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Research paper

Decision support system analysis with the graph model on non-cooperative generic water resource conflicts

Ahmed E. M. Al-Juaidi*

Assistant Professor, Civil Engineering Department, King Abdulaziz University
**Corresponding author E-mail: aaljuaidi@kau.edu.sa; aealjuaidi@gmail.com*

Abstract

This paper aims to resolve four non-cooperative generic water disputes using the Graph Model approach for conflict resolution. Therefore, a Decision Support System (DSS) has been utilized integrating multiple-criteria decision analysis, stability analysis, and uncertainty analysis using the info-gap technique. The DSS has been applied to four different non-cooperative water conflict including: (1) groundwater common pool; (2) environmental problem between two countries; (3) river conflict dispute between two countries; and (4) sustainable development game. The DSS demonstrates four stability concepts, including Nash Stability (R), General Metarationality (GMR), Symmetric Metarationality (SMR), Sequential stability (SEQ) to illustrate how results differ with regard to the stability concepts. After classifying the preferences of stakeholders, the DSS recognized the most stable solution, considering the potential actions and counteractions of all stakeholders. Consequently, solution robustness was tested under the uncertainty related to stakeholders' perspective, under non-cooperative attitudes. When there are no sufficient details about the conflict and what decision to be prepared, the DSS proved to be useful in modeling complex disputes, determining most robust solution, and examining the effect of uncertainty.

Keywords: *water disputes; generic conflict resolution; graph model; decision support systems; and multiple criteria decision analysis.*

1. Introduction

In a water conflict, different parties can be participated in decision making process as decision makers (DMs), where each DM can make selections with an agreement with other parties. Combined alternatives of all players can find out the possible endings of the conflict. Instead of moving with cooperation with other parties, DMs can choose to collaborate or form coalitions. In such situations, Game theory methods, such as the Graph Model for Conflict Resolution, offer useful and accurate tools for discussing conflicts. The graph model presents thoughtful details how to resolve disputes efficiently [14]. Game theory is essentially a mathematical method that deals with cooperation through forming coalitions of competition between conflicting parties. It explains how the combination between the players can be directed to a best outcome solution which satisfies the DMs preferences. The best outcome may not been discussed or even planned by any party [19]. Games are mathematically defined and have many players with strategies (alternatives) and potential outcomes (payoffs). The payoffs to competitors or players decide the decisions made and the nature of the game being played. When the value of the payoffs is zero or a constant, the DMs don't have the same interests and are playing a zero/constant-sum game. In other words, if one DM wins, the other DM loses. In such situation, the players need to cooperate or form coalitions [14]. Decision makers in water conflicts are trying to achieve their goals to defeat one another by predicting the decision of each other. The resolution of a game can be determined as end results of the players' decisions. Game theory technique allows parties plan to maximize their benefits (payoffs). A good answer to a game recommends the set of decisions that each decision maker takes at the end. One major advantage of game theory when compared to classical optimization methods is its competence to consider the actions and counteractions during the negotiation process, until all stakeholders accepted the final solution [14].

Many researchers have attempted to analyse water conflicts in a game-theoretic framework. Hipel et al. [7] provided a resolution of conflict associated with carcinogen in the groundwater that supply Elmira city in Canada. Adams et al. [1] developed a non-cooperative framework on water policy negotiation in California. Dinar and Howitt [5] developed cooperative model for allocation of cost of environmental control for polluters in California. Simon et al. [18] used a non-cooperative model for negotiations of water prices for agricultural production and reservoir sizes among different players. Ambec and Ehlers [2] developed cooperative solution concepts for better sharing of river among countries. Madani and Lund [15] investigated the water disputes for San Francisco-San Joaquin delta using Monte-Carlo game theoretic approach. Obeidie et al. [16] addressed a conflict of exporting water from Canada. Raquel et al. [17] developed a cooperative solution concept for balancing the economic benefits versus negative environmental impacts from agriculture production. Wang et al. [20] considered a cooperative model for allocation of water among different users in Canada.

This paper uses the graph model for conflict resolution as a useful method for resolving different water and environmental disputes [6]. To facilitate its application, a decision support system (DSS), called "congress", has been used based on the early work of Kassab et al. [9]. The DSS is then applied to generic water and environmental disputes. The DSS helps to select the optimum decision and to examine its robustness under the decision makers' preferences uncertainty.

2. The graph model

The graph model consists of three major steps [6]: modeling, stability analysis, and sensitivity analyses.

2.1. Modeling

The graph model deals with any conflict engage decision makers DMs, their options, and their preferences. In other words, the graph model is clarified using "prisoner's dilemma" conflict. Here, two suspicious people associates in a crime are apprehended and positioned in prison so that they cannot talk to each other. The court does not have satisfactory information to convict them of the crime. Therefore, to reach a confession, the legal representative shows each suspect with the next offers:

1. If one prisoner collaborate C with his associate (i.e., does not confess) and the other one does not collaborate D (i.e., confesses), the one who collaborates will receive a 10-year sentence while the other prisoner will be discharged.
2. If both prisoners do not collaborate with each other (i.e., both confess), each one will get 5 years confinements in prison.
3. If both collaborate by not confessing on each other, each will get one year of confinement in prison.

In prisoner's dilemma, each DM contains two choices known by C and D. Therefore, four potential states will happen when each DM chooses a policy which are described as CC, CD, DC, and, DD, where left letter correspond to the first prisoner (DM 1) plan and the right letter correspond to the second prisoner (DM 2) plan. Figure 1 shows an illustration of the four decision states. Figure 1 shows that DM 1 can pick either Strategy C or D, while DM 2 can also select either C or D. This will end up with four states CC, CD, DC, and DD, respectively, as shown in Figure 1, and shown as states 1, 2, 3, and 4.

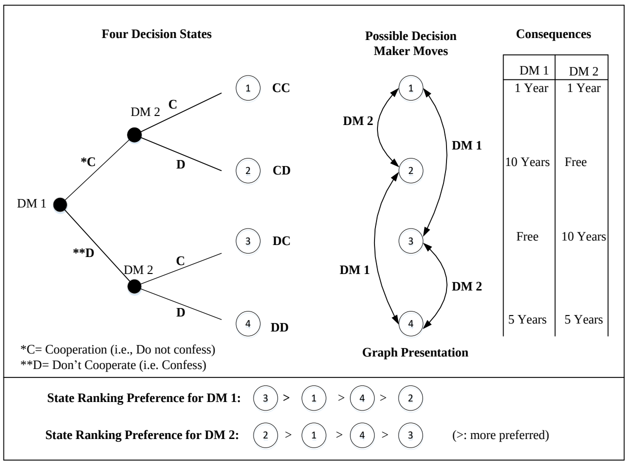


Figure 1: Graph representation of Prisoners dilemma (Adopted from [10]).

The middle section of Figure 1 demonstrates the integrated graph model for the dispute. It shows how possibly the dispute move from one state to another, where a node symbolizes a state and an arc symbolizes the DM. For instance, DM 1 can let the conflict move from State 1 (CC) to State 3 (DC) through not collaborating with DM 2 telling the court about the crime (see Figure 1). In sequence, DM 2 can let the dispute to expand from State 3 (DC) to State 4 (DD) by not to collaborate. Further information about the prisoner's dilemma DM actions and counteractions can be obtained from [10]. The prisoner's dilemma comprises a common conflict shows how collaboration and non-collaboration be modeled in a conflict. In fact, water conflicts are more sophisticated than the prisoner's dilemma as clarified by real-world disputes studied in this paper.

2.2. Stability analysis

The stability analysis is performed to find the stability of each state for every DM. When a state is stable for a DM, (if and only if), it implies that DM has no motivation to move from it unilaterally in a certain attitude, typically referred to as a stability definition. Equilibrium is a state which all DMs discover to be stable under a particular stability definition. A stability definition concept describes how DMs may perform in a conflict where each DM wants to reach his or her goals. Since DM may act in a different way in a conflict, many solution concepts have been presented and used (e.g. Nash Stability (R), General Metarationality (GMR), Symmetric Matarationality (SMR), and Sequential Stability (SEQ)). Each concept imitate different way of performance [6] that include carefulness and enthusiasm of a DM to make deliberate recognitions, risk behavior, and awareness of others DMs preferences [8]. Table 1 shows more details about the stability definition. These stability concept definitions are elaborated in [8].

Table 1: Stability concepts definition

Solution concept	Description
Nash Stability (R)	No other decisions bring a better payoff.
General Metarationality (GMR)	If a better option is decided, opponent's counter-actions are safe.
Symmetric Metarationality (SMR)	If a better option is decided, opponent's counter-actions are safe and not harmful to opponent.
Sequential Stability (SEQ)	If a better option is decided, opponent's beneficial counter-actions are safe.

2.3. Sensitivity Analysis

The stability analysis step can be explained in terms of the actual conflict by analysts, actual DMs, or involved stakeholders. Recent information occasionally supports recalculation; a user can make convenient alteration in the model and reanalyze it before progressing with more modeling scenarios. In sensitivity analyses, model parameters and decisions are changing regularly to measure the stability and robustness of the results. Sensitivity analyses are also implemented to test how results changes against model parameter alterations, "what if" questions.

3. Information-gap theory

Information-Gap theory is used to assess the uncertainty that exists between a system and what DMs want to identify and know [12]. This process will allow the DM to forecast how convincing and vigorous the decision is against the uncertainty which represents by the shortage of associated information. Uncertainty is exceptionally important in decision making, where stakeholders are doubtful about their options and their preferences. Here, a range of ± 10 percent is used for the uncertainty by each DM.

4. Decision support system (DSS) implementation

To facilitate the analysis of the water conflict for the suggested four water conflict cases, a decision support system (DSS), called "**con**flict /**G**ame\ **res**olution" or "**conGres**" has been developed at the University of Waterloo based on the work of Kassab et al. [9,11]. As shown on Figure 2, the DSS combines three procedures: (1) the elimination method [13], to shortlist the alternatives, and is a multiple criteria decision analysis (MCDA) method or technique; (2) the graph model for conflict resolution [6] to mediating process which will be presented here; and (3) the information gap (info-gap) theory [3, 4] to select the best decision while considering stakeholders preferences uncertainty (see Figure 3). Figure 4 shows the main interface of "conGres" as applied to the Sustainable development game case study, with the following steps showing the details of the implementation, for the goal of identifying the best solution. The examples in following DSS steps only described for the sustainable development game (see Figure 5D).

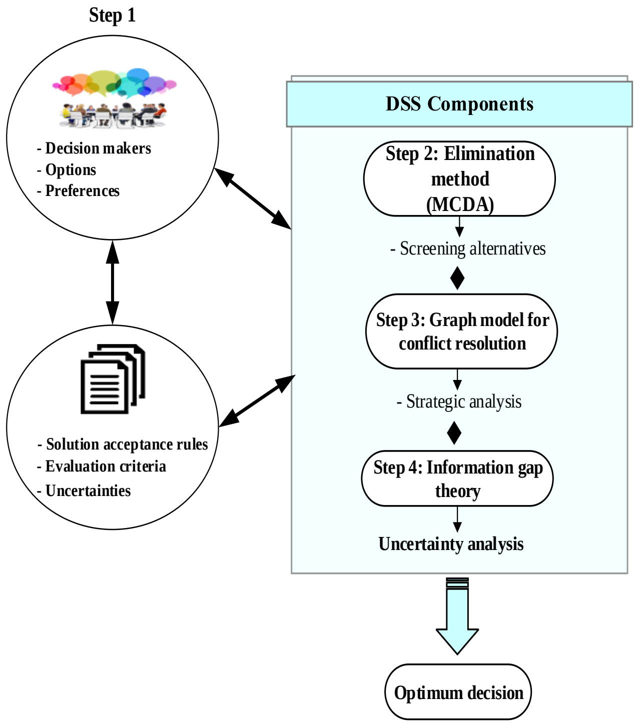


Figure 2. The decision support system (DSS) component for conflict resolution.

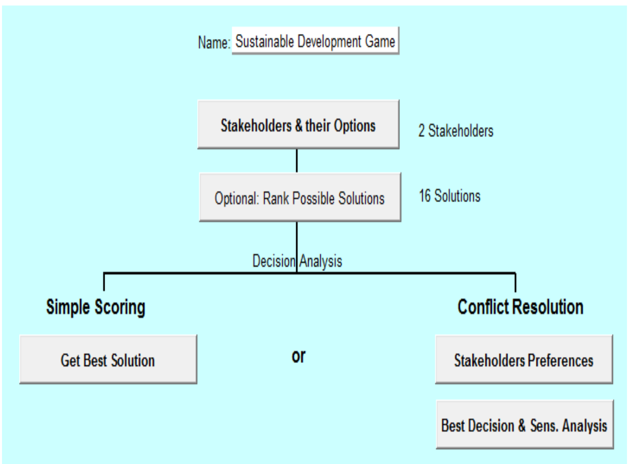
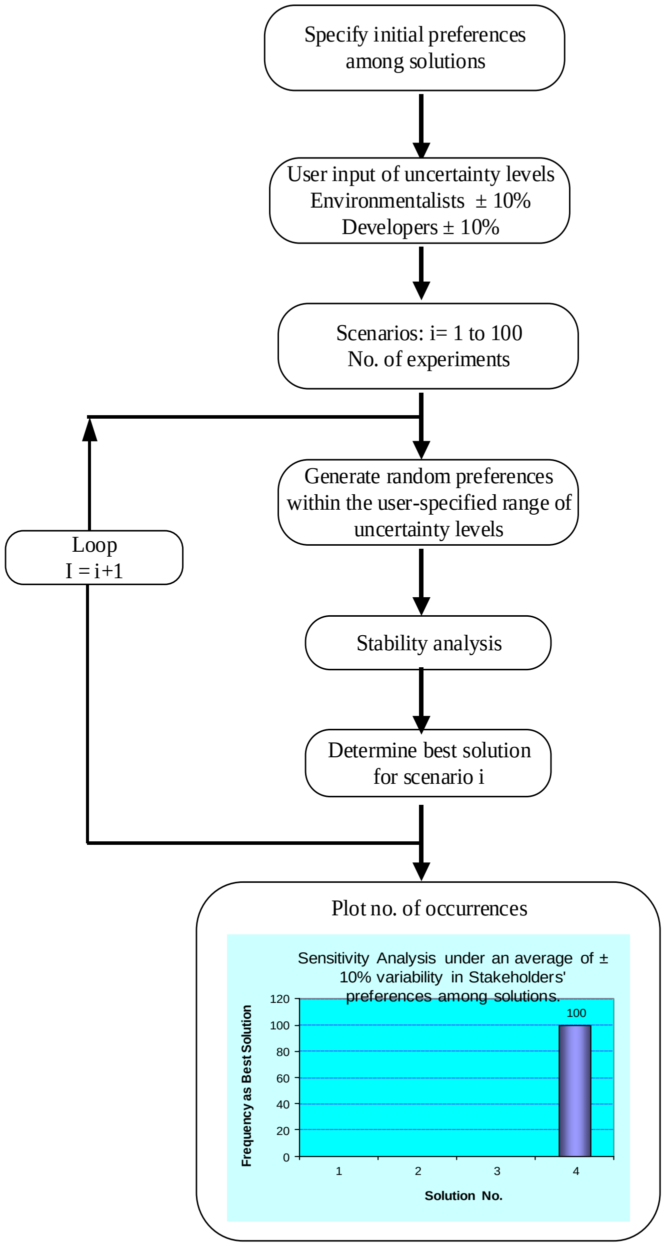


Figure 4: DSS for sustainable development game case**.**



Example showing solution 4 with 100% robustness

Figure 3: The uncertainty analyses process flowchart.

Step 1: Define Stakeholder and their options

For the Sustainable development problem, two decision makers (DMs) with conflicting concerns: the developers and the environmentalists. Figure 5D show the combinations of the developers and environmentalists preferences. Each of these two DMs can accept any of the four options mentioned earlier (A, B, C, D), as shown in Figure 6. Therefore, there exists a set of 4 x 4 = 16 "solution states" (or possible resolutions) that combine the decisions of the two DMs. For example, decision state 3 (highlighted on top of Figure 7) represents a decision in which both environmentalists DM is willing to eliminate problems before they happened (Proactive P), while the developer DM is willing to practice sustainable development (SD).

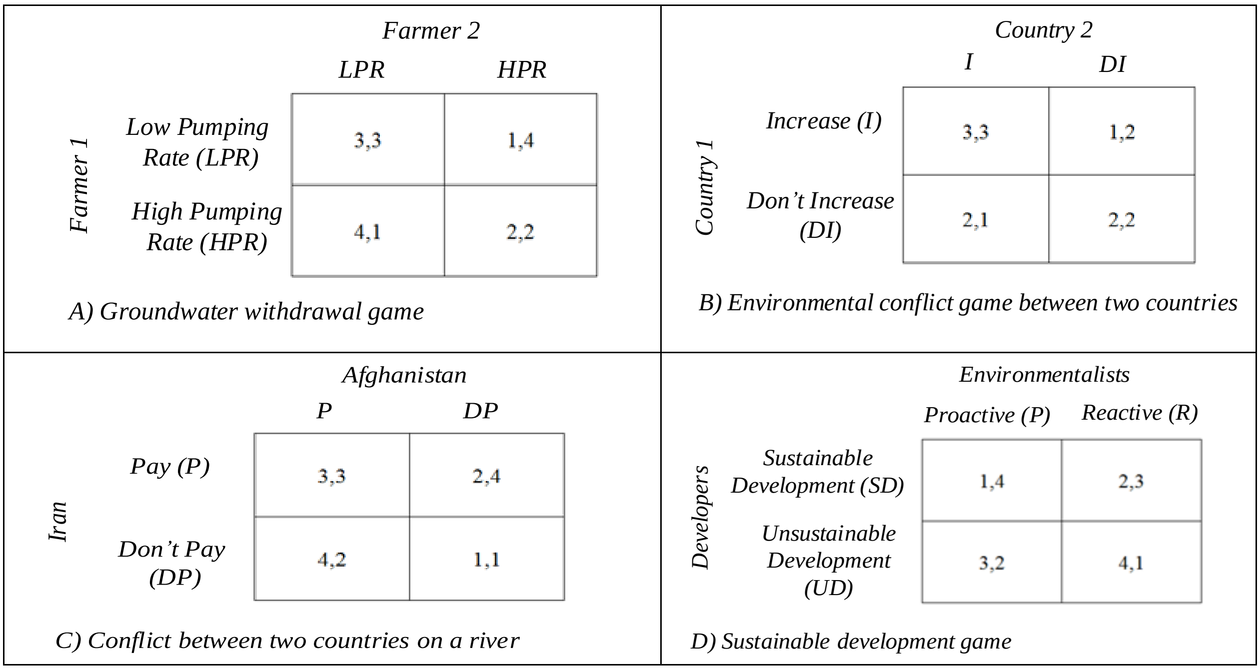


Figure 5: Generic water resources games (adopted from [21]).

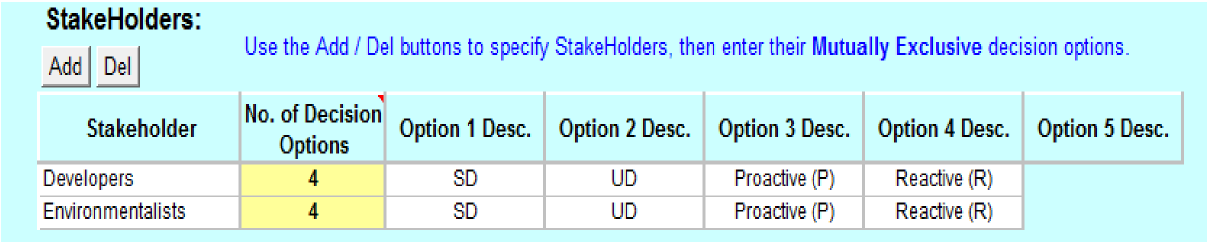


Figure 6: Stakeholders and their discrete options.

Step 2: Shortlist feasible solutions

For this example, 16 solutions or decision states are formed. It is crucial to eliminate any solution with infeasible solution to give priority to the important ones. The elimination process has the capability to reduce the alternative which don't stakeholder's acceptability threshold. Figure 7 shows possible supportive outcomes, occurring when both DMs select similar strategy. Based on the game structure suggested by [9] shown in Figure 7, twelve options were eliminated. The DSS allows the user to set any number of criteria to use for the elimination process. After the user evaluates each decision state in terms of these criteria, the DSS ranks the solution states. Accordingly, the user can eliminate the lower ranked options. Following this process, only the four solutions in which both parties agree to a certain solution are feasible, therefore producing the short list in Figure 8.

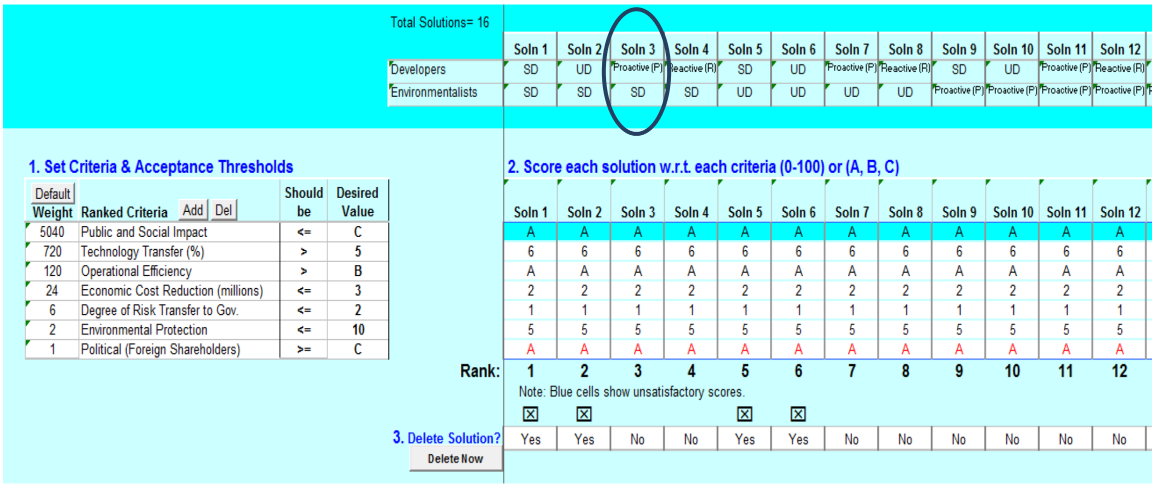
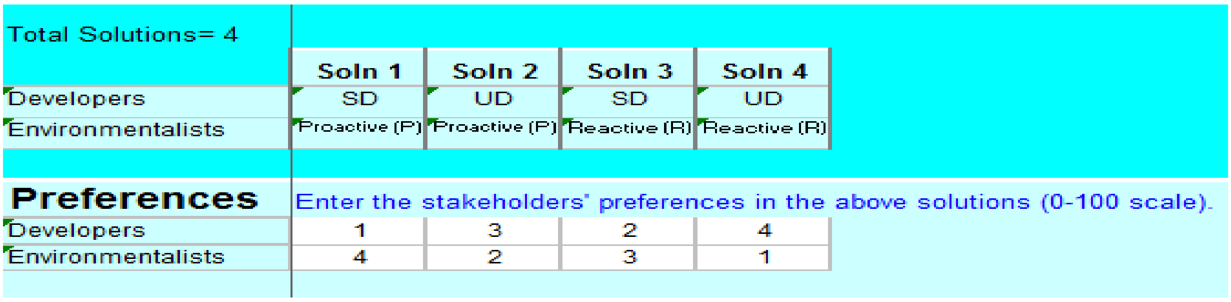


Figure 7: Solution states and the elimination method.



Total Solutions= 4				
	Soln 1	Soln 2	Soln 3	Soln 4
Developers	SD	UD	SD	UD
Environmentalists	Proactive (P)	Proactive (P)	Reactive (R)	Reactive (R)
Preferences	Enter the stakeholders' preferences in the above solutions (0-100 scale).			
Developers	1	3	2	4
Environmentalists	4	2	3	1

Figure 8: Shortlisted decision states (after elimination) with stakeholders' preferences

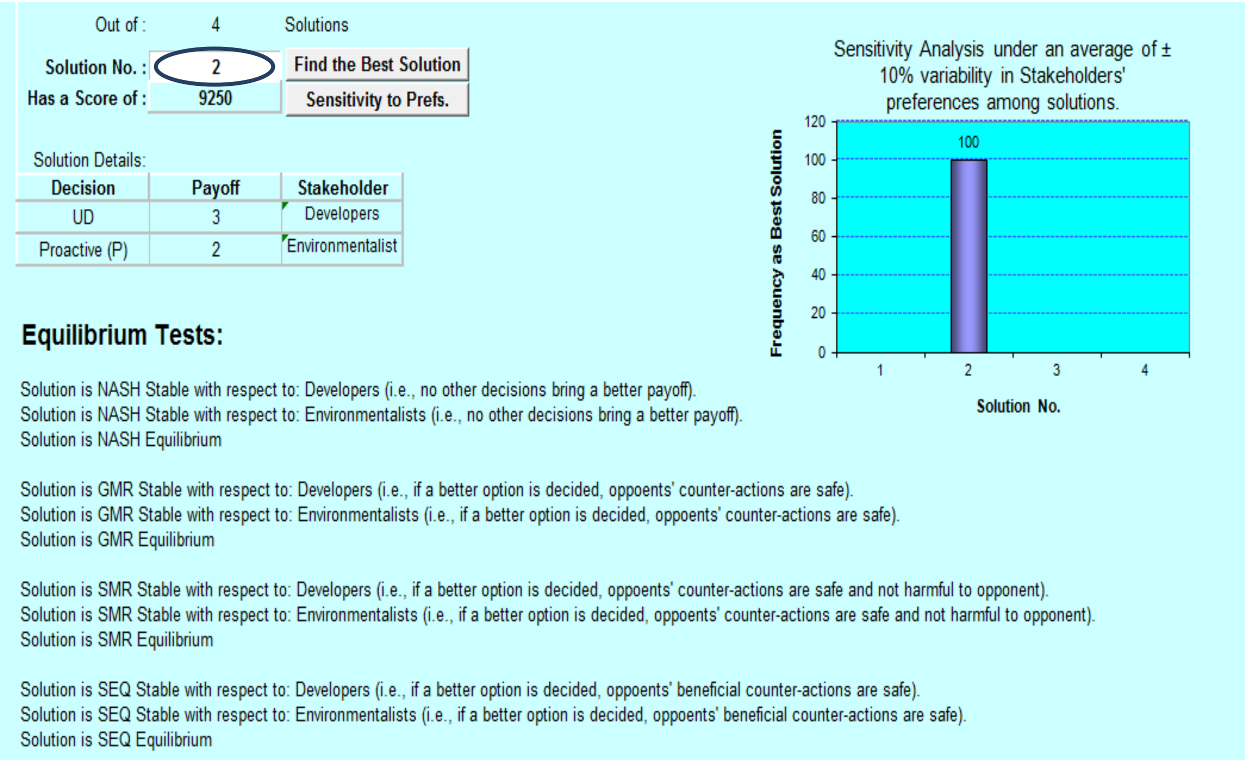


Figure 9: Decision optimisation using conflict resolution.

Step 3: Analysis of conflict resolution

Here, conflict resolution with the graph model is presented. Also process which tests the stability of the DMs' preferences shortlisted solutions is discussed. Following the Graph Model approach of [6], the preferences or favorites of each DM in the shortlisted solutions are first specified. To do that, this study uses ordinal matrix provided by [21], higher values represent higher preference of the DM. Based on these values, it is possible to rank the alternatives for each DM.

Once the preferences were determined, the Graph model uses the stability concepts (Nash (R), General Metarationality (GMR), Symmetric Metarationality (SMR), Sequatial Stability (SEQ)), listed in Table 1, to test each solution in terms of stability and equilibrium (i.e., stability for all DMs). For mathematical definitions, more details are discussed in [6] and [10]. Each stability concept has a different perception. For instance, a decision state is Nash stable for one DM if the DM cannot unilaterally move to more preferred state. When a decision state is stable for all the stakeholders, this indicates that this decision state achieved equilibrium situation and satisfied to all stakeholders preferences.

Using the DSS for water and environmental cases in this study, the shortlisted solutions were further examined based on the stakeholders' preferences shown at the bottom of Figure 8. Based on the stability analyses tests for sustainable development case study, solution 2 was determined to be the determined to be the optimum one and is in equilibrium with respect to all the stability concepts, as shown on Figure 9. Solution 2 (UD, P) received the highest number of score of 9250. More detailed results and discussion will be presented next section.

Step 4: Accounting for uncertainty

In this step, the uncertainties linked to vagueness in stakeholder favorites are considered. The measurement of uncertainty impact on the final decision of the conflict is considered. To specify the degree of uncertainty, an uncertainty process and range is shown in Figure 3 for the performance of only the Sustainable development game case. A value of 10% uncertainty range was considered for each DM. The uncertainty gives a good representation of the variability in the preferences. Based on these ranges, the DSS uses the info-gap theory [3] to give the user with the capability to think about uncertainties. The info-gap method allows systematic and formal inquiry the vigorous of a decision of stakeholder preferences under the uncertainty [4]. After specifying the uncertainty level, which are 10% for each DM, the DSS then carry outs a number of experiments (e.g. 100 for this example) varying the preferences randomly within the uncertainty range. The uncertainty results are presented in the form of a histogram (See Figure 10).

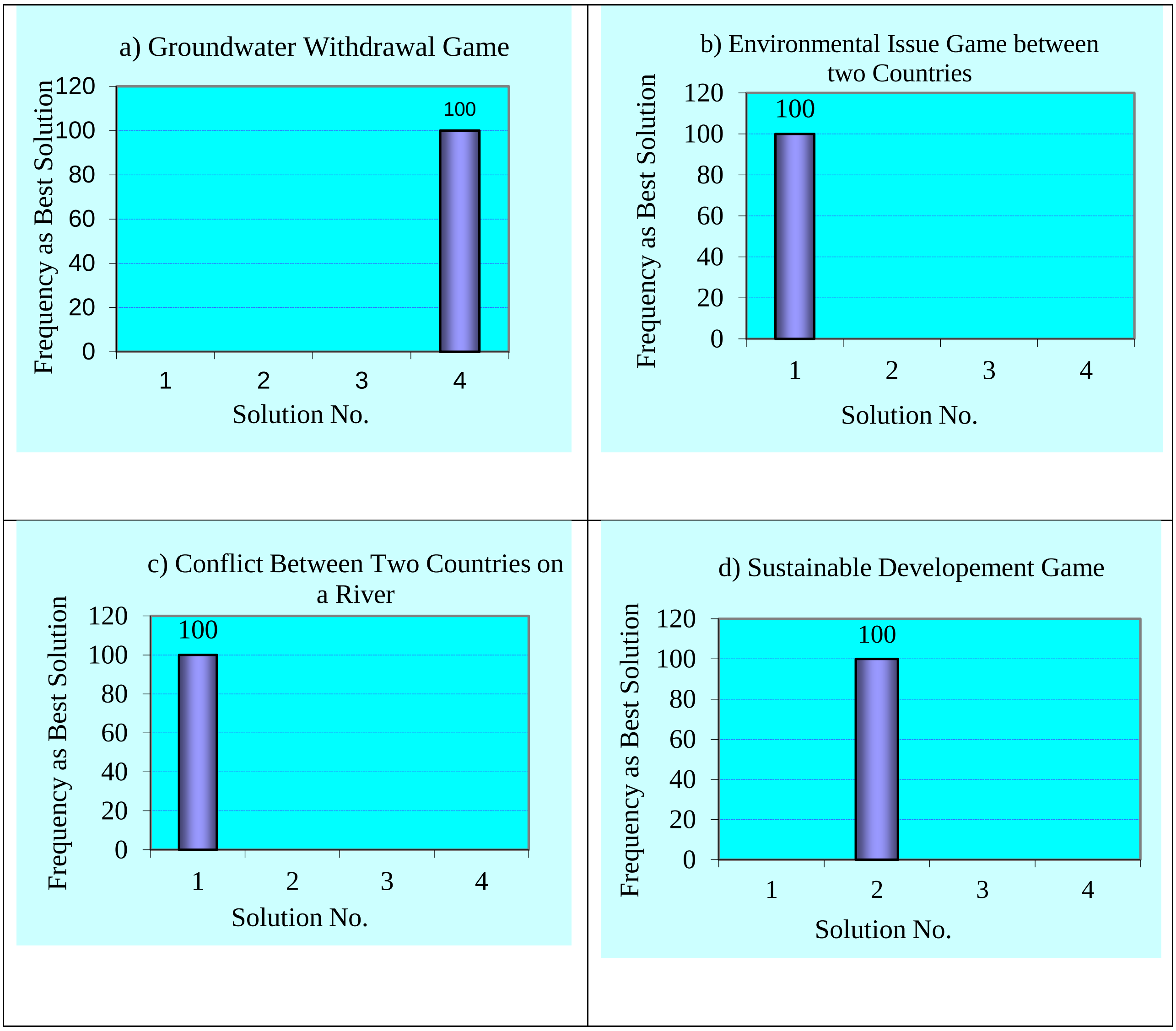


Figure 10: Sensitivity analysis under an average of 10% variability in stakeholder's preferences among solutions.

5. Applying graph model to generic water resources games

In this study, different non-cooperative generic game will be introduced to show the involvement of decision making process into approaching and solving water conflict problems. Four general water conflict problems are introduced with some descriptions of each problem. All of the problems which are described in this study considered ordinal payoffs. Then, the decision support system (DSS), "**conGres**" has implemented on each problem based on [9], [11].

5.1. Groundwater withdrawal game

This game discusses conflict between two farmers sharing the same aquifer (see Fig. 6a). The profit obtained from the crop yield minus the cost of pumping is the payoff for this conflict. It is possible for farmers to continue pumping at a low cost if they reduced their pumping rate (LPR). Due to over drafted aquifer, pumping at a higher rate will result in closing the pumps and therefore reduction in profit. Therefore, farmers can cooperate with each other through lower pumping rate which generates higher net benefits. However, the higher pumping rate is the dominant practice and the main strategy for this game.

This game is considered as a non-cooperative groundwater game because the lack of reliance on groundwater abstraction and monitoring. If a farmer is sure that he will change the pumping rate when the other farmer reduce or change the pumping rate, this problem will be changed to be cooperative game between the two farmers. But if a farmer is not sure about the pumping rate of the other farmer, then it is a non-cooperative game.

The stability results for this groundwater game are shown in Table 2. According to all stability condition considered in this study, it is established that the (HPR, HPR) is stable for both players. Table 2 shows that the (HPR, HPR) as it best solution and achieved the highest score of 9000. This indicated that both farmers are not cooperating with each other (HPR, HPR), this may not lead to sustainable use of groundwater. In other words, no farmer be able to get a better result or better outcome to the game. Moving from high pumping rate for both farmers (HPR, HPR) to lower pumping rate (LPR, LPR) for both farmers, a cooperative strategy or forming coalition has to be exist between farmers.

Table 2: Computed stability analysis results for the groundwater withdrawal game (Figure 5a).

Stability definition	(LPR, LPR)		(HPR, LPR)		(LPR, HPR)		(HPR, HPR)	
	Stable for Farmer							
	1	2	1	2	1	2	1	2
Score	3500		8250		8250		9000	
Payoff	3	3	4	1	1	4	2	2
Nash (R)			√			√	√	√
GMR			√	√	√	√	√	√
SMR	√	√	√	√	√	√	√	√
SEQ			√	√	√	√	√	√

5.2. Environmental issue game between two countries

Two countries are sharing a lake for this game (Figure 7b). Each country has river and is discharging to the lake. Flowing water to the lake is necessary to the maintain ecosystem of the lake. Both countries must allow flowing water to the lake because of high rate of evaporation. In other word, flowing water into the lake from one country is not sufficient to maintain the ecosystem due to the evaporation. The payoff of each country (see Fig. 6b) shows the amount of environmental benefit it achieves from the lake. The environmental benefits can be defined as the total inflow to the lake plus the benefits from upstream user's consumption. When both increase its release of water to the lake, the environmental benefits will go beyond benefit loss due to reduction of upstream consumption. However, when one country increases its release to the lake, environmental benefits will be minimal. Thus, the country payoff will reduced due to benefit losses from reduced upstream consumption [21]. For this game, the stability results are shown in Table 3. It is found that (I, I) and (DI, DI) solution are the stable solutions for this problem based on R, GMR, SMR, and SEQ (see Table 3). It is found that two solution are stable for this problem cooperative (I, I) and non-cooperative (DI, DI), but with different scores. The best solution is (I, I) and received the highest scores of 10,000 followed by (DI, DI) with scores of 9333 (see Table 3). These results indicated that in order to moved from the non-cooperative situation (DI, DI) to cooperative solution (I, I), the two countries may sign an international water agreement on this problem.

Table 3: Computed stability analysis results for environmental issue game between two countries (Figure 5b).

Stability definition	(I, I)		(DI, I)		(I, DI)		(DI, DI)	
	Stable for Country							
	1	2	1	2	1	2	1	2
Score	10000		8000		8000		9333	
Payoff	3	3	1	2	2	1	2	2
Nash (R)	√	√		√	√		√	√
GMR	√	√	√	√	√	√	√	√
SMR	√	√	√	√	√	√	√	√
SEQ	√	√	√	√	√	√	√	√

5.3. Conflict between two countries on a river

The Hirmand River located between Iran and Afghanistan is main source for irrigation for those countries and naturally viable for Hamun Lake ecosystem in Iran. Despite there is a water treaty to share water between the two countries, the Afghanistan government is unwilling to cover the operation and maintenance of Kajaki Reservoir. This lack of operation and maintenance adversely impacted the agriculture and water supply for both countries. The Iranian government cover the expenses of repairing part of the system which is located in Afghanistan, in spite the fact that each country are benefited from the lake [21]. The benefit from agricultural water supply plus the environmental benefits cover the maintenance and operation cost (see Figure 7c). This game is considered a non-cooperative because both countries are not willing to pay for operation and maintenance to have better payoff. Therefore, the Don't Pay (DP) for maintenance is the main strategy for both countries, which may lead to undesirable results to highly demanded agricultural and urban users. The stability results of this game are shown in Table 4. It is found that (P, P) solution is the only stable for this problem based on R, GMR, SMR, and SEQ (see Table 4). This stable solution (P, P) had received the highest scores of 9500. This cooperative situation (P, P) is the likely solution when both parties behave similar to each other.

Table 4: Computed stability analysis results for conflict between two countries (Iran-Afghanistan) on a river (see Figure 5c).

Stability definition	(P,P)		(DP, P)		(P, DP)		(DP, DP)	
	Stable for Player							
	I	A	I	A	I	A	I	A
Scores	9500		8500		8500		4500	
Payoff	3	3	2	4	4	2	1	1
Nash (R)	√	√		√	√			
GMR	√	√	√	√	√	√	√	√
SMR	√	√	√	√	√	√	√	√
SEQ	√	√	√	√	√	√		

Table 5: Computed stability results for the sustainable development game (Figure 5d).

Stability definition	(SD,P)		(UP, P)		(SD, R)		(UD, R)	
	Stable for Player							
	D	E	D	E	D	E	D	E
Scores	8250		9250		4250		8250	
Payoff	1	4	3	2	4	2	1	1
Nash (R)		√	√	√			√	
GMR	√	√	√	√	√		√	√
SMR	√	√	√	√	√	√	√	√
SEQ	√	√	√	√			√	√

5.4. Sustainable development game

This game (Fig. 6d) corresponds to a usual dispute between environmental authorities and investors (developers). For example water exporters or developers concern about their own benefits such as building dams on a river for power production. The payoff of each party represents its value and benefits from the outcome of the game. That is, developer's goal to obtain more benefits and the environmentalist's main goal is to protect the environment. However, developers can practice sustainability through their projects and actions and to stop practicing unsustainable development as usual. These practices generally have negative impact to the public and environment due to the lack of developer's awareness as the profit maximization is the only goal for developers. The environmentalists can be proactive in encourage responsible environmental planning with sustainable practices by developers, or may prefer to react to environmental abuse whenever they happen. Therefore one player benefits from the game and harms the other player. In generally, the developers desire to exercise unsustainable development with environmentalists demand. Therefore, the most desired outcome for the developers is (UD, R) with practicing unsustainable development to achieve more economical benefits in absence of environmental regulations and demands from the environmentalist's authorities. The unsustainable development by developers produces the lowest desirable result for the environmentalists due to elevated cost of environmental development.
When developers practice pro-active and supporting responsible environmental developments (SD, P), leads to favorite outcomes to environmentalists. This eventually will reduce the economical benefits for developers, making (SD, P) the lowest desired outcome for the developers. Regardless of adopting sustainable or unsustainable development practices by developers, the obtained environmental benefits are always higher for the society and public when environmentalists take into consideration pro-active measures. Therefore, P is the environmentalist's principal strategy. Similarly, UD is the developers main strategy as they steadily practicing policy with unsustainable developments. The results found that (UD, P) is the stable solution with all stability concepts. This solution has the highest score of 9250 (see Table 5). In-spite of the how many move were allowed during this game, the solution (UD, P) is the not in favor for the environmentalists. In such cases, it is recommended to adopt new strategies such as educating the developers about how costly their action to the environment, reduced taxes to encourage sustainable environmental development, and encourage of imposing new strict environmental regulations.

6. Summary and concluding remarks

This study introduced the graph model for four generic water and non cooperative disputes problem. These areas face serious water conflict problems that affect the social welfare from water use and allocation among different users or nations. This proposed DSS was used to find the optimum solution based on stakeholders preferences. In theses problem, all alternatives were reduced to only 4 feasible solutions. In addition, using conflict resolution with info-gap theory led to the stable and best solution for each conflict. Uncertainty analyses with ±10% variability for different DM with 100 experiments were considered. The stable solution was successful in achieving equilibrium in four stability concepts of Nash, GMR, SMR, and SEQ. The application of these stability concepts on non-cooperative water conflict would provide decision makers a precious insight to resolving these conflicts.

The developed DSS, "congress", proved to be practical and can be used for variety of disputes. The elimination process is one of the great advantages, particularly in larger disputes that involve a large number of infeasible solution states. The simplicity of the DSS makes it a viable tool for applying conflict resolution, stability analyses, and robustness analysis. This study ignores other issues, which may indirectly affect this conflict, such as water allocation among other parties or states, agricultural cropping rotation, pumping rates, and climate change. It is examined the practicality of using graph model for resolving non cooperative water disputes.

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