

# Graphic model-based software for supporting the search for efficient environmental strategies: method, real-life applications and future developments

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**Abstract:** Application of a new graphic multi-criterion model-based approach to integrated assessment and screening of environmental strategies is described. The approach is based on integration of mathematical models and visualization of the Pareto-efficient (non-dominated) frontier. In the case of linear integrated models, the visualization is based on application of the Interactive Decision Maps (IDM) technique that visualizes the frontier in the form of multiple animated decision maps provided on-line. Interactive visualization of the Pareto-efficient frontier helps the user to understand potentialities of choice and criterion tradeoffs for 3 to 7 criteria. Moreover, the IDM technique supports identification of a preferred non-dominated feasible goal directly on display and subsequent automatic computation of an associated efficient strategy. In the case of a non-linear integrated model, the model helps to generate a database that describes outputs of a large finite number of decision alternatives (may be, millions of them). Then, the IDM technique is used for visualization of the Pareto-efficient frontier of the convex hull of the criterion points associated with above decision alternatives. Though a goal identified by the user is only reasonable, several selected decision alternatives are in line with user's preferences (Reasonable Goals Method). The approach was applied in several DSS for exploration of environmental decision problems and selecting preferable environmental strategies. In this paper, applications are outlined that are related to water management and global climate change. Future Internet implementation of the approach for supporting the democratic paradigm of environmental decision making is discussed in short.

**Keywords:** environmental decision support; multi-criterion decision support; computer visualization; water management; global climate change.

## 1. INTRODUCTION

This paper is devoted to the new graphic approach to supporting decision making in environmental problems and its application in several decision support systems (DSS). The approach can be used at the early screening phase of the decision process. Screening is aimed at a search for a small number of decision alternatives, which are a subject of further detailed exploration during the phase of final selection of environmental projects. Robert Dorfman [1965] seems to be the first to stress the importance of the screening phase. Since one can not explore the whole lot of possible decision strategies on the basis of detailed sophisticated models, he proposed to use simplified models at this phase. Decision screening in environmental decision problems requires integration of knowledge from a number of disciplines, which provide information about

subsystems of different nature. For this reason, an integrated mathematical model applied in the process of screening must be based on simplified models of subsystems.

Environmental decision making is usually associated with conflicting interests. Even in the case of a single decision maker, conflicting decision criteria like cost, various environmental indicators, etc., must be taken into account. Fairly often such decision making is related to a negotiation process that involves several (or even multiple) decision makers with different interests and goals. Because of this feature, environmental decision making usually results in multiple criterion formalization, which assumes involvement of human beings into the decision process. Preferences of various decision makers (as well as other people involved) are used to settle balance between criteria. To provide a simple computer support for all these people at the screening phase,

we apply visualization of the Pareto-efficient (non-dominated) frontier of the variety of feasible criterion vectors. Such frontier describes limits of what is possible in terms of decision criteria and informs how an improvement of one particular criterion is related to losses in other criteria – the Pareto-efficient frontier describes the criterion tradeoff. The idea to compute and display the frontier for two criteria was introduced by Gass and Saaty [1955] and transformed into a generic approach to environmental decision problems by Cohon [1978]. The Interactive Decision Maps (IDM) technique develops the idea for the case of multiple criteria (three to seven, and even more).

The screening phase can last for months and even years in the case of environmental planning. Due to this, multiple stakeholders, independent institutions and political groups, as well as experts associated with them, make take part in screening activities. For this reason, decision screening must be transparent and simple. In particular, multiple questions concerning decision maker's preferences must be avoided. Visualization of Pareto-efficient frontier provided by the Interactive Decision Maps (IDM) technique satisfies the above requirements. Due to it, the graphic approach to screening of environmental strategies outlined here turned out to be fairly practical and was used in multiple environmental decision problems, from regional to international (see in Lotov et al. [1999], [2001]).

The content of the paper is as follows. Section 2 outlines the approach including the preparation of an integrated model and application of the IDM technique. Three DSS for water quality planning in river basins that are based on the approach are outlined in Section 3. Section 4 describes two different studies related to abatement of the global climate change. Finally, main ideas of Internet-based supporting the democratic paradigm of environmental decision making are outlined in Section 5.

## 2. INTEGRATION AND VISUALIZATION OF ENVIRONMENTAL DECISION MODELS

A universal approach to construct a simplified integrated model of an environmental system can be based on approximation of the input-output dependencies of its subsystem. If a mathematical description of a subsystem exists, a simplified model can be deducted from that description. In an opposite case, expert judgments and empirical data may be used. The most important and well-known example of such simplified models is provided by influence matrices, which are linear descriptions of the relations between input and output. An influence matrix can be constructed precisely in the case of a linear model. In the non-linear case,

an influence matrix usually describes the dependencies only approximately.

Selection of a method for constructing an influence matrix depends upon a scientific field. The universal approach is based on simulation of original models of sub-systems and application of regression analysis of the input-output data. Along with the approximation of the input-output dependencies, simulation provides their applicability ranges. If an adequate mathematical model for a subsystem does not exist, an influence matrix can be constructed through regression analysis of experimental or historical data. Sometimes, experts can provide both an influence matrix and its applicability range. It is important to note that the expert or empirical information can be arranged in some form that differs from the influence matrices. An example of such forms is provided in our paper.

An integrated model of an environmental system is given by a combination of influence matrices, balance equations, other descriptions and various constraints. A simplified integrated model is typically less precise than original models of sub-systems, but this fact is not of great importance as integrated models are used on the screening phase. Such feature can be compensated later, at the phase of a detailed analysis of a small number of decision alternatives.

Now let us introduce the IDM technique that is used for visualization of the Pareto-efficient frontier of the variety of all feasible criterion vectors. To do it, we approximate the Edgeworth-Pareto Hull (EPH) of the feasible criterion set instead of the feasible criterion set. The EPH is more convenient for visualization of the Pareto-efficient frontier since it is the largest variety in criterion that has the same Pareto-efficient frontier, but the dominated frontiers disappear. Description of the algorithms can be found in Lotov et al. [1999] and [2001].

Let us describe application of the IDM technique using an example discussed in the next section. It is related to screening of projects for water quality improvement in a river basin. Let consider three screening criteria:

- maximal (in the river) nitrates concentration;
- maximal (in the river) concentration of oil products; and
- cost of the project.

Concentrations are given in relative units such that one is a desirable value, and cost is given in billions of US\$. Let us start with the case of two criteria – cost ( $F$ ) and nitrates concentration ( $Z5$ ). In Figure 1 the values of for the pollution are given along the vertical axis and the values of cost are given along the horizontal axis.

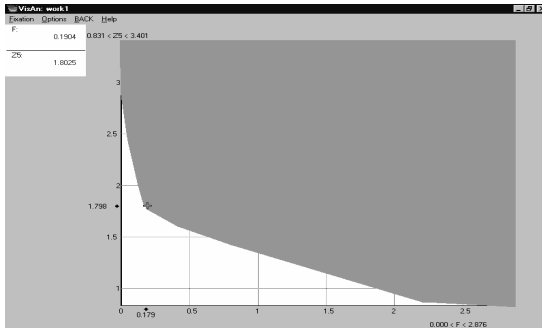


Figure 1. Feasible values of two criteria

The EPH is given by the shaded area, which is colored in computer display. The combinations outside the shaded area are not feasible. Note that the decrement of both criteria is of interest. The frontier of the shaded area (the Pareto-efficient frontier or the efficient criterion tradeoff curve) provides the limits of what is feasible. By comparing two points of the frontier, the user obtains information on the additional payment related to a decrement of pollution. For example, pollutant concentration can be decreased substantially from its maximal value  $Z5 = 3.4$  till  $Z5 = 1.8$  for the cost of only \$190 million (see the cross). So, about one half of the possible pollution decrement is provided only by 7% of the maximal investment. Further cost, however, is not so efficient: the slope of the frontier changes drastically in the vicinity of the cross. One can easily estimate that  $Z5 = 0.85$  can be achieved for not less than \$2.2 billion, and the rest of investment (about \$700 million!) is practically inefficient. This example shows that a simple-minded minimization of the pollution level results in wasting of the money!

Now let us consider three criteria. In this case the user has to explore a decision map (a collection of slices of the EPH). Let us consider the decision map given in Figure 2. Here concentration of oil products  $Z4$  and concentration of nitrates  $Z5$  are given along axes and the values of cost are given by shading (color on display).

Let us consider the minimal (internal) gray slice related to the cost of US\$0.300 billion. The frontier of the slice informs on limits of what is possible for this value of cost. One can see how one concentration can be converted into another. There is a kink on this frontier that displays a reasonable combination of pollutant concentrations for this cost. Other frontiers display information on the results related to higher values of cost. Relation between cost and the shading are given in the palette under the graph. By comparing the frontiers of different slices, the user understands the influence of an increment of cost on feasible concentration of both pollutants and their frontier.

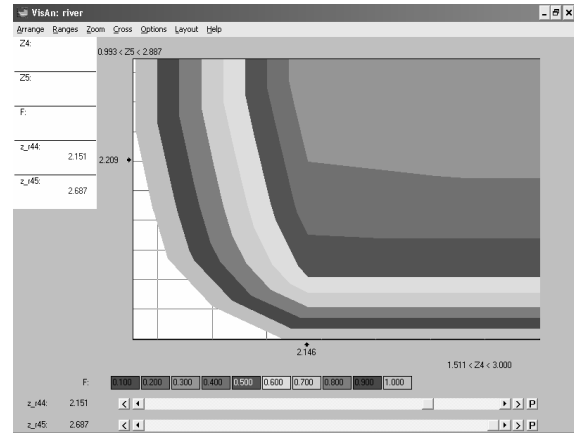


Figure 2. Decision map (black-and-white copy)

Two scroll-bars given under the decision map in Figure 2 provide the values of the fourth and fifth criteria. These criteria describe concentrations of the above pollutants in an important region ( $z\_r44$  and  $z\_r45$ ). By moving the sliders of the scroll bars, the user can change the criterion values. The decision map changes automatically in accordance with the movements. Moreover, animation (automatic movement of a slider) can be used. By this the user can study the influence of the fourth and fifth criteria. Due to scroll-bars, influence of a larger number of criteria can be explored, too. Note that the user can easily receive any decision map and any animation. In addition, matrices of decision maps related to several fixed values of the fourth and the fifth criteria can be displayed. If needed, they can be animated (say, for exploration of the influence of the sixth criterion). Once again, to compute and depict the decision maps on-line, the user has to approximate the EPH first. Since approximating is carried out automatically, the user does not need to trouble about it.

To express his/her preferences, the user has to identify a preferred feasible combination of criterion values (feasible goal) directly on display by a click of the computer mouse. In contrast to the standard goal methods, the goal is feasible now. It means that there exists an investment strategy that results in the identified goal. That is why such method for decision screening is termed as the Feasible Goals Method (FGM). The efficient decision associated with the feasible goal is computed automatically. One can see that the procedure of decision screening is fairly simple. In addition, the decision maps can be used for explanation of the reasons for identification of a particular feasible goal. Due to it, the selection of the goal is transparent.

### 3. WATER-RELATED PLANNING

The above approach was used in a series of DSS developed in 90s on the request of Russian water managers. The DSS supported a search for strategies of water quality improvement in several river basins (see Lotov et al., [1997], [1999] and [2001]). The DSS are based on the integrated models that include three simplified models:

1. a pollution transport model that computes pollutant concentrations for given discharge,
2. a wastewater discharge model that describes pollutant discharge attributed to particular regions, river segments and industries,
3. a wastewater treatment model that relates the decrement of wastewater discharge to cost.

The simplified models of pollution transport are based on influence matrices for particular pollutants. The first DSS [1997] was based on expert estimation of the influence matrices. Two recent DSS [2001] apply the well-known system for modeling of rivers and channels MIKE 11 for constructing the matrices. The pollution transport model of MIKE 11 needs to be calibrated first. Constructing of the matrices is based on its simulation during low-flow period. Influence matrices for particular pollutants relate wastewater discharge to pollutant concentration at monitoring stations. The model of wastewater discharge is based on discharge reports received from the industrial enterprises and municipal authorities. The simplified model of possible discharge treatment installations applies the concept of wastewater purification technologies, which are described by data developed by experts.

Influence matrices, balance equations, discharge and technological data constitute the integrated models. Decision variables of them describe the investment into particular purification technologies in particular regions and industries. The first DSS (Lotov et al., [1997]) is industry-oriented, the second DSS describes regional aspects (Lotov et al., [1999] and [2001]). Due to the fact that the first two DSS apply linear models, the EPH can be approximated without any problem and the IDM technique can be applied. Figure 2 illustrates the second DSS related to regional aspect of strategies screening (the Oka River was studied; the regional concentrations are related to Moscow region).

The third DSS is used to screen environmental strategies in small regions. A finite (but large) number of investment strategies can be studied. Because of it, visualization has a special feature – the Pareto-efficient frontier of the envelope (convex hull) of a finite number of criterion vectors is visualized. So, the convex hull of the EPH, denoted as CEPH, is approximated. It helps

to apply the IDM technique in the case of finite number of alternatives in the following way. A generator of the full list of possible strategies is developed first. Then, the simplified integrated model helps to evaluate the strategies against the screening criteria (and other attributes, if needed). As the result, a table is produced, any row of which is associated to a certain strategy and any column corresponds to an attribute. The strategies can be represented as points (vectors) of the criterion space. Then, the methods developed for the convex sets are used to approximate the CEPH, and the user can apply the IDM technique to explore decision maps as easily as in the linear case. Figure 3 displays the black-and-white copy of the decision map that depicts slices of the CEPH that envelopes about 400 thousands of environmental strategies. Here cost is given in horizontal axes, and concentration of one of the pollutants is given in vertical axes. Concentrations of two other pollutants are given in color and on scroll-bar.

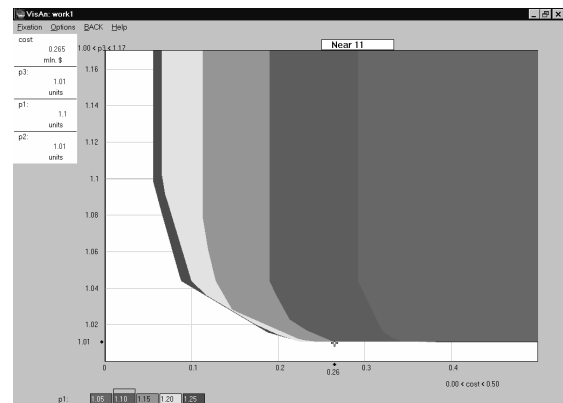


Figure 3. A black-and-white copy of the decision map that describes about 400,000 strategies

One can see that there is no difference between exploration of decision maps in both cases. Moreover, identification of the goal is done in the same way. However, since the Pareto-efficient frontier of the convex hull of points is visualized, the goal is not feasible, but only reasonable now! Therefore, all strategies must be selected that are close to the goal. In Figure 2, eleven strategies turned out to have such feature. All of them must be given to the user for a subsequent selection. This is the main idea of the Reasonable Goal Method (RGM). The DSS that implements the RGM is described in the book by Lotov et al. [2001].

It is important that the DSS described in this section have tools for specification of desired screening criteria. Due to this, different people are able to use the DSS to search for a strategy in accordance to their interests.

#### 4. GLOBAL CLIMATE CHANGE

In this section two IDM-based tools are described. They support the process of searching for efficient strategies related to global climate change. The first one is related to strategies for national energy sector, and the second one – to global strategies.

Methods for supporting a search for a national strategy of development of the power generation system are exemplified by the Israeli case study (see Soloveitchik et al. [2002]). Experts used an optimization model to construct a collection of scenarios of electricity sector development for the years 2003 – 2013. Cost and reduction of emission of greenhouse gases were taken into account in both the objective function and the constraints. The collection of scenarios was studied using the RGM/IDM technique as a base for making decisions on energy and environmental policy. Five following screening criteria were used:

- percentage of CO<sub>2</sub> reduction;
- percentage of NO<sub>x</sub> reduction;
- additional total cost;
- marginal abatement cost;
- average cost of electricity.

Several decision maps and a matrix of decision maps for this problem along with its discussion is given in Solovietchik et al. [2002].

The second study is devoted to the search for cost-efficient global strategies aimed at the greenhouse gas emission reduction. Here we outline a simple version of the tool. The linear integrated model that was used contains at least four models:

- a model that describes the influence of investment decisions on CO<sub>2</sub> emission;
- a model of global cycle of CO<sub>2</sub>; it relates the concentration of CO<sub>2</sub> in the atmosphere to the emission;
- a climate model that describes regional consequences of CO<sub>2</sub> concentration change;
- a model that describes the influence of climate changes on economic development and standards of life for particular nations.

In the simple demonstration version, five groups of nations were considered. The climate change during the time period 1990-2050 was studied. The carbon dioxide emission was assumed to be a function of energy consumption, which depends on the gross domestic product (GDP) and energy consumption per unit of the GDP. The last value was supposed to decrease due to energy-related investment. The GDP for a group of nations was estimated by forecasting the population growth and the dynamics of the GDP per capita. A simple balance model was used to describe the carbon dioxide concentration. In contrast, the climate

model was obtained by simulation and parameterization of a global circulation model. Influence matrices that describe the dependence of economic losses in different world regions on the climate change (changes of solar radiation, precipitation and temperature) were given by an expert.

The user has to specify several criteria. Then, the EPH is approximated, and the user can explore the decision maps. Black and white copy of a decision map is given in Figure 4. It contains a decision map for discounted investment during 60 years in post-industrial countries (*I1*, horizontal axes) and in post-socialist countries (*I2*, vertical axes) for several levels of discounted decrement of global losses during 60 years (US\$, billions) given by shading. The investment in other groups of nations is restricted by some values.

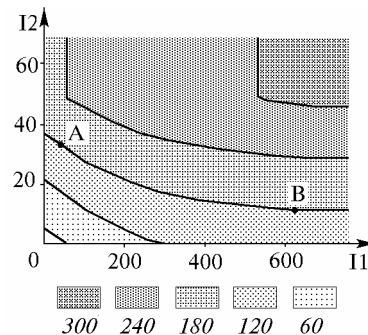


Figure 4. Decision map for investment in two groups of countries for different values of losses

The frontiers provide important tradeoff information. Let us consider two points *A* and *B* that belong to the frontier related to losses of \$180 billion. The user can decrease the required investment in the first group of nations by moving the goal from point *B* to point *A* (38 billion in point *A* instead of 630 billion in point *B*). A relatively minor investment increment in the second group is needed (34 billion in point *A* instead of 12 billion in point *B*). So, additional investment of 22 billion in the second group can save about 600 billion of investment in the first group!

This knowledge has a simple interpretation: energy consumption per dollar of GDP is now about three times higher in the second group than in the first one. For this reason, decrement in energy consumption (and the related decrement in carbon dioxide emission) is much more expensive in the first group than in the second one. This example shows how decision maps can advise experts and politicians to find efficient strategies for the decrement of carbon dioxide emission. Though the models used in the study are pretty rough, this simple version proves potential usefulness of the

approach in global studies (for details see Lotov et al. [1999] and [2001]).

## 5. ON INTERNET TOOLS THAT SUPPORT THE DEMOCRATIC PARADIGM OF ENVIRONMENTAL DECISION MAKING

Recent situation in the field of environmental decision making differs from what it was, say, about 50 years ago. Multiple political parties and interest groups, mass media and even particular citizens want to be involved now into decision process (for details see Cunge and Erlich [1999]). It is important that these players are non-experts. Usually, they have minimal knowledge on the problem and especially on the ways, how to solve it. In the framework of the traditional approach, known as the technocratic or expert-oriented paradigm, the DSS do not provide tools that can involve non-experts into the decision process. The democratic paradigm is based on the desire to involve non-experts into the process. Internet tools may help non-experts understand the problems and prepare for subsequent negotiation, legal and political actions. Involvement of non-experts into the screening phase is especially important since it is actually the phase of negotiation preparation. The approach described in this paper can help to develop Internet tools for environmental decision screening assessable for non-experts.

It is important that the IDM technique can be easily implemented on computer networks. Indeed, approximation of the EPH or the CEPH, which is related to 99% of the computing efforts, is performed automatically and is separated from the exploration of decision maps. Therefore it can be done on a server while exploration of decision maps can be carried out by means of Java applets on user's computer. So, ordinary Internet users can apply such Internet tool individually for screening the variety of possible strategies. Illustrations of this concept are provided by two Web resources (Lotov et al. [2000a] and [2000b]).

## 6. CONCLUSIONS

The Interactive Decision Maps technique is a new graphic multi-criterion approach to environmental decision screening based on integration of mathematical models and visualization of the Pareto-efficient frontier. Its application in several DSS proves effectiveness of the technique. Internet applications of the IDM technique can help non-experts to find preferable environmental decisions.

## 7. ACKNOWLEDGMENTS

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## 8. REFERENCES

- Cohon, J. L., *Multiobjective Programming and Planning*, Academic Press, New York, 1978.
- Cunge, J.A., and M. Erlich, Hydroinformatics in 1999: what to be done ?, *Journal of Hydroinformatics*, 1(1), 21-32, 1999.
- Dorfman R., Formal Models in the Design of Water Resource Systems, *Water Resources Research* 1(3), 329-336, 1965.
- Gass, S., and T. Saaty, The computational algorithm for the parametric objective function, *Naval Research Logistics Quarterly*, 2, 39-53, 1955.
- Lotov A.V., Computer-Based Support for Planning and Negotiation on Environmental Rehabilitation of Water Resource Systems, in: *Rehabilitation of Degraded Rivers: Challenges, Issues and Experiences*, ed. by D. P. Loucks, Kluwer Academic Publishers, NY, 1998.
- Lotov, A.V., V.A.Bushenkov, and O.L.Chernykh, Multi-criteria DSS for River Water Quality Planning, *Microcomputers in Civil Engineering*, 12(1), 57-67, 1997.
- Lotov, A.V., V.A.Bushenkov, and G.K. Kamenev, Feasible Goals Method: Mathematical Foundations and Environmental Applications. Mellen Press, NY, 1999, (in Russian).
- Lotov, A.V., V.A. Bushenkov, and G.K. Kamenev, Feasible Goals Method: Searching for smart decisions. Moscow: Computing Center of Russian Academy of Sciences, 2001.  
<http://www.ccas.ru/mmes/mmeda/book5.htm>
- Lotov, A. V., V.A. Bushenkov, A.A. Kistanov, and Chernov, A.V. Experimental Resource for Development of Independent Strategies, (2000a)  
<http://www.ccas.ru/mmes/mmeda/resource/>
- Lotov, A. V., A. A. Kistanov, and A. D. Zaitsev, Graphic tool that helps to select preferable rows from large lists, (2000b)  
<http://www.ccas.ru/mmes/mmeda/rgdb/>
- Soloveitchik, D., N. Ben-Aderet, M. Grinman, A.Lotov, Multiobjective optimization and marginal pollution abatement cost in the electricity sector – Israeli case study, *European Journal of Operational Research*, 2002 (in print).