Nuclear Security Situation Analysis Using the Graph Model for Conflict Resolution

Hanlin You[1, a], Mengjun Li[1, b], Jiang Jiang[1, c], Bingfeng Ge[1, d], Xueting Zhang[1, e] and Jianguo Xu[1, f]

[1] College of Information System and Management, National University of Defense Technology, Changsha, China

[a]hlyou1990@hotmail.com, [b]mjli11260744@gmail.com, [c]jiangjiangnudt@hotmail.com, [d]bingfengge@nudt.edu.cn, [e]zhangxueting0807@163.com, [f]15673125410@163.com

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Abstract. Nuclear security is considered as a major challenge for entire human community. One of the most important problems is to address the conflict amongst nuclear states, which has been discussed in recent researches. To handle this problem, the graph model for conflict resolution is utilized for nuclear security situation analysis in this paper. First, a conflict model is calibrated based on the proposed basic definitions and hypotheses. Then, stability analysis and status quo analysis are proposed for evolution paths of states. Next, the influences of attitudes and option set changes on equilibrium states are studied for strategies to cope with nuclear war threats. Finally, appropriate conclusions are summarized.

Introduction

Since the first nuclear attack to Japan in 1945, the horrible mass destruction weapon has been the nightmare of the whole human civilization, just like the opened Pandora's Box. Considering the huge lethality of nuclear weapons, there will be no winners in a full-scale nuclear war. Once a war starts, millions of people will be killed, countless wealth will be ruined, and the ecological environment will be damaged disastrously. Due to fierce nuclear superpower games for state interests, some emergencies, such as the Cuban Missile Crisis in 1962, will drive the world to the borderline of nuclear catastrophes. Although the dreadful nuclear conflicts has never happened in reality, the scale of nuclear arsenals have increased out of control, the cost of maintaining and managing the dangerous weapons has become unbearable and the risk of nuclear disasters has become the Sword of Damocles for the earth. The serious danger and resource wastes of the nuclear threats make the nuclear security problems to be a common challenge of all mankind [1].

With the evolution of the international political situation and the development of military technologies, the characteristics of the nuclear security research have been changing in different periods. However, root of nuclear security problems is perpetually identified as the interactive nuclear superpower games, the purpose of which is to maximize the state interests using the available information and strategies. Based on the information of game players, tactics and the value orientation, the graph model for conflict resolution (GMCR) methodology can offer the supporting information for decision makers, and communication and analysis service in mediation and analysis service of the third party analysts [2]. In this paper, a hypothetical conflict between two nuclear states is analyzed using the GMCR and strategies to tackle nuclear war threats and lead to win/win resolutions will be discussed, which are meaningful contributions to nuclear security.

The remainder of this paper is organized as follows. Recent relative researches are reviewed in Section 2. Basic structure definitions and hypotheses of the conflict model are introduced in Section 3. Conflict model is completed based on definitions and hypotheses and evolution paths of states are studied using the stability analysis and status quo analysis of graph models in Section 4. Influences to the nuclear security situation of different parameters are analyzed and the countermeasures of nuclear war threats are proposed in Section 5. Some relative conclusions are discussed and summarized in Section 6.

Literature Review

Nuclear security is one of research focuses for scholars in different fields. Highlighted nuclear threats in each period and the corresponding countermeasures have been proposed in foregoing researches. Scheffran researched the implications and interconnectedness of nuclear security and climate change [1]. It pointed out that the current main threats were the nuclear war, nuclear proliferation and nuclear terrorism. What is more, a framework for handling the common challenges of nuclear weapons and climate change by international negotiation and cooperation was proposed in the report. The nuclear-proliferation was studied from the perspective of the international politics [3]. The international relationships, security strategies and domestic politics were analyzed and their influence to the nuclear policy was discussed. Besides, three solution paths to control nuclear proliferation were proposed in this paper. Two important international treaties, the Comprehensive Nuclear Test Ban Treaty and the Treaty on the Non-Proliferation of Nuclear Weapons, were analyzed and their effect to promote the nuclear disarmament and facing challenges were discussed [4]. In the views of the influence of new advanced nuclear technologies, Gape considered the effect to handle the nuclear disarmament and non-proliferation problems of the Generation IV nuclear energy systems [5]. The strategic stability of the nuclear states was studied by Li, in which interdependence between nuclear states is implied and its influence to strategy stability assessment was analyzed [6].

The foregoing results are effective to unveil the nuclear threats and work out the countermeasures. However, the conflicts and compromises of nuclear superpower games for state interests, which have significant importance in nuclear security study, have not been researched systematically and effectively. Due to the fundamentality and confidentiality for the national defense of nuclear strategies, it is difficult, even possible, to obtain the complete and accurately quantified information. As a result, the traditional approaches of the game theory are not suitable to handle this problem. Fortunately, new theories and approaches have been proposed in relative papers. An improved approach with more flexible and comprehensive analysis function, named the Graph Model for Conflict Resolution (GMCR), was proposed to model the interactive moves and countermoves of decision makers [7][8]. Based on GMCR, the status quo analysis [9] is used to track moves and countermoves from the status quo state to reachable states, and the coalition analysis [10] is used to analyze result differences for decision makers by joining a coalition. In the recent practical researches, the GMCR was successfully applied for the conflict problems of happened wars [11], Cuban Missile Crisis [2] and maritime threat response system of systems portfolio selection [12].

GMCR is applied for nuclear security situation analysis in this paper. Based on the foregoing theory researches and history data, the graph models and their parameters, which are used to describe the procedures of nuclear superpower games, are proposed to analyze the nuclear security situation and discuss how to tackle nuclear threats.

Basic Definitions and Assumptions

GMCR consists of the nodes, which describe feasible game states, and the directed edges, which represent legal state transitions. The evolution paths of the nuclear superpower game will be discovered by studying state moves in the directed graph model. The theory foundations of the nuclear conflict model including the structure of graph model, definitions for model analysis and hypotheses for nuclear security model are introduced in this section.

Basic Definitions. As mentioned above, GMCR is a flexible tool for conflict analysis with limited information. The four key components of graph model include decision makers (DMs), feasible states, legal state transitions and relative preferences [13].

Definition 1: The graph model is represented as the structure $G=(N,S,(A_i)_{i\in N},(P_i)_{i\in N})$, where:

1) $N=\{1,2,...,n\}$ is the set of all DMs and $|N|\in[2,+\infty)$;

2) S is the set of all feasible states and $|S|\in[2,+\infty)$;

3) For each $i \in N$, $A_i \in S \times S$ contains the movements in one step controlled by DM_i. If $(s,t) \in A_i$, the transition from state s to state t is available.

4) For each $i \in N$, $P_i \in \{\succ_i, \sim_i\}$ represents the relative preferences of DM_i. $s \succ_i t$ indicates that DM_i prefers state s to state t. If $s \sim_i t$, the two states have no significant difference.

Based on the assumption that the preferences of DMs is transitive, the preference ranks is available with the set $(P_i)_{i \in N}$. Then, the other two definitions with the concepts of unilateral moves (UMs) and unilateral improvements (UIs) are introduced as follows [13].

Definition 2: For each $i \in N$ and $s \in S$, the states which are reachable with the UMs of DM_i in one step from state s are listed as $R_i(s) = \{t \in S \mid (s,t) \in A_i\}$.

Definition 3: For each $i \in N$ and $s \in S$, the states which are reachable with the UIs of DM_i in one step from state s are listed as $R_i^+(s) = \{t \in S \mid (s,t) \in A_i \wedge t \succ_i s\}$.

Stability analysis is one of the most important components in conflict resolution, which focus on the special states from which DMs have no incentives to move. The four most universal stabilities, including Nash Stability (Nash), general metarationality stability (GMR), symmetric metarationality stability (SMR), and sequential stability (SEQ), have been proposed for conflict analysis [13]. With different types of stable states for every DMs identified, all of the equilibrium states, from which no game player has any motivations to move away, will be discovered for resolutions for the conflict.

The attitudes of DMs, which have a significant influence on the relative preferences, have been applied for conflict analysis. The basic definitions, such as the relational preference (RP), total relational preference (TRP) and total relational reply (TRR) will be introduced for the application of attitude analysis. Based on the definitions, similar stabilities, such as the relational Nash stability (RNash), relational general metarationality (RGMR), relational symmetric metarationality (RSMR) and relational sequential metarationality (RSEQ), can be analyzed and discussed [11].

Assumptions for Nuclear Conflict Model. The realistic procedure of nuclear superpower games is extremely complex. Then, some assumptions are proposed to simplify and abstract player options and influence factors for the conflict model.

Assumption 1: The nuclear attacks can never be repealed and weakened once started.

Due to the mass destruction of nuclear weapons, every nuclear option is unidirectional. Moreover, this rule has been accepted by all DMs.

Assumption 2: All of the DMs are absolutely rational.

As mentioned above, the only goal of nuclear superpower games is state interests. The influence factors of decision-making include political relationships, military capabilities, interest dependence except emotions.

Assumption 3: Influence factors of the conflict model are simplified and abstracted as three parameters, such as political relationships, military capabilities and interest interdependence, where:

1) The political relationships (P) include alliance, friendly, neutral, hostile and extremely hostile. Then, the parameters are respectively defined as $P \in \{2, 1, 0, -1, -2\}$.

2) The military capabilities (M) include absolutely overmatch, overmatch, equilibrium, inferior and absolutely inferior. Then, the parameter are respectively defined as $M \in \{2, 1, 0, -1, -2\}$.

3) The interest interdependence (I) includes closely interdependence, indifference and competition. Then, the parameter are respectively defined as $I \in \{1, 0, -1\}$.

The parameters impact on both the conflict model and analysis from three aspects. The preferences of DMs will change in different political relationships, attitudes matrices depend on interest interdependence, and the military capabilities will decide the available option sets of DMs. All of them will be considered in nuclear security situation analysis.

Graph Model for Nuclear Conflict

In this section, the graph model for the hypothetical conflict between two strongest nuclear superpowers in the world, namely United States (US) and Russia (RA), whose nuclear weapons amount are more than 90% of the summation [6] will be proposed. Then, the stability analysis and status quo analysis of the model will be demonstrated for the evolution paths of states.

The option sets of two DMs are both {Full-scale Destroy (FD), Limited Attacks (LA)}. If neither of the two options is chosen, the situation remains as "peace", which is the most general and best for human race. The former one means to impose unacceptable losses or even total destroy on enemies and the latter indicates to force opponents to surrenders with limited attacks, as how U.S. defeated Japan in 1945. Obviously, two options can never be chosen synchronously. Based on filtering conditions mentioned above, the feasible states are illustrated in Table 1.

Table 1 Feasible States of Conflict Model

DMs	Options	1	2	3	4	5	6	7	8	9
US	FD	N	Y	N	N	Y	N	N	Y	N
	LA	N	N	Y	N	N	Y	N	N	Y
RA	FD	N	N	N	Y	Y	Y	N	N	N
	LA	N	N	N	N	N	N	Y	Y	Y

Another key model component, namely relative preferences, depends on political relationships. Generally, DMs will live with their allies and friends in peace and tend to attack their competitors and enemies. However, all of DMs prefer LA to FD in every condition without consideration of countermoves due to the disastrous damage to the Earth of nuclear weapons. What is more, no DM has any motivation to consume his nuclear weapons unless he can achieve benefits by beating enemies or competitors. The loss of enemies means the benefits of DMs while the situation is totally contrary for allies and friends. Meanwhile, the national dignity, which is called 'forcing invaders to pay more', is highlighted by all DMs, especially when the political relationship is worse than 'neutral'. At last, the preference ranks of two DMs, which are specified by rules mentioned above, are depicted in Table 2.

Table 2 Preference Ranks

P	DMs	Preference Ranks
2	US	$1 \succ 3 \succ 7 \succ 9 \succ 2 \succ 4 \succ 8 \succ 6 \succ 5$
	RA	$1 \succ 7 \succ 3 \succ 9 \succ 4 \succ 2 \succ 6 \succ 8 \succ 5$
1	US	$1 \succ 3 \succ 2 \succ 9 \succ 8 \succ 7 \succ 5 \succ 6 \succ 4$
	RA	$1 \succ 7 \succ 4 \succ 9 \succ 6 \succ 3 \succ 5 \succ 8 \succ 2$
0	US	$1 \succ 3 \succ 2 \succ 8 \succ 9 \succ 7 \succ 5 \succ 6 \succ 4$
	RA	$1 \succ 7 \succ 4 \succ 6 \succ 9 \succ 3 \succ 5 \succ 8 \succ 2$
-1	US	$3 \succ 1 \succ 2 \succ 8 \succ 9 \succ 5 \succ 7 \succ 6 \succ 4$
	RA	$7 \succ 1 \succ 4 \succ 6 \succ 9 \succ 5 \succ 3 \succ 8 \succ 2$
-2	US	$3 \succ 2 \succ 1 \succ 8 \succ 9 \succ 5 \succ 6 \succ 7 \succ 4$
	RA	$7 \succ 4 \succ 1 \succ 6 \succ 9 \succ 5 \succ 8 \succ 3 \succ 2$

Based on all of component information, the graph model for nuclear conflict is structured, which is shown in Fig. 1.

When $P \in \{2,1,0\}$, it is a consensus for two DMs that keeping the peace, namely state s_1, is the best resolution. Obviously, no rational DM has any incentives to attack his allies, friends or even strangers using murderous and expensive weapons. As a result, the focus transfers to the evolution paths of states in the case $P \in \{-1,-2\}$. With the stability analysis, it's discovered that the results of stability analysis are the same in the condition $P = -1 / P = -2$ without consideration of military capabilities and interest interdependence. The stability results are listed in Table. 3.

The sets of equilibriums are both identified as $\{s_1, s_5, s_9\}$. Then, what is the difference between $P = -1$ and $P = -2$? It is accepted that both the two DMs will only move in UIs with *Assumption 2.*

Noticing the truth that $s_1 \xrightarrow{US} s_2$ and $s_1 \xrightarrow{RA} s_4$ are not UIs when $P = -1$, the possible transition paths form the status quo s_1 to the worst equilibrium s_5 are

$$\begin{aligned} & s_1 \xrightarrow{US} s_3 \xrightarrow{RA} s_6 \xrightarrow{US} s_5 \\ and \quad & s_1 \xrightarrow{RA} s_7 \xrightarrow{US} s_8 \xrightarrow{RA} s_5 \end{aligned} \tag{1}$$

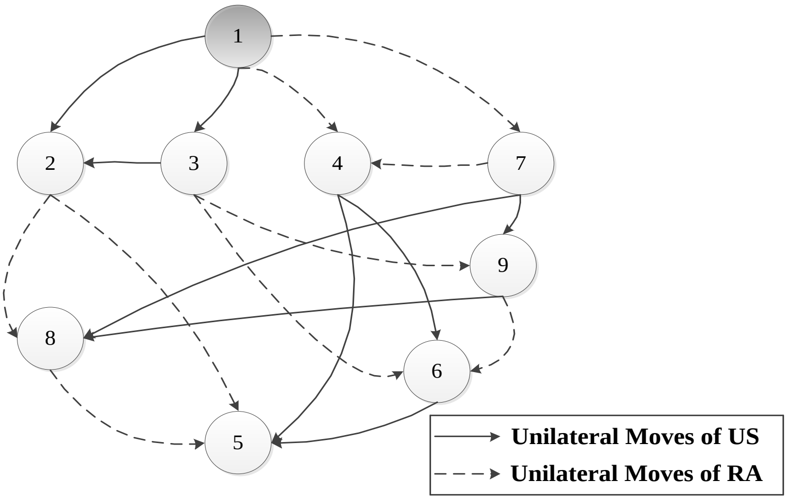

Fig. 1 Graph model of nuclear conflict

These transitions need two fool and myopic conflict escalation while one myopic move can lock the tragedy when $P = -2$.

$$\begin{aligned} & s_1 \xrightarrow{US} s_2 \xrightarrow{RA} s_5 \\ and \quad & s_1 \xrightarrow{RA} s_4 \xrightarrow{US} s_5 \end{aligned} \tag{2}$$

Table 3 Stability Results (P= -1/P= -2)

States	Nash			GMR			SMR			SEQ		
	U	*R*	*E*	*U*	*R*	*E*	*U*	*R*	*E*	*U*	*R*	*E*
1				√	√	√	√	√	√	√	√	√
2	√			√			√			√		
3	√			√			√			√		
4		√			√			√			√	
5	√	√	√	√	√	√	√	√	√	√	√	√
6		√			√			√			√	
7		√			√			√			√	
8	√			√			√			√		
9				√	√	√	√	√	√	√	√	√

However, considering $s_1 \succ_{US} s_9 \succ_{US} s_5 \wedge s_1 \succ_{RA} s_9 \succ_{RA} s_5$ is true under both circumstances, every rational and non-myopic DM will keep the peace even if the status quo s_1 is not a Nash stable state. That is why no nuclear attack has ever been launched during the whole Cold War even the political relationship between the two superpowers are extremely hostile in 1962.

Nuclear Security Situation Analysis

In this section, the sensitivity of equilibriums is to be analyzed. The impact of military capabilities and interest interdependence on the graph model will be illustrated.

The military capabilities have a great effect on the option sets of DMs. When $M = 0$, the option set will keep unchanged. However, when $M_{US} = 1$ ($M_{RA} = -1$), the FD will be unavailable for Russia if

United States chooses the option first. Moreover, when $M_{US}=2$ ($M_{RA}=-2$), although it is hardly possible to occur, the FD will be unavailable for Russia if United States take either kind of attack first.

The new graph model which contains both two situations is depicted in Fig. 2. Moreover, the stability analysis results, see Table. 4, are found the same when $P\in\{-1,-2\}$ and $M\in\{1,2\}$.

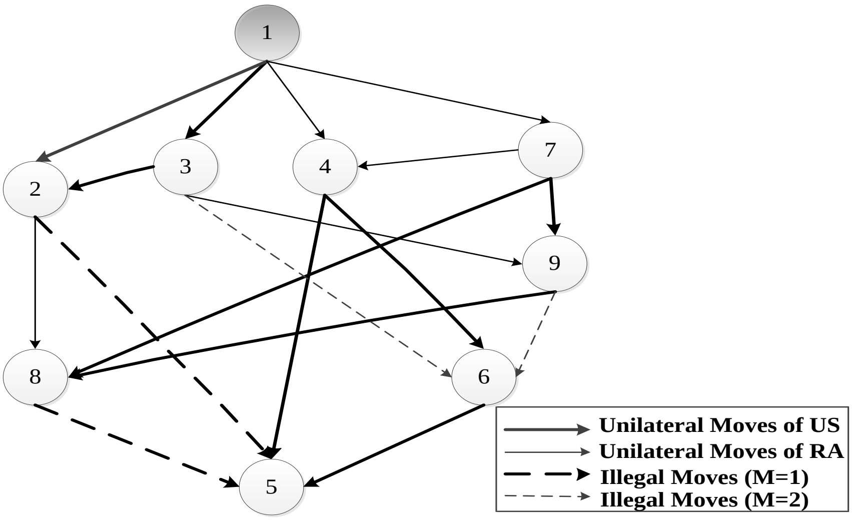

Fig. 2 Graph model of non-equilibrium military capabilities

The all sets of equilibriums are analyzed as $\{s_1,s_5,s_8\}$. When $P=-1\wedge M=2$, the transition paths from the status to other equilibriums are shown as

$$s_1\xrightarrow{US}s_3\xrightarrow{RA}s_9\xrightarrow{US}s_8 \quad \text{and} \quad s_1\xrightarrow{RA}s_7\xrightarrow{US}s_8 \tag{3}$$

Table. 4 Stability Results (P= -1/P= -2, M=1/M=2)

States	Nash			GMR			SMR			SEQ		
	U	*R*	*E*	*U*	*R*	*E*	*U*	*R*	*E*	*U*	*R*	*E*
1				√	√	√	√	√	√	√	√	√
2	√			√			√			√		
3	√			√			√			√		
4		√			√			√			√	
5	√	√	√	√	√	√	√	√	√	√	√	√
6		√			√			√			√	
7		√			√			√			√	
8	√	√	√	√	√	√	√	√	√	√	√	√
9		√			√			√			√	

When it changes to the situation $P=-2\wedge M=2$, the additional paths are

$$s_1\xrightarrow{US}s_2\xrightarrow{RA}s_8 \quad \text{and} \quad s_1\xrightarrow{RA}s_4\xrightarrow{US}s_5 \tag{4}$$

If the value of M changes as 1, for both $P=-1$ and $P=-2$ the additional path is

$$s_1\xrightarrow{US}s_3\xrightarrow{RA}s_6\xrightarrow{US}s_5 \tag{5}$$

Considering that $s_8\succ_{US}s_5\wedge s_5\succ_{RA}s_8$ is true under all circumstances, the LD option will never be chosen by Russia. Although the status quo s_1 is still one of equilibriums and the best resolution, both of two DMs have strong incentives to *fire the first shot*, which is very dangerous for both two states, even the whole world.

The attitude matrix of graph model, which have a great impact on preferences, depends on interest the interdependence including trade, investment, finance, environment protection et.al. [6]. If the two states have a large amount of common interests, namely $I=1$, the attitude matrix is defined as E_1. The situation that there are neither common interests nor interest conflicts, namely $I=0$, is defined as E_2. If the interdependence is negative, the matrix is defined as E_3, which is shown as Eq. 6.

$$E_1=\begin{bmatrix} + & + \\ + & + \end{bmatrix}, E_2=\begin{bmatrix} + & 0 \\ 0 & + \end{bmatrix}, E_3=\begin{bmatrix} + & - \\ - & + \end{bmatrix} \quad (6)$$

When $I=1$, the $TRR(e)_i(s)$ for every $i \in N$ and $s \in S$ is calculated and the results are listed in Table. 5. There are no UIs for either DM from any state, because the TRR list of each state contains only itself. As a result, all states are strong equilibriums, from which no DM has any incentives to move away. It is obvious that no rational DM will damage his own interests. If the common interests are abundant and important enough to cover divergence and conflicts, no nuclear attack will happen any longer.

Table. 5 Total Relational Reply List (P= -1/P= -2, M=0/M=1/M=2, I=1)

DMs	1	2	3	4	5	6	7	8	9
U.S.	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}
Russia	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}

The stability results of $I=0$ are shown in Table. 3 and Table. 4, and results of $I=-1$ are identical. Due to the *Assumption 1*, both options are harmful for the other DM. There are no differences for stability analysis results between indifferent and negative attitude.

Summary

The approaches of GMCR are applied to analyze nuclear security situations. The graph model for the nuclear conflict between United States and Russia is proposed based on the proposed basic definitions and hypotheses. The stability analysis and status quo analysis are used to discover evolution paths of states. The influences of military capabilities and interest interdependence to stability analysis are researched for nuclear security situation analysis. In this section, the conclusions are summarized as follows.

First, improving the political relationships amount nuclear states, especially the relationship between U.S. and Russia, is important for nuclear security.

Second, the equilibrium of military capabilities is even more important than the capricious political relationships. The balance of nuclear strength, even the 'Mutually Assured Destruction', can be the last defense line of nuclear wars.

At last, strengthening the interest interdependence among superpowers is an appropriate approach for nuclear conflict resolution. Besides effects to tackle the threats of nuclear war, it is also powerful advantages for nuclear disarmament and nuclear non-proliferation, which promote an international cooperation procedure for a perfect win/win situation, called nuclear-free world.

In next researches, the graph model of nuclear conflicts will be improved by introducing more DMs and influence factors. Quantitative approaches will be applied to specify relative preferences for a more exact measure of the incentives and possibilities of state transitions. Moreover, the other threats, namely the nuclear arms race and nuclear proliferation, will be studied and a new assessment technique of the comprehensive nuclear security will be developed.

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References

[1] Scheffran. J, “Climate Change, Nuclear Risks and Nuclear Disarmament From Security Threats to Sustainable Peace,” in World Future Council, Research Group Climate Change and Security, KlimaCampus, University of Hamburg, 2009.

[2] K. W. Hipel, D. M. Kilgour, and L. Fang, “The graph model for conflict resolution,” Wiley Encyclopedia of Operations Research and Management Science, vol. 3, J. J. Cochran, Ed. New York, NY, USA: Wiley, pp. 2099-2111, 2011.

[3] L. Yan, “The states decisions of forgoing nuclear weapons: approaches in terms of security, gains and norms,” International Forum, vol. 13, no.4, pp.16-20, 2011.

[4] A. Pietrobon. “Nuclear Powers’ Disarmament Obligation under the Treaty on the Non-Proliferation of Nuclear Weapons and the Comprehensive Nuclear Test Ban Treaty: Interactions between Soft Law and Hard Law,” Leiden Journal of International Law, vol. 27, no.1, pp. 169-188, 2014.

[5] S. Grape, S. J. Svärd, and C. Hellesen, et al. “New perspectives on nuclear power—Generation IV nuclear energy systems to strengthen nuclear non-proliferation and support nuclear disarmament,” Annals of Nuclear Energy, vol.73, pp. 815-819, 2014.

[6] D. Li, “The Elements of Interdependence in the Strategic Stabilities,” Ph. D. thesis, Political Science, Tsinghua University, Beijing, P. R. China, 2012.

[7] L. Fang, K. W. Hipel and D. M. Kilgour, et al. “A decision support system for interactive decision making, Part I: model formulation,” IEEE Trans Syst Man Cybern C Appl Rev, vol. 33, no. 1, pp. 42-55, 2003.

[8] L. Fang, K. W. Hipel and D. M. Kilgour, et al. “A decision support system for interactive decision making, Part II: analysis and output interpretation,” IEEE Trans Syst Man Cybern C Appl Rev, vol. 33, no. 1, pp. 56-66, 2003.

[9] K. W. Li, D. M. Kilgour, and K. W. Hipel, “Status quo analysis in the graph model for conflict resolution,” J. Oper. Res. Soc., vol. 56, no. 6, pp. 699-707, 2005.

[10] T. Inohara and K. W. Hipel “Coalition analysis in the graph model for conflict resolution,” Syst Eng, vol. 11, no. 4, pp. 343-359, 2008.

[11] T. Inohara, K. W. Hipel, and S. Walker, “Conflict analysis approaches for investigating attitudes and misperceptions in the war of 1812,” J. Syst. Sci. Syst. Eng., vol. 16, no. 2, pp.181-201, 2007.

[12] B. Ge, K. W. Hipel and L. Fang et al. “An interactive portfolio decision analysis approach for system-of-systems architecting using the graph model for conflict resolution,” IEEE Trans Syst Man Cybern., Syst., vol.44, no.10, pp.1328-1346, 2014.

[13] D. M. Kilgour and K. W. Hipel, “Conflict analysis methods: The graph model for conflict resolution,” Handbook of Group Decision and Negotiation, Advances in Group Decision and Negotiation 4, D. M. Kilgour and C. Eden, Eds. New York, NY, USA: Springer, 2010, pp.203–222.