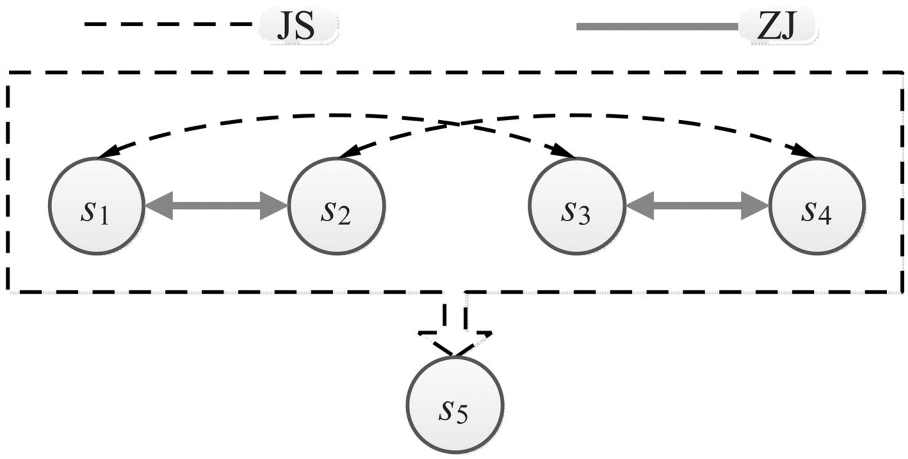


**Figure 2.** Basic integrated graph model.

formed. The set of all subsets of $O=\cup_{i\in N} O_i$ is $2^O$, so a state is $s\in 2^O$, and $s$ can be written as $s=(g_1,\ g_2,\ \cdots,\ g_i,\ \cdots,\ g_n)$, where $g_i\in 2^{O_i}$.

In practice, some states (option combinations) are impossible or otherwise unattainable. These infeasible states must be removed from the conflict model. For instance, sometimes a DM cannot choose two options at the same time; hence, those states with both of the two mutually exclusive options selected are infeasible and should be omitted. In addition, option combinations that are essentially equivalent or indistinguishable should be coalesced and treated as a single state (also called an indistinguishable state) in a conflict model. A powerful feature of GMCR II [*Hipel et al.*, 1997; *Fang et al.*, 2003a, 2003b] is that it employs flexible procedures that can remove all infeasible option combinations and coalesce all equivalent option combinations in any option form.

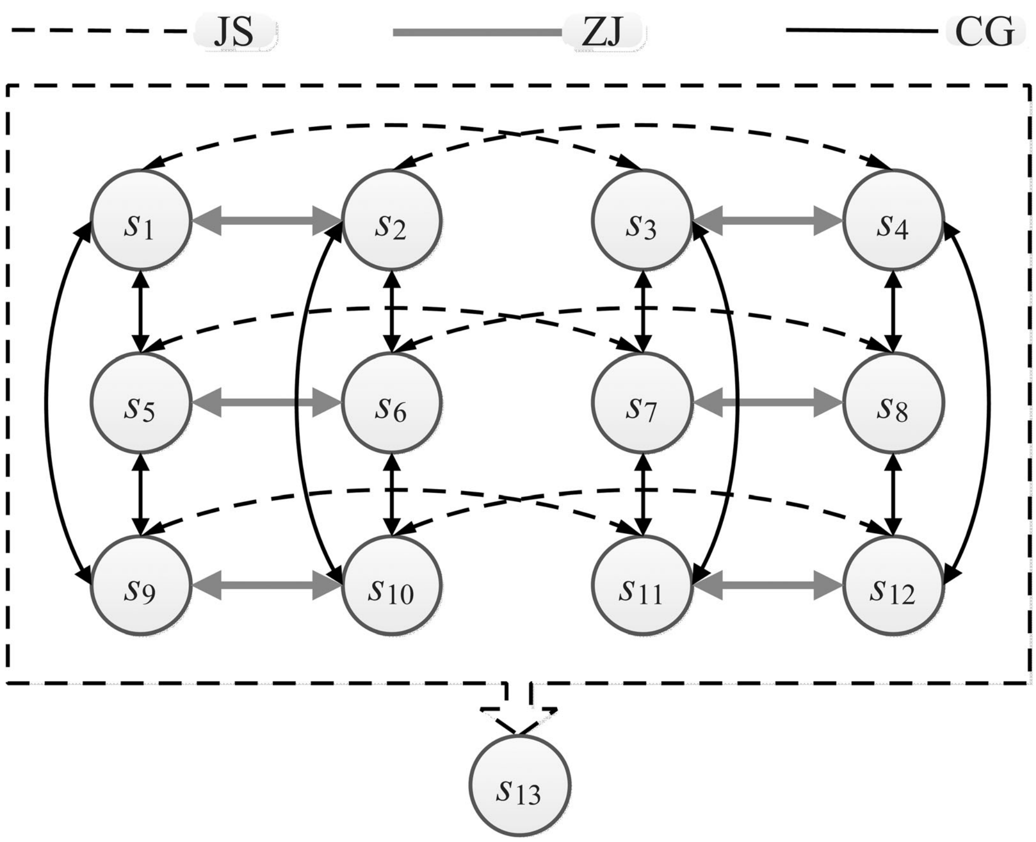


**Figure 3.** Integrated power-asymmetric graph model.

**Table 2.** Four Stability Concepts and Their Descriptions and Characteristics

| Stability Concepts | Descriptions | Characteristics: Foresight | Characteristics: Disimprovement | Characteristics: Knowledge of Preferences |
|---|---|---|---|---|
| Nash stability (Nash) [*Nash*, 1950, 1951] | A state is Nash stable for a DM if the DM cannot move to a preferred state | Low (1 move) | Never | Own |
| General metarationality (GMR) [*Howard*, 1971] | A state is GMR for a DM if all of the DM's unilateral improvements are sanctioned by subsequent unilateral moves of others | Medium (2 moves) | Sanctions only | All |
| Symmetric metarationality (SMR) [*Howard*, 1971] | A state is SMR for a DM if all of the DM's unilateral improvements are still sanctioned by others, even after a possible response by the original DM | Medium (3 moves) | Sanctions only | All |
| Sequential stability (SEQ) [*Fraser and Hipel*, 1979, 1984] | A state is SEQ for a DM if all of the DM's unilateral improvements are sanctioned by subsequent unilateral improvements of others | Medium (2 moves) | Never | All |

After the infeasible states are eliminated, what remains is the set of feasible states. Assume $S$ is the set of feasible states in a model when HDM's power options are included. $S^{\neg p}=\{s_1,\ s_2,\ \ldots,\ s_k,\ldots,\ s_{t-1},\ s_t\}$ is the set of states in which no power options are taken by HDM; it is also the set of all states when HDM has no power. Let $S^p=\{s_{t+1},\ s_{t+2},\ \ldots,\ s_{t+k},\ldots,\ s_{t+v}\}$ $(v \geq 0)$ be the set of states in which HDM chooses at least one power option. The number of feasible states can differ after the exercise of power by the HDM, so $v \geq 0$. It is obvious that $S=S^{\neg p} \cup S^p$.

As an example of the above definitions, consider a power-asymmetric conflict model shown in Table 1. The left column in the table lists the three DMs, while the second column contains the options controlled by each DM. Each of the numbered columns on the right-hand side in Table 1 represents a feasible state in the conflict: a "Y" means yes, the option is selected by the DM controlling it; an "N" indicates an option is not taken; and a dash ("-") stands for Y or N. In Table 1, options $o_{32}$ and $o_{33}$ are HDM's positive and negative direct power options, respectively. In state $s_{11}$, for example, HDM has selected option $o_{33}$, while LDM 1 is taking option $o_{12}$, and LDM 2 chooses option $o_{21}$.

Hence, $S=\{s_1,\ s_2,\ \ldots,\ s_{12}\}$ is the set of all feasible states in the model given in Table 1. The set $S^{\neg p}=\{s_1,\ s_2,\ s_3,\ s_4\}$ is the set of states where no power option is taken by HDM, and therefore Ns appear opposite options $o_{32}$ and $o_{33}$ in each of these states. The set of power states $S^p=\{s_5,\ s_6,\ \ldots,\ s_{12}\}$ is the set of states in which at least one power option is taken by HDM.

### 3.1.4. Preferences

For each DM $i \in N$, let $\{\succ_i,\ \sim_i\}$ represent DM $i$'s preferences on $S$, with the interpretation that $s_k \succ_i s_t$ means that DM $i$ prefers state $s_k \in S$ to state $s_t \in S$, while $s_k \sim_i s_t$ indicates that DM $i$ has equal preference for these two states, or is indifferent between them.

The influence of the power asymmetry on a DM's preference can be considered from two perspectives. First, a given LDM $i$'s preference for his own options might be changed when HDM chooses power options. For the conflict in Table 1, for example, assume LDM 1 (also written as $L1$) prefers to choose option $o_{11}$ rather than $o_{12}$ ($s_1 \succ_{L1} s_3$) when HDM does not exercise power (selects option $o_{31}$) and LDM 2 chooses option $o_{21}$. But after HDM's exercise of power (selecting option $o_{32}$ or $o_{33}$), LDM 1 may prefer to choose option $o_{12}$ rather than $o_{11}$ ($s_7 \succ_{L1} s_5$ or $s_{11} \succ_{L1} s_9$). Second, HDM (also written as $H$) generally prefers to exercise negative direct power more than positive direct power ($o_{33}$ rather than $o_{32}$) due to the former's lower cost ($s_{11} \succ_H s_7$). An LDM (power receptor), however, may prefer that HDM exercise positive direct power ($s_7 \succ_{L1} s_{11}$).

### 3.1.5. State Transitions

DM $i$'s reachable list or unilateral moves from state $s=(g_1,\ g_2,\ \cdots,\ g_n) \in S$ can be defined as: $R_i(s)=\{q \in S : q=(y_1,\ y_2,\ \cdots,\ y_n),\ y_j=g_j \text{ for all } j \in N\text{-}i,\ y_i \neq g_i\}$.

**Table 3.** Basic Conflict Analysis Model

| DMs | Options | $s_1$ | $s_2$ |
|---|---|---|---|
| LDM | $o_{l1}$ | **Y** | N |
| | $o_{l2}$ | N | **Y** |
| HDM | $o_{h1}$ | **Y** | **Y** |

Because a DM may be tempted to unilaterally move to a more preferred situation, the concept of a unilateral improvement is important. In particular, DM $i$'s possible unilateral improvements from state $s \in S$ are $R_i^+(s)=\{q \in R_i(s) \text{ and } q \succ_i s\}$.

**Table 4.** Direct Power-Asymmetric Conflict Analysis Model

| DMs | Options | $s_1$ | $s_2$ | $s_3$ | $s_4$ |
|---|---|---|---|---|---|
| LDM | $o_{l1}$ | **Y** | N | **Y** | N |
| | $o_{l2}$ | N | **Y** | N | **Y** |
| HDM | $o_{h1}$ | **Y** | **Y** | N | N |
| | $o_{h2}$ | N | N | **Y** | **Y** |

The conflict in Table 1, for example, assumes that HDM's preferences over states $s_1$, $s_5$, and $s_9$ are as follows: $s_9 \succ_H s_5 \succ_H s_1$. Then HDM's reachable list or unilateral moves from state $s_5$ is $R_H(s)=\{s_1, s_9\}$, and HDM's possible unilateral improvements from state $s_5$ is $R_H^+(s)=\{s_9\}$.

#### 3.1.6. Directed Graphs

For $i \in N$, let $A_i \subseteq S \times S$ be the set of oriented arcs, which represents the moves in one step controlled by DM $i$ so that for $s_k, s_t \in S$, $(s_k, s_t) \in A_i$ if and only if (iff) $s_t \in R_i(s_k)$. Then, $D_i=(S, A_i)$ is DM $i$'s directed graph when power options can be selected by HDM in the model. Similarly, $A_i^{\neg p} \subseteq S^{\neg p} \times S^{\neg p}$ is the set of arcs controlled by DM $i$ when power options are not available for HDM as is illustrated in Table 1. If $s_k, s_t \in S^{\neg p}$, then $(s_k, s_t) \in A_i^{\neg p}$ iff $s_t \in R_i(s_k)$. The integrated graph of all DMs is $D=\langle S, \{A_i\}_{i \in N}\rangle$ when power options can be selected, and $D^{\neg p}=\langle S^{\neg p}, \{A_i^{\neg p}\}_{i\in N}\rangle$ when power options are not available. Note that one could also define a direct graph for the set of states $S^p$ as $D^p=\langle S^p, \{A_i^p\}_{i\in N}\rangle$ when it is assumed that a power option is always chosen. For examples of directed graph models, please see Figures 2 and 3.

#### 3.1.7. Graph Model

The asymmetric power between DMs in the conflict often affects the HDM's selection of power options and at least one LDM's preferences structure, and thus may change a DM's preferences over the feasible states and the results of the stability analysis. Therefore, the complete conflict analysis when power asymmetry is considered can usually be divided into two stages: basic conflict analysis (for the set of states $S^{\neg p}$) and power-asymmetric conflict analysis (for the set of states $S$). Based on the above definitions, the basic conflict analysis graph model is $G^{\neg p}=\langle N, S^{\neg p}, \{A_i^{\neg p}\}_{i\in N}, \{\succ_i, \sim_i\}_{i\in N}\rangle$, while the power-asymmetric conflict analysis graph model is $G=\langle N, S, \{A_i\}_{i\in N}, \{\succ_i, \sim_i\}_{i\in N}\rangle$. In some situations, one may wish to carry out a stability analysis of the power-based conflict model (for the set of states $S^p$) $G^p=\langle N, S^p, \{A_i^p\}_{i\in N}, \{\succ_i, \sim_i\}_{i\in N}\rangle$.

A variety of abstract game models are available for representing a conflict. Any form of the conflict model puts the available information into perspective and systematically structures the problem [*Fang et al*., 1993]. The normal form [*Von Neumann and Morgenstern*, 1944], for example, is widely utilized in the classical game theory, while the option form [*Howard*, 1971; *Fraser and Hipel*, 1979, 1984] has been employed in the study of real-world conflicts. Both the normal form and the option form representations of games have some drawbacks. Particularly, movements among states in either the normal or the option format are automatically constrained by these special structures.

However, the graph form [*Kilgour et al*., 1987; *Fang et al*., 1993] is a more comprehensive and flexible representation of conflicts. For instance, reachable lists are given to provide a complete, but simple and efficient, description of the strategic structure of a conflict model. The option form and the normal form are symmetric in the sense that if DM $i$ can reach state $s_t$ from state $s_k$, then DM $i$ can also reach state $s_k$ from state $s_t$. But the graph form is not restricted by the symmetry assumption. The graph form can also model the possibility of common moves, in which more than one DM can move from one state to another. The extra flexibility to represent both irreversible moves and common moves constitutes an important advantage of the graph form for modeling conflicts [*Fang et al*., 1993].

### 3.2. Stability Analysis

Employing the graph model methodology to analyze a strategic conflict usually comprises two steps: first, conflict modeling, or specifying a graph having all the above mentioned elements, and second, conducting stability analyses on the graph, as well as other extended analysis techniques such as status quo analysis [*Li et al*., 2004b, 2005] and sensitivity analysis [*Ma et al*., 2011] if deemed appropriate.

**Table 5.** Indirect Power-Asymmetric Conflict Analysis Model

| DMs | Options | $s_1$ | $s_2$ | $s_5$ | $s_6$ |
|---|---|---|---|---|---|
| LDM | $o_{l1}$ | **Y** | N | **Y** | N |
| | $o_{l2}$ | N | **Y** | N | **Y** |
| HDM | $o_{h1}$ | **Y** | **Y** | N | N |
| | $o_{h3}$ | N | N | **Y** | **Y** |

For a graph model, a state is stable for a DM if the DM would not choose to move away from it. A state that is stable for all DMs is named an equilibrium. Once one determines the set of feasible states, $S^{\neg p}$, in the basic conflict model; $S^p$, in the power-based model; and $S$, in the power-asymmetric model; as well as the preferences for each of the DMs among

**Table 6.** DMs, Options, and Feasible States of the Basic Graph Model

| DMs | Options | $s_1$ | $s_2$ | $s_3$ | $s_4$ | $s_5$ |
|---|---|---|---|---|---|---|
| JS | 1. Retain | **Y** | **Y** | N | N | - |
| | 2. Reduce | N | N | **Y** | **Y** | - |
| | 3. Close | N | N | N | N | **Y** |
| ZJ | 4. Negotiate | **Y** | N | **Y** | N | - |
| | 5. Block | N | **Y** | N | **Y** | - |
| CG | 6. Persuade | **Y** | **Y** | **Y** | **Y** | - |

the states for each of these three conflicts, a stability analysis can be carried out separately for each of these disputes to find the basic equilibria, power-based equilibria and power-asymmetric equilibria, respectively.

A solution concept defines mathematically how DMs may behave under conflict. Four commonly used solution concepts, along with their descriptions and characteristics regarding how they work, are provided in Table 2. In the characterization, foresight refers to the maximum number of moves foreseen by a DM. Nash stability looks one move ahead; both GMR and SEQ look two moves ahead, while SMR looks three moves ahead. Disimprovement is a unilateral movement to a state which is less preferred than the current state by a DM. A DM might be willing to sanction other DMs' unilateral improvements by moving to a worse state. No disimprovement exists for either the focal DM or other DMs in Nash stability and SEQ; in GMR and SMR, sanctions by other DMs may be disimprovements. Stability definitions also differ with respect to levels of preference knowledge: a DM only needs to know his own preferences in Nash stability, GMR, and SMR, while the DM must know the preference information for all other DMs in SEQ.

The mathematical definitions of the above mentioned stability concepts are given as follows:

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 (iff) $R_i^+(s)=\phi$.

GMR: For $i \in N$, state $s \in S$ is GMR stable for DM $i$, denoted by $s \in S_i^{GMR}$, iff for all $s_1 \in R_i^+(s)$, there exists $s_2 \in R_{N-i}(s_1)$, such that $s \precsim_i s_2$.

SMR: For $i \in N$, state $s \in S$ is SMR stable for DM $i$, denoted by $s \in S_i^{SMR}$, iff for all $s_1 \in R_i^+(s)$, there exists $s_2 \in R_{N-i}(s_1)$, such that $s \precsim_i s_2$, and $s \precsim_i s_3$ for all $s_3 \in R_i(s_2)$.

SEQ: For $i \in N$, state $s \in S$ is SEQ stable for DM $i$, denoted by $s \in S_i^{SEQ}$, iff for all $s_1 \in R_i^+(s)$, there exists $s_2 \in R_{N-i}^+(s_1)$, such that $s \precsim_i s_2$.

Since DMs in a conflict may have different levels of foresight, risk attitudes, and knowledge levels, selecting a proper stability definition is a challenging task. When there is uncertainty about the characteristics of DMs, it is helpful to carry out stability analysis under a range of stability concepts to see how the strategic behavior of DMs reflects their capabilities and attitudes, and reveal how the conflict resolution depends on DMs' behavior patterns. The capability to accommodate different stability concepts is what makes GMCR flexible, and improves its validity.

One can employ the decision support system GMCR II [*Hipel et al*., 1997; *Fang et al*., 2003a, 2003b] to calculate stability according to each of the four solution concepts given in Table 2 for each of the DMs for every state separately for any graph model, along with the associated equilibria. The preferences and stability analysis for a dispute similar to that shown in Table 1 are provided in section 4 for a real-world water pollution conflict in China.

### 3.3. Two-Person Example

As mentioned earlier, an HDM can change an LDM's preferences when direct power is used via the selection of a direct power option. When an HDM levies indirect power by choosing an indirect power option, an LDM's preferences may be changed, though this is not necessarily the case. Three different models are now used to illustrate how a two-person power-asymmetric conflict can be expressed within the framework of GMCR, as well as how to identify if there is power asymmetry in a conflict.

In this two-person conflict, HDM's option set with no power is $O_h^{-p}=\{o_{h1}\}$, and is $O_h^p=\{o_{h2},\ o_{h3}\}$ with power, where option $o_{h2}$ represents direct power and option $o_{h3}$ stands for indirect power. LDM's option set is $O_l=\{o_{l1},\ o_{l2}\}$. Tables 3–5 show the basic conflict analysis model, the direct power-asymmetric conflict analysis model, and the indirect power-asymmetric conflict analysis model of the two-person conflict, respectively.

**Table 7.** JS's Preference Statements

| Statements | Descriptions |
|---|---|
| −3 | Do not choose "Close" to completely reduce and control the pollution |
| 1 | Select "Retain" to do nothing about the pollution |
| −5 | ZJ does not choose "Block" to escalate the conflict |

**Table 8.** ZJ's Preference Statements

| Statements | Descriptions |
|---|---|
| 3 | JS chooses "Close" to completely reduce and control the pollution |
| 2 | JS selects "Reduce" to partially reduce and control the pollution |
| 4 IF 2 | Select "Negotiate" if JS chooses "Reduce" to partially control the pollution |
| 5 IF 1 | Select "Block" to escalate the conflict if JS chooses "Retain" to do nothing about the pollution |

Assume that HDM always prefers that LDM chooses option $o_{l2}$. However, if HDM exercises no power, and thereby chooses option $o_{h1}$, LDM prefers to select option $o_{l1}$ (see Table 3). But LDM is vulnerable to HDM's power (options $o_{h2}$ and $o_{h3}$). When HDM chooses option $o_{h2}$ (exercises direct power), LDM prefers to select option $o_{l2}$ (see Table 4); when HDM chooses option $o_{h3}$ (exercises indirect power), LDM may prefer to select option $o_{l1}$ or $o_{l2}$ (see Table 5).

When there is no power asymmetry in the two-person conflict, i.e., $O_h^{-p}=\{o_{h1}\}$, $S^{-p}=\{s_1,\ s_2\}$, the basic conflict model is shown in Table 3. HDM's preference order is $s_2 \succ_h s_1$. LDM's preference order is $s_1 \succ_l s_2$. The basic equilibrium, which is Nash stable for all the DMs, is found to be state $s_1$ by conducting a stability analysis using GMCR II.

Table 4 shows how HDM exercises direct power by adding option $o_{h2}$ on its own, where $O_h=\{o_{h1},\ o_{h2}\}$, $S=\{s_1,\ s_2,\ s_3, s_4\}$. HDM's preference order is $s_2 \succ_h s_4 \succ_h s_1 \succ_h s_3$. Because LDM's preference order is $s_1 \succ_l s_4 \succ_l s_3 \succ_l s_2$, LDM is vulnerable to HDM's power. Thus, the power-asymmetric equilibrium (Nash) is state $s_4$.

When HDM uses indirect power (adding option $o_{h3}$, see Table 5), $O_h=\{o_{h1},\ o_{h3}\}$, $S=\{s_1,\ s_2,\ s_5, s_6\}$. In contrast to direct power, indirect power does not act directly, but through enhancing the LDM's sense of identification or approval of the HDM, thus perhaps changing the LDM's behavior. Indirect power usually does not have a cost of use, but whether the power can change LDM's behavior or not is uncertain. Therefore, HDM's preference order is $s_2 \succ_h s_6 \succ_h s_1 \succ_h s_5$. But LDM's preference is uncertain, and the uncertain preference information is $s_1 \succ_l (s_5\ \ U_l\ \ s_6) \succ_l s_2$, where the brackets indicate that LDM may prefer state $s_5$ more than state $s_6$ or state $s_6$ over state $s_5$. The power-asymmetric equilibrium (Nash) would be state $s_1$ or $s_6$ depending on whether $s_5 \succ_l s_6$ or $s_6 \succ_l s_5$, respectively. Therefore, indirect power is effective for HDM if $s_6 \succ_l s_5$, but is ineffective if $s_5 \succ_l s_6$.

The analysis demonstrates that to recognize whether there is power asymmetry in a conflict model the analyst should check whether one DM's preference is vulnerable to an option of another DM. More specifically, if one DM's option can change another DM's preference, this option can be regarded as direct power or effective indirect power; if one DM's option can make another DM's preference be uncertain, this option can be regarded as indirect power.

## 4. Application to a Water Pollution Conflict

A useful case study illustrating the applicability of this paper's conflict analysis model is a well-known water pollution conflict between China's Jiangsu and Zhejiang Provinces. Although this conflict has also been studied and analyzed using GMCR [*Yu et al*., 2013], the effect of asymmetric power was not considered in their study. The real-life case in this section is more of a water quality conflict at the regional level, but we believe that the afore-established power asymmetric conflict analysis model can be employed to analyze other kinds of water conflicts at both the regional and international levels. Meanwhile, because water conflicts typically involve many decisions and these are the result of many different factors affecting DMs, to reduce a conflict to a model having only a few DMs with a certain number of options removes unnecessary complexity at the expense of having a less exact representation of reality. However, this does not necessarily mean the model is ineffective, since nearly all kinds of modeling methodologies attempt to represent real-world cases as simply as possible for clarity of understanding and gaining insights.

**Table 9.** CG's Preference Statements

| Statements | Descriptions |
|---|---|
| 3 | JS chooses "Close" to completely reduce and control the pollution |
| 2 | JS selects "Reduce" to partially reduce and control the pollution |
| −5 | ZJ does not choose "Block" to escalate the conflict |

### 4.1. Conflict Modeling

#### 4.1.1. Background

In China, Maxi Port is a small river located at the boundary of Shengze Town (in Suzhou City, Jiangsu Province) and

**Table 10.** Preference Information

| DMs | Preference Rankings |
|---|---|
| JS | $s_1 \succ s_2 \succ s_3 \succ s_4 \succ s_5$ |
| ZJ | $s_5 \succ s_3 \succ s_4 \succ s_2 \succ s_1$ |
| CG | $s_5 \succ s_3 \succ s_4 \succ s_1 \succ s_2$ |

Wangjiangjing Town (in Jiaxing City, Zhejiang Province). As shown in Figure 1, the river flows from Shengze Town to the northern part of Jiaxing City. The 27 large dyeing and printing enterprises in Shengze Town produce large quantities of pollution, releasing about 100,000 tons of untreated industrial wastewater into Maxi Port on a daily basis, causing serious water pollution in the northern areas of Jiaxing City. In the late 1980s, the water quality of the Maxi Port was found to be Class III, which reflects middle level of water pollution. In the 1990s, it rapidly deteriorated, reaching Class IV in 1992, and Class V in 1996. The health and quality of life of many people were seriously endangered by this pollution. According to the available statistics, in the 1990s, the pollution cost the fisheries of Jiaxing City a cumulative loss of 50 million yuan; 150,000 people were directly affected; the drinking water of 800,000 people was polluted; and many had to obtain drinking water from 5 km away. During the 1990s, disputes frequently arose at the border of Jiangsu and Zhejiang, and the problem was never properly resolved. Under the coordination of the Taihu Basin Administration (TBA), which is led by both the Ministry of Water Resources (MWR) and the State Environmental Protection Administration (SEPA) of China, Jiaxing negotiated with Suzhou many times, but failed to reach an agreement. Eventually, on 22 November 2001, a hostile event occurred.

That night, a crowd of people from Jiaxing, using four bulldozers, sank 28 concrete boats full of thousands of sand bags at Maxi Port, thereby blocking industrial wastewater released into the Maxi River from reaching the northern part of Jiaxing City. This action was paid for by citizens from Jiaxing, who self-raised over 1 million yuan. The event attracted the attention of the Central Government (CG) of China, which then ordered and authorized the TBA to coordinate and solve the conflict properly, and as soon as possible. Under the permission and instructions of CG, the TBA received the right (or power) to support or punish Suzhou. Finally, through the CG's coordination, Jiangsu and Zhejiang conducted a formal negotiation, resulting in an agreement jointly signed by the two provinces, the MWR and the SEPA. Under this agreement, Suzhou had to reduce its pollution emissions to less than 40% of the original, and subsequently, Zhejiang removed the blockage. The water pollution conflict had been effectively solved.

#### 4.1.2. Decision Makers and Options

The first step of a conflict analysis is to recognize the relevant DMs. As explained earlier, the water pollution conflict involves Suzhou City, Jiaxing City and the TBA, which individually fall under the control of Jiangsu (JS) Province, Zhejiang (ZJ) Province and CG, respectively. Therefore, the three DMs in the conflict are the upstream region located in JS, the downstream region in ZJ, and the coordinator, which is CG. The two provinces are in the same administrative positions and therefore have equal power, while the CG occupies a superior administrative position and has more power. According to the foregoing definitions, JS and ZJ are the LDMs, while CG acts as the HDM.

In addition to the DMs' identities, their options need to be known as well. Specifically, JS has three available options under its control: "Retain": Retain the status quo by keeping the existing economic growth mode and the current pollution controls; "Reduce": Increase the intensity of pollution control to reduce the pollution levels; "Close": Shut down the polluting industries to completely eliminate their emissions. There are two options for ZJ: "Negotiate": Through negotiations, determine the reduction in pollution released by JS; "Block": Via coercive action taken by its citizens, try to force JS to reduce its pollution.

Before 22 November 2001, TBA, as the representative of CG, had only one option: "Persuade": Act as a coordinator to persuade JS to reduce its pollution. After this date, under the instructions and authorization of CG, TBA had two additional options: "Reward": Use direct positive power to encourage JS to reduce its pollution by using an incentive compensation policy. That is, if JS does well in reducing the pollution, CG will provide capital or technological support to JS; "Punish": Use direct negative power to force JS to reduce the pollution by using a punitive policy. That is, water quality standards are set in certain sections of the river, and JS is punished if the water quality is substandard. CG tends to use its direct negative power due to its lower associated cost. In this case, the option of "Persuade" can also be regarded as ineffective indirect power.

**Table 11.** Stability Analysis Results

| Stability | $s_2$ | $s_5$ |
|---|---|---|
| Nash | √ | √ |
| GMR | √ | √ |
| SMR | √ | √ |
| SEQ | √ | √ |

As mentioned, the power asymmetry between the two classes of DMs can influence the equilibrium results of a conflict

**Table 12.** DMs, Options, and Feasible States of the Power-Asymmetric Graph Model

| DMs | Options | $s_1$ | $s_2$ | $s_3$ | $s_4$ | $s_5$ | $s_6$ | $s_7$ | $s_8$ | $s_9$ | $s_{10}$ | $s_{11}$ | $s_{12}$ | $s_{13}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JS | 1. Retain | **Y** | **Y** | N | N | **Y** | **Y** | N | N | **Y** | **Y** | N | N | - |
| | 2. Reduce | N | N | **Y** | **Y** | N | N | **Y** | **Y** | N | N | **Y** | **Y** | - |
| | 3. Close | N | N | N | N | N | N | N | N | N | N | N | N | **Y** |
| ZJ | 4. Negotiate | **Y** | N | **Y** | N | **Y** | N | **Y** | N | **Y** | N | **Y** | N | - |
| | 5. Block | N | **Y** | N | **Y** | N | **Y** | N | **Y** | N | **Y** | N | **Y** | - |
| CG | 6. Persuade | **Y** | **Y** | **Y** | **Y** | N | N | N | N | N | N | N | N | - |
| | 7. Reward | N | N | N | N | **Y** | **Y** | **Y** | **Y** | N | N | N | N | - |
| | 8. Punish | N | N | N | N | N | N | N | N | **Y** | **Y** | **Y** | **Y** | - |

analysis. This influence can be clearly determined by conducting a basic conflict analysis, as in section 4.2, as well as a power-asymmetric conflict analysis, as in section 4.3.

### 4.2. Basic Conflict Analysis

Because the DMs had equal powers at the time this conflict started before 22 November 2001 when the river was blocked, a basic conflict analysis approach is used. The option form is shown in Table 6 for the water pollution conflict. Notice that in Table 6, CG had the single option of "Persuade" before 22 November 2001. After the river was blocked, CG's options increased, as explained in the analysis of the conflict using a power-asymmetric graph model in section 4.3.

#### 4.2.1. Feasible States

Because each option can either be selected or not, there are a total of $2^6=64$ mathematically possible states. However, when the infeasible states that cannot possibly occur in the real world are removed and states that are essentially the same are combined into state $s_5$, the five feasible states displayed on the right in Table 6 remain.

In state $s_2$, for example, JS has selected the option "Retain" in which it does nothing, ZJ has decided to "Block" the Maxi Port, and CG is taking the option "Persuade," for which it is encouraging JS and ZJ to cooperate. Under state $s_5$, JS has chosen to "Close" the dying industries, and therefore it does not matter whether other options are taken or not, as represented by the dashes – the conflict is solved.

Figure 2 displays the integrated graph model of the basic conflict for which the moves controlled by a given DM are indicated by the type of line that is drawn. The circles represent the feasible states. The directed arcs represent the transitions between states under the control of the corresponding DM. The arc tails represent the initial states, and the arrowheads represent the reachable states which can be attained from the initial states. Notice that ZJ, for example, can cause the conflict to move from state $s_1$ to state $s_2$ by changing its option selection from "Negotiate" to "Block," as indicated in states $s_1$ and $s_2$ in Table 6 for which the option selections of the other two DMs remain fixed.

#### 4.2.2. Preferences

Three flexible approaches (option weighting, option prioritization, and direct ranking) are available in GMCR II for conveniently specifying preference information in terms of options for each DM. In this article, option prioritization is utilized for the ranking of states for each DM. This approach furnishes an intuitive specification based on preference statements explained in terms of option numbers listed from the most important at the top to least important at the bottom. Tables 7–9 contain explanations of the preference statements for JS, JZ, and CG, respectively. For example, as shown at the top of Table 9 on the left, the most important preference statement for CG is that JS chooses "Close" by selecting option 3 in order to completely reduce and control the pollution. A negative sign beside an option, such as "−5" in Table 9, indicates that CG prefers that ZJ not choose option 5. Notice, as shown at the bottom of Table 8, that a DM can use conditional preference statements. In this case the least preferred statement for ZJ is that

**Table 13.** JS's Preference Statements

| Statements | Descriptions |
|---|---|
| −3 | JS does not choose "Close" to completely reduce and control the pollution |
| 6 | CG selects "Persuade" to coordinate the conflict |
| 1 IF 6 | JS prefers to choose "Retain" if CG selects "Persuade" |
| 2 IF 7\|8 | JS prefers to choose "Reduce" if CG selects "Reward" or "Punish" |
| 7 | CG selects "Reward" to coordinate the conflict |
| −5 | ZJ does not select "Block" to intensify the conflict |

**Table 14.** ZJ's Preference Statements

| Statements | Descriptions |
|---|---|
| 3 | JS chooses "Close" to completely reduce and control the pollution |
| 2 | JS selects "Reduce" to partially reduce and control the pollution |
| 4 IF 2 | ZJ chooses "Negotiate" to cooperate with JS if JS chooses "Reduce" to partially reduce and control the pollution |
| 5 IF 1 | ZJ selects "Block" to intensify the conflict if JS chooses "Retain" to do nothing about the pollution |
| 8 | CG chooses "Punish" to coordinate the conflict |
| 7 | CG selects "Reward" to coordinate the conflict |

this DM prefers to choose "Block" (option 5) if JS selects "Retain" (option 1). In fact, the preference statements obey the rules of what is called first-order logic.

After all of the hierarchical preference statements are entered, and assuming that the preferences are transitive, GMCR II generates and displays the state rankings for each DM in which the states are ordered from most preferred on the left to least preferred on the right, where ties are allowed. Table 10 presents the ranking of states for each DM, where in the top row "$s_1 \succ s_5$" means that JS prefers state $s_1$ over state $s_5$ and the other listed states. As shown in Table 10, for JS, "Retain" is the most preferred option, while "Close" is the least preferred option. State $s_5$ is the most preferred state for both ZJ and CG. Because of the preference statement "5 IF 1" at the bottom of Table 8, notice that state $s_2$ is preferred over state $s_1$ for ZJ in Table 10. From the ordering of states for ZJ in Table 10, one can see that state $s_3$ is preferred to state $s_4$ because ZJ prefers to "Negotiate" over "Reduce," which is implied by the preference statement "4 IF 2" in Table 8. CG hopes that the conflict can be solved, and that ZJ does not choose "Block."

#### 4.2.3. Stability Analysis

The stability analysis is conducted using GMCR II. The analysis results are as shown in Table 11, where state $s_2$ and state $s_5$ are the equilibria in the basic conflict analysis. State $s_2$, the existing reality, represents that the conflict broke out and TBA's coordination did not work. State $s_5$, which did not occur in reality, shows an indistinguishable state when JS chooses "Close."

### 4.3. Power-Asymmetric Conflict Analysis

The event on 22 November 2001 drew great attention from CG, who then gave certain rights to the TBA to coordinate and solve the conflict. Thus, TBA had two more options: "Reward" and "Punish." In the model, as the power between the DMs becomes asymmetric, the aforementioned power-asymmetric conflict analysis should be conducted. Options "Reward" and "Punish" reflect the direct positive power and the direct negative power of the HDM (CG), respectively.

#### 4.3.1. Feasible States

From a logical point of view, $2^8 = 256$ states will be produced by three DMs from a total of eight options. However, each DM must choose at least and at most one option at one time. State $s_{13}$ is an indistinguishable state. After the infeasible states are eliminated, the feasible states are as shown in Table 12. The integrated graph model is depicted in Figure 3.

#### 4.3.2. Preferences

Tables 13–15 furnish an explanation of the preference statements for JS, JZ, and CG, respectively. By comparing the preference statements in the basic conflict analysis, it is obvious that under power asymmetry, JS's preference is changed by CG's power, as is reflected by the statements "1 IF 6" and "2 IF 7|8" in Table 13. The preference statements of JZ and CG in Tables 14 and 15 are basically the same as those in Tables 8 and 9, respectively. Between the two new additional options of CG (options 7 and 8), option 8 ("Punish") is preferred by both ZJ and CG to option 7 ("Reward"), because direct negative power ("Punish") usually has a lower cost of use and higher effectiveness than direct positive power ("Reward"). This is also why JS prefers CG not to use any powers, and why between "Reward" and "Punish," JS prefers the former.

**Table 15.** CG's Preference Statements

| Statements | Descriptions |
|---|---|
| 3 | JS chooses "Close" to completely reduce and control the pollution |
| 2 | JS selects "Reduce" to partially reduce and control the pollution |
| −5 | ZJ does not choose "Block" to intensify the conflict |
| 8 | CG selects "Punish" to coordinate the conflict |
| 7 | CG chooses "Reward" to coordinate the conflict |

After all of the hierarchical preference statements are entered, and assuming that the preferences are transitive, GMCR II generates and displays the state rankings for each DM. Table 16 presents the ranking of states for each DM. The states are ordered with the most

**Table 16.** Preference Information

| DMs | Preference Rankings |
|---|---|
| JS | $s_1 \succ s_2 \succ s_3 \succ s_4 \succ s_7 \succ s_8 \succ s_{11} \succ s_{12} \succ s_5 \succ s_6 \succ s_9 \succ s_{10} \succ s_{13}$ |
| ZJ | $s_{13} \succ s_{11} \succ s_7 \succ s_3 \succ s_{12} \succ s_8 \succ s_4 \succ s_{10} \succ s_6 \succ s_2 \succ s_9 \succ s_5 \succ s_1$ |
| CG | $s_{13} \succ s_{11} \succ s_7 \succ s_3 \succ s_{12} \succ s_8 \succ s_4 \succ s_9 \succ s_5 \succ s_1 \succ s_{10} \succ s_6 \succ s_2$ |

preferred on the left to least preferred on the right, where ties are allowed.

#### 4.3.3. Stability Analysis

The stability analysis is conducted using GMCR II to produce the results shown in Table 17. States $s_{11}$ and $s_{13}$, the equilibria, are strongly stable. State $s_{13}$ (the same as state $s_5$ in the basic conflict analysis) is the equilibrium, which did not happen in reality. State $s_{11}$, as the final resolution which took place in reality after CG exercised its direct negative power, is also called the power-asymmetric equilibrium according to the foregoing definitions. States $s_3$, $s_4$, $s_7$, $s_8$, and $s_{12}$ are weakly stable.

The actual trajectory of the water pollution conflict from the status quo (state $s_1$) via intermediary states to the final equilibrium (state $s_{11}$) is shown in Table 18. The arrows in the table show how the conflict developed. For instance, the conflict can be transferred from state $s_1$ to state $s_2$ through ZJ changing his option from "Negotiate" to "Block." It can be seen that the above analysis is clearly consistent with the actual trajectory of the conflict, which verifies the feasibility and applicability of the conflict analysis model under the power asymmetry established in this paper.

In the trans-boundary water pollution conflict, the local governments (JS and ZJ), who only consider their own benefits and ignore the overall interests of the river basin, are at the same administrative level, so it is hard for them to cooperate to jointly control the pollution. Therefore, a coordinator is necessary to encourage JS and ZJ to cooperate. However, TBA, as the coordinator in this conflict, lacked the authority and means to influence the local governments before 22 November 2001, which meant the dispute could not be effectively solved, and thereby caused the "block dam" event. This incident forced CG to pay attention to the conflict and then authorize TBA to have certain powers to coordinate and solve the conflict. Eventually, through the effects of CG's punitive policy, the conflict was effectively solved. The success of the coordination in this conflict provides important reference value for conflicts like this.

Actually, this conflict was analyzed using GMCR in [*Yu et al*., 2013], but the influence of power asymmetry was not considered, resulting in a conflict model that is less consistent with reality than the one in this paper. For instance, in the conflict model established in [*Yu et al*., 2013], only two options of CG ("Reward" and "Punish") are considered; the infeasible states when CG selects both "Reward" and "Punish" are not deleted; the indistinguishable states when JS chooses "Close" are not combined; and the model includes eighteen feasible states. As well, because CG is not regarded as a DM with higher power than JS and ZJ, CG's options "Reward" and "Punish" are not considered as positive and negative power. Assuming symmetric roles for the DMs means that some important strategic insights are missed in that paper.

However, the conflict analysis model with power asymmetry established in this paper was used to analyze the water pollution conflict both before and after the use of power by the coordinator, yielding different outcomes. Specifically, state $s_2$ (in which the conflict is not resolved effectively) is an equilibrium of the conflict before the use of power by CG, while state $s_{11}$ (where it is resolved) is the equilibrium after CG uses its power. The analysis makes clear the effects of CG's power to change the option selections and preferences of other DMs, and therefore the final outcome of the conflict. This analysis provides a better understanding of the evolution of the conflict, producing significant strategic insights for both practitioners and researchers. For instance, comparison of the basic analysis and the power-asymmetric analysis of this conflict shows that CG's expected goals and use of power have a significant impact on the development and the equilibria of the model and thus on the cooperation of JS and ZJ. The key to understanding this and similar conflicts is to take into account the coordinator's strategy or power. Note that the above mentioned strategic insights cannot be achieved using only the earlier analysis in [*Yu et al*., 2013].

**Table 17.** Stability Analysis Results

| Stability | $s_3$ | $s_4$ | $s_7$ | $s_8$ | $s_{11}$ | $s_{12}$ | $s_{13}$ |
|---|---|---|---|---|---|---|---|
| Nash | | | | | √ | | √ |
| GMR | √ | √ | √ | √ | √ | √ | √ |
| SMR | √ | √ | √ | √ | √ | √ | √ |
| SEQ | | | | | √ | | √ |

## 5. Conclusions

Asymmetrical power relationships are typical of many conflict interactions. However, most research in game theory and conflict analysis assumes symmetrical roles for the DMs, which

**Table 18.** Actual Trajectory of the Water Pollution Conflict

| DM | Option | Status Quo | | Intermediary States | | Equilibrium |
|---|---|---|---|---|---|---|
| JS | Retain | **Y** | **Y** | **Y** → | N | N |
| | Reduce | N | N | N → | **Y** | **Y** |
| | Close | N | N | N | N | N |
| ZJ | Negotiate | **Y** → | N | N | N → | **Y** |
| | Block | N → | **Y** | **Y** | **Y** → | N |
| CG | Persuade | **Y** | **Y** → | N | N | N |
| | Reward | N | N | N | N | N |
| | Punish | N | N → | **Y** | **Y** | **Y** |
| | Label | $s_1$ → | $s_2$ → | $s_{10}$ → | $s_{12}$ → | $s_{11}$ |

means that some strategic insights must inevitably be missing. Here within the framework of GMCR, the authors have developed a formal procedure for modeling the strategic influence of power asymmetry in a conflict. First, a graph model under power asymmetry is established, so that any shift in stability or equilibrium becomes clear in a power-asymmetric situation. Then a water pollution conflict is investigated using the new model. The analysis of this case study demonstrates the feasibility and the applicability of the model.

Employing a power-asymmetric model can make a predicted resolution more realistic. Simply put, if there is power asymmetry in a real-world conflict, then only a power-asymmetric model can reflect the interactive decision process. Using a better model should improve predictions, and provide strategic insights into the conflict. As the application showed, many water resources planning and management problems with multiple agents can benefit from the proposed methodology in the paper, because many agents have asymmetric status or powers.

As an abstract concept, power is difficult to measure. The exercise and the effect of power are difficult to express mathematically. However, the authors believe that DMs' powers are generally represented by one of the three kinds of specific options (direct positive, direct negative, and indirect power options) according to the three types of powers (direct positive, direct negative, and indirect powers) defined here. Moreover, the exercise of power is expressed through HDM's additional power options, which can change at least one LDM's preferences. The foregoing paradigm for expressing and ascertaining power asymmetry is mathematically incorporated into the framework of GMCR in this paper. The conclusions that can be drawn from this paper are as follows:

1. Generally, two steps exist in analyzing power asymmetry in conflicts. The first is to model and understand the conflict using a basic conflict analysis. The second is to determine how an HDM causes a basic equilibrium to become a power-asymmetric equilibrium by using power to control the environment and thereby change the conflict outcome.
2. The analysis approach proposed here in this paper is suitable for analyzing n-person conflicts with power asymmetry. It focuses on the HDM's ability to change other DMs' option selections and preferences, clearly showing the effects of powers.
3. The HDM's views and behavior have a significant impact on the outcome of a conflict. In a power-asymmetric conflict, the HDM is in the dominant position and can control an LDM to some extent. The development trend and the equilibrium solution of the conflict depend on the HDM's expected goals and use of power.
4. Asymmetric power is sometimes helpful for the resolution of conflicts, especially those regarding the use or allocation of a natural resource such as water, or assigning responsibility for remediation, such as treating polluted water. In such conflicts, a coordinator must usually be responsible for participating in and coordinating the mediation. If the coordinator does not have more power, or a higher position, than other DMs, the mediation may not be effective.
5. There is good reason to expect that most third-party-intervention conflicts [*Zawahri,* 2009b; *Kinsara et al.*, 2012] can be investigated using the power-asymmetric analysis model developed here, because nearly all the strategies that mediators can undertake can be classified into direct positive or negative powers and indirect powers.
6. Different kinds of power usually have different costs of use and achieve different effects. In addition, the use of indirect power can cause uncertainty, in that it may not work. Generally, the use of direct power can turn uncertain preferences into strict preferences.

All in all, this research indicates that power asymmetry has both theoretical and empirical value in conflict analysis. More insights can be obtained with respect to the evolution of a conflict by studying asymmetric power in detail. Because it is strategically dynamic, asymmetric power can delineate a path from non-cooperative behavior to cooperative behavior in certain intractable conflicts. This insight can assist DMs in making strategic decisions. However, the power-asymmetric conflict model established in this research possesses only two levels of power structure and only one HDM is considered in the model. Thus, it is desirable to extend the hierarchical asymmetric power model to include more than one HDM.

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