

## A Software System for Multicriteria Analysis and Optimization\*

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### Introduction

The multicriteria analysis (MA) and multicriteria optimization (MO) problems are multicriteria decision making problems. In MA and MO problems several criteria are simultaneously optimized. In the general case there does not exist one alternative(solution), which optimizes all the criteria. The solution of MA or MO problem is a set of alternatives, called a set of the non-dominating or of the Pareto optimal alternatives. Each alternative in this set could be a solution of the multicriteria problem. In order to select one alternative, it is necessary to have additional information set by the so-called decision maker (DM). The information that the DM provides reflects his/her global preferences with respect to the quality of the alternative sought.

The methods developed to solve MA problems, can be grouped in three separate classes: weighting methods, outranking methods and interactive methods. The main element in the weighting methods is the way of determining the criteria weights, which reflect DM's preferences to the highest degree. Many methods for criteria weighting have been developed. A value tradeoff method is proposed in [10]. The analytic hierarchy process (AHP weighting method) is developed in [30], using pair-wise criteria comparison. This method is generalized to reflect DM's uncertainty about the estimates in the reciprocal matrix. A direct ranking and rating method is proposed in [40]. A mathematical programming model with sensitivity analysis is used in [15] to determine the intervals of weights, within which the same ranking result is produced. The weighting methods use a DM's preference model, which does not allow the existence of incomparable alternatives and the preference information obtained by the DM (different types of criteria comparison) is sufficient to determine whether one of the alternatives must be preferred or whether the two alternatives are equal for the DM.

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The outranking methods use a DM's preference model which allows the existence of incomparable alternatives and the preference information obtained by the DM may be insufficient to determine whether one of the alternatives is to be preferred or whether the two alternatives are equal for the DM. The criteria and the alternatives are not compared by the DM in these methods, but he/she has to provide the so called inter- and intra-criteria information. Some of the more well-known representatives of the outranking methods are ELECTRE I-IV methods [28], PROMETHEE I-II methods [3], TACTIC method [33] and others.

In order to solve MA problems with a large number of alternatives and a small number of criteria, the "optimizationally motivated" interactive methods have been suggested (VIMDA method [12], aspiration-level method [14], LBS method [9], RNIM method [22]). The first two methods use the first type of DM's preference model and the DM must define the desired or acceptable values of the criteria at every iteration. The last two methods use the second DM's preference model and the DM has to give not only the desired values of the criteria but also inter- and intra-criteria information at every iteration.

There are two main approaches in solving MO problems: a scalarizing approach [16] and an approximation approach [6]. One of the most developed and widespread methods for solving multicriteria optimization problems are the interactive methods [7, 16]. MO problems is treated in these algorithms as a decision making problem and the emphasis is put on the real participation of the DM in the process of its solution. The interactive methods are the most developed and widespread due to their basic advantages – a small part of the Pareto optimal solutions must be generated and evaluated by the DM; in the process of solving the MO problem, the DM is able to learn with respect to the problem; the DM can change his/her preferences in the process of problem solution; the DM feels more confident in his/her preferences concerning the final solution. The interactive methods of the reference point (direction) and the classification-oriented interactive methods) are the most widely spread interactive algorithms solving MO problems. Though the interactive methods of the reference point are still dominating, the classification-oriented interactive methods enable the better solution of some chief problems in the dialogue with the DM, relating to his/her preferences defining, and also concerning the time of waiting for new non-dominated solutions that are evaluated and selected.

A variety of methods to approximate the set of Pareto optimal solutions of different types have been proposed. Some methods [6] are exactly equipped with theoretical proofs for correctness and optimality while some other methods [5] are heuristic and often theoretically unsupported. The main representatives of the heuristic methods are the multicriteria genetic (evolutionary) methods. The MO problem is treated in these methods rather as a vector optimization problem, than as a decision making problem and the stress is placed on the determination of a subset of potential Pareto optimal solutions, which approximates well enough the whole Pareto optimal set. This is achieved, supporting a population of candidates for the approximating subset during the whole process of optimization. This population is improved at each iteration with the help of different operators, modeling the basic processes of biologic genetic such as selection, recombination and mutation.

The software systems supporting the solution of MA problems can be divided in two classes – software systems with general purpose and problem-oriented software systems. The general-purpose software systems aid the solution of different MA prob-

lems by different decision makers. One method or several methods from one and the same group are usually realized in them for solving MA problems. The problem-oriented MA systems are included in other information-control systems and serve to support the solution of one or several types of specific MA problems. Hence some simplified user's interface modules are usually realized in them. That is why methods from different groups of MA methods are included in some of these systems.

The general-purpose software systems developed [29], Web-HIPRE [20], HIVIEW [27], ELECTRE III-IV [28], PROMCALC and GAIA [3], Decision Lab [4], VIMDA [12] realize one method or several methods from one and the same group, above described. Two representatives of the problem-oriented systems are: the FINCLAS system – for financial classification problems [42]) and Agland Decision Tool – for agricultural property [26].

The software systems developed to aid the MO problems solution can be divided also into two groups: software systems of general purpose and problem-oriented software systems. Some well-known general-purpose software systems, which solve problems of MO, are the systems VIG [11], NIMBUS [17], DIDAS [13], CAMOS [25], LBS [9], DINAS [24], MOLP-16 [34], MONP-16 [34], MOIP [35]. The first type comprises the interactive algorithms of the reference point and of the reference direction [11, 41]. These are systems such as DIDAS, VIG, CAMOS, DINAS and LBS. The second type of interactive algorithms includes the classification-oriented algorithms [1, 16, 21, 38]. These interactive algorithms are built in the systems NIMBUS, MOLP-16, MONP-16 and MOIP. One representative of the problem-oriented systems is ADELAIS system – for portfolio selection [43].

The present paper describes some basic elements of the software system developed (called MultiDecision-1), which consist of two separate parts (the systems MKA-1 and MKO-1) and *which is designed to support decision makers in solving different MA and MO problems*. The class of the problems solved, the system structure, the operation with the interface modules for input data entry and the information about DM's local preferences, the operation with the interface modules for visualization of the current and final solutions are discussed, as well as the help information, given in a digital and graphical form.

## Purpose of MultiDecision-1 system

The system MKA-1, the first part of the system MultiDecision-1, is designed to support decision makers in solving different multicriteria analysis problems. The multicriteria analysis problem can be defined [8] as  $(AL, f)$ , where  $AL$  is a finite feasible set of alternatives  $AL = \{a_1, a_2, \dots, a_n\}$  and  $f$  is a vector-valued ( $k$ -dimensional) criterion  $f = \{f_1, f_2, \dots, f_k\}$ . For an alternative  $a \in AL$   $f_j(a), j \in \{1, \dots, k\}$  represents the evaluation of the  $j$ -th criterion. Each criterion  $f_j$  is assumed to be either maximized –  $\max_{a \in AL} f_j(a)$ , or minimized –  $\min_{a \in AL} f_j(a)$ . The notation  $a_{ij} = f_j(a_i)$  may also be used to denote the  $j$ -th criterion value for alternative  $a_i$ . The matrix  $A = \{a_{ij}\}, i = 1, \dots, n$  and  $j = 1, \dots, k$ , is denoted as a decision matrix.

In the general case there does not exist a solution, which optimizes all  $k$  criteria simultaneously. From a mathematical viewpoint there exists a set of so-called non-

dominated or Pareto optimal solutions and this set is a solution of the multicriteria analysis problem. It can be described as follows:

$$P(AL, f) = \{a \in AL \mid \text{not exist } b \in AL, b \text{ dominates } a\},$$

where the alternative  $b \in AL$  dominates  $a \in AL$  if  $f(b) \neq f(a)$  and

$$f_j(b) \geq f_j(a),$$

if  $f_j$  is to be maximized or

$$f_j(b) \leq f_j(a),$$

if  $f_j$  is to be minimized for each  $j = 1, \dots, k$ .

From a practical point of view, the solution of a multicriteria analysis problem is finding of a non-dominated alternative (alternative, belonging to the set  $P(AL, f)$ ), which satisfies the DM to the greatest extent.

In MKA-1 system an attempt has been made to realize three methods – a weighting method, an outranking method and an interactive method. These methods are respectively AHP method [30], PROMETHEE II method [2] and CBIM method [22]. They are the most often used methods in the three groups of methods. The interface modules in the system allow the successful realization of different types of procedures for obtaining information by the DM and also for the entry of different types of criteria – quantitative, qualitative and ranking criteria.

The system MKO-1, the second part of the system MultiDecision-1, is designed to support decision makers in solving the following linear and linear integer problems of the multicriteria optimization.

To optimize simultaneously the criteria

$$(1) \quad \{f_k(x), k \in K\}$$

under the constraints

$$(2) \quad \sum_{j \in N} a_{ij} x_j \leq b_i, \quad i \in M,$$

$$(3) \quad 0 \leq x_j \leq d_j, \quad j \in N,$$

$$(4) \quad x_j - \text{integers}, \quad j \in N', \quad N' \subset N,$$

where to optimize simultaneously means that some of the functions may be maximized, and the rest – minimized;

$$f_k(x), k \in K, \text{ are linear criteria, } f_k(x) = \sum_{j \in N} c_j^k x_j;$$

$$x = \{x_1, \dots, x_j, \dots, x_n\}^T \text{ is the variables vector;}$$

$$f(x) = (f_1(x), \dots, f_k(x), \dots, f_p(x))^T \text{ is the vector of the criteria;}$$

$$K = \{1, 2, \dots, p\}, M = \{1, 2, \dots, n\}, N = \{1, 2, \dots, m\} \text{ and}$$

$N' = \{1, 2, \dots, n' \mid n' \leq n\}$  are sets of the indices of the linear criteria, the linear constraints, the variables and the integer variables.

Three classification-oriented interactive algorithms [36, 37] are included in MKO-1 system, which enable the DM define not only desired and acceptable levels of the criteria (as in reference point interactive algorithms), but also desired and acceptable intervals and directions of alteration in the values of the separate criteria. The first interactive algorithm, called GAMMA-L is intended to solve linear problems of the MO: The second and the third algorithms, called GAMMA-I1 and GAMMA-I2 re-

spectively, are designed to solve linear integer problems. In solving integer problems of the MO, the dialogue with the DM is influenced to a large extent by the time, during which he/she is expecting new non-dominated solutions for evaluation and choice. This is so, because the single-criterion integer problems [23], solved at a given iteration, are NP-problems and the time for their exact solution is an exponential function of their dimension. When the solution time proves to be much longer, the DM may lose patience and interrupt the dialogue, refusing to look for a new solution. The classification-oriented interactive algorithms GAMMA-I1 and GAMMA-I2 allow at each iteration the solving of single-criterion problems with two basic properties: a known initial feasible solution and a comparatively “narrow” feasible region. The properties of this type of single-criterion problems, above indicated, facilitate their solution, and also enable the use of approximate single-criterion algorithms. There exists at that high probability that the solutions found will be close to or coincide with the non-dominated solutions of the multicriteria problem.

### Basic features of MultiDecision-1 system

The system MKA-1, the first part of the system MultiDecision-1, consists of solving modules, interface modules and internal-system modules. This modularity enables greater flexibility when including new methods or new interface realizations.

The current version of MKA-1 system contains three solving modules. Every module encloses a software realization of one of the three methods – AHP method, PROMETHEE II method and CBIM method and help procedures for each method as well.

The interface modules ensure the interaction between MKA-1 system, the DM and the operating system. This interaction includes the entry of the data for the multicriteria problems, the entry of information specific for every method, information about DM’s preferences, visualization of the current results and of the final result, graphical presentation of the solutions, print out, reading and storing of files, multi-language support, etc.

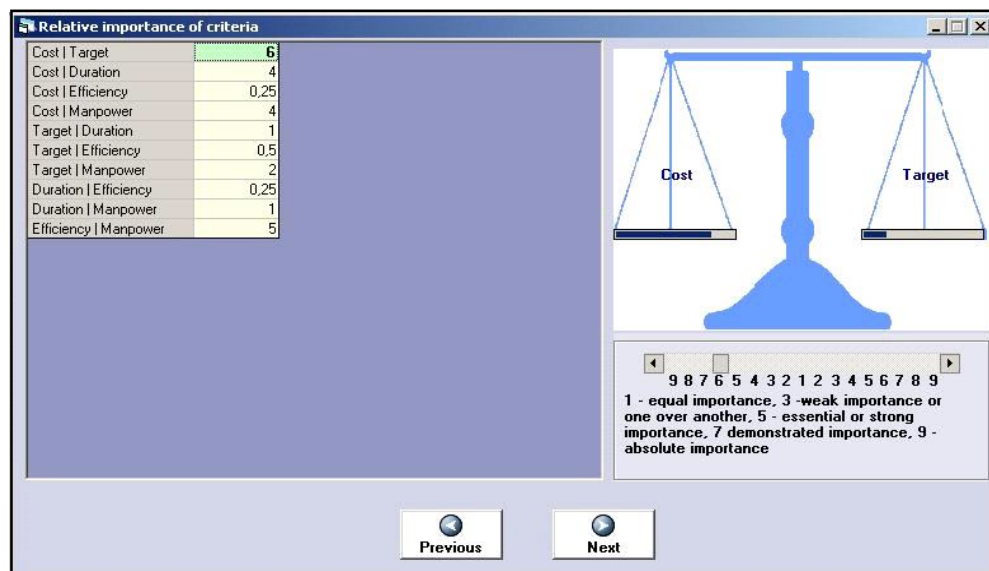


Fig. 1. MKA-1 system AHP solving windows

Fig. 1 shows a window with information about the pair-wise comparison of the criteria for one real multicriteria analysis problem, concerning the selection of an appropriate marketing action for advertising of bicycle manufacturing company products [4]. This is information about DM's preferences in operation with AHP method. Fig. 2 presents a window with information about DM's preferences in operation with PROMETHEE II method.

	Cost	Target	Duration	Efficiency	Manpower
News	60	900	22	Average(Fair)	8
Herald	30	520	31	Essential bad(low)	1
Panels	40	650	20	Good(High)	2
Malling	32	750	60	Bad(Low)	3
DMM	52	780	58	Exceptionally good(high)	1
NCB	80	920	4	Very good(high)	6

**Properties of criterion: Cost**

Criterion Type: Quantitative

Min/Max: Minimum

Weight: 1

Preference Function: V-Shape with indit.

Indifference Threshold: 10 (Max Val - Min Val)

Preference Threshold: 40 (62)

Gaussian Threshold: [ ]

Threshold Unit:  Absolute  Percent

Average Performance: 59

Unit: 1 000 USD

**Legend**

Min value(rating) [Green Box]

Max value(rating) [Red Box]

**Quantitative's Scale**

1- Exceptionally bad(low)	6- Good(High)
2- Essential bad(low)	7- Very good(high)
3- Very bad(low)	8- Essential good(high)
4- Bad(Low)	9- Exceptionally good(high)
5- Average(Fair)	

Buttons: Previous, Set Values, Solve

Fig. 2. MKA-1 system PROMETHEE solving windows

The interface with the DM is realized on the principle of an adviser – a sequence of windows (steps), each one with a distinctly expressed function, which considerably assists and facilitates DM's work. The DM has the possibility to move forward to a following step and also backward, returning for some corrections to the information already entered. The windows, which must be accessible in more than one stage of DM's operation with MKA-1 system, are included in the menu or in the instruments band. MKA-1 system possesses dynamic context help information. It gives a brief description of every visual component just by dragging the mouse over it. In addition to this a debug window is used, that outputs service information about the system internal processes. It can be printed out or stored in a text file. This allows the obtaining of exact debug information when an error occurs. MKA-1 enables the storing in a file of the input data for every multicriteria problem and of the data about the solution process. Thus the solution process of a multicriteria problem can be interrupted at any stage and activated from the place of its interruption at any time. MKA-1 system has comparatively rich printing functions – every piece of the data (entered or computed) may be printed. In this way the entire process of decision making is documented – you can review the input data of the multicriteria problem, the DM's preferences entered, the current values obtained, and the final result also, which on its turn can be printed out in the form of values or graphics.

The system modules contain all global definitions of variables, functions and procedures of general purpose. The object possibilities of Visual Basic are utilized in MKO-1 system, creating several classes with respect to internal system structures. They are: a class for messages, which capsules the output of error messages, dynamic context help information and registering of events in the debug window; a class matrix with some specific procedures, necessary for AHP method, a class for storing the information specific for the criteria in PROMETHEE method and a class for storing system site. The renewal function starts the installation procedure.

MKO-1 system, the second part of the system MultiDecision-1, consists of the following three main parts: a control program, optimization modules and interface modules. The control program is an integrated software environment for creating, processing and saving of files associated with MKO-1 system (ending by “.mko” extension) and also for linking and executing different types of software modules. The basic functional possibilities of the control program can be divided in three groups. The first group includes possibilities to use the standard for MS Windows applications menus and system functions – “File”, “Edit”, “View”, “Window”, “Help” and others in system own environment. The second group of control program facilities includes the control of the interaction between the modules realizing: creating, modification and saving of “.mko” files associated with MKO-1 system, which contain input data and data concerning the process and the results from solving multicriteria linear and linear integer problems; interactive solution of the multicriteria linear and linear integer problems which have been entered; localization and identification of the errors occurring during the system operation. The third group of the functional features of the control program includes possibilities for visualization of important information concerning the DM and the system operation as a whole.

The interface modules realize the dialogue between the DM and MKO-1 system during the entry and correction of the input data necessary for the multicriteria problems during the interactive process of these problems solution, and also for the dynamic visualization of the main parameters of the process. An editing module serves to enter, alter and store the descriptions of the criteria, of the constraints, and also of the type and bounds of variables alteration. Another interface module enables the setting of DM's local preferences for alteration in the values of the separate criteria. A third interface module realizes two types of graphic presentation of the information about the values of the criteria at different steps and the possibilities for comparison. Dynamic Help is provided, which outputs specific information about the purpose and way of use of the fields and radio buttons in a separate window.

The optimization modules realize three classification oriented interactive algorithms GAMMA-L, GAMMA-I1 and GAMMA-I2, and also exact and approximate single-criterion algorithms solving problems of the linear and linear integer programming.

MKO-1 system is working under MS Windows. It can be added to Programs group and/or with a Desktop icon, from where it is started. The system registers the “.mko” extension and associates it. Thus at double clicking on a valid “.mko” file, the system will be started and this file will be loaded. There is a menu in the main window with the standard for MS Windows drop-down menus and commands. With their help the operation of a new file is started or an existing “.mko” file is loaded and the operation may continue with the information stored in it.

The entry and correction of the problem criteria and constraints is realized in “MKO-1 Editor” window (Fig.3). Every criterion and every constraint is entered separately in the respective text field for edition. Syntax check is accomplished when they are added to the data already entered. The syntax accepted is similar to the mathematic record of this class of optimization problems. The type of the optimum looked for is entered first – “min” or “max”. After that the digital coefficient with its sign is entered, followed by the variable name it refers to.

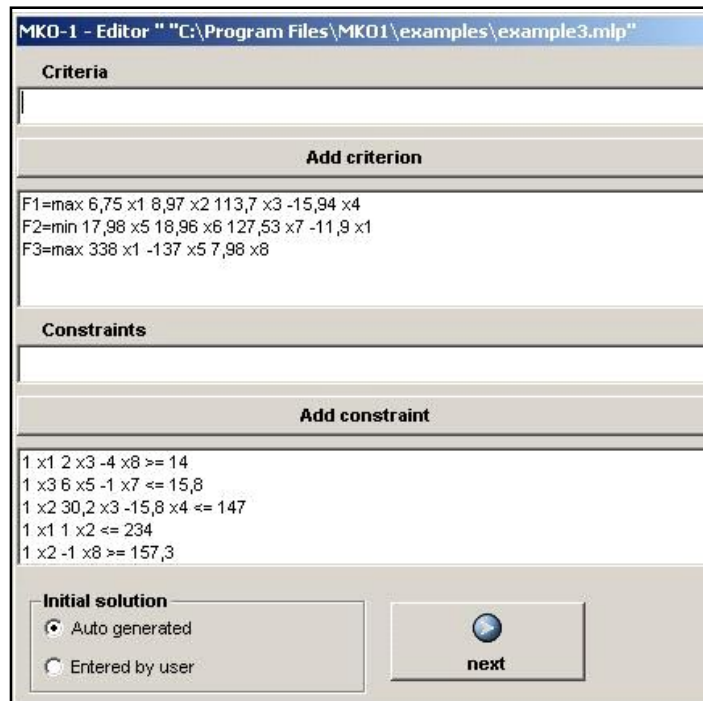


Fig. 3. MKO-1 editor

The variables names can be an arbitrary set of letters and numbers. Each one of these elements is separated by a space. The constraints have similar syntax – digital coefficients and variables names are successively entered. The type of the constraints is defined by some of the symbols “<=”, “>=” or “=”). By double clicking on the constraint or criterion already entered, they are transferred to the editing field again, if subsequent corrections are necessary.

The interactive problems solution is realized in “MKO-1 Solving” window. “MKO-1 Solving” window is divided into several zones (Fig. 4). Its upper part contains a band with buttons that realize the main functions of the process for interactive solution of multicriteria linear and linear integer problems. These are the buttons:

- *Solve* – for starting the optimization module in order to find a new current solution of MKO-1, solving the scalarizing problem generated at this iteration;
- *Info* – for visualization of the variables values at the current solution in a separate window;
- *Graphic* – for opening the window for graphic comparison of the results obtained at the separate steps;



- *Back* and *Forward* – buttons for navigation. They allow the DM go back to preceding steps and reconsider the solutions found;
- *Options* – for opening different system setups.

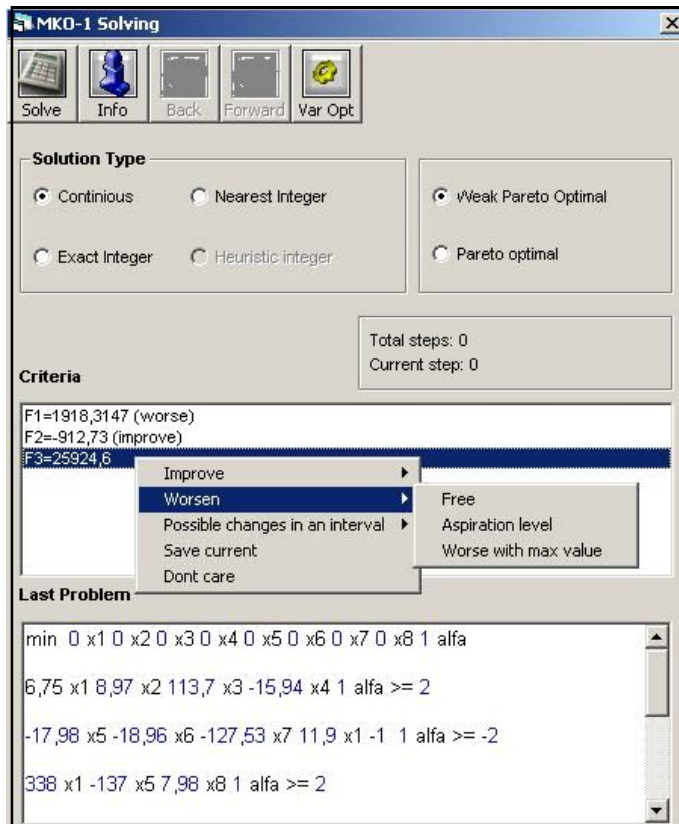


Fig. 4. MKO-1 solving

The next field of “MKO-1 Solver” window contains radio buttons for setup of the MKO-1 solution looked for: continuous, integer, approximate integer, the closest integer, as well as weak Pareto optimal or Pareto optimal. Below them information is found about the time of the system operation for the current problem in seconds, the number of the step being currently considered and the total number of the executed steps.

Two text fields follow. The first one outputs successively the values of the criteria obtained at the current step. It is an operating field where DM’s preferences relating to the search of the next solution are set. After marking each one of the criteria, a context field is opened with the help of the mouse right button, where the DM sets the desired alteration in the value of this criterion at a following iteration. In case the selection is connected with the necessity to enter a particular value, MKO-1 system opens an additional dialogue window and waits for the entry of the corresponding digital information.

When interactive algorithms are used for multicriteria problems solving, it is an advantage to present information not only about the last solution found, but also about

the process of search, about all the previous steps. Given that some significant solutions are made on the basis of these results, it is important for the DM to be able to “testify” how he has reached this solution. That is why the information about the interactive process of MO problem considered, which consists of the problem input data, the solutions obtained at each step, the preferences set by the DM for a new search and the constructed scalarizing problems, saved in \*.mko files associated with MKO-1 system serve not only for restarting an interrupted solution process, but also for documentation. “Print” command from the main menu can be used for selective print of the type of information chosen by the DM.

## Conclusions

MultiDecision-1 system is designed to support DMs in solving different MA and MO problems. MKA-1 system is designed to support the DM in modeling and solving problems of multicriteria ranking and multicriteria choice. MKO-1 system is designed to model and solve linear and linear integer problems of multicriteria optimization. The user-friendly interface of MKA-1 system and MKO-1 system facilitates the operation of DMs with different qualification level with regard to the analysis and the optimization methods and software tools. MKA-1 and MKO-1 systems can be used for the purposes of education and for experimental and research problems solving as well.

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## Программная система для многокритериального анализа и оптимизации

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### (Резюме)

Представлена многокритериальная система принятия решений, называемая MultiDecision-1. MultiDecision-1 система включает две независимые части – система МКА-1 и система МКО-1. МКА-1 система предназначена для решения многокритериальных задач анализа, а система МКО-1 – для решения многокритериальных задач оптимизации. В работе описываются основные функции, структуры, использованные методы и интерфейс с потребителем двух систем МКА-1 и МКО-1.