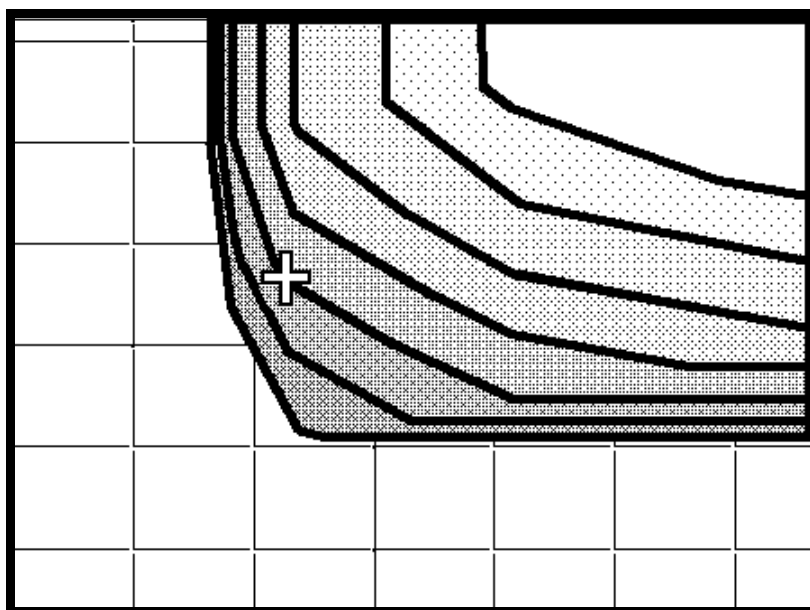


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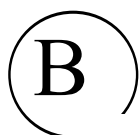
A.Lotov, V.Bushenkov, G.Kamenev

**Feasible Goals Method
Search for Smart Decisions**



МОСКВА 2001

А.В. Лотов, В.А. Бушенков, Г.К. Каменев



МОСКВА 2001

УДК 519.83

академик А.А.Петров

целей, основанный на компьютерной визуализации множества

целевого подхода к поиску эффективных решений.

экономических проблем; дается упрощенное описание
вычислительных алгоритмов метода. Обсуждаются
возможности применения метода в компьютерных сетях, в том

решений, основанной на использовании сети Интернет.

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фундаментальных исследований, грант № 01-01-00530б;

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, грант № 00-15-96118.

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*The book is dedicated to the memory of
brilliant researcher OLEG CHERNYKH,
who passed away too early,
in commemoration of his contribution
to the studies described in this book.*

Foreword and Acknowledgments

Computer based visualization of information proved to be a convenient and effective technique that can help people to assess information. Usually one understands visualization as a transformation of symbolic data into geometric figures that are supposed to help human beings to form a mental picture of the symbolic data. About one half of human brain's neurons is associated with vision, and this fact provides a solid basis for successful application of visualization techniques. One can consider computer visualization of information as a direct way to its understanding.

In this book a new approach to visualization of decision information is described. We concentrate on supporting a search for preferable decision alternatives. It is assumed that mathematical models are used to describe the decision situation and that conflicting interests must be taken into account. This feature results in multiple criterion formalization of the decision problem, which requires involvement of human beings into the decision process – preferences of decision makers (as well as other people involved into the process) must be taken into account. We propose to support these people with visualization of aggregated decision information.

The visualization method that we apply is based on the ideas of goal programming. Goal programming is a classic approach to solution of decision problems, which is used fairly often in the case of conflicting interests. In the framework of it, users have to

identify goals that represent their desires. Then, decision alternatives are computed that are related somehow to the goals. Sometimes, user comes across the problem: how to identify a goal that would be not understated or overstated? Both underestimation and overestimation of existing opportunities may result in serious negative consequences. We propose a solution to this problem. We visualize the whole variety of feasible goal vectors. Due to this, user receives information concerning the frontier of what is feasible and can identify the preferable goal vector consciously. Therefore, the method described in this book is a further development of goal programming; it applies visualization for supporting decision makers, experts or other users during goal identification in the problems characterized by conflicting interests.

The book describes the results of studies carried out at Computing Center of Russian Academy of Sciences (RAS). Authors are grateful to researchers of Computing Center of RAS for their important advice, constructive critical remarks and moral support in the process of the studies. The authors would like to stress the influence of two distinguished Russian scientists Nikita N. Moiseev (1917-2000) and Germogen S. Pospelov (1914-1998) on their research. As soon as in 60s, these scientists have stressed the need for visualization of the variety of feasible goal vectors. This idea was a starting point of the research.

The book is devoted to the memory of Dr. Oleg L. Chernykh (1954-1996). Oleg Chernykh belongs to the team of researchers who have developed the method described in the book. He was the author of effective robust algorithm for constructing the convex hulls of multi-dimensional points. This algorithm has provided a computational basis of methods for polyhedral approximation of convex bodies. He has coded the software that implements his algorithm, developing by this an effective tool for application of the

method in the case of large linear problems. He was one of the authors of the algorithm for computing a series of two-dimensional slices of a convex polytope; this algorithm helped to develop efficient visualization software. He took part in a large part of the case studies described in this book.

We express our sincere gratitude to full member of RAS, Professor Alexander A. Petrov, Head of the division of Computing Center of RAS where the research was carried out, for his patience and help during the long years of the research. The authors are deeply grateful to full member of RAS, Professor Oleg I. Larichev, Chairman of the Council of RAS on multiple criteria decision methods, for his important moral support.

Jared L. Cohon, President of the Carnegie-Mellon University, was the first who recognized the potential of our visualization techniques as a multiple criteria decision support method. The authors are grateful to him for his concepts that played an important role in the progress of their research. Authors would like to express their gratitude to the members of the International Society for Multiple Criteria Decision Making for their permanent support. We are especially grateful to Presidents of the Society Stan Zionts, Ralph Steuer, Pekka Korhonen and Valerie Belton. Bestowing A. Lotov with the Edgeworth-Pareto Award of the Society in 2000 is another example of the support provided by the MCDM Society to our research.

For 20 years, authors have been involved into collaboration with Finnish researchers supported by joint projects of Academy of Finland and Russian Academy of Sciences. Authors like to stress the importance of this collaboration, which provided an effective bridge to the research of Western decision science community. Our research was partially supported by the International Institute for Applied Systems Analysis (IIASA) located in Laxenburg, Austria.

We are grateful for this opportunity to former members of the IIASA Dr. Andrzej Wierzbicki (Poland), Dr. Janusz Kindler (Poland) and Dr. Sergei Orlovski (Russia). Large part of the job related to writing of this book was fulfilled during the stay of one of the authors at the University of Siegen, Germany. We are grateful to Professor Manfred Grauer, Vice-rector of the University, for this opportunity.

Authors are grateful to researchers who co-authored the papers, material of which was used in this book: Professors O.Hellman (University of Turku, Finland), Matti Pohjola and Jyrki Wallenius (Helsinki School of Economics, Finland), Hannele Wallenius (Helsinki University of Technology, Finland), Pete Loucks (Cornell University, USA), Piotr Jankowski (University of Idaho, USA), and Antonio Camara (New University of Lisbon, Portugal). Professor O. Hellman was the first to include our methods into his lectures.

On the basis of the visualization method described in this book, a computer-based laboratory work was developed that demonstrates a simple graphic way for constructing reasonable environmental strategies. The laboratory work was started at Moscow Institute for Physics and Technology, and since 1995 at Lomonosov Moscow State University, Russia, and University of Idaho in Moscow, Idaho, USA. Authors would like to thank Professor A. Kurzhanski and Professor P. Jankowski for their readiness to teach our method.

We are grateful to Dr. L. Bourmistrova who carefully read the book and corrected multiple typos and vague statements. We like to stress her role in the development of the algorithms and software. Former and current Ph.D. students V.Berezkin, A.Biryukov, A.Chernov, D.Gusev, R.Efremov, A.Kistanov, D.Kondratiev, A.Zaitsev, and N.Zezulinski took part in our research and coding the software. We would like to express our gratitude to them.

Introduction

In the classic book of Nobel prize winner, Professor Herbert Simon 'The New Science of Management Decision' (Simon, 1960), a decision making process is split in four main phases: *intelligence*, *design*, *choice* and *review*. The intelligence phase concentrates on identification of the decision problem and collection of related information. The second phase, design, is concentrated on developing a relatively small number of decision alternatives that must be studied in details. The choice phase is related to selecting a decision alternative from the list of alternatives prepared at the design phase. The final phase, review, is actually the phase of implementation of the selected decision and obtaining additional experience in this process.

So, the decision is made in the framework of two phases:

- *designing* a relatively small number of decision alternatives, and
- *final choice* of a single decision alternative from a small list.

The scheme of these two phases is provided in Figure 1.

These two phases are totally different – their goals, information and methods used differ drastically. On the phase devoted to developing a relatively small number of decision alternatives (this phase is often denoted as *early screening* of decision alternatives), one has to take into account all possible courses of action. In contrast, on the phase of detailed analysis and final choice, decision makers restrict themselves to a short list of prepared alternatives. Selection from the short list is made on the basis of a detailed exploration of the alternatives.

Computer visualization tools play now an important role in supporting decision processes. However, their applications are concentrated around the phase of detailed analysis and final choice. The phase of detailed analysis is often based on simulation of comprehensive mathematical models combined with a detailed exploration of simulation output. Modern visualization tools turned out to be extremely helpful in output analysis. Multimedia tools, virtual reality, and geographic information systems, which provide decision makers with exciting opportunities of rapid graphic assessment of one or a few decision alternatives, step-by-step find their proper place in the real-life decision processes.

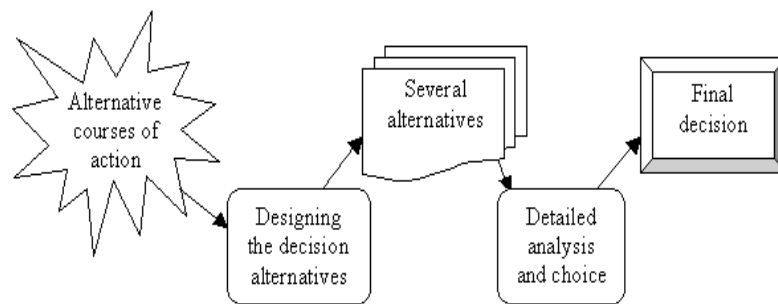


Fig. 1. Phases of the decision making process

In contrast, decision design is usually *not supported* by modern visualization tools. It does not seem to be wise since screening of decision variants plays an extremely important role in decision processes. Indeed, decision alternatives excluded at the screening phase cannot be revived later. Traditionally, decision makers have to providing several decision alternatives for detailed analysis, guided by their experience and feelings. An attempt to support the

decision design by using the single-criterion optimization actually failed since it was not able to incorporate intuition and interests of decision maker. So, decision makers still have to solve the decision design problem without any computer support.

Often, experts are asked to develop a small number of decision alternatives for further detailed exploration. Expert involvement saves time for decision makers, but introduces additional complications related to the fact that the alternatives developed by experts usually reflect their experience, perceptions, and goals, which may differ from those of decision makers. It can result in deadlock during the final phase since decision makers are forced to choose among decision alternatives that do not reflect their opinions or interests: the courses of action that could satisfy decision maker's interests may be excluded in the screening phase. It means that new tools are needed that can involve decision makers into the screening phase and amplify their experience and intuition. Visualization must play an important role in these tools.

It is important to add that the final phase of decision making is often a negotiation process that involves decision makers with different experience, interests and goals. In this case, the decision design phase plays the role of the *negotiation preparation*. On this phase, negotiators need to find such decision alternatives that are preferable for them and acceptable for other negotiators. This requires the direct involvement of negotiators decision design.

Note that the pre-negotiation activities are often separated from the negotiations. It means that the time requirements may be not so restrictive as in the process of the negotiations. Say, the screening phase may last for months and even years, especially in such public problems as environmental planning. Due to this, multiple stakeholders, independent institutions and political groups can take part in designing and screening activities by developing, selecting

and rejecting possible decision alternatives. Computer methods, which are to be applied by these people, must be transparent and simple. Involvement of ordinary people, which is permanently getting more important in public decision problems (especially environmental problems), only amplifies this requirement.

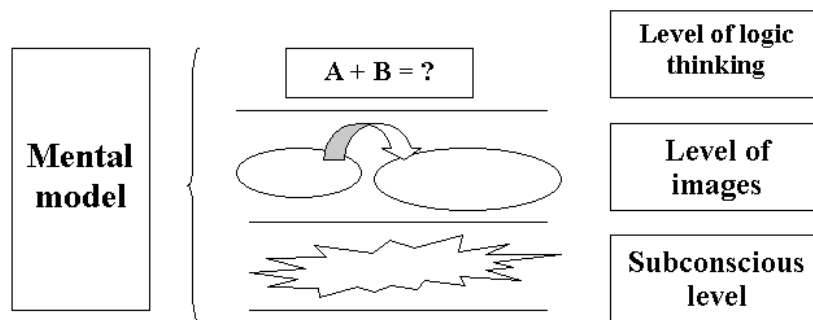


Fig. 2. Levels of a mental model

The modern psychology states that human beings make their decisions on the basis of their *mental models of reality*. The mental models are usually comprised of several levels (Figure 2). The upper, rational (logical) level is based on logical inference. The second level includes images, relations of which (in contrast to the upper level) may be not logical. The third level contains vague subconscious relations. All levels interact, and process of coordinating them is permanently under way, however, certain discordance between levels is a natural feature of human thinking processes. The mental decision processes incorporate activities of all the levels, and it is very complicated to estimate, which level has been most responsible for the final choice of a particular decision. One has to take into account that the imaginary and subconscious

elements of the decision process are usually camouflaged by the logical inference that is used to justify a decision after it has been made. Therefore, it is important to influence all the levels of mental models.

The need to influence the mental models is related to the fact that these models are often not only rough, but not true in many aspects. In particular, people often underestimate or overestimate the feasibility of the goals. Therefore, one of the effective forms of decision and negotiation support may consist in correcting the mental models. The computer-based visualization methods (especially animation) have a chance to modify logical constructions, images and subconscious relations simultaneously. If the graphic information is given in an assessable form, it may help a human being to assimilate it not only consciously but on subconscious levels, too. In the framework of the method described in this book, information about potentialities of choice and their frontiers is visualized in the form that is supposed to influence all levels of mental image. The method does not force anyone to answer preference-related questions; instead, it visualizes information that is hidden in equations and parameters of mathematical models and helps by this to improve the mental models.

The visualization method described in this book is based on four following assumptions concerning the decision design problem under exploration:

- original knowledge and information on the problem have been already transformed into a *mathematical model* that describes the situation in an integrated form; by this, the problem of decision design is transformed into the problem of selecting a

small number of alternatives from a given large (or even infinite) variety of all feasible alternatives;

- *conflicting interests* that must be taken into account can be identified;
- users are eager to know about the limits of what is possible and how conflicting interests can be exchanged; and
- though users may not want to provide detailed preference information, they agree to identify a *preferred combination of particular goals (goal vector)*.

Application of these assumptions results in the *Feasible Goals Method* (FGM) described in this book. The FGM can be applied in the case of several (more than two) conflicting goals. Decision design criteria are used to describe levels of achievement of particular goals. Using the mathematical model, the FGM transforms the variety of feasible decision alternatives into the variety of feasible combinations of design criteria (criterion vectors). The variety of feasible criterion vectors is visualized. Since it coincides with the variety of those goal vectors that can be achieved using feasible decision alternatives, the variety of *feasible goal vectors* is actually displayed.

It is important to stress that we provide a free interactive access to the variety of feasible goal vectors. To influence the mental models of reality, the variety is displayed in the form of beautiful colorful decision maps, which are collections of slices of the variety. Specially developed software technique, the *Interactive Decision Maps* (IDM) provides on-line display of the variety and helps user to detect frontiers of what is possible for three and more conflicting goals. In addition to the display of pictures in dialogue with user, the IDM technique can animate them. Such display of pictures can influence different levels of user's mental model

including the logical level, the level of images and, hopefully, the subconscious level.

The frontier of the variety of feasible goal vectors provides user not only with graphic information on limits of what is possible, but, in addition, it shows how achievement of one particular goal can be transformed into achievements of another goals. Sometime, one says that the frontier describes the *efficient (criterion) tradeoff* between achievements of these goals. Various collections of two-criterion tradeoffs are displayed by the IDM technique. The most important form of such collections is provided by the so-called decision maps, which display criterion tradeoff for three criteria.

Graphic information on the variety of feasible goal vectors and especially on its frontiers supports user in the process of designing the ideas about the *preferred feasible goal* vector. To identify the preferred goal vector (or, simply speaking, the goal), user has to click the computer mouse on a feasible point of a decision map. Then, computer finds a feasible decision alternative, which output coincides with the identified goal. Thus, the FGM/IDM technique helps to select a decision alternative in a simple way. Decision alternatives selected in this way can be explored in details later using *multimedia tools, virtual reality, and geographic information systems*. Important that the procedure of selecting a decision alternative is fairly transparent since it is reduced to identification of a feasible goal vector, for explanation of which decision maps can be used.

The FGM/IDM technique can be effectively applied on *computer networks*. Due to Internet, computer-literate people have got now an access to data concerning particular public problems. These data are collected by national, regional or local authorities or by private people. The FGM/IDM technique can provide additional opportunities in this field. It can help ordinary Internet users to

study all possible alternative solutions of public problems and to design *independent strategies* of solution of public decision problems in a simple graphic way. It is important that the information on all possible solutions of public problems will be not screened and edited by news agencies, newspapers and TV channels. This information will help ordinary people to understand decision problems faced by authorities and, from another point of view, to control decision processes actively.

Due to visualization, computer-literate people can master the FGM/IDM-based Web tools fairly fast. Such tools can be implemented in Web resources with moderate coding efforts; several Web resources have been coded already. A demo Web resource that illustrates the Internet application of the FGM for independent decision making was started as soon as in 1996. Now a new version of it, which implements Java applet technique, can be found in Web at:

<http://www.ccas.ru/mmes/mmeda/resource>

Internet application of the FGM in public problems seems to be important for the development of the civic society. In particular, the FGM can be used in the framework of democratic paradigm of environmental decision making. The concept of democratic paradigm is a reaction on recent situation in the field of environmental decision making. Multiple stakeholders, parties, mass media and ordinary citizens want now to be involved into decision processes. They are non-experts and often have minimal knowledge concerning the problem. Traditional technocratic paradigm of environmental decision making, in the framework of which experts develop environmental projects and professional decision makers approve or reject them, is not able to help non-experts. Therefore, something must be done to help non-experts to be involved into the decision processes. Visualization-based simple

Internet tools can be used to implement the democratic paradigm by supporting ordinary people in their active computer-based preparation for legal and political actions. The FGM can be easily applied in the framework of them.

The book consists of four chapters. In Chapter 1, the FGM technique is introduced on the basis of an example problem of regional environmentally sound economic planning. Then, the general concept of the FGM is discussed, and the most important problems of the FGM implementation are outlined in a simple form. Finally, the prototype Web resource for independent design of preferable strategies in the regional development problem is described.

Possible applications of the FGM in environmental decision making are exemplified in Chapter 2. The following problems are considered:

- a problem of sea dumping of sluges in the Lower bight of the New York City;
- a problem of long-term national development taking unemployment and environmental issues into account;
- international problems of atmosphere pollution exemplified by the case of Finland, Russia and Estonia;
- a problem of sustainable development of a small agricultural region (Peel region in the Netherlands); and
- a problem of designing smart strategies aimed at the abatement of the global climate change.

Real-life applications of the FGM are described in Chapter 3. First, the concept of real-life application of a decision support

technique is considered, and the first real-life application of the FGM for supporting the national goals selecting at the State Planning Agency of the USSR in 80s is outlined. Then, experience of real-life applications of the FGM/IDM technique in 90s in several decision support systems for water quality planning in large river basins is given in details.

Chapter 4 provides an introduction to the computational algorithms of the FGM/IDM technique. We do not consider the mathematical basis of these algorithms, which involves methods of differential geometry, algebraic topology and theory of functional spaces – it is described elsewhere (Lotov et al, 1999b). Instead, the computational algorithms are introduced in a simple form. However, in contrast to the previous chapters of the book, certain mathematical background is required from reader. Three basic groups of algorithms are described. In Section 4.1, the convolution techniques for linear inequality systems introduced by J.B. Fourier in 19th century are applied for constructing the variety of feasible goal vectors for linear systems. Section 4.2 is devoted to the algorithms of polyhedral approximation of the above variety in the convex case. The algorithms are based on combination of optimization with the convolution techniques for linear inequality systems. An algorithm for approximating the non-convex varieties of feasible goal vectors by systems of boxes is described in Section 4.3. Approximation is based on simulation and filtering of random feasible decisions. Section 4.4 is devoted to approximation of the Edgeworth-Pareto Hull (EPH) of the variety of feasible goal vectors, i.e. of the variety that has the same non-dominated frontier as the variety of feasible goal vectors, but looks much simpler. The EPH is used in the process of visualization of the frontier in the form of decision maps.

In Conclusion, the FGM-based scheme of an integrated Internet resource is described that implements democratic paradigm of environmental decision making. The Internet resource is able to support ordinary people in the process of active preparation for legal and political actions. Though the scheme is developed for the case of water-related problems, it can be used in a more general scope of environmental decision making.

The content of this book is based on shortened and updated translation of the book (Lotov et al., 1997) from Russian. Several issues that have been discussed in that book are omitted here. In particular, we do not discuss applications of the FGM to non-linear problems, methods for identification of parameters of non-linear models, etc. New applications of the IDM technique for visualization of databases (Reasonable Goals Method) are discussed in this book only in short in Chapter 1 and in Conclusion.