WATER RESOURCE CONFLICT RESOLUTION BASED ON INTERACTIVE TRADEOFFS DISPLAY

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OVERVIEW

Rehabilitation of degraded water resource systems, especially large scale systems such as Danube, Mississippi or the Volga River, inevitably involve conflicts over who pays, who benefits, and how much. This paper reviews the application of computer-aided approaches to water resources conflict resolution based on the generation and interactive display of the efficient tradeoff curves among conflicting performance criteria associated with various possible decisions. Computing of efficient tradeoffs is based on a mathematical model describing the system being managed. The model is supposed to be mutually acceptable to all stakeholders. Negotiators can interactively explore the full implications of solutions that represent efficient tradeoffs among identified performance criteria. In this way they can become more informed about compromises that can be made among conflicting criteria. This approach is applied to the real-time allocation of water to agricultural and environmental users whose demand for water usually exceeds the supply. Application of these procedures using computer networks (e.g., Internet or intranets) is discussed.

1. INTRODUCTION

The restoration of large-scale river systems, and the management of these systems whether degraded or otherwise, involve conflicts. These conflicts are over who gets how much water in times of scarcity and over the development and implementation of structural and non-structural measures for managing instream water quantity and quality. The resolution of these conflicts requires negotiations. There is an increasing interest in the development and use of interactive computer-based simulation models to aid those involved in such negotiations. Modern computer-aided simulation tools which can include graphics, sound, and video interfaces provide opportunities to assist those involved in negotiation processes. Indeed, display of useful information in pictures, on maps or by other multimedia tools (in contrast to numbers) can facilitate an integrated assessment of alternative management policies (see, for example, [3]). Using these tools, individuals can become better informed about the impacts of the decisions proposed by particular negotiators.

The above issue- or position-oriented negotiation can become difficult without the aid of some computer-based information management tools. Such tools can help identify common policies, especially in situations involving large amounts of information. Multiplying the amount of information related to one decision alternative by the number of alternatives and taking into account that the position of each negotiator will likely change somewhat during the process of negotiations, one may find that this position-oriented approach becomes impractical in many cases. This is especially so if a coordinated decision must be elaborated in real time and via computer networks. For this reason, simulation computer-based tools, while often useful, can not guarantee conflict resolution.

An alternative to position-oriented negotiations is the concept of Principled Negotiations (PN) [8, 22]. PN focuses on interests rather than on particular positions of individual negotiators. PN involves a search for a coordinated balanced combination of recognized interests among the variety of options in an effort to reach an equitable and acceptable compromise decision.

Here, we study problems related to water resource systems that are being designed or managed. Stakeholder interests may be associated with a small number of performance indicators (choice criteria). In such cases, if a mathematical model describing the system is developed, the PN concept can be implemented based on the computer-based tools. These tools may be able to help identify attractive alternative policies that may not have otherwise been considered, and they can help focus the negotiations on the essential issues whose resolution is crucial if an agreement is to be achieved [23, 24].

In this paper, a new approach to the same problem is considered. It is based on the generation and interactive display of the efficient (Pareto-optimal) tradeoff curves among conflicting performance criteria associated with various possible decisions. An efficient tradeoff curve between two criterion values is defined by the frontier of what can be achieved and shows how one criterion may be exchanged for another. The notion of the efficient tradeoff clearly differs from the notion of the value tradeoff. Value tradeoff is the subjective compensation of losses in one criterion by gains in another.

Generation of efficient tradeoff curves in this paper is based on a mathematical approach named the Generalized Reachable Sets (GRS). The GRS is a method for constructing and displaying a variety of attainable output vectors for a given large or infinite variety of possible input variable values. The most important applications of the GRS method are related to decision problems. The GRS method transforms a variety of feasible decisions to a variety of feasible combinations of criteria values. The GRS-based techniques may be used to derive and display information given in the integrated mathematical model of production and environmental systems [14]. Usually, GRS-based techniques are associated with decision support. Such applications of them are exemplified in several publications [13, 15, 16, 17, 18].

The most known GRS-based tool for decision support is the Interactive Decision Maps (IDM) technique. In the IDM technique, the information on decision situation is displayed in graphical form called decision maps. A decision map provides information on the relation among three criteria by displaying efficient tradeoff curves among two criteria depending on the value of the third one (see, for example, p.53, Figure 7, of [12] or p.464, Figure 12.10, of [11] where an application of decision maps is discussed). The tradeoff curves look like the elevation contours of a topographical map. The IDM technique provides an interactive tool for fast display of various decision maps in the case of three, four, five or more criteria. Actually, myriad of virtual decision maps may be generated in interaction with the user of the program. Animation of decision maps is also possible.

The IDM technique is usually used to support the identification of a preferred feasible combination of criteria values (feasible goal). This can be done by a simple mouse click on a decision map (possibly via Internet as discussed by Lotov et al., [15]). Then, a feasible decision which leads to the identified goal is computed (the Feasible Goals Method). This helps to solve the problem of screening the large (or even infinite) varieties of feasible decisions. The concept of screening the water planning and management decisions was introduced by Dorfman [7], and it was considered, for example, by Jacoby and Loucks [19], Cohon and Marks [5]), Loucks et al. [19], and Moiseev [21] among many others.

In Thiessen and Loucks [23, 24] negotiation support systems are categorized according to their functions either as Negotiation Preparation Systems or Negotiation Process Support Systems. The former support pre-negotiation strategic planning, and the latter facilitate negotiation processes. Interactive application of the efficient tradeoffs display in computer-based systems for preparation of negotiations on rehabilitation of water resources is considered in more detail in [14, 16]. Here we concentrate on applications of the GRS-based techniques for supporting the processes of principled negotiation.

Mediators may play different roles in Negotiation Process Support systems. In the Interactive Computer-Aided Negotiations Support (ICANS) system (see [24]), mediators model preferences and then reveal such combinations of interests (and related decisions) which may be accepted by negotiators. In contrast, here negotiators interact directly or via computer network using interactive tools that display efficient tradeoff curves among their interests. Negotiators may explore the efficient tradeoffs and try to develop a coordinated feasible combination of criteria. Though the IDM technique can support a non-structured process of this kind, here we propose to base the search for a coordinated combination of criterion values on the concept of a Single Negotiation Text (see [22]). Assuming a starting point from which negotiation take place, negotiators add their coordinated improvements to the Single Negotiation Text. In our procedure, a single Non-dominated Criterion Point (NCP) is used as the Single Negotiation Text. The NCP is displayed on collections of efficient tradeoff curves. It is moved by negotiators along the curves directly. Negotiations can focus their discussions on the coordinated movements of the NCP. Therefore, the negotiation procedures may be viewed as a navigation among various collections of tradeoff curves. Navigation on a decision map resembles the travel on a usual geographical map. The IDM technique provides a display of the current NCP and of its movements.

In this paper, a new GRS-based tool — the Point-Associated Tradeoffs (PAT) technique is used along with the IDM. The PAT technique introduced in Lotov et al. [17] was developed for supporting a single decision maker, but here it is applied in negotiation support. Negotiators receive collections of efficient tradeoff curves associated with the current NCP. In a collection, one criterion is depicted versus all other criteria. Thus, the PAT technique provides additional convenient opportunities. Comparison of the tradeoff curves among different pairs of criteria helps identify a most appropriate tradeoff curve for movement of the NCP.

Let us discuss the relation among the procedures based on the GRS-based techniques and the methodology of Principled Negotiations. In the GRS-based techniques, the initial description of the problem given in terms of the feasible set of decision variables is transformed into the description given in terms of criteria. By this, decisions (positions) are hidden; they do not obscure relations among criteria. Negotiators are informed about potentialities of choice in terms of the criteria representing their interests. Possible combinations of interests are described by the variety of feasible combinations of criterion values. Moreover, negotiators are informed about tradeoffs among the criteria. They can search for mutual gains with respect to their interests by moving the NCP on tradeoff curves.

The negotiation support techniques described in this paper may be implemented via the computer networks, e.g., Internet and intranets. In the framework of computer networks, negotiators can use the IDM and the PAT software as well as software providing navigation of the NCP. Since the current position of the NCP is the only information exchanged among negotiators via a computer network, the procedure may be coded using simple network tools. In the case of computer networks, we restrict ourselves with the case of simple preference pattern: the only criterion known in advance represents main interests of a negotiator. In this case, the movements of the NCP may be decided in negotiation sessions involving only two negotiators who consider two related criteria. The values of all other criteria are held constant. A negotiator can identify a most appropriate partner for bilateral negotiations with the help of the PAT technique: a negotiator receives and compares efficient tradeoff curves associated with the current NCP while his/her criterion is depicted versus all other criteria.

The reminder of this paper consists of six sections. The second section is devoted to the introduction of the PAT technique. In the third section, a negotiation process support applying the GRS-based techniques is described. The fourth section describes the problem of real-time water allocation. The fifth section outlines some experiments with the negotiation support procedure for water allocations. The concept of the computer network-based support is outlined in section six. Mathematical description of the problem of real-time water allocation can be obtained from the authors. Mathematical features of the GRS-based techniques are provided on the Web (http://www.ccas.ru/ mmes/mmeda/grs.htm).

2. POINT ASSOCIATED TRADEOFFS TECHNIQUE

The Point Associated Tradeoffs technique is explained through the same example which was used in the proceeding paper [14]. A river containing a lake discharges into a sea. The strategies of further economic development of the river basin are considered using three criteria: agricultural production, level of the lake, and water pollution in the lake. The example is related to real-time water allocation among agricultural and environmental users located along a river. The agricultural demand of water during a dry season exceeds the supply of water and results in negative impact on wetlands, and hence a conflict between production and environment exists. A compromise decision needs to be identified by the users, and this needs to be done periodically. This is a real-time problem since the forecasts of precipitation as well as of water feasibility are changing with time. New water-allocation decisions need to be negotiated every time the forecast is updated.

We start with the Interactive Decision Maps [14]. Figure 1 shows the black and white copy of the color computer display — one of the decision maps related to this regional problem. The values of production (measured in percent of its maximal feasible value) are given in the horizontal axis, and the values of the level of the lake (given in percent of its operating range) are given in the vertical axis. In the figure, one can see several frontiers of possible combinations of these two criteria for several restrictions imposed on the value of pollution (measured in milligrams of pollutant per liter). The related restrictions on pollution are specified for each frontier.

Any frontier displays the efficient (Pareto-optimal) tradeoff between two criterion values. Also, it defines the limits of what can be achieved. It is impossible to increase the values of agricultural production and lake level beyond the efficiency frontier. The furthest left internal frontier is related to a low level of pollution. It shows how the level of the lake may be exchanged for additional production while keeping a low level of pollution. For small values of production (less than about 20%), the maximal level (100%) of the lake is feasible. Then, with the increment of the production, the maximal feasible level of the lake starts to decrease more and more abruptly. The maximal (for low pollution) value of the production (a little bit less, than 60%) is related to the minimal level of the lake. Note that it is necessary to exchange a substantial drop of the level (about 30% starting at point **D**) for a small increment of the production needed to achieve its maximal value.

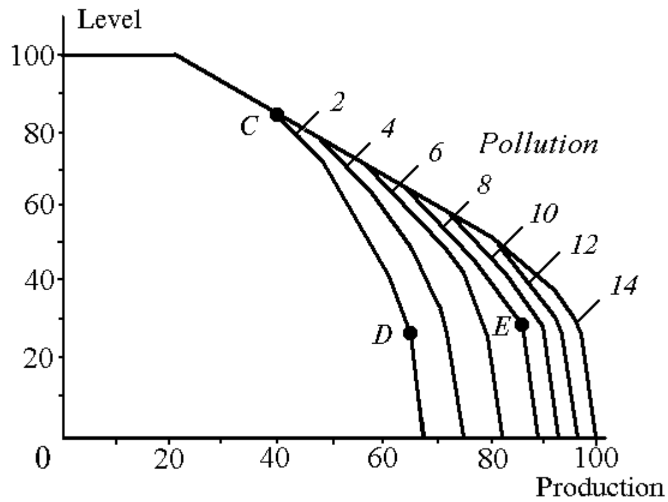

Figure 1. One of the decision maps for the regional problem (production versus level)

Other tradeoff curves have the same shape. Note that as allowable level of pollution increases, the possible production level increases as well. The outer curve is related to the situation when restrictions on the pollution limit the maximum efficient concentration to 14 mg/l. In the case of three criteria, the IDM technique provides arbitrary arrangement of criteria in a decision map (see Figures 2 and 3), and the opportunity to change the number of the tradeoff curves and to zoom.

The role of the IDM technique is much more important in the case of four and more criteria since decision maps for various restrictions imposed on the values of the fourth and the fifth criteria may be displayed immediately. Moreover, decision maps for arbitrary combinations of criteria may be obtained at once in the form of matrices of decision maps [14, 16].

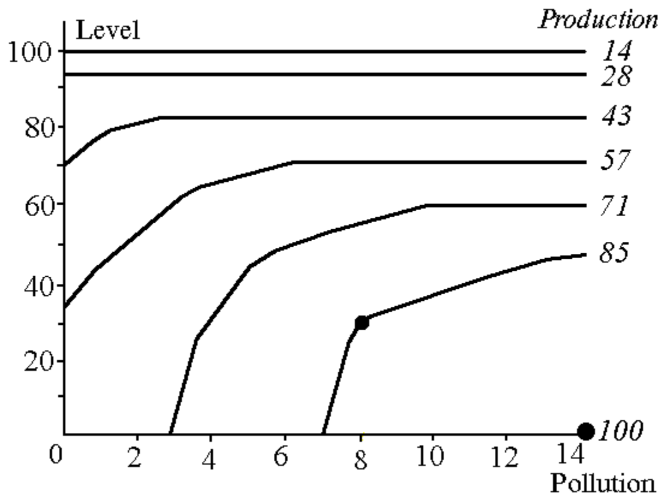

Figure 2. Pollution versus level of lake tradeoffs. Values of production are given to the right of the curves. Note that the maximal (100%) production is related to a single point.

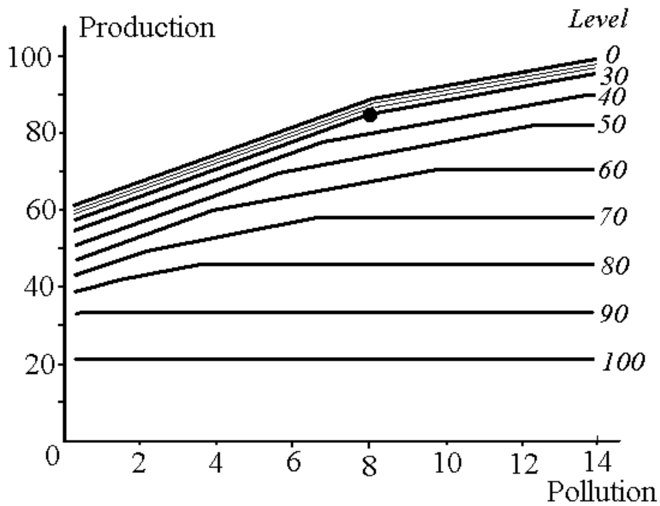

Figure 3. Pollution versus production tradeoffs. Note that the frontiers related to the 90% and 100% level are horizontal, i.e. zero is the only efficient value of pollution.

The Point-Related Tradeoffs (PAT) technique provides additional insights. Note that a non-dominated criterion point (NCP) defines a single efficient frontier of possible values of a certain pair of criteria assuming all other criterion values are fixed. Let us consider an example related to the NCP given by point **E** in Figure 1. In this NCP, production is about 86%, lake level equals 30%, and pollution is 8 mg/l. The same NCP is given by in Figures 2 and 3. In Figure 1, the tradeoff curve of production and lake level passing through the point **E** is related to the fixed pollution value of 8 mg/l. Let now pollution and level of the lake be the pair of non-fixed criteria, i.e. the value of production is fixed on the value given by point **E**. The single tradeoff curve among pollution and level passes through the black point in Figure 2. The same curve is given separately in Figure 4. Now, let us consider another pair of non-fixed criteria comprised of pollution and production. The tradeoff related to the same NCP is given in Figure 3 by the curve marked by the black point. It is provided separately in Figure 5.

Since level of the lake and production are measured in the same units, we may draw both tradeoff curves in the same axes. To do it in general case, we have to measure the criteria in the same related units, for example, in percents of their ranges. Actually, pollution could be given in percents of maximal efficient value, but we use the original scale for the sake of simplicity.

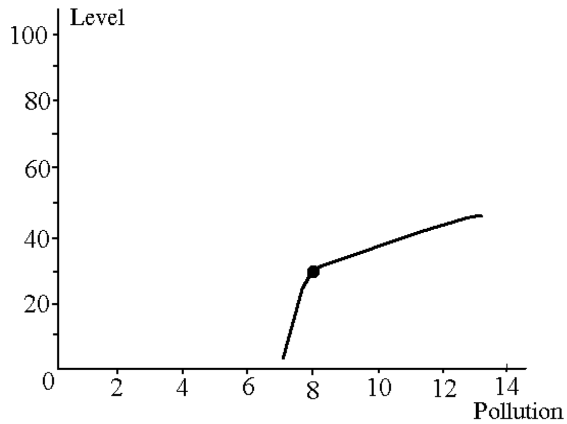

Figure 4. Tradeoff curve pollution versus level related to the NCP

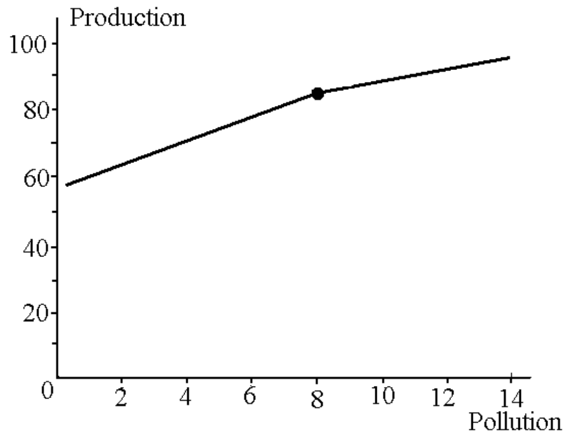

Figure 5. Tradeoff curve pollution versus production related to the NCP

In general, choosing one criterion as the leading criterion whose values are on the horizontal axis, we draw the NCP-related tradeoff curves between the leading criterion and other criteria in the same axes. The number of tradeoff curves may be large, say, five or six. This collection of tradeoff curves is denoted as the PAT picture related to a given NCP.

In Figure 6, one can see a vertical line going through the current (i.e., associated with the NCP) value of the leading criterion (in this case, pollution). The value of pollution is given by point 1. The vertical line crosses the tradeoff curves in the points 2 and 3: the values of two related criteria. The tradeoff curves show how the value of the leading criterion may be exchanged for the value of the related criterion while the values of other criteria are fixed.

One can see, that this collection of tradeoff curves is different from a decision map. In a decision map, all tradeoff curves are related to a certain pair of criteria while in a PAT picture, the tradeoff curves displayed are among all such pairs of criteria. For this reason, the current NCP (point **E** in Figure 1) is represented by several points in a PAT picture (points 1, 2 and 3 in Figure 6). Moreover, a decision map does not depend on the position of the NCP. In contrast, a change of the NCP changes the PAT picture. At the same time, the movement of a point along a selected curve does not change the values of the criteria not being studied. This feature of the PAT technique is discussed a little later. The PAT pictures can be generated and displayed very quickly at the user's request.

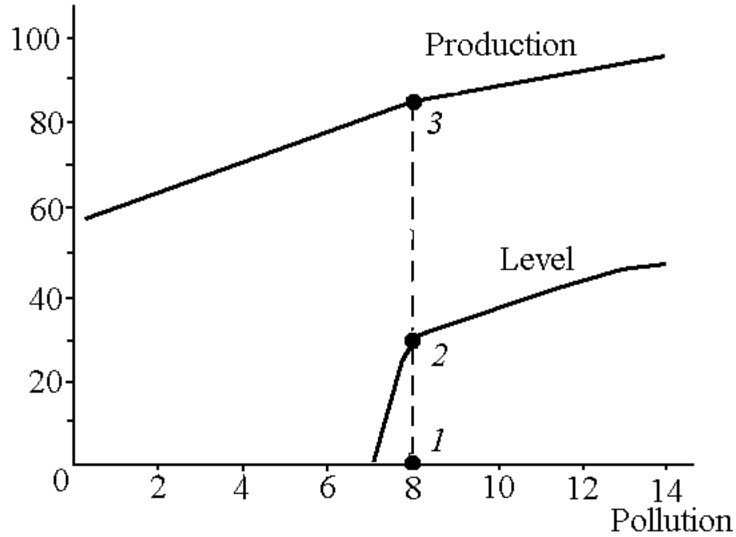

Figure 6. A PAT picture. The upper curve displays the 'production-pollution' tradeoff, the upper curve displays the 'level-pollution' tradeoff.

3. APPLICATION OF THE IDM AND PAT TECHNIQUES IN NEGOTIATIONS

In this section we discuss the applications of the GRS-based techniques to the support of negotiations. We start with their application to negotiation preparation. Consider again the above regional problem, i.e. negotiations among inhabitants of the city, farmers and businessmen. It is assumed that all participants are in agreement with the assumptions in the model that generates the data used to compute the decision maps and that all negotiators have the decision maps as are displayed in Figures 1-3.

Two different zones may be identified in the decision maps: the zone with low values of the agricultural production (20-30%) and the zone of high production (30-100%). In the first zone, there is no conflict between the city and the recreation businesses. In this range of low agricultural production, water quality is reasonable and independent of the level of the lake. In the second zone, this conflict may exist. For this reason, the inhabitants of the city may be interested in establishing a political coalition with the recreation businesses. For example, they may start negotiations with the proposal of a high level of the lake (not less than 90% of maximal). If this coalition is strong enough, the result of negotiation may be placed around point C in Figure 1. Farmers may be interested in preventing this coalition. To do it, they may try to make some side deal with the recreation businesses. A coalition between farmers and the municipality inhabitants is unlikely to occur since large values of crop production can not be obtained without high levels of pollution. The conclusions reached above are a result of a superficial look on the decision maps. Additional insights may be obtained from more detailed explorations of them [17].

It is important to note, that if only one of multiple negotiators has access to the decision maps while preparing for negotiations, he/she would know what criterion values are feasible and how the efficient tradeoffs look. Using this information, he/she will be able to develop decisions which are profitable to him/her and acceptable for other negotiators. Moreover, he/she may use this information to help convince other negotiators to accept his/her proposal. To evaluate this option personally, one may want to visit the demo Internet resource that is based on the IDM technique and the Feasible Goals Method (http://www.ccas.ru/mmes/mmeda/resource/). The resource provides an opportunity to develop a preferable strategy for solving the problem.

Now let us consider possible applications of the GRS-based techniques in negotiation process support systems. The IDM technique can support negotiations process by displaying the feasible combinations of efficient (non-dominated) criterion values for all criteria at any moment in an ongoing negotiation process. Actually, the IDM technique is used in this case as a part of Negotiation Information Management [23, 24] which provides information on the decision situation, but not on interests.

To apply the PAT technique in negotiation process, the negotiators should agree to use a single current non-dominated criterion point (NCP) as a basis for negotiations. After a NCP is provided, negotiator can request any PAT picture with any criterion chosen as the leading one (say, pollution in Figure 6). Since the PAT technique separates criterion values into the tradeoffs among pairs of criteria, possible exchange of only two criterion values may be considered. Look at Figure 7. Suppose negotiators agree to move the NCP described by points 1, 2 and 3 along the pollution-production tradeoff curve into a new NCP given by points 1', 2' and 3'. The values of pollution and production changed. Improvement of the pollution (from point 1 to point 1') was exchanged for the drop of production (from point 3 to point 3'). It is important that the level of the lake didn't change (the level is the same in points 2 and 2'). Instead of it, the pollution-level tradeoff curve changed from the solid one to the dashed one. This can be understood quite easily: any movement of a point along a tradeoff curve results in the change of the NCP, and hence the remaining tradeoff curves shown in the PAT display may change.

If negotiators agree to use a single non-dominated criterion point (NCP) to describe the current state of negotiation process, they have to coordinate movements of the NCP along the efficiency frontiers without any structured dialogue. They can explore the decision maps and PAT pictures with the current point independently (in this case it resembles the pre-negotiation stage) or in groups.

In the remainder of this paper focuses on structured negotiation procedures, i.e. procedures with a given structure of interaction among negotiators. Procedures of this kind may be implemented on computer networks. To develop a structured negotiation procedure, for this discussion we assume the main interests of each party in the negotiation are expressed by only one criterion in the model. This criterion can conflict with the criteria of other negotiators.

Since each negotiator has the only criterion that represents his/her main interests in negotiations, this criterion may be chosen to be the leading one in his/her PAT display. Each negotiator can study the tradeoffs among his/her criterion and the criteria of other negotiators by viewing the personal PAT display. By this, he/she may be able to identify other negotiators who may be willing to enter bilateral negotiations on the movement of the NCP along their tradeoff curve. Successful bilateral negotiations result in changes in the NCP (like in Figure 7). The values of other negotiator's criteria are not changed.

The question may arise why negotiators are able to move the NCP along the tradeoff curve. Indeed, movements of the NCP along a tradeoff curve result in the exchange of the main interests of one negotiator for the main interests of the other one. The answer to the question is related to the fact that the negotiators may have (or develop) interests that are not described in the model. In real-life negotiations, negotiators may include auxiliary topics in their discussions. These topics may have nothing to do with the negotiation issues, but they are of interest to the negotiation parties. For example, farmers and businessmen discussing the above problem of water quantity and quality, may take into account the opportunities of preparing a common legislative proposal related to changes in the regional tax system. These implicit side interests may help in finding an agreement since they enrich the forms of payments [22]. In the case of farmers and businessmen, they may use concessions in the field of the legislative proposal to improve the position in the framework of the water quality planning.

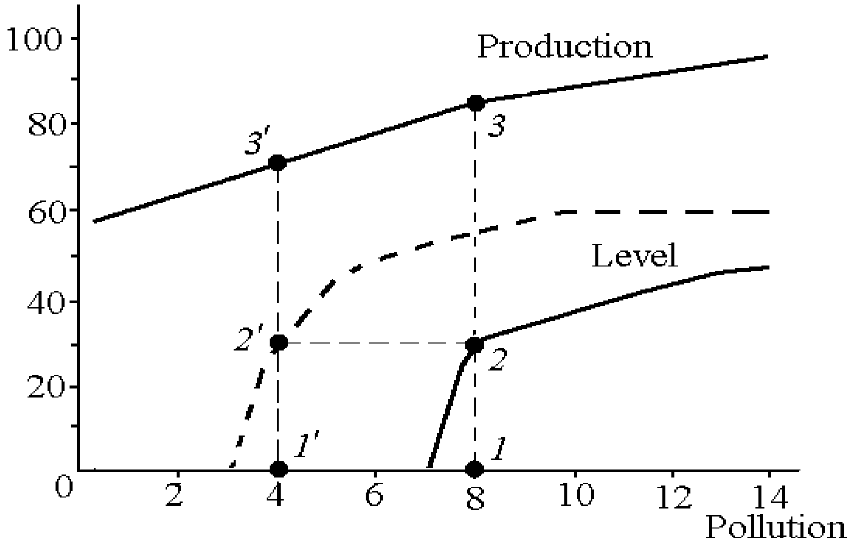

Figure 7. Values of pollution and production are exchanged. Point 1 is moved by negotiators to the point 1'. Point 3 shifts to the point 3' along the tradeoff curve. Point 2 shifts to the point 2' in which level of the lake is the same, but the tradeoff curve between pollution and level of the lake transforms into the new curve. Movements along tradeoff curve among pollution and production cause changes in the second tradeoff curve.

The idea of the implicit side payments is clearly different from the usual concept of side payments used widely in the theory of games (see, for example, *Luce and Raiffa* [20]. In contrast to the usual side payments, the implicit side payments aren't included in the model. The mediators may have no idea about them. Nevertheless, the implicit side payments may exist or be developed in the real life situations. As the result, the implicit side payments may provide an incentive to move along the efficiency frontier exchanging the displayed interests for the implicit ones. The experiments with the example problem described in Section 5 support this idea.

As stated above, these structured negotiation procedures can be implemented on computer networks. Computer networks provide new opportunities for supporting the remote negotiation processes. On the other hand, to provide network interaction of negotiators, the negotiation procedure needs to be somewhat structured.

The IDM and PAT techniques may be easily implemented in computer networks: negotiators can move the NCP along the tradeoff curves. Since the techniques separate the tradeoffs among interests of two negotiators from other interests, they give the opportunity for bilateral negotiations. The visual display of tradeoffs provided by the PAT technique and the informal knowledge about opportunities of hidden payments among negotiators help to identify who of the potential partners may be. (Imagine that the inhabitants of the city and the farmers will agree to move the NCP like in Figure 7). Once again, due to the separation of interests provided by the IDM and the PAT techniques, the criterion values of the other negotiators stay the same (in Figure 7, the level of the lake isn't changing since the movement of the NCP results in exchange of pollution and production only).

The techniques are related to information exchange among two negotiators, i.e., two criteria, only. The Edgeworth-Pareto Hull (EPH) which is the source of the decision maps [14], and the PAT picture is constructed in advance by mediators. Before the negotiations start, the EPH is provided to negotiators (jointly with the IDM and the PAT software). This means that various decision maps may be quickly displayed to negotiators on request without applying to the computer network. Since a NCP is given, the PAT pictures may be displayed as well. The data exchange via the computer network may be associated with the current NCP only. The initial NCP should be prepared on the basis of some kind of «fair principle». before the procedure is started.

The negotiation process via computer network consists of a finite number of steps that have the same structure. Any step is reduced to discussing the coordinated movements of the feasible goal on a tradeoff curve. The current point is moved directly by two negotiators. The movements are decided on bilateral sessions where the interests of only two negotiators are exchanged.

3.1 A Structured Procedure

Stage 1. Negotiators receive the current NCP. The software provides negotiators with the personal PAT pictures, i.e. the criterion which represents the main interest of a negotiator is chosen to be the leading indicator on his/her PAT picture.

Stage 2. Negotiators study the tradeoffs among their criterion and the criteria of other negotiators by viewing their personal PAT pictures. They try to involve appropriate partners into bilateral negotiations on the movement of the NCP. Computer networks and other contacts may be used by negotiators.

Stage 3. Mediators register the first pair of negotiators who announce that they want to move the NCP along their tradeoff curve. Other negotiators may have informal discussions or influence the pair of negotiators.

Stage 4. After the bilateral session is over, mediators inform negotiators about the new position of the current NCP. Other negotiators should agree since the values of their criteria have not changed. The procedure returns to stage 1.

It is important to stress once again that the opportunity to move the current NCP along the tradeoff curves is related to the exchange of implicit side agreements that are out of the framework of the model. The procedure is completed when negotiators refuse (or are unable) to move the current NCP.

4. A WATER ALLOCATION EXAMPLE

To provide an example of application of the above techniques for supporting economic and environmental negotiations, we consider a problem in which water is to be allocated among agricultural production and environmental applications. An agricultural region located along a river is studied. At the mouth of the river a wetland exists which is an important environmental site. It is assumed that the production of farms in the region is based on the application of water from the river: there is a lack of water during the dry season. Water deficits also influence the environmental system of the wetland.

Water allocation decisions are negotiated among the environmental authority and the groups of farmers. The farmers are interested in income obtained from the agricultural production, i.e. they try to diminish losses arising due to water deficit. The environmental authority tries to minimize the negative influence of the water deficit on the environmental system.

The problem has a real-time nature, since water allocation decisions need to be updated periodically given the uncertainty of forecasts of precipitation. Water allocations have to be identified at each time improved forecasts are made. Let us suppose that the forecasts are updated weekly. In this case, the water allocation decisions should be made every week. When deciding on next week's allocations, negotiators have to take into account the entire set of allocations over the remainder of the growing season – each decision involves allocations up to the end of the growing season. Each water allocation plan should take into account the existing water supplies and expected future rainfall and losses throughout the remainder of growing season.

The main variables of the production model are the maximum potential incomes from the harvest, i.e. incomes that may result if the moisture in the soil is optimal for crop growth, and the degradation of the environmental system of the wetland. Because of the lack of water, the potential incomes may decrease and the state of the environmental system may increase in time. The production losses that arise due to the water deficit are described by the given functions of precipitation and water application. In the case of wetland, the degradation factor depends upon the water flow.

The problem discussed in the negotiations is how to allocate the forecast total amounts of water among farm groups. One has an infinite number of feasible variants of water-allocations, and therefore it is reasonable to apply the IDM and the PAT techniques to support the water allocation negotiations. It is clear that farmers are interested in minimizing their losses of income due to water deficit during the time-period till harvest, and the environmental authority is interested in minimizing the degradation of the environmental system of the wetland at the end of the dry period. In this example we limit the number of groups of farmers to be no greater than six. Otherwise, the negotiations would have a hierarchical structure.

5. EXPERIMENTS

In simulated experiments using university students, a highly simplified version of the water-allocation model was used. It was assumed that a single crop is produced, all the fields have the same kind of soil and water is distributed uniformly among the fields of a group of farmers. In this case, the moisture in all fields of a farm group is the same, and so one can introduce the soil moisture for a group of farmers.

In the simplified experiment, we assumed two groups of farmers. The dry season contained only two weeks. The loss functions were the same. The water application during the first week had no influence on the soil moisture during the second week. Finally, the water flow in the mouth of the river was fixed. In this simple case, the efficiency frontier can be constructed without needing a computer: it has the form given in Figure 8. These simplifications were used in the experiment, since the main aim of it was to evaluate the ability of people to move the NCP along the efficiency frontier. Several negotiation sessions among pairs of students who played the role of farmers have been arranged.

The first experiment involved two students who had never met before and who were in the fifth year of university education. One student was from the Lomonosov Moscow State University, another one — from the Moscow Institute (University) for Physics and Technology. The students were paid with cash depending on the result they negotiated. The reward was proportional to the decrement of losses. The feasible values of losses were displayed to them in the form given in Figure 8.

At the very beginning of the experiment, students were given the initial NCP denoted by the point **O** (Figure 8). The initial point is 'fair', but it is related to small rewards for both students. The movement along the efficiency frontier resulted in the decrement of the reward for one of the students while the reward of another student increased. So, to move along the frontier, students had to develop some kind of payments hidden from mediators.

Students were informed that they would not be asked about why they decided to move the NCP along or above the efficiency frontier. After about ten minutes, the students agreed on a new NCP. In Figure 8 this point is denoted by a star. This decision was rather unfair: one student received about 10% of possible reward while another one received about 90%. The chosen point seemed to be the result of the maximization of the sum of rewards for the given efficiency frontier. One may suppose that the students summed up their rewards and then shared the sum in a fair way. But this is only a suggestion since the secrecy of hidden payment was one of the conditions of the experiment. For example, one can loosely imagine that they went jointly to a restaurant to spend the money. In this experiment, the students were rewarded with money, i.e. with an unrestrictedly transferable utility [20].

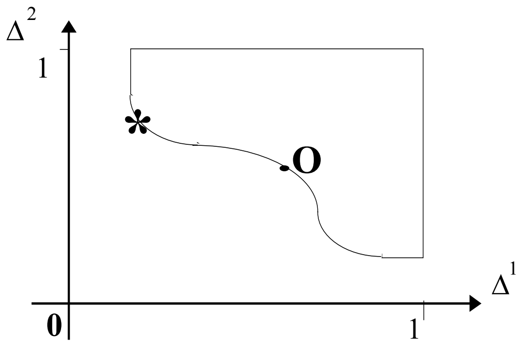

Figure 8. The initial and the resulting negotiated goal values for the first experiment. Each of the two students was paid based on how well they minimized their values of Δ.

The next experiments involved non-transferable rewards. In this second experiment, twelve students of the fourth year from the Lomonosov Moscow State University grouped themselves in accordance to their wishes into six groups. The students were studying the theory of multiple objective optimization, and so the experiment had the form of a laboratory work on the concept of efficiency frontier. In the framework of the second experiment, for a non-transferable rewards, the additional score (or mark) during the examination was used. Movements along the efficiency frontier were related to the increment of the additional score for one student and to the decrement for another. Clearly, in this case the development of a hidden payment isn't so easy.

Each pair of negotiators received the same set of feasible losses with the same initial point **O**. They were informed that they could refuse to take part in the experiment (in this case they simply would not receive additional score for the examination). It took from 15 minutes to one hour to find an agreement.

One pair decided to stay at the point **O**, but all other pairs decided to move the NCP. All the final positions of the NCP are given in Figure 9 by stars. It is clear that the final criterion points (except the point **O**) approximately provide local minima of the sum of the losses. One of each pair of students achieved very good results and the other was willing to accept very poor results. Therefore, one can state that the experiment with the non-transferable rewards resulted in practically the same outcome as the experiment involving money rewards! The question of the reasons of such behavior may arise. In one case, one of the sides clearly decided to be more decent. In other cases, a hidden payment was used. One pair announced that they will never tell anyone the form of the payment.

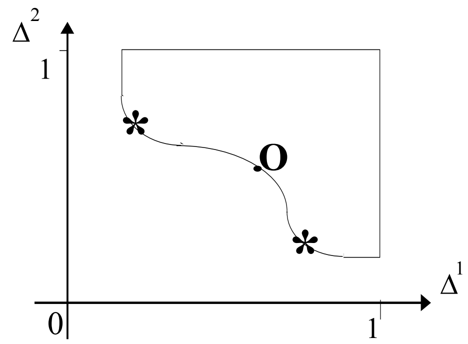

Figure 9. The initial and the resulting goals for the second experiment

The results of the experiments show that negotiators may develop hidden side payments pretty fast, and so they can move along the efficiency frontiers using them. In turn, this may suggest that the developed negotiation support technology might be useful in real-life negotiations.

6. SUPPORTING WATER ALLOCATION NEGOTIATIONS ON COMPUTER NETWORKS

Let us adapt the structured negotiation procedure described in Section 3.1 to real-time water allocation negotiations on computer networks. In this particular example, assume a coordinated decision must be developed every week, hence negotiations are regularly required. In this case it is useful to distinguish between the data that are not changing from week to week (non-variable data) and the data that change (variable data). The non-variable data are supposed to be provided before the negotiations start. The variable data should be collected and shared every week. In this particular problem, such parameters of the model as forecasts, soil moisture, state of the wetland, etc., are subject to change every week. Hence mediators have to collect this information to construct the updated EPH (the source of the decision maps and PAT pictures) and to provide the EPH to negotiators every week. This should be done before the weekly negotiation session starts.

6.1 Real-Time Structured Negotiation Procedure

Stage 1. Mediators receive the corrected forecasts of precipitation and of water feasibility. Simultaneously, farmers inform them about the updated potential incomes and decrement functions, and the environmental authorities inform them about the state of the wetland. This information can be provided to mediators via the computer network.

Stage 2. Mediators construct the EPH and provide it via the computer network to environmental authorities and farmer groups. The initial (for this step) NCP is provided as well. It may be based on the water allocation decisions negotiated during the previous week.

Stage 3. The IDM software displays decision maps as well as «personal» PAT pictures associated with the current NCP to negotiators.

Stage 4. Negotiators explore the decision situation in general using the decision maps and the tradeoffs among their «personal» losses and losses of other negotiators. This is done using the «personal» PAT pictures to identify appropriate partners in bilateral negotiations on the movement of the NCP along the tradeoff curves.

Stage 5. Mediators register a pair of negotiators who announce (via the computer network or by usual phone) that they want to start bilateral negotiations. Then, the bilateral session starts. Other negotiators may try to influence in an informal way the results of the bilateral session.

Stage 6. After the bilateral session is over, mediators inform negotiators via the computer network about the new position of the NCP. The procedure turns to the stage 3.

Since the coordinated decision should be found during a short time-period (say, in a day), it is possible to establish a deadline, after which the current position will be «frozen» or the water allocations will be chosen by the regional authorities. Surely, this will provide an incentive for negotiators to find a coordinated NCP in time. After a NCP is negotiated, mediators calculate the water allocation plan from now to the end of the growing period. As usual, the selected water-allocation plan may be provided via the computer network to groups of farmers, environmental authorities and ordinary citizen. It may be displayed in a multimedia GIS in the various ways.

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