COMPUTER-BASED SUPPORT FOR PLANNING AND NEGOTIATION ON ENVIRONMENTAL REHABILITATION OF WATER RESOURCE SYSTEMS

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Abstract. Strategies of environmental rehabilitation of water resource systems are usually characterised by multiple performance indicators which represent interests of different social groups. To support negotiations aimed at solution of the problems of this kind, we use a computer methodology based on integrated assessment of environmental problems with Feasible Goals Method (FGM) and Interactive Decision Maps (IDM) techniques. The methodology provides the display of tradeoffs among the performance indicators. By this negotiators, experts and public opinion are informed on potentialities of choice and on non-dominated combinations of indicators values. Non-dominated goals may be identified and efficient environmental rehabilitation strategies may be developed by a simple mouse click.

The methodology can be used for supporting both planning and negotiations. An example of planning support system is provided. Concept of INTERNET resources devoted to informing the public opinion on the environmental rehabilitation problems is introduced.

Keywords: environmental rehabilitation/ planning and negotiation support/ multiple criteria decision making/ interests/ tradeoffs/ interactive decision maps/ feasible goals/ efficient strategies / GIS/ public opinion/ INTERNET

Introduction

It is clear that the ultimate practical goal of the research in the field of the environmental rehabilitation (ER) consists in providing a support for negotiations and planning. This support should help to develop reasonable strategies which can solve the ER problems. New computer-based methods aimed at providing the decision support of this kind are described in the paper.

It is important to stress from the very beginning that we don't discuss in this paper how to establish and to maintain natural zones in which economic and other activities of peoples are restricted or totally forbidden. In contrast, the problems of coexistence of the peoples and of the nature in environmental systems of general type are considered here. Sometimes, it is supposed that the aim of the ER (like it is in the case of natural zones) consists in converting of an environmental system into “a natural state" which corresponds to the situation when peoples haven't ever touched the nature. This approach is related to several contradictions. The first one is: how to define “the natural state"? The climate and the biota are both the developing systems which are in a permanent natural change. For example, the level of the Caspian Sea (which is the internal sea) is changing in time because of changes in the precipitation in its basin, of the geological changes and of many other reasons which aren't clear yet. Therefore, the proposal transfer water from the northern Russian rivers into the Caspian Sea basin to maintain its “natural” level (the proposal was discussed broadly in the former Soviet Union about twenty years ago) hasn’t too much sense. The ill-statement of the proposal is especially clear now when we know about the recent dramatic rise of the level of the Sea. Secondly, the concept of “a natural state" isn't favourable to the mankind: how people can survive without interacting with the nature at all? So, to our opinion, the problems of the ER are related to the search and the accomplishment of strategies which correspond to a reasonable balance among both the environmental and the economic objectives and help to develop environmental systems in the form favourable to peoples who live on the earth now and who will live in the future.

Several features of the ER problems sophisticate the development of a convenient negotiation and planning support. First, the modeling of the ER problems is usually related to a variety of scientific fields like the ecology, the economics, the geographic and social sciences, etc. The description of an environmental problem includes the descriptions of a lot of subsystems like production, pollution discharge treatment, pollution transport, ecological and medical influence of pollution, economic aspects of the discharge treatment and of the other environmental actions, etc. Therefore, integration of the knowledge obtained in various fields is needed. Secondly, the decisions are made by the politicians who have no time to study many volumes of information related to an ER problem they consider, i.e. the aggregated description of the problems is needed. Third, the politicians tend to consider the whole totality of their relations at once, though negotiations may be formally devoted to a particular ER problem. Fourth, the personal interests of politicians may turn to be much more important for them than the officially recognized objectives they have to represent. Fifth, resolution of the ER problems is usually related to a balance of interests of various social groups. Sixth, the ER problems are related to the interests of particular ordinary peoples who want and who have right to know why this or that strategy is chosen, i.e. the public opinion should be informed as well. Moreover, opinion of ordinary peoples should be taken into account.

Here, we suggest a computer-based methodology which takes into account the features of the ER problems listed above and provides convenient support for the development of the ER strategies. The methodology is based on several main principles which follow.

1. We use aggregated economic and environmental performance indicators to inform negotiators, experts and general public on potentialities of choice expressed in terms the performance indicators. This is done on the basis of mathematical models which describe natural and economic relations involved into the problem. At the same time, we don't discuss the preferences of planners or negotiators and their relations one with another, i.e. we don't intervene into the unstructured and even hidden processes and don’t describe them in the model. The politicians are given a full freedom of choice with respect to the non-dominated combinations of the economic and environmental indicators.
2. We display the tradeoffs among the indicators using the decision maps which are similar to usual geographic maps and therefore may be easily assessed. To be precise, we apply the technique of the Interactive Decision Maps (IDM) in the framework of which myriad of various decision maps may be displayed very fast and by simple operations. Moreover,

animation of decision maps may be used as well. The IDM technique may be treated as a new multimedia tool for an easy assessment of information on decision situation.

3. By informing on opportunities of choice (applying the IDM technique), we help to identify a preferable non-dominated combination of indicators (a feasible goal). Then, a strategy which is efficient from the environmental and economic points of view and which outcomes result in the identified goal is calculated by computer (the Feasible Goals Method, the FGM).
4. We use an integrated mathematical description of the problem to construct the tradeoffs among the indicators in a particular ER problem. The integrated mathematical model combines simplified mathematical models of the subsystems of the system under consideration with expert judgements and empirical data.
5. Since the strategies are obtained on the basis of a simplified integrated description of the problem, they are checked and corrected in simulation experiments with adequate models of subsystems.
6. The public opinion may be informed about an ER problem on the basis of the IDM as well. To inform the general public, we propose to establish INTERNET resources which provide information about the problem. One may apply the FGM/IDM technique to explore the potentialities of choice and the tradeoffs among criteria and to identify a feasible goal in accordance to his/her preferences. By this he/she develops an independent efficient strategy which outcomes coincide with the feasible goal identified by him/her. Presumably, this will help to understand the situation and the negotiators choice. Moreover, public control on negotiators may be provided as well. It is important that the FGM/IDM technique is related to a very simple information exchange among user and computer and, therefore, may be accomplished in the World Wide Web pages.

Note that the idea to base the negotiations on the exploration of combinations of recognized interests, but not on strategies proposed in advance, was introduced in the concept of Principled Negotiations (Raiffa, 1982, and Fisher and Uri, 1983). The FGM/IDM technique provides a computer implementation of the ideas of Principled Negotiations in negotiations on the ER problems. Here, application of the methodology on negotiation preparation stage is considered. Its applications for supporting the processes of negotiation is beyond of the scope of this paper (see Lotov et al., 1997c).

The paper consists of six sections and Appendix. First, we introduce the Feasible Goals Method and the Interactive Decision Maps techniques. In the second section, the concept of the Principled Negotiations and its application in the ER problems is considered. In the third section, constructing the integrated models of the ER problems is discussed in brief. The fourth section is devoted to the summary of the methodology we suggest here. In the fifth one, an example of application of the methodology in planning and negotiation support for development of the ER strategies for river basin water resource systems is provided. The concept of the INTERNET resources for the ER topics is introduced in the sixth section. In Appendix, mathematical description of the FGM/IDM technique is given.

1. The Feasible Goals Method and the Interactive Decision Maps

The Feasible Goals Method and the Interactive Decision Maps are the techniques based on the Generalized Reachable Sets (GRS) method which is an universal mathematical tool for exploration of open mathematical models, i.e. the models in the framework of which the values of input variables aren't given in advance (see Lotov, 1984 and 1989). The GRS method transforms the given sets of feasible input variables into the sets of attainable combinations of values of output variables. In decision problems, the inputs are the decisions (strategies) and the outputs are the performance indicators (or the choice criteria). The GRS may be implemented in several forms. Here we describe a particular form of it which is based on the application of the Interactive Decision Maps technology. Let us start with a simple example model based on a study described in the paper by Bushenkov et al (1982). In (Lotov, 1984), this example was used for introduction of the FGM technique. Since then, this example has been permanently used for this purpose. Moreover, it is used now in computer laboratory works at the Lomonosov Moscow State University, at the Moscow University for Physics and Technology, and at the Russian University for Friendship of Nations. In addition, the educational environmental computer game LOTOV_LAKE (see Lotov et al, 1992) is based on it. Now, it used in the demo INTERNET resource (Lotov et al., 1996) discussed later.

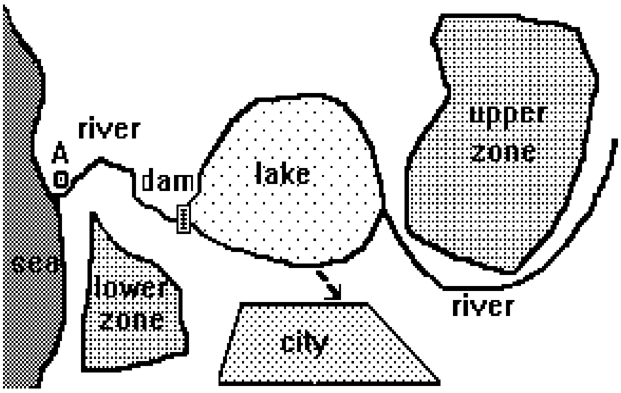


Figure 1.The map of the region

We consider a regional agricultural production system placed in the basin of a river which runs through a lake and then into a sea (see Figure 1). The lake serves as the municipal water supply source. Moreover, the lake is an important ecological and recreational unit. The agricultural (here grain-crops) production in the region has an impact on the environmental situation. It is related to the fact that the application of chemical fertilizers and water for irrigation has increased substantially the grain-crops output, but at the same time, it has resulted in negative environmental consequences:
i) part of the chemical fertilizers is finding its way into the river with the withdrawal of water,
ii) a shortage of water in the lake arises during the dry season because of the irrigation.

Two agricultural zones exist in the region. In the upper zone, the irrigation and the fertilizer application results directly in a drop of the water level in the lake and in the increment of pollution concentration in its water. The irrigation and the fertilizer application in the lower zone (which is lower than the lake) also have an influence on the lake, but in an indirect form. There is a monitoring point near the mouth of the river where restrictions on the water flow and pollution concentration are imposed. For that reason, the irrigation and the fertilizers application in the lower zone may result in the additional water flow from the lake into the river (which is regulated by the dam) to fulfil the requirements of the pollution control.

A finite number of technologies of grain-crops production are considered. Intensive technologies are related to high levels of water consumption and of fertilizers application. Several technologies are related to low water consumption and fertilizers application, but the production is low. Moderate technologies which use moderate amounts of water and fertilizers and produce moderate grain-crops output exist as well. The ER of the lake requires implementation of balanced strategies of agricultural production and of water release through the dam.

Several economic and environmental indicators represent different interests in the problem: farmers are mainly interested in the grain-crops production while recreational business is mainly interested in the level of the lake, and the inhabitants of the city who are drinking the water from the lake are mainly interested in water quality. Let us consider three performance indicators (choice criteria):

- income of farmers from the agricultural production,
- profit of recreational business,
- additional sickness rate due to polluted water.

The interests of social groups considered here are clear: to improve the value of the indicator which reflects their own interests. The FGM/IDM technique provides the following supportof negotiations between these social groups.

Let us consider only two first indicators. In this case, all possible (feasible) combinations of the income of the farmers and of the profit of the recreational business may be displayed on computer monitor. In Figure 2 where the values of the income are given on the horizontal axes and the values of the profit are given on the vertical axes, the feasible combination of values of two indicators are displayed in a form of a black spot. If somebody would identify one of the feasible points (for example, the point Q), computer will be able to calculate a feasible strategy of regional agricultural production and water release which will result in the identified point. In contrast, if the point R would be chosen, no feasible strategy resulting in it will exist. Therefore, the set of the combinations of the indicators values displayed in Figure 2 may be denoted as the set of the feasible goals. For this reason, the method based on its display is named as the Feasible Goals Method. Usually, the set of the feasible goals set isn't displayed in the framework of various procedures based on the goal approach (Charnes and Cooper, 1961, Steuer, 1986). This results in a sophisticated question: what strategy should be constructed if the chosen goal (say, the point R) isn't feasible. The FGM doesn't meet problems of this kind since only feasible goals are supposed to be chosen.

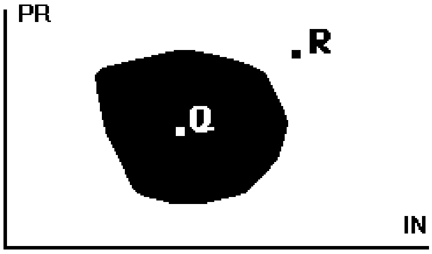


Figure 2. The feasible combination (Q) and the non-feasible combination (R) of income and profit

Before we consider the case of three and more indicators, let us discuss several features of the set displayed in Figure 2. In Figure 3, in addition to the point Q, we consider another feasible point N. It is clear that N is better than Q since both indicators, income and profit, do increase when we choose N instead of Q. Usually one says that N dominates Q. In contrast, it is clear from the Figure 3 that there is no other feasible goal which dominates N. Feasible goals of this kind are denoted as non-dominated. Reasonable strategies are related to non-dominated goals. Therefore, if negotiators want to find a reasonable strategy, they have to identify a non-dominated goal. It is important that all non-dominated goals are displayed in Figure 3: they form the "north-eastern" non-dominated frontier of the set of the feasible goals (known as efficiency frontier).

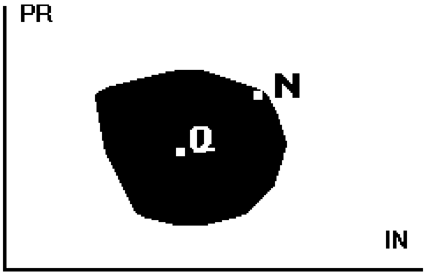


Figure 3. The dominated (Q) and the non-dominated (N) combinations of income and profit

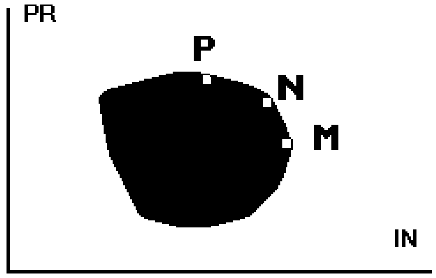


Figure 4. Points of the efficiency frontier

The efficiency frontier of the set of the feasible goals shows potentialities of choice. Moreover, it displays the tradeoff among the indicators. Indeed, let us consider two additional non-dominated goals (P and M) in Figure 4. In the vicinity of the point P, if we move along the efficiency frontier, a miserable decrement of the profit of businessmen needed for a substantial increment of the income of farmers. Vice versa, in the vicinity of the point M, a miserable decrement of the income of farmers results in the substantial increment of the profit of businessmen. In the vicinity of the point M, to receive a substantial growth of one of the indicators, a substantial decrement of another one is needed. So, the efficiency frontier shows how income of farmers is transformed into profit of businessmen for non-dominated goals: it displays the tradeoff curve among them. For this reason, this frontier may be helpful during negotiations on the constructing a reasonable strategy. The idea to display the tradeoff curve among two criteria was introduced by Gass and Saaty (1955). In the framework of the FGM, tradeoffs for more than two performance indicators is displayed. It may be based on the concept of the Interactive Decision Maps. To introduce them, we start with the idea of the Edgeworth-Pareto Hull.

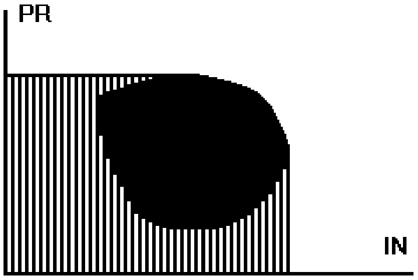


Figure 5. The Edgeworth-Pareto Hull of the feasible goals set

Since one is interested in the efficiency frontier mainly, we may simplify the picture by using broader sets with the same efficiency frontier. In Figure 5, the original and a broader sets are depicted. Note that they have the same efficiency frontier. The broader set depicted here is named the Edgeworth-Pareto Hull (EPH) of the set of the feasible goals. Actually, in the case of two indicators, it plays minor role whether the original set of the feasible goals or its EPH will be depicted, but in the case of larger number of them it is very important.

Let us consider the case of three indicators, i.e. the sickness rate is considered as well. In this case, we may superimpose several two-indicators EPH related to different restrictions on the value of the third indicator (see Figure 6). Note that the frontiers of the slices don't intersect (though they may coincide sometimes). For this reason, slices may be loosely placed in the same picture without interfering each other. This makes them especially convenient for negotiators. If frontiers of different slices coincide, this could mean (like in a usual geographical map) that there is a steep, i.e. the substantial increment of the third indicator doesn't move the efficiency frontier.

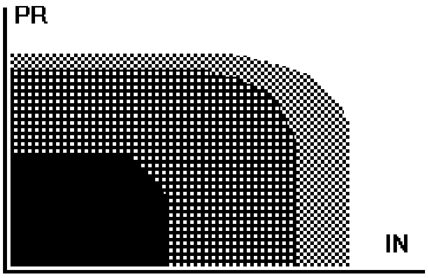


Figure 6. The decision map

To a certain extent, our technique reminds the usual decision maps, i.e. the multiple criteria technique which was developed for the case of three choice criteria: several cross-sections of the non-dominated frontier of the feasible goals set are depicted. They are defined by several fixed values of the third criterion. Examples of real-life application of decision maps are provided in (Louie et al., 1984, p.53, Figure 7, or Jewel, 1986, p.464, Figure 13.10).

To display a decision map, we use a different concept: we construct the EPH for three and more indicators in advance and then superimpose their two-dimensional slices. Constructing the EPH and the display of it in the form of collections of two-dimensional slices (like in Figure 6) provides an opportunity to implement the concept of the decision maps practically: collections of efficiency frontiers of slices comprise a picture in many features resembling a decision map. Therefore, we'll make no difference between the traditional decision maps and the decision maps provided in the form two-dimensional slices of the EPH.

The IDM technique is related to the constructing of the EPH for more than two indicators and to further interactive display of it in the form of decision maps. So, we don't construct a particular decision map in advance, but, in contrast, we give an opportunity to construct different maps on request. In the case of three indicators, one may choose for the third indicator any of the three indicators, or may change the number of the efficiency frontiers, or can zoom a map (an example is given in the section 5).

The opportunities of the IDM are especially important in the case of four and more indicators (see Figures 7-9). In the case of four indicators, we may display several decision maps in a row. For any decision map, the fourth indicator isn't worse than a certain value which can be chosen automatically or by the researcher. The values of this kind may be changed easily. Moreover, any indicator can be easily chosen to be the fourth one. Animation of a decision map related to the monotonic increment (or decrement) of the value of the fourth indicator may be provided as well. In the case of five indicators, a matrix of decision maps may be displayed. For any decision map, the fourth and of the fifth indicators aren't worse than certain given values. The maximal number of rows and columns in the matrix of decision maps depends on display quality.

Let us stress once again that a matrix of decision maps can be displayed very fast. An updated matrix of decision maps is displayed in a few seconds after the values of the fourth and the fifth indicators have been changed. Moreover, it is possible to change the list of three indicators which tradeoffs are displayed in decision maps. The updated matrix will be displayed in a few seconds as well. Note that on display, the decision maps is depicted in a coloful form.

Another opportunity in the case of four and five indicators is based on the application of scroll-bars which are so common in modern software. In this case we display only one decision map, but it is changed in correspondence to the positions of the sliders identifying the values of the fourth and the fifth indicators. Though the combination of scroll-bars and matrices of decision maps can be used for display of the EPH for any reasonable number of indicators, we usually restrict the number of indicators by seven. In opposite case, it is too complicated to assess the situation.

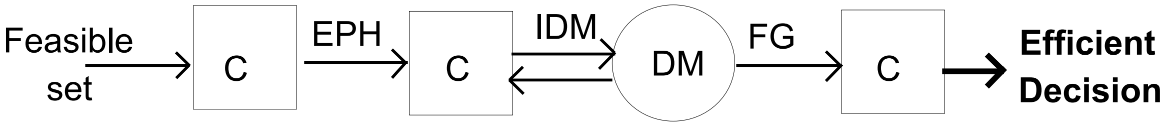
After the exploration of the IDM, decision makers or negotiators may identify a preferable non-dominated goal. A feasible strategy is computed after a short time and may be displayed in any convenient form. Say, the spatial strategies may be displayed in a GIS. Moreover, any forms of multimedia and virtual reality may be used to display the strategy found in this way.

Let us summarize the main steps of the FGM/IDM approach to constructing the reasonable strategies in the case when a mathematical model and the set of feasible strategies are given in advance. These steps are the following:

1) constructing the EPH of the feasible set in the indicators space, i.e. the set which contains along with the feasible set all dominated combinations of indicators values;

2) interactive display of the tradeoff curves among pairs of indicators in the form of decision maps: the tradeoffs are displayed as collections of two-dimensional slices of the EPH; since the EPH constructed in advance, it is possible to display of decision maps vary fast and to animate them;
3) identification of the preferable non-dominated goal;
4) calculation and display of the feasible strategy which should lead to the chosen goal.

The steps of the Feasible Goal Method are given in Scheme 1. Computer processing is denoted by **C** and the decision makers activity is denoted by **DM**.



Scheme 1. The steps of the Feasible Goal Method

We want to stress that we don’t model preferences of user. In contrast, in accordance to the concept of multiple-criteria generating methods (see Cohon and Marks, 1975, and Cohon, 1978) we support a free search among non-dominated criterion values.

The modern psychology states that any person makes his/her decisions on the basis of a mental model of reality (see, for example, Lomov, 1984). The mental models are usually comprised of several levels. The upper, rational (logical) level which is based on logical inference. The second one includes images which (in contrast to the upper level) aren't totally logical. The third level contains the vague subconscious relations. It is important that the imaginary and subconscious elements of the decision process are usually camouflaged by the logical inference which is used to justify a decision after it has been made. This is the reason why it is so difficult to involve real decision makers or negotiators into logical procedures like preference acquisition, etc.

The mental models are often not only rough, but not true in many aspects. Therefore, one of the purposes of the decision and negotiation support may consist in the correcting the mental models. This may turn to be efficient form of the computer-based decision support. Modification of images and subconscious relations may be based on the information procedures in which user explores the decision situation. If the information is given in a colorful graphical form, it may help the user to assimilate the information not only consciously but on subconscious levels, too. In the context of the FGM/IDM technique, one obtains information about potentialities of choice and tradeoffs among interests in an explicit graphic form which may influence all levels, i.e. logical, imaginary and subconscious levels of his/her mental image. The FGM/IDM technique which does not force anyone to choose decisions immediately helps to improve the negotiation outcomes through the improvement of the mental models, i.e. through better understanding of the situation.

In the case of decision making problems with a single decision maker, the performance indicators correspond to his/her choice criteria which represent his/her interests. In this case, we inform him/her about the tradeoffs among criteria and help by this to find a reasonable balance of the criterion values without trying to model his/her preferences. In the case of group decision making or negotiations, the problem is more complicated, and there exist several approaches to utilization of the FGM/IDM technique in this field. Let us discuss how the FGM/IDM technique may be used in the framework of the concept of Principled Negotiations.

2. Principled Negotiations on Environmental Rehabilitation

The concept of Principled Negotiations (PN) is based on a group of ideas. In short, these ideas can be described as follows. First of all, objective merits of the problem itself should be separated from egos and personalities of those involved in the negotiations. Secondly, it is important to focus on interests, i.e. multiple objectives and their values, rather than on particular positions such as being for or against a particular strategy. Thirdly, a variety of possibilities, i.e. different strategies, should be generated; this should help to search for mutual gains with respect to all recognized interests. Finally, all parties should first decide on the basis for deciding what will be the fair agreement (see Loucks and Somlyody, 1988).

The ER problems discussed in this paper have one important feature which differs them from negotiations on, say, pure political issues: at least in principle, a mathematical model describing the features of the situation and shared by all negotiators (see Loucks et al., 1996) can be developed. This means that the first idea of the PN in the field of the ER may be implemented on the basis of the application of the scientific knowledge. Surely, constructing a model related to an complicated ER problem isn't a simple task. Moreover, different variants of a mathematical model can be related to different interests of negotiators. Nevertheless, an scientific basis exists in any case.

It is clear that recognized interests aren’t usually related to details of strategies. In contrast, there exist several performance indicators which describe the strategies an aggregated form and which are directly related to the interests. For example, in the problem discussed in the previous section, the relation between the interests and the performance indicators was quite clear. In different situations, this relation may be more complicated. The performance indicators constitute a special group of variables of the mathematical model.

In addition to the list of the performance indicators, a mathematical model describing an ER problem should include decision variables representing feasible strategies (possible positions of negotiators). Auxiliary variables which describe relations among the performance indicators and decision variables usually exist in the model, too. The description of the set of feasible strategies should be given.

In the position-oriented approach to the negotiations, one could suggest a position (feasible strategy) and make use of the model for calculating the criterion values. To accomplish the concept of the PN, we propose to apply the FGM/IDM technique for the exploration of the mathematical model. This provides an opportunity to focus on the performance indicators and to avoid discussion of positions (strategies). Actually, the set of the feasible strategies is transformed (using the mathematical model) into the set of feasible values of the performance indicators(to be precise, into its EPH), and then the tradeoff curves among indicators are displayed. It is important that the strategies are hidden, and so they don't obscure relations among the indicators (the second feature of the PN is involved). Negotiators receive information about potentialities of choice and about dependencies among indicators in a clear form. They may translate these dependencies into dependencies between interests on the basis of their subjective mental models. It is important that myriad of possible outcomes are displayed in this way. This display provides an opportunity of search for mutual gains with respect to all interests represented by the performance indicators. This means that the third feature of the PN is involved as well.

Now let us discuss the problem of the recognized interests. In any problem, interests of two kinds do exist: personal interests of those involved in the negotiations and the recognized interests related to the goals of parties they represent. Since the recognized interests only are supposed to be based on the performance indicators described in the model, the first feature of the PN is hopefully accomplished by this, too.

Negotiators may identify various non-dominated feasible goals in terms of indicators. Then, computer provides efficient strategies which outcomes coincide with the chosen goals. By this negotiators return to the positions, but now the positions reflect their knowledge about interdependence of performance indicators and (to certain extent) of the recognized interests. If the strategies received in this way, aren't satisfactory since several important features haven't been included into the model, it is possible to change the model, to construct the EPH once again and repeat its exploration. One of strategies may turn to be acceptable for all of the negotiators

Another approach to supporting the negotiations is based on generation of a sequence of strategies which may be approved by the negotiators (see Thiessen and Loucks, 1992). The FMG/IDM method may be applied in procedures of this kind by mediators developing such strategies. This application may consist in modeling of subjective preferences (in addition to the model of the situation), in constructing the tradeoff curves among interests and in identifying a preferable feasible goals in interests space. Discussion of procedures of this kind is beyond the scope of this paper.

Let's return to exploration of the tradeoffs among the performance indicators. It is important to mention that if the method will be used by one of the negotiators this would provide him/her with additional advantages in negotiations. Indeed, he/she will be able to explore tradeoffs, to identify reasonable non-dominated goals and to receive related strategies. This may help him/her to construct strategies which are advantageous to him/her and acceptable for the partners. Moreover, the negotiator will receive an opportunity to argue reasonably in negotiation process, convincing the partners to accept the strategy suggested by him or her.

3. Integrated Models in the ER Problems

As it was mentioned in the introduction, implementation of the PN concept in a particular ER problem should be based on the exploration of a simplified integrated model of the system. Original mathematical models describing the subsystems of the ER problem (for example, economy, pollution transport, ecology, etc.) usually are diverse and are elaborated by specialists in a lot of fields. Every field has its own mathematical language, and so it is quite complicated to combine or coordinate them at once. Therefore, simplification and integration of models are needed. Sometimes, expert judgements and empirical data have to be included, too. The methods for constructing the simplified integrated models are outlined in short in this section.

A simplified model may be obtained by approximating the input-output dependencies of original models of the subsystems (so called parameterization of models). To give an idea of it, let us start with a simple stationary linear model of pollution transport. Let several sources of pollution with fixed discharges per unit of time be given. Let us suppose that a linear model in partial derivatives can be applied for calculating the pollutant concentration at any place of the region under consideration. If the problem is formulated correctly, this problem can be solved and a single variant of distribution of the pollutant concentration can be found. If the discharges aren't given in advance, it is possible to apply the method of the point sources which follows. First, one has to construct the source functions which describe the concentrations resulting from the individual sources in the case of unit discharge intensity. Since the model is linear, the concentration at any given point (for example, at a monitoring point) may be calculated by summation of the products of the source functions values on real discharges. If we treat a finite number of monitoring points where the pollutant concentrations are of interest, the concentrations at these points can be calculated by multiplication of the matrix (constructed on the basis of source functions) on the discharge vectors. This matrix is usually denoted as the influence matrix. It is clear that the application of the influence matrices makes the exploration of decision problems related to pollution abatement much more convenient. Constructing the influence coefficients in water management problems is described, say, in (Becker and Yeh, 1972).

In linear case, influence matrices may be calculated precisely, by calculating the values of the source functions. In non-linear case, the influence matrices may provide an approximate dependencies of pollution concentrations points on the discharges. Constructing the influence matrices depends upon the particular scientific field. The universal approach consists in application of the regression analysis of data on input-output dependencies obtained in simulation with a non-linear model. Along with the approximation of the influence matrix, simulation provides applicability ranges for the influence matrix. Surely, analytical methods may sometimes help to construct the influence matrix and to evaluate its applicability range.

Often it is impossible to construct an unique influence matrix which applicability range covers all possible inputs. In this case, several influence matrices may be developed. Any influence matrix will be related to a certain applicability range, and all of them will cover all possible inputs.

If an adequate mathematical model of a subsystem doesn't exists, an influence matrix may be constructed on the basis of regression analysis of experimental or historical data of input-output dependencies. As an example, one can mention the input-output matrices for national economies. Sometimes, experts can provide influence matrices and their applicability ranges.

Note that in the ER topics, one can identify a special applicability range in which the disturbances of the environmental system are reversible. This means that the existence of an environmental system in this "environmentally stable" range corresponds to the qualitatively satisfactory state of the system. Moreover, the "environmentally stable" range may related to an opportunity of further complete rehabilitation (returning to a "natural" state of it) which may be provided in the future (our preferences and opportunities may develop in time). In this range, the environmental system may be described by linear models in the form of the influence matrices. If the frontiers of the applicability range of this kind will be violated, the existence of the system in the same form may happen to be impossible.

Combining influence matrices and other simplified descriptions, we receive an integrated model describing an ER problem. Sometimes, the concept of integrated simplified models is criticized since they aren't so precise as adequate models are. This disadvantage isn't so important since the integrated models are used on the first stage of the process of the development of reasonable strategies when the mental models of negotiators are influenced and improved. In this situation, the rough description given by a simplified integrated model is appropriate for identification of a feasible goal. Moreover, it is supposed that any strategy calculated on the basis of a simplified model will be checked and improved later on the basis of simulation with the adequate models of the subsystems. So, integrated models and the FGM/IDM technique are actually used for screening of a large (or infinite number) of feasible strategies. The idea to use simplified screening models was introduced by Dorfman (1965). Its application in water management problems are described, for example, in Jacoby and Loucks (1972), Cohon and Marks (1973), Loucks, Stedinger, and Haith (1981), Moiseev (1982), Loui, Yeh, and Hsu (1984). The FGM/IDM technique provides new opportunities of screening.

The summary of the methodology of integrated assessment of the ER problems is given in the next section.

4. Methodology of Negotiation Support in the ER problems

We suppose herein that the concept of the ER means that the strategies should be restricted to an "environmentally stable" range of the system. The stages are as follows.

1. Qualitative analysis of the problem is provided by experts. They develop a list of subsystems which will be considered in the framework of the study as well as the list of the recognized interests which will be taken into account.
2. The experience of the study of the subsystems (including mathematical modeling of them) and of their interaction is collected. Researchers develop the list of variables which will describe the interaction among the subsystems and list of performance indicators which will provide the basis for the recognized interests.
3. The ranges of possible variations of the variables are identified.
4. Mathematical models of the subsystems are developed (or adapted) and calibrated, or experimental and historical data are collected. May be, experts are found.
5. Influence matrices and other simplified descriptions of subsystems are developed and the applicability ranges are evaluated. If the applicability range of a single influence matrix of a sub-model doesn't contain the ranges of its input variables, the variable ranges may be squeezed. Several influence matrices which applicability ranges cover the ranges of input variable may be developed as well. The integrated model is constructed by the unification of the influence matrices along with their applicability ranges and input variable ranges for all subsystems.
6. Feasible set of strategies is formulated.
7. The EPH in the space of the performance indicators is constructed. This means that the integrated model is supposed to be studied by means of the FGM/IDM technique.
8. The negotiators start their exploration of the IDM independently or in a group (contacts among negotiators aren't controlled). They explore potentialities of choice and tradeoffs among indicators. Negotiators are supposed to identify one or several non-dominated feasible goals. By this, screening of the feasible strategies is performed.
9. The constructed efficient strategies are displayed to negotiators using various multimedia, virtual reality and other appropriate computer technologies. Geographical Information Systems may play especially important role in display in the case of spatial strategies.
10. One or several coordinated strategies are selected by negotiators. They provide a starting point for the detailed development of plans for the ER of a system under consideration. The development of plans, in contrast to the previous stages, is supposed to be based on adequate models and on simulation experiments.

The scheme provided here is a simplified one. In real life, various loops of the process are possible. For example, if a developed strategy isn’t satisfactory since it violates constraints which haven’t been included into the model in advance, these constraints may be imposed, and so the set of feasible strategies is changed. After it, the process turns to the sixth stage. If the exploration of a strategy has proved that the simplified (or even original) model of a subsystem isn’t precise enough, it is necessarily to return to the second stage and to continue the research related to the development of the subsystem’s model. Note that the research fulfilled at the fourth and fifth stages may be provided by several groups of specialists independently.

In economic studies, the experience of application of the methodology described here is related to negotiations on identifying the long-time national goals in the fields of social and economic development (Lotov, 1984) as well as to negotiations concerning strategies of economic reform in Russia (Kamenev and Kondratiev, 1992). In the ER topics, demonstration versions of the computer-based support of negotiations on the regional strategies of the ground water management (Kamenev et al., 1986), on international strategies of the atmosphere pollution abatement (Bushenkov et al., 1994) and on the development of the response strategies to the global climate change (Lotov, 1994) have been constructed. Additional details about the above methodology are given in (Lotov, 1994). Practical application of the methodology in the ER problems is related to water quality planning. It is described in the next section.

5. Example: Negotiation Support for Water Quality Planning

In this section, a negotiation support system for planning the water quality in Russian rivers is outlined in short. The system has been developed on request of the Russia's State Institute for Water Management Projects (now Institute for Water Information Research and Planning, Inc.). The detailed description of the system is given in (Lotov et al., 1997a).

The problems of water pollution abatement in Russia's rivers are aggravated now by the difficult economic situation in the country. Therefore, the need for the efficient application of the environmental investment is very high. Moreover, to obtain a moderate investment, environmental engineers need to prove to the federal and regional authorities as well as to the owners and management of industrial enterprises that the investment will result in a substantial improvement of the environment. In the problem under consideration, the recommendations must be made regarding to the wastewater treatment in the industries and the municipalities along a river.

Earlier, environmental engineers have applied optimization procedures to obtain plans related to the minimal cost that met medical and ecological requirements. Calculation of the optimal plan was fulfilled on the basis of a mathematical model of pollution transport and wastewater treatment. Often it was impossible to find a feasible plan which met the requirements, and so environmental engineers had to change these requirements somehow. Moreover, in the cases when plans have been found, they were of too expensive to be fulfilled during 80s and certainly they have nothing to do with the real life now. Therefore, environmental engineers had to "improve" the optimal plans by the deleting of several investment decisions from the plan in accordance to their experience. This has resulted in inefficient strategies which have been sharply criticized.

This is why a new decision support technology of water quality planning has been elaborated. The new technology was developed as an example of the new methodology for planning and negotiation support in the ER problems. In the framework of the decision support, the measures devoted to the water quality improvement are split into two phases:

i) implementation of a reasonable balance among cost and pollution which is found by screening of myriad of feasible plans;

ii) final resolution of water quality problem.

A support for the first phase was developed. Performance indicators have been used as the criteria for constructing the reasonable strategies and for negotiating on them. Along with the cost criterion, several water quality criteria were incorporated into the analysis. In accordance to the above methodology, the FGM/IDM technique is used for display of the tradeoff curves among cost and pollution criteria. After exploring various decision maps, engineers identify several reasonable feasible goals and receive related strategies of investment. These strategies are displayed in a graphical and table forms as well as in a specially developed GIS.

A river under consideration is supposed to be split into a finite number of reaches. At the downstream end of any reach, monitoring stations observe pollutants concentrations. The production enterprises are grouped into industries which include the enterprises with analogous production technology and pollutants output structure. Municipal services are grouped in the same way. Usually about 20 types of industries and services are considered. Moreover, the production enterprises and municipal services are grouped in accordance to the reach they belong. The problem is reduced to planning of investment for constructing the wastewater treatment facilities. The investment (not given in advance) should be allocated among production industries and municipal services in reaches of the river.

The integrated model used in the planning support system consists of two parts:

- a linear pollution transport model providing an opportunity to calculate concentrations of pollutants at monitoring stations for a given discharge;
- models of wastewater treatment; any model relates the decrement of pollutants emission to the cost of wastewater treatment in a industry or a service.

The pollution transport model used now is based on evidence and expert judgement, but it is planned to substitute it with a parameterization of a comprehensive pollution transport simulation model. Models of wastewater treatment are collections of wastewater treatment technologies. Decision variables characterize wastewater treatment. A decision variable describes the fraction of wastewater, which should be treated by a technology in an industry or a service in a given reach.

Water quality criteria are based on pollution indicators. Since more than twenty pollutants are considered in the software, environmental engineers use grouping of the pollutants to obtain aggregated environmental criteria. An indicator for a pollutants group is based on relative pollutants concentrations. The latter is defined as the ratio of the actual concentration to so called maximum admissible concentration which represents a priori medical and ecological requirements. The pollution indicator for a group equals to the sum of relative pollutant concentrations for the pollutants included into the group. It is clear that it is reasonable to decrease the values of pollution indicators. For each pollutant group the maximal (i.e., the worse) value of a water quality indicator among monitoring stations is used for the environmental criterion. The desirable value of such criterion is one. It is important to stress that the model used now provides only one example of possible models.

In Figure 7, a decision map obtained by environmental engineers on computer display is given. The tradeoff among two pollution criteria (general pollution indicator and fishing degradation indicator) for several values of cost are displayed. Since we aren't able to present here the copy of the colored screen, the black and white copy of it is given. Surely, it provides only the idea of the picture on a color display: instead of the colored slices, only the frontiers of them are depicted. Instead of relation between the cost and the color, we provide the cost values written near corresponding frontiers by hand.

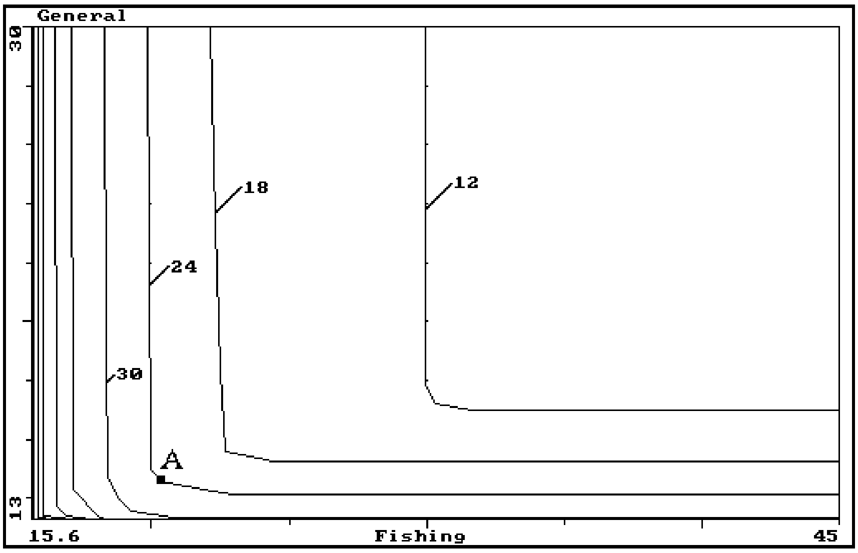


Figure 7. A decision map for water quality planning

The IDM technique provides the opportunity to zoom a part of the picture (see Figure 8).

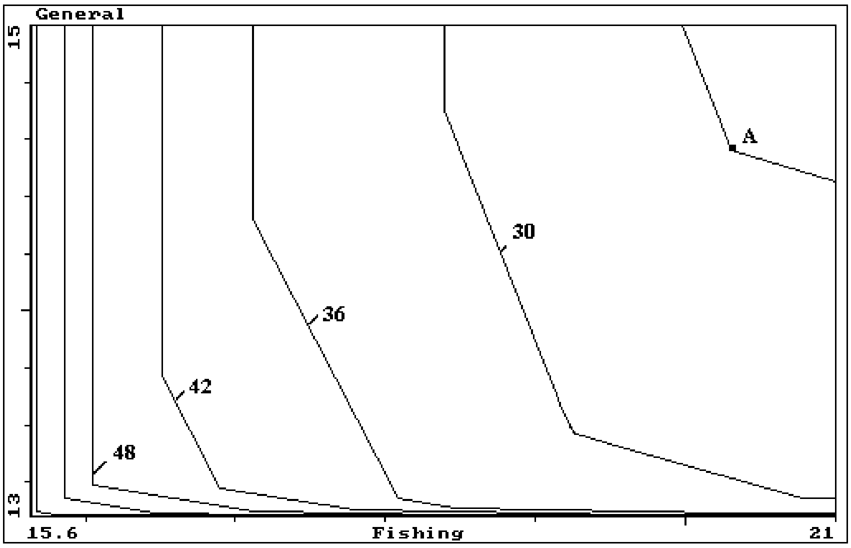


Figure 8. A zoomed part of the decision map

Let's explore one of the frontiers marked with the point **A**. The form of it shows how much the drop of the fishing indicator is related to the increment of the general one. The non-dominated frontier gives full information on the tradeoff among these two criteria for a given cost. Changing one image for another, one can see how the increment of the cost results in the expansion of the slice (i.e. in the reduction of both pollution indicators).

In the case of five criteria (for example, sanitarian and toxicological indicators are added), environmental engineers can draw a decision map (analogous to one given in Figure 7) for given constraints imposed on the values of the fourth and of the fifth criteria. Moreover, a matrix of decision maps may be constructed (see Figure 9). Any decision map of the natrix corresponds to certain values of constraints imposed on the fourth and the fifth criteria. These values of the fourth criterion may be chosen by the researcher or automatically.

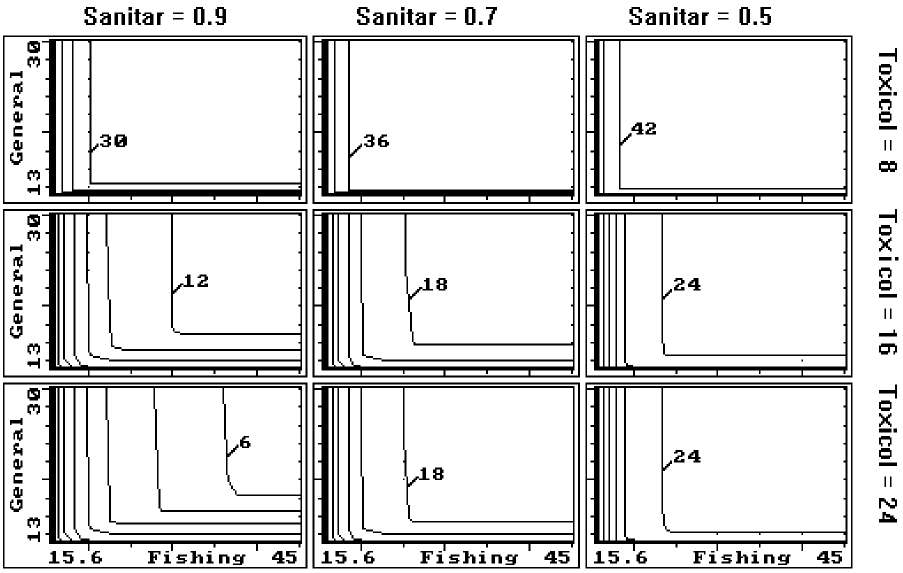


Figure 9. A matrix of the decision maps

Comparing the decision maps for properly chosen values of constraints, environmental engineers understand influence of the fourth and the fifth criteria on the tradeoff among the first three criteria. The number of the decision maps in a row or in a column depends on quality of monitor. Moreover, the software provides an opportunity of animation of the decision maps.

Let us return to the planning support system. It consists of five main subsystems:

- Data preparation subsystem
- Subsystem for constructing the EPH
- Subsystem for exploration of the EPH and identification of non-dominated goals
- Subsystem for computing of strategies
- Subsystem for display of strategies

On the first stage, environmental engineers have to prepare information about water balance and initial pollutant concentrations, parameters of pollution transport matrices, parameters of possible wastewater treatment facilities, etc. The subsystem provides a simple data compatibility test and converts the initial files into the internal form of the software.

Constructing the EPH is performed by the second subsystem automatically. At the start of the EPH exploration, the software automatically chooses two axes criteria (for which tradeoffs will be depicted) and one criterion related to color. Moreover, it chooses initial values of the row and column criteria as well. The choice is based on a simple logic. Environmental engineers may change current axes and color criteria for other ones. Values of the fourth and the fifth criteria may be changed and ranges of criteria can be modified. This can be done by simple operations.

After the exploration of the EPH, environmental engineers identify one or several feasible goals. First they choose one of the pictures. By this the values of row and column criteria are fixed. After exploration of the chosen decision map (for example, given in Figures 7 and 8), environmental engineers identify preferable combinations of water quality indicators and of the cost. In Figures 7 and 8, one of the identified goals is marked by **A**. Afterwards, the plans of wastewater treatment resulting in the identified feasible goals are calculated automatically by computer in the fourth subsystem. Computing the wastewater treatment strategy (i.e. technologies for every industry or service) related to a goal takes usually a few minutes.

The fifth subsystem displays the strategy in the form of column diagrams describing cost allocation as well as the pollution concentrations in monitoring stations. To be precise, icons are placed on the map of a river basin and the diagrams are drawn if the corresponding icon is clicked. Moreover, reference information related to the problem may be requested in the same manner. Actually, the subsystem for the strategy display is a specialized GIS. Furthermore, the subsystem helps to prepare the decision in the form of usual tables traditionally used by environmental engineers.

A structured negotiation procedure among the real decision makers proved to be impossible. For this reason, environmental engineers had to construct several variants of the project which they provide to decision makers. Decision makers take this information into account. Hopefully, this improves their understanding of the situation. Therefore, environmental engineers play the role of experts screening the whole set of feasible decisions and identifying several most interesting strategies. The FGM/IDM technique gives an opportunity to do it on the basis of the information on potentialities of choice and tradeoff curves.

The system was implemented for the development of water quality improvement projects for several rivers. In particular, the project for a small river in Moscow Region, named Nara river, was developed. The tradeoff curves in Figures 7, 8 and 9 correspond to the case of this river. One can easily realize that the river is heavily polluted. In the framework of the old optimization procedure, environmental engineers failed to develop a feasible plan, since the medical and ecological requirements can't be met in this case. The software helped to solve this problem, too.

Strategies developed by environmental engineers with the help of the planning support system provide the starting point for negotiations among real decision makers: to the federal and regional authorities as well as to the owners and management of industrial enterprises. Application of the FGM/IDM technique helps environmental engineers to defend the proposed plan of environmental investment.

6. Concept of INTERNET-resource for ER problems

The screening of reasonable strategies resolving the ER conflicts constitutes a part of the problem only. Another part of it is related to informing the general opinion on the conflict and on the merits of the strategy which is the result of the negotiation process. Indeed, the ER of water resources is usually related to the interests of many thousands (or even millions) of peoples, and they have right to know why the this or that strategy was chosen. To inform the general public about it, we propose to apply the concept of an INTERNET resource which provides an opportunity to develop an independent efficient strategy.

Usually under informing of general public, one understands general access to information. Since ordinary peoples aren't specialists in the fields related to the ER problems, they need, like the negotiators, an integrated assessment of a problem. We propose to do it on the basis of the methodology described above. In particular, we propose to provide an opportunity for any interested person to develop an independent strategy using the FGM/IDM technique.

After the information has been collected, the models have been constructed, the software of the FGM/IDM technique adapted to the models (actually, the same job is needed as in the case of preparation of the negotiation support), any person may use the developed system to explore potentialities of choice and the tradeoffs among interests in the decision maps. It is especially important that he/she may choose a non-dominated goal independently, without any influence of politicians. As the result, he/she may receive a strategy which will reflect his/her preferences. Surely, to display the developed strategy, he/she may use the same modern computer technologies prepared for negotiators, i.e. multimedia, virtual reality, GIS, etc. Presumably, generating an independent strategy will help him/her to understand the merits of the strategy elaborated during the negotiation process. Moreover, generating independent strategies may help the general opinion to evaluate the behaviour of politicians in negotiations and to understand whether politicians are haunting recognized interests or their own goals. Presumably this will make negotiators to strive for strategies which reflect interest they promised to represent.

We want to stress that the application of the FGM/IDM technique in the framework of INTERNET for the development of an ER strategy makes a person independent from the judgements of the government, of the press or of anybody else. Moreover, it may be considered as a new form of active mass media. In contrast to usual mass media, the active mass media gives an opportunity of active interaction with the information source. Instead of reading or listening to the comments on the strategy proposed by somebody else, one may develop his/her own proposal and submit it to anyone by INTERNET. This may provide a totally new situation in discussions on the ER and other topics in the information society of the next century. Prototype version of the INTERNET resource of this kind has been established on Web pages (see Lotov et al, 1996).

Appendix. Mathematical introduction of the FGM/IDM technique

General mathematical formulation of the FGM/IDM is as follows. Let the decision variable x be an element of the decision space W. Let the set of feasible values of decision variables be $X \subset W$. Let the criterion vector y be an element of the linear finite-dimensional space R^m. It is supposed that the criterion vectors are related to decisions by a given mapping

$$f : W \to R^m .$$

Then, the feasible set in criterion space (FSCS) is defined as the variety of criterion vectors attainable by feasible decisions

$$Y = \left\{ y \in R^m : y = f(x),\, x \in X \right\}.$$

Let us suppose that negotiators are interested in the increment of the criterion values. Then, the non-dominated frontier of the FSCS is defined as

$$P(Y) = \left\{ y \in Y : \left\{ y' \in Y : y' \geq y,\, y' \neq y \right\} = \varnothing \right\}.$$

To provide collections of the efficiency frontiers among two criteria for given restrictions imposed on the value of other criteria (decision maps), instead of the FSCS, we construct the set

$$Y_p = Y + R_+^m$$

where R_+^m is the non-negative cone of R^m. Note that the efficiency frontier of the broadened set remains the same

$$P(Y^*) = P(Y)$$

but the dominated frontiers disappear. In other words, the set Y^* may be defined as

$$Y^* = \left\{ y \in R^m : y \le f(x),\ x \in X \right\}.$$

The method in general consists in approximating the FSCS and related sets (like the EPH) and in further display of them via collections of two-dimensional slices. The IDM technique is based on approximation of the EPH and on interactive display of the collections of tradeoff curves.

In linear case, two groups of methods have been developed for approximating the FSCS and its EPH. The first group of methods is based on constructing the projections of polyhedral sets — the convolution methods (Fourier, 1826). Application of the convolution methods was suggested in (Lotov, 1973) for the FSCS and in (Lotov, 1983) for the EPH. The convolution methods are usually related to an exponential growth of the number of inequalities during the process of constructing the FSCS. This can result in difficulties while applying the convolution methods even when the number of decision variables is rather small. Our experimental and practical calculations show that the efficiency of convolution methods greatly depends on particular coefficients of the model. The algorithms of this kind are reviewed in (Lotov, 1996).

The second group is based on iterative procedures for approximating the convex sets by polytops. These methods have been developed for the systems with a small number of criteria (three to seven) and a large number of decision variables (hundreds or thousands). They are based on the evidence that the FSCS is (in linear case) a convex body given by a procedure of calculation of its support function. To be precise, the support function can be calculated by computer for a finite number of its argument values. The methods of this kind were suggested by in the beginning of 80s (Bushenkov, 1985). The approximation theory was elaborated in (Kamenev, 1992), and the algorithms are described in (Chernykh, 1988) and (Kamenev, 1994).

In the non-convex case, situation is much more complicated. Algorithms for constructing various collections of simple figures (say, cubes or spheres) approximating the FSCS were developed. They are described in the next section.

The full review of the methods used for constructing the FSCS is given in (Bushenkov et al, 1995). The approximation of the EPH is based on approximation of the set Y^* by the sum of the cone ($-R^m_+$) and of a simple set approximating Y (like polytop or a system of cubes). In particular, it was shown that the convex EPH may be approximated by iterative methods as well (Chernykh, 1995).

The EPH is displayed in the form of collections of its two-dimensional slices. Let $I^0 = \{1, 2, \dots, m\}$. Let $I \subset I^0$, $|I| = 2$. Finally, let $I^* = I^0 \setminus I$. Let us denote by $R(I)$ the subspace of criteria with numbers from I. Then, a two-dimensional slice of the set $V \subset R^m$ related to $z \in R(I^*)$ can be defined as

$$G(V, z) = \left\{ u \in R(I) : (u, z) \in V \right\}.$$

It is important to note that in the case of the EPH, i.e. the set Y^*, the slice of it contains the combinations of the values of criteria from I which are feasible if the values of criteria from I^* aren't worse than z.

Since the EPH is constructed in advance, a collection of its two-dimensional slices can be depicted quite fast. Efficient algorithms for constructing the two-dimensional slices of approximating polytops were developed in (Chernykh and Kamenev, 1992). In the framework of the IDM and TON techniques, various collections of tradeoff curves which are the frontiers of the two-dimensional slices of the EPH approximated in advance are displayed.

If the Feasible Goals Method is used, this information helps to identify a preferable non-dominated goal. After an appropriate feasible goal y' is identified, it is regarded as the ''reference point'' (Wierzbicki, 1980), i.e. an efficient decision is obtained by solving the following optimization problem

$$\min_{1\le j\le m}\left(y_j - y'_j\right) + \sum_{j=1}^{m}\left\{\varepsilon_j\left(y_j - y'_j\right)\right\} \Rightarrow \max,$$

while

$$y = f(x), \quad x \in X,$$

where $\varepsilon_1,\ldots,\varepsilon_m$ are small positive parameters.

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