Negotiation Support for Cooperative Allocation of a Shared Water Resource: Application

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Abstract: Simulation experiments were conducted with the negotiation support system (NSS) presented by Kronaveter and Shamir to evaluate its efficacy in improving the negotiation process, and in getting to an agreed cooperative solution in which both sides gain relative to a simple bargaining process. Two sets of experiments were conducted: (1) with real actors—participants who played the negotiation game; and (2) with simulated actors, where the negotiation process was run through more iterations using objectives and preferences provided by participants. A hypothetical case study was used, in which two adjacent countries are competing for water from a finite common source. The paper describes the experiments and results, and draws conclusions regarding the value of using a negotiation framework in which multiobjective evaluation (using the analytic hierarchy process) and economic evaluation (using the water allocation system) are embedded.

DOI: 10.1061/(ASCE)0733-9496(2009)135:2(70)

CE Database subject headings: Negotiations; Decision support systems; Computer aided simulation; Conflict resolution; Decision making; Economic factors; Water resources.

Introduction

This paper presents the experimental part of the research performed by Kronaveter and Shamir (2008) on design of a negotiation support system (NSS) for the resolution of disputes over international (shared) water resources, which leads to a cooperative allocation of the shared resource. The NSS is designed to assist two parties in advancing from a simple, position-based bargaining to an interest-based negotiation which has a potential to lead them to a cooperative solution for allocation from the shared resource. The principles of the methodology embedded in the NSS are: (1) symmetry, with respect to the type, amount, and quality of information and supporting tools available to the parties; (2) efficiency, as economic efficiency of water utilization as well as "no gains left on the table" when an agreement has been reached; (3) equity in selecting a fair and equitable solution; and (4) stability, a quality of the negotiation solution that assures the parties' long-term respect of the agreement.

Negotiation experiments (simulations) were conducted for the purpose of first, gaining understanding of the process of negotiation over a scarce resource and, in particular over shared waters, and second, for experimental evaluation of the NSS. The experimental evaluation was designed to test the premise that the use of the NSS improves the process and the outcome of negotiation over international water resource. Three series of experiments were conducted: (1) the first was used to study and investigate the structure and tools of the NSS; (2) the second helped to finalize the NSS; and (3) the third was used to test the NSS and evaluate is efficacy.

Evaluating the efficacy of an NSS can only be achieved through simulations as there is no "correct" or "optimal" outcome of negotiations. The efficacy is measured along two dimensions: (1) an objective measure, represented by the values achieved by the parties (their utilities, as defined in our previous paper); and (2) a subjective measure, represented by the satisfaction of the parties with the process and its outcome, elicited by a postsimulation questionnaire. The design of the experiments includes: (1) selection of the type of experiments; (2) design of the case study; (3) design of the content and format of the data to be collected from the experiments, and definition of measures for quantification and analysis of the results; (4) selection of the participants, conducting the simulations, recording of data; and (5) analysis and interpretation of the results.

Types of Experiments

The first two series of experiments were experiments with real actors (ERAS) in which pairs of participants acted out the negotiation process. In the first series, the negotiations were performed in the conventional way, without any decision or negotiation support tools. The results were evaluated by comparing the results of the pairs who reached an agreement and those who did not. In the second series (with a different set of participants), the pairs in the test group were aided by the NSS while the pairs in the control group negotiated without the NSS.

The third series of experiments [exercises with simulated actors (ESA)] was conducted by us using information elicited from participants (real actors)—their initial preference structures—while all further steps of the process were controlled by us. Since a detailed presentation of the results of all the exercises (found in

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Note. Discussion open until August 1, 2009. Separate discussions must be submitted for individual papers. The manuscript for this paper was submitted for review and possible publication on September 25, 2006; approved on July 1, 2008. This paper is part of the ***Journal of Water Resources Planning and Management***, Vol. 135, No. 2, March 1, 2009. ©ASCE, ISSN 0733-9496/2009/2-70–79/$25.00.

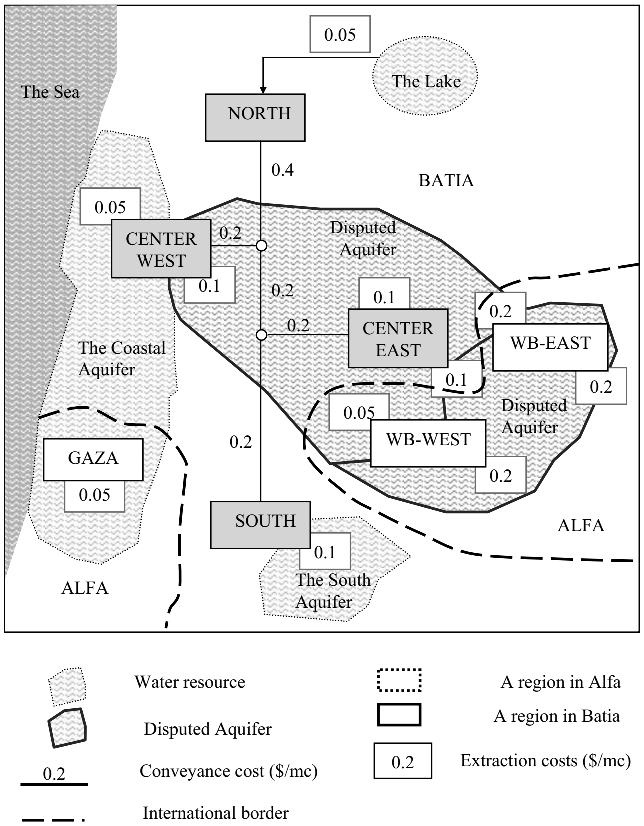

Fig. 1. Map of region and two countries

Kronaveter, 2005) would take too much space, we present here only the main results and conclusions.

Experiments with Real Actors

Participants

The participants in the first series of experiments were engineering students at the Technion (Israel Institute of Technology, Haifa), studying towards a B.Sc. or M.Sc. in various fields. In the second series, the participants were teachers and trainers in courses on negotiation and mediation (from various backgrounds) at the Israeli Center for Negotiation and Mediation ⟨http://www.icn.org.il⟩.

Case Study

A hypothetical case was designed, rich enough to provide a challenging environment for the experiments yet simple enough to allow the simulations (with real actors) to be concluded within a reasonable time frame, yielding results that are amenable to statistical analysis. The negotiation game played in all simulation exercises was based on the same hypothetical situation: two neighboring countries (Alfa and Batia,) who share a long history of disagreements and mutual mistrust, claim rights to a common water resource. Though based on the same basic idea, the case studies in the three series of experiments differed in the level of complexity of the problem and in the amount of information available to the negotiators.

General Background of Case Study for Simulations—As Provided to Participants

Two countries, Alfa and Batia, are negotiating the allocation of a shared water resource—the Aquifer—over which both of them claim rights ("disputed aquifer," Fig. 1). The current arrangement between the two countries is the result of previous negotiations: Alfa has ownership and the right to use 20%, while Batia has ownership and the right to use 80% of the resource. There are other water sources in the region that are not in dispute between the two countries. The territory of Alfa is divided into two separate parts. Annual renewable quantities of water in all the resources, including the aquifer, have already been utilized. In order to satisfy the high demand for water of its consumers, Batia has been desalinating seawater. Except for expensive seawater desalination, there are no other ways to increase the quantity of water available to the two countries. Both Alfa and Batia are expecting an increase in population in the future and are interested in getting as much of the aquifer's water as possible. The two countries have a long history of disputes and hostilities, and their relationship suffers from a lack of mutual confidence.

Both Alfa and Batia, as well as the "outside world," perceive the negotiations over the disputed aquifer as an important part of an ongoing overall peace process aimed at improving the relationship between the two countries. Each country is divided into a number of districts, each represented by three water demand sectors.

Measures for Analyzing Outcomes of Negotiation Exercises

Two types of measures were used for analysis of the negotiation process: qualitative measures for characterizing the process of negotiation, and quantitative measures, for analyzing the negotiation outcome.

Qualitative measures were derived from the answers of the participants to a postsimulation questionnaire, which consisted of 20 statements related to six characteristics of the negotiation process: (1) negotiators' clarity about their individual preference structure; (2) dynamic development of their preference structures; (3) the level of information exchange during the negotiations; (4) cooperative manner of interaction; (5) the level of creativity in searching for alternative negotiation solutions; and (6) availability and value of data on economic costs and benefits related to alternative negotiation solutions, as provided by the water allocation system (WAS) model (Fisher et al. 2002, 2005).

The participants' responses to the questionnaire were processed by standard methods and analyzed with the Alpha Kronbach method (Gliem and Gliem 2003), and statistically compared to obtain the differences between each two group of participants (Montgomery 1997): between the participants who did and those who did not reach an agreement in the first series of exercises, and between the participants who used and those who did not use the NSS in the second series.

Three quantitative variables were used to assess the quality of the negotiation outcome: individual overall utilities, the Nash product of the utilities for each pair of negotiators, and net economic benefits, achieved in the final negotiation resolution (Kronaveter and Shamir, 2008). Participants who negotiated without the NSS (all the pairs in the first series of experiments, and the pairs in the Control Group in the second series) evaluated their preference systems and utility values after the simulation [by the analytic hierarchy process (AHP)] (Saaty 1980). Economic

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net benefits to these participants were also calculated *a posteriori*, by the WAS model.

First Series of Experiments—Understanding Negotiation Process

Eighteen students participated in the first series of simulation exercises. The exercises were conducted one per day, in a 4 h session, which included the time spent on learning the case study and becoming familiar with the role they were to play. Analysis of the participants' responses to the postsimulation questionnaire showed some differences in the answers of those who reached agreement and those who did not. Throughout the following presentation of the results, the students who reached an agreement are denoted as W/AGREE (with agreement) while those who did not as WO/AGREE (without agreement).

Summary of Statistical Analysis of Responses to Postsimulation Questionnaire

Individual System of Preferences. The participants in the W/AGREE pairs felt that they had a clear view of their own objectives, while the WO/AGREE pairs did not share this view. Furthermore, most participants could not tell how important each objective was relative to the others. Of the 18 participants, seven believed they could tell how much they preferred one outcome to another, while 11 could not tell or were undecided regarding the clarity of individual preference structures.

Dynamics in the Set of Individual Objectives. None of the participants changed their set of objectives during the simulation. Six participants agreed with the statement that the importance of some objectives changed during the negotiations while 12 did not agree, or were undecided.

Level of Creativity. All the participants agreed that the level of creativity during the negotiations was high.

Exchange of Information. Here, too, there was no significant difference in the opinions between the W/AGREE and WO/AGREE groups. Seven participants (out of 18) believed they freely discussed their objectives and preferences with their counterpart and that the level of information exchange was high, while the rest do not share this view, or are undecided.

Cooperative Manner of Interaction. Among the participants who reached an agreement more than half agreed with the statement that the interaction with their counterpart was conducted in a cooperative manner. None of the participants in the WO/AGREE group believed that the interaction was cooperative.

Relevance of Economic Data. All the participants agreed that the economic information was important during the negotiation process and assisted in searching for both cooperative and noncooperative solutions. Furthermore, the participants who reached an agreement believed that the economic data provided a basis for cooperation, while those who did not reach agreement do not think so.

Summarizing these findings, the following conclusions can be drawn from the first series of simulations: (1) a high level of clarity and self-confidence regarding individual preference structure can provide a good basis for reaching an agreement: the participants in the W/AGREE pairs believed they had well defined objectives, while the participants in the WO/AGREE group could not identify explicitly their objectives during the negotiations; (2) providing the negotiating parties with opportunities and conditions for cooperation increases the chances that they will reach an agreement: according to the opinion of the participants in the W/AGREE pairs, the level of the cooperation was high; and (3) economic considerations in water allocation problems are an attractive way of "enlarging the pie:" four out of five pairs who reached agreement included trade in water in their agreement. In three out of four negotiations that ended without an agreement, trade in water was proposed as an alternative.

Quantitative Analysis of Negotiation Outcome

The pairs in this series of simulation exercises considered up to six alternative solutions, including the status quo alternative, i.e., breaking off the negotiations and staying with the existing allocations from the shared source. Five of the nine pairs reached an agreement. A postsimulation analysis (by the AHP model) showed that four of these five pairs agreed upon the alternative which maximized the product of their utilities (the Nash product). For one of the pairs who did not reach an agreement, the postsimulation analysis proved that breaking off the negotiation and staying with the status quo was in fact the Nash optimal solution. For the other three pairs, at least one alternative had a Nash product higher than the status quo alternative. We can conclude that poor communication between the parties prevented them from understanding the advantages of other alternatives: such effects could have been recognized only by analyzing the alternatives within a joint utility space (Kronaveter and Shamir 2008).

Minutes recorded during the exercises show that trade in water was being considered in a majority of proposed alternatives. Also, minimizing water supply costs was among the criteria of at least one of the parties in all simulations. From this it can be concluded that the parties were interested in the economic aspects of the water allocation problem, and that they could have benefitted from the WAS model.

Value and Contribution of WAS and AHP Models

The results of the first series of experiments demonstrated the validity of our premises regarding the potential contribution of the two models to be used in the NSS: a water allocation model based on maximizing the economic value of water (WAS) and a tool for structuring and analyzing preferences (AHP). These premises are as follows:

1. The NSS assists the parties in searching for alternative negotiation resolutions. By changing the values of model parameters relating to allocations, infrastructure, national and international water policies, a WAS user can access a range of water allocation solutions which would not be easily recognized otherwise. The AHP model enables decision makers to define their objectives and preferences (weights) in an explicit form. Thus, the difference in preferences assigned by each party to his own objectives and between the two parties become clearer and more evident, and the opportunity for tradeoff between objectives is more easily recognized.
2. The NSS provides the parties more opportunities to exchange information. It has been found that negotiators who query

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the other party for information about their interests, and who provide information about their own interests, make more accurate judgments, and earn higher payoffs (Thompson and Hastie 1990). While brainstorming and exploring solutions with the assistance of the WAS model, the parties have the opportunity to recognize the advantages of exchanging information.

3. When using the NSS, the parties can interact in a more cooperative manner. When two parties who have a long history of hostilities negotiate, the advantages of cooperation and cooperative solutions can easily be overlooked because the negotiator's tendency is to achieve a sense of having won an argument and not necessarily having obtained an efficient and satisfactory outcome. One of the assumptions of this research is that the use of the NSS can encourage the parties to be motivated by the goal of utility maximization.
4. When using the NSS, the parties are likely to define their system of preferences more clearly. This proposition relates to the following assumptions: (1) a party who uses the NSS, has a clearer picture about his objectives, the relative importance of each objective, and how much he prefers one outcome to another; and (2) a party who uses the NSS relates to his objectives in a more dynamic manner: he discovers new objectives and/or removes objectives which are found to be irrelevant or unimportant during the negotiation process, and has a greater propensity to adapt and change the relative importance of his objectives.
5. When using the NSS, the parties can consider negotiation alternatives that are economically more efficient. The WAS model helps the negotiators to recognize the objective value of the economic criteria, and the opportunity for enlarging the value that can be generated by sharing the water.
6. NSS users are more likely to achieve a higher level of general satisfaction from the agreed negotiation outcome. This proposition rests on the following assumptions: (1) the use of the NSS tools expands the negotiation (alternative) space and provides opportunity to reach a solution that will result in higher utility scores for both parties; and (2) the iterative nature of the negotiation process, aided by the NSS, contributes to maximization of the utility scores. If there is a new iteration, it means either that new options were added to the solution space, new objectives were added to the set of objectives, or less valued objectives were traded for those that are valued more. We further challenged our own assumptions in the second series of simulated negotiations.

Second Series of Experiments—Experimental Evaluation of NSS

The NSS, in the version which was experimentally evaluated in the second series of simulations, consisted of the WAS and the AHP models, combined within a protocol of interaction (Kronaveter 2005). This version of interaction protocol consisted of general rules, which specified its elements and prescribed the content (what to communicate) and not the process of the interaction (how and when to communicate) (Kronaveter and Shamir 2008).

Twelve participants in the second series of experiments were given a 1/2 h lecture/explanation about the economic value of water as well as the principles of the WAS model, and another 1/2 h lecture about the AHP model. They were then randomly grouped into six pairs, three of which performed the simulation with the NSS while three other pairs performed the simulation without it. In simulations with the NSS (W/NSS, test group) the quality of the outcome was obtained during the negotiation process. In simulations without the NSS (WO/NSS, control group) it was obtained in a postsimulation analysis, as was done in the first series of the experiments.

Statistical Analysis of Responses to Postsimulation Questionnaire

Individual System of Preferences. The participants who used the AHP model stated that it provided them with a better view of their preference structure, while those who did not use it, did not indicate a clear view of the objectives and preference structure.

Dynamics in the Set of Individual Objectives. The opinions of the participants regarding dynamic changes of the objectives are statistically similar over the two groups. Of the six participants who used the AHP model, four changed both their set of objectives and their weights during the negotiations. Only one of the six participants in the second group (WO/NSS) changed his set of objectives, and three participants changed the weights.

Level of Creativity. Participants of both groups agree, without significant difference between them, that the set of alternatives was enlarged and that creativity in searching for alternative solutions was at a high level during the negotiations.

Exchange of Information. All 12 participants believe they shared information effectively, regardless of whether they used the NSS or not.

Cooperative Manner of Interaction. On average, all participants stated that the interaction between the parties was conducted in a cooperative manner.

Relevance of Economic Data. The W/NSS participants were, on average, undecided regarding the relevance of economic data, while the WO/NSS participants agree, on average, that the economic data did represent relevant information. Also, the participants in the W/NSS group do not think, on average, that the economic information was important, while all six participants from WO/NSS believe that the economic information was important. Furthermore, all participants, without significant difference between the W/NSS and WO/NSS groups, believe that the economic information improved creativity in searching for new negotiation resolutions, and provided a basis for cooperation.

A detailed examination of the original individual responses, as well as written records taken by the participants, shows that four of the six participants who used the WAS model (W/NSS group) agree that economic information helped in searching for new noncooperative and cooperative alternatives, while two do not think so or are undecided. All three pairs in this group reached an agreement which included a side payment (a payment made by one side to the other in return for getting more water). The size of side payments was, in all three cases, proportional to water supply costs.

Summary of Statistical Analysis

1. The AHP model assisted the negotiators in constructing and understanding their individual system of preferences. Those

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who used the model had a clearly defined set of criteria according to which they accepted or rejected alternatives. They also believe they could determine the relative importance of the objectives. Those who did not use the AHP model did not have a clearly defined criteria structure.

2. The use of the AHP model could not affect the dynamics in the sets of individual objectives, because it was used only once, at the beginning of the negotiation process (this aspect is addressed in the third set of simulations).
3. All participants believe that they shared information freely, were creative in searching for new alternatives, and negotiated in a cooperative manner. Since the participants in this set of simulations were trained mediators, they knew the benefits of cooperative negotiations and were, most probably, predisposed to negotiate in this manner.
4. None of the participants based their opening arguments on economic information, but turned to these data later in the negotiation process. Generally, the participants felt comfortable with the information about water supply costs: it was clearly presented, easy to understand, and manipulate (calculate). Data about the net economic benefits were problematic and obviously not clearly understood by the participants.

Quantitative Analysis of Negotiation Outcome

In the second series of simulations, the pairs considered up to three alternative solutions, including the status quo alternative. Five of the six pairs reached an agreement. Four of these pairs agreed on the alternative which maximized the Nash product of the individual utilities—two pairs from W/NSS, and two from WO/NSS—without being explicitly aware of it while they were negotiating. The pair that did not reach an agreement negotiated without the NSS. A postsimulation analysis of their preference structures showed that the two other alternatives, which they considered during the negotiations, would have increased the utility value of at least one party. All three pairs who negotiated with the NSS agreed upon a solution that brought positive economic benefits to both parties, which was not the case for the WO/NSS group.

Experimental Evaluation of NSS with Real Actors: Conclusions

Due to the logistical limitations of executing simulations with real actors, the second series of exercises cannot be considered a complete evaluation of the NSS. This can be explained, at least in part, by the short time that the participants could afford for learning and understanding the principles and components of the NSS, the short duration of the negotiation exercise, nonuniform abilities of the participants to comprehend the functions of the NSS components, and by deficiencies in defining some of our statements in the postsimulation questionnaire.

From the first two series of simulations we derived a better understanding of what was missing in the NSS and what components should be added that would improve the negotiation processes and its outcome. Consequently, a different and more detailed protocol of interaction was designed, to keep the parties focused on efficient and productive elements of the interaction. With this interaction protocol, stricter rules for carrying through the negotiation process, as well as the use of individual and joint decision support tools, were imposed on the parties. Also, the Nash model, which proved to be a relevant *a posteriori* measure of the joint efficiency of the negotiation outcome, was included as an "on-line" means for selecting the "best" alternative in each iteration. The final version of the NSS is presented in Kronaveter and Shamir (2008). By this time it was no longer feasible to perform another series of simulations with real actors (ERA). So, to test the NSS in its final form we chose to perform "exercises with simulated actors" (ESA).

Experimental Evaluation of NSS with Simulated Actors (ESA)

In the ESA the initial "independent subjective input" regarding the ranking of the parties' initial objectives was provided by two selected candidates from the exercise with real actors (ERA), and we then carried out the remaining steps of the negotiations. The ESA exercises use the same case study (Fig. 1) except that the data are more detailed and closer to a real-world situation, in particular the input to the WAS model. This includes data on the water supply system, water demands of the three water users (households, industry, and agriculture) in each district of the two countries, water supply and conveyance costs, and data regarding the use of recycled wastewater.

Background

The initial list of objectives and their relative importance was taken from one of the pairs in the previous (ERA) set. Fig. 1 is a map of the two countries—Alfa and Batia—the sources, demand districts, and conveyance system. The numbers beside the sources and links are the production and conveyance costs. The rest of the data are given below.

Alfa's Concerns regarding Water Supply

Because of the expected increase in population, it is of critical importance for Alfa to intensify it's agricultural production. Alfa is less prosperous than Batia, and agriculture is the best way to increase its gross domestic product (GDP). Intensification of agriculture depends on the availability of additional quantities of water. Seawater desalination is too expensive. At the same time, Alfa is concerned about the economic efficiency of its water utilization. The aquifer is a much cheaper water source. About 80% of the aquifer's recharge area is within Alfa's territory, which it uses as the basis to claim rights to more than 20%, its current share of the aquifer's waters. Alfa is also aware that only an improved relationship with Batia can provide the basic conditions for Alfa's further development. However, until this happens, Alfa prefers to have its water supply independent of Batia.

Batia's Concerns regarding Water Supply

Batia is more prosperous than Alfa. About two thirds of its annual water supply is used in agriculture. Intensive agricultural production is important to Batia; due to the tense relations with its neighbors, it prefers to be independent in food production. Also, agriculture enables keeping the remote parts of the country (along the borders) populated, which is important for strategic reasons. Were it not for these strategic considerations, Batia could allow its agricultural sector to decrease, so that it could be satisfied with about half of the present annual water consumption. However, a significant decrease in the agricultural sector would cause unem-

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ployment and, because of the great influence that this sector has on the political scene, would also cause social instability. If agricultural production were decreased, Batia would also need to invest heavily in dealing with the resulting unemployment and disrupted social stability.

Batia incurs large expenditures on seawater desalination. Meanwhile, however, there is no other way to cover the difference between the high annual demand for water and the available quantities of water in Batia's natural resources. A decrease in its share in the aquifer's waters would mean an increase in expensive seawater desalination. Batia is aware that improving its relationship with Alfa would bring many benefits, but until this happens, it prefers to have its water supply independent of Alfa: meanwhile it limits the supply from the disputed aquifer to its most populated Center-West district to 15 million cm/year.

Alfa and Batia's representatives have each established their own sets of objectives (the acronyms in parentheses are used later in explaining the outcomes). Alfa's objectives are to: (1) increase of the ownership over the shared aquifer (OWN); (2) have economic efficiency of water use (EC); (3) have water supply independent of Batia (IND); (4) have intensification of agricultural production in Alfa (AGR); and (5) have improvement of the relationship with Batia (RELAT). Batia's objectives are as follows: (1) have economic efficiency of water use (EC); (2) have an independent water supply (IND); (3) have a reliable water supply (RELIA); (4) have social stability within the country (SOC); and (5) have an improvement in the relationship with Alfa (RELAT).

Negotiation Process

The following sections tell the story of the negotiation process, step by step, but, for the sake of brevity, in a very concise manner. The situation opens as follows: the negotiation process was already begun some time ago in a simple bargaining manner, and has reached the point at which Batia faces the choice between breaking the negotiations or offering to "give up" an additional 20% of the resources to Alfa, relative to the current ownership of 20:80% to Alfa and Batia, respectively. Giving up 20% of the aquifer means that the final allocation of the rights of use of the aquifer's water will be 40:60%. Alfa has the option of responding to this offer by: (1) accepting the offer (alternative denoted as a_1), or (2) breaking off the negotiations (status quo alternative).

Alfa's Individual Consequence (Utility) Space

Alfa examines its water allocation alternatives according to all of her criteria, excluding that regarding her own part in the aquifer (all domestic allocations are equally "good" with respect to the OWN objective). The utility function Alfa is obtained by using the AHP algorithm is

$$U^A(a_i) = 0.424w_i^{\text{EC}} + 0.038w_i^{\text{IND}} + 0.424w_i^{\text{AGR}} + 0.114w_i^{\text{RELAT}} \tag{1}$$

where a_i stands for domestic scenario i from the set of all possible domestic scenarios considered by Alfa; and w_i^j=performance (achievement) of scenario a_i according to Alfa's objective j, j=EC, IND, AGR, and RELAT. The weights represent the relative importance of Alfa's objectives.

Alfa uses the countrified version of the WAS model to explore several alternatives for the domestic allocation of its 40 and 20% share in the aquifer. While creating the alternatives, Alfa considers free price (resulting from the WAS model) and fixed price (a priori determined) policies, a change in the distribution system (by adding a conveyance facility to connect the two separated parts of the country), as well as intensification of agricultural production (by subsidizing the water for agricultural consumers). Alfa measures the economic efficiency of the alternatives (EC) by the net economic benefit, and intensification of agriculture (AGR) by the quantity of water supplied to its agricultural sector. Alfa considers that independence in water supply (IND) is related to the existence of the conveyance system between the two parts of the country. The relations with Batia (RELAT) are generally better when there is a conveyance system connecting the two parts of the country, and when Alfa does not subsidize the prices charged to agricultural consumers (Batia intuitively considers that the subsidy will raise Alfa's demand function, increase its allocation, and consequently its benefit from water).

According to the overall utility values [calculated by Eq. (1)], in the case where Alfa accepts the 40:60 offer, the "best" scenario would be to subsidize the prices charged to agricultural consumers and to connect the two parts of Alfa by a conveyance system. If Alfa gets only 20% of the aquifer (the negotiations are broken) WAS output indicates that, according to both "fixed" and "free" price policies, all the available water in Alfa is consumed. The alternatives with a subsidy are irrelevant, since all water is already used and increasing the supply can only be achieved with expensive seawater desalination. An AHP analysis of the 20:80 alternative reveals that the policy of current fixed prices of water with a pipe linking the two parts of the country (current water policy) yields the highest value of Alfa's utility.

Batia's Individual Consequence (Utility) Space

In a similar manner, Batia analyzes both 40:60 and 20:80 allocations. While creating her "domestic water supply scenarios" Batia considers the possibility of relaxing the limitation on supply to the Center-West district (see "Batia's Concerns"), changing the present fixed price to a free-price policy, and also supplying only the minimal required quantity of water to agriculture. She uses the whole set of her objectives to obtain the following utility function:

$$U^B(a_i) = 0.042w_i^{\text{EC}} + 0.335w_i^{\text{IND}} + 0.143w_i^{\text{RELIA}} + 0.396w_i^{\text{SOC}} + 0.084w_i^{\text{RELAT}} \tag{2}$$

where a_i stands for domestic scenario i considered by Batia. Batia's representative analyzes the output of his own countrified WAS model and ranks the scenarios using the AHP algorithm. WAS output is interpreted as follows: reliability of water supply (RELIA) is measured by the quantity of desalinated water (desalination is the most "reliable" water resource); relationship with Alfa (RELAT) is better if Batia does not limit the supply of water to the Center-West; and the effect of the scenarios on the social stability (SOC) is measured by the quantity of water allocated to agriculture. The results of the AHP analysis reveal that the best policy for Batia is the one based on a fixed-price water supply policy, which does not limit water supply to the Central-West district.

In case the negotiations are suspended, the relations between the two countries will be seriously damaged. While analyzing all possible consequences of the 20:80 alternative, Batia excludes the objective Relations with Alfa (RELAT), assuming that domestic

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scenarios for allocation of water within the country cannot affect the relations with Alfa, once the negotiations are broken. The new weights of the other four objectives are calculated by the AHP method, and Batia's modified utility function is

$$U^B(a_i) = 0.035w_i^{\text{EC}} + 0.573w_i^{\text{IND}} + 0.122w_i^{\text{RELIA}} + 0.270w_i^{\text{SOC}} \quad (3)$$

According to the WAS and AHP outputs, the scenario which is "best" with Batia's new utility function is the status quo scenario, with water allocated within the country according to a fixed-price policy with a limitation on the supply to the Central West district.

Enlarging Set of Alternatives: Trade in Water

If Alfa accepts the 40:60 allocation, it will not use all 40% of the aquifer's water: according to the results of WAS, it would not be economically justified for Alfa to use all of its allocation: beyond a quantity that is less than 40% of the aquifer it would mean supplying at costs higher than the consumers″ willingness to pay. At this point, one of the parties (or possibly a mediator) suggests trade in water, denoted as alternative a_2. Depending on the domestic scenario Alfa will decide to adopt, there will be between 60 and 143 million cm of the aquifer's water available for trade. The suggestion is deemed by the parties worth pursuing, so Alfa's and Batia's negotiators turn to the NSS to analyze it.

Individual analyses of the consequences of the "trade" alternative show that the scenario with the highest utility value to Alfa is the one that does not increase water supply from the aquifer to Alfa's agricultural sector (for the side payment she can get from Batia, Alfa can desalinate at least 30 million cm of seawater, and use it in agriculture). In Batia's case, the best domestic water allocation scenario will be the one with a fixed price policy and the supply of water from the Aquifer to the Central-West district limited to 15 million cm/year.

Joint Utility Space

At this stage Alfa and Batia have three alternative negotiation solutions, while they each have determined their own optimal domestic water allocation scenario. The status quo alternative also represents the *Reference Alternative 1*, as the allocations it prescribes are already guaranteed to the parties as a default if the negotiations are broken off. If one of the other two alternatives is selected as the "best," it will be a candidate for the final negotiation resolution, and will also be the new solution guaranteed to the parties. Its stability will be challenged in the next round of negotiations.

Each negotiation alternative is represented by a bundle $(Q_{\text{Alfa}}(a_i), v_{\text{Alfa}}(a_i))$, and $(Q_{\text{Batia}}(a_i), v_{\text{Batia}}(a_i))$, where $Q_{\text{Alfa}}(a_i)$ and $Q_{\text{Batia}}(a_i)$ are the allocated quantities of the aquifer's water to the two parties (expressed as percentages) and $v_{\text{Alfa}}(a_i)$ and $v_{\text{Batia}}(a_i)$ are the net additional economic gains to the parties to be achieved by selecting alternative a_i over the *Reference Alternative 1*. Allocated quantities of the aquifer's water to the parties are the quantities of water to which the parties have the "right to use."

Each party individually performs its own AHP analysis of these three alternatives, with respect to its set of objectives. Alfa adds the objective "increase in the ownership over the aquifer" (OWN) and calculates the weights of the new utility function it will use to evaluate the alternatives within the joint utility space. Batia uses the utility function given in Eq. (2). For the jointly "best" alternative, the NSS selects the one for which the Nash product of Alfa's and Batia's utilities is maximal.

First Round of Negotiation—Summary

The following three alternatives are under consideration by the parties in the first round of negotiations:
1. Rejecting the 40:60 allocation (*Ref. Alternative 1*);
2. Accepting the 40:60 allocation (a_1); and
3. 40:60 allocation and consider trading water (a_2).

Individual Decision Making

The following are the ″best″ domestic scenarios for each party, one for each alternative, generated by the individual decision-making process, using the WAS and AHP models. For each scenario, the country's share in the aquifer is given in percent and the net economic gain from accepting the scenario, in millions of dollars:

Alfa

1. *Ref. Alternative 1:* fixed-price policy and a conveyance system between the two parts of Alfa (20%; \$0 million);
2. a_1: prices to agriculture subsidized and a conveyance system between the two parts of Alfa (40%; \$11 million); and
3. a_2: fixed-price policy with a conveyance between the two parts of Alfa plus desalination of seawater for use in agriculture (23%; \$65 million).

Batia

1. *Ref. Alternative 1:* fixed-price policy with limited water supply to the Central West district (80%; \$0 million);
2. a_1: fixed-price policy with unlimited water supply to the Central West district (60%; −\$118 million); and
3. a_2: fixed-price policy with limited water supply to the Central West district and desalination of seawater for use in agriculture (77%; −\$64 million).

Individual Utilities in Joint Utility Space

Alfa's utility function

$$U^A(a_i) = 0.4w_i^{\text{EC}} + 0.05w_i^{\text{IND}} + 0.39w_i^{\text{AGR}} + 0.04w_i^{\text{OWN}} + 0.12w_i^{\text{RELAT}} \quad (4)$$

Batia's utility function

$$U^B(a_i) = 0.04w_i^{\text{EC}} + 0.34w_i^{\text{IND}} + 0.14w_i^{\text{RELIA}} + 0.40w_i^{\text{SOC}} + 0.08w_i^{\text{RELAT}} \quad (5)$$

Tables 1 and 2 show the results of the parties' individual evaluation of the three alternatives.

Joint Evaluation

The Nash products of the individual utilities for the three alternatives are as follows:
1. *Ref. Alternative 1:* 0.16;
2. Alternative a_1: 0.44; and
3. Alternative a_2: 0.69.

The maximum Nash product is obtained for alternative a_2, namely to accept the 40:60 allocation and consider trading water. It now becomes *Reference Alternative 2*.

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Second Round of Negotiations

The mediator (or one or both of the parties) decides to challenge *Reference Alternative 2* with "regional" alternatives, which view the Aquifer as a common pool. In a "regional" alternative the optimal allocation of the aquifer to the two parties is determined by the regional version of the WAS model (Kronaveter and Shamir 2008). In addition to the common pool alternative, each party considers a free-price policy while ensuring a minimum allocation of water to each consumer in each district, in both Alfa and in Batia. New utility functions are formulated by the parties, reflecting the conclusions they have drawn from the previous round. The economic gains—relative to *Reference Alternative 2*—are based on the assumption that half of the total net economic gains are allocated to each party; in reality, the split of the total gains is subject to negotiation between the parties and could well be affected by the agreement to view the aquifer as a common pool.

Second Round of Negotiations—Summary

Alternative Negotiation Solutions

1. *Ref. Alternative 2:* 40:60 allocation and trade in water; and
2. The regional scenario:
   a. The aquifer is considered a common pool;
   b. Alfa: free-price policy with ensured minimum demands and no subsidy to agriculture; and
   c. Batia: free-price policy with ensured minimum demands; supply from the aquifer to the Central West district is limited to 15 million cm/year.

This regional scenario is expressed as four negotiation alternatives by adding the following components:

1. Alternative a_1: a decrease in the quantity supplied to agriculture in Batia limited to 20% (relative to the present supply), and the water conveyance system between the two parts of Alfa;
2. Alternative a_2: a decrease in the quantity of water supplied to agriculture in Batia limited to 20% (relative to the present supply) without the conveyance system between the two parts of Alfa;
3. Alternative a_3: the decrease in supply to agriculture in Batia is not limited, and the conveyance system between the two parts of Alfa; and
4. Alternative a_4: the decrease in supply to agriculture in Batia is not limited, and without the conveyance system between the two parts of Alfa.

Individual Decision Making

The parties use the models to calculate the following benefits from the four alternatives, given as percent of the aquifer they use and the benefit in $millions (See Table 3).

Individual Utilities in Joint Utility Space

Alfa's utility function

$$U^A(a_i) = 0.43w_i^{\text{EC}} + 0.43w_i^{\text{AGR}} + 0.14w_i^{\text{RELAT}} \quad (6)$$

Batia's utility function

$$U^B(a_i) = 0.11w_i^{\text{EC}} + 0.16w_i^{\text{IND}} + 0.16w_i^{\text{RELIA}} + 0.30w_i^{\text{SOC}} + 0.27w_i^{\text{RELAT}} \quad (7)$$

Tables 4 and 5 show the results of the parties' individual evaluation of the five alternatives.

Joint Evaluation

The Nash product of individual utilities for each negotiation alternative is as follows:

1. *Ref. Alternative 2:* 0.16;
2. Alternative a_1: 0.49;
3. Alternative a_2: 0.63;
4. Alternative a_3: 0.49; and
5. Alternative a_4: 0.58.

The maximum Nash product is obtained for alternative a_2, which now becomes *Reference Alternative 3*. The Nash products indicate that the fairest alternative is a_2. Even though it seems "unfair" toward Batia to select this alternative as the next reference solution, it is found as the Nash solution because Alfa gains much more than Batia loses, relative to *Reference Alternative 2*.

Stability of Solution—Third Round of the Negotiation

In the next stage of the negotiation the mediator and/or the parties explore the possibility to improve from *Reference Alternative 3*. Up to this point, the parties have moved gradually from clear dispute positions toward cooperation in terms of trade in water, and from there toward a regional solution in which criteria such as ownership over the aquifer and independence in water supply have lost a great deal of their relative importance. According to Alfa's two most important objectives from the last negotiation round, a solution "better" than *Reference Alternative 3* could be one which increases the economic gain and/or contributes to intensification of Alfa's agriculture. Alfa's approval of this solution would positively affect the relationship between the parties—which is one of the two most important criteria in Batia's set (as seen in its utility function in the second round of negotiation). The mediator considers a scenario which would utilize the regional water sources in an economically efficient way.

Since the concerns regarding independent water supply have been removed (by Alfa) or relaxed (by Batia), the mediator suggests an integrated system regional scenario, to challenge the stability of *Reference Alternative 3:* a pipeline connected to Batia's national conveyance system would supply water to Alfa's coastal area (see map in Fig. 1). In order to balance such dependency of Alfa on Batia, Batia would allow unlimited quantities of water to be supplied from the disputed aquifer to its Central West district. The rest of the features of the scenario are the same as in the *Reference Alternative 3*.

A regional WAS is run, and the optimized results show that the new pipeline supplies an annual quantity of 38 million cm to Alfa's coastal area. This scenario provides more water to agricultural consumers in Batia, and a higher joint net economic benefit from water use than *Reference Alternative 3*. The new alternative allocates much less of the aquifer to Alfa than *Reference Alternative 3* (down from 28 to 20%). However, it still satisfies the future demand for all water uses in Alfa (additional water is imported from Batia by the new pipeline).

Assuming the same utility functions as in the previous round of negotiations, the new alternative is better than *Reference Alternative 3:* it increases the level of satisfaction of both parties, and

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Table 1. First Round of Negotiations—Alfa's Weights and Overall Utilities of Three Alternatives

Objective	Ref. 1	a_1	a_2
w^{EC}	0.11	0.26	1
w^{IND}	1	1	1
w^{AGR}	0.18	1	0.35
w^{OWN}	0.19	1	1
w^{RELAT}	0.13	0.36	1
Overall utility	**0.19**	**0.62**	**0.75**

therefore the Nash product as well (see the third round of negotiation). Under the assumption that neither the parties nor the mediator have new ideas for further improvement, this alternative is agreed to be the final negotiation outcome.

Third Round of Negotiation

Alternative Negotiation Solutions

1. *Ref. Alternative 3:*
2. Alternative (a) with the regional scenario that includes the following elements:
   a. The Aquifer is considered a common pool;
   b. Alfa implements a free-price policy with ensured minimum demands and no subsidy to agriculture;
   c. Batia implements a free-price policy with ensured minimum demands to its urban and industrial consumers; supply from the Aquifer to the Central-West district is unlimited; and
   d. A pipeline connected to Batia's national conveyance system supplies water to Alfa's coastal area.

Individual Decision Making

In the following, the countries' shares in the aquifer are given in percents and the net economic gain from accepting the scenario, in millions of dollars:

- Alfa: alternative a: (20%; \$10 million); and
- Batia: alternative a: (80%; \$10 million).

Individual Utilities in Joint Utility Space

Alfa's utility function

$$U^A(a_i) = 0.43w_i^{EC} + 0.43w_i^{AGR} + 0.14w_i^{RELAT} \tag{8}$$

Batia's utility function

$$U^B(a_i) = 0.11w_i^{EC} + 0.16w_i^{IND} + 0.16w_i^{RELIA} + 0.23w_i^{SOC} + 0.27w_i^{RELAT} \tag{9}$$

Tables 6 and 7 show the results of the parties' individual evaluation of the two alternatives.

Table 2. First Round of Negotiations—Batia's Weights and Overall Utilities of Three Alternatives

Objective	Ref. 1	a_1	a_2
w^{EC}	1	0.25	0.25
w^{IND}	1	1	1
w^{RELIA}	0.22	1	0.57
w^{SOC}	1	1	1
w^{RELAT}	0.11	0.43	1
Overall utility	**0.82**	**0.70**	**0.92**

Table 3. Shares from Aquifer and Benefits for Four Alternatives

	Alfa		Batia	
Alternative	(%)	(\$ million)	(%)	(\$ million)
a_1	21	81	79	81
a_2	28	95	72	95
a_3	21	61	79	61
a_4	27	80	73	80

Table 4. Second Round of Negotiations—Alfa's Weights and Overall Utilities for Five Alternatives

Objective	a_1	a_2	a_3	a_4	Ref. 2
W^{EC}	0.58	1	0.33	0.58	0.15
W^{AGR}	1	1	1	1	0.25
W^{RELAT}	1	1	1	1	1
Overall	**0.82**	**1**	**0.72**	**0.82**	**0.22**

Joint Evaluation

The Nash products of the individual overall utilities are as follows:

1. *Ref. Alternative 3:* 0.30; and
2. Alternative a: 0.87.

The maximum Nash product is obtained for alternative a, which is the final negotiation resolution.

Comments on Exercise with Simulated Actors

The exercise with simulated actors (ESA) shows in detail the stages of a hypothetical negotiation process, supported by the NSS. Except for the initial subjective inputs regarding objectives and their weights, which were taken from two negotiating participants in the exercise with real actors, all other inputs and considerations were introduced by us. Obviously, the progress of these negotiations is only one possible outcome. It does, however, indicate how a real negotiation process might proceed, given the same initial conditions (the same subjective inputs). Furthermore, the conclusions drawn from this exercise regarding the validity and value of the NSS are not affected by the specific subjective considerations and subjective preference systems that were used.

In the exercise with simulated actors we could demonstrate the full potential of the NSS. Simulations with real actors, at least in our case, could not be performed on such a complex case and in such detail because the participants could not devote sufficient time to carry out a full round of iterative negotiations, like the one described here.

Table 5. Second Round of Negotiations—Batia's Weights and Overall Utilities for Five Alternatives

Objective	a_1	a_2	a_3	a_4	Ref. 2
w^{EC}	0.58	1	0.33	0.58	0.15
w^{INd}	1	1	1	1	1
w^{RELIA}	0.30	0.30	0.56	0.56	1
w^{SOC}	0.16	0.16	0.42	0.42	1
w^{RELAT}	1	1	1	1	0.33
Overall	**0.58**	**0.63**	**0.68**	**0.71**	**0.73**

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Table 6. Third Round of Negotiations—Alfa's Utilities of Two Alternatives

Objective	a	Ref. 3
w^{EC}	0.58	0.15
w^{AGR}	1	0.25
w^{RELAT}	1	1
Overall	**0.82**	**0.22**

Table 7. Third Round of Negotiations—Batia's Utilities of Two Alternatives

Objective	a	Ref. 3
w^{EC}	0.58	0.15
w^{INd}	1	1
w^{RELIA}	0.30	1
w^{SOC}	0.16	1
w^{RELAT}	1	0.33
Overall	**0.58**	**0.73**

Summary and Conclusions

This paper presents the methodology and logistics of an experimental evaluation of the negotiation support system designed to aid parties involved in disputes over water resources to move from a bargaining stance (zero-sum game) to cooperative benefit maximization. The simulations with real actors (ERA) were only partially successful, due to the difficulty in getting participants to spend the length of time that would be required to conduct several rounds of negotiations so as to demonstrate the full potential of the NSS, in terms of the process as well as the negotiation outcome/solution. The self-driven set of simulations with simulated actors (ESA) was used to complement what could be obtained from simulations with real actors.

Results of the experimental work indicate that parties involved in disputes over international/shared water resources could benefit from decision and negotiation support tools included within the NSS. The individual decision support provided by the AHP algorithm assisted the parties in structuring and weighing their preferences and priorities. The WAS model and the other NSS components were shown to have the potential to improve the communication and information exchange between the parties, as well as their creativity in searching for alternative negotiation solutions.

Acknowledgments

Scholarships from the Technion—Israel Institute of Technology over several years enabled the studies of Lea Kronaveter. The writers are grateful to Yona Shamir and her team at the Israel Center for Negotiation and Mediation (ICNM) and to Technion students for participating in the simulations in which we tested the NSS methodology.

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