1. Purpose of MKO-2 system

Decision making problems are non-formalized or weak formalized problems, the solution of which requires the participation of the so called decision maker (DM). The solutions obtained are to a great extent subjective and depend on DM’s preferences. The decision making problems are divided into three main classes: decision making problems at many criteria (multicriteria problems), decision making problems under conditions of risk and decision making problems under uncertainty conditions.

Different problems of planning, control, analysis and monitoring in economy, transport, industrial production, education, ecology and other spheres may be reduced to decision making problems at many criteria. The decision making problems at many criteria can be divided in two separate classes depending on their formal statement. In the first class a finite number of explicitly set constraints in the form of functions defines an infinite number of feasible alternatives. These problems are called continuous multicriteria decision making problems or problems of multicriteria optimization. This class of problems covers also the linear continuous decision making problems. In the second class a finite number of alternatives is explicitly given in a tabular form. These problems are called discrete multicriteria decision making problems or problems of the multicriteria analysis.

Normally in multicriteria optimization problems, several criteria (objective functions) are simultaneously optimized in a feasible set of solutions (alternatives). In the general case there does not exist one alternative, which optimizes all the criteria. There exists, however, a set of non-dominated alternatives, called a Pareto optimal set, each element of which may be a solution of the multicriteria problem from a mathematical point of view. On the other hand in practice it is necessary to have one selected alternative as a final solution of the problem. Its selection requires additional information, which is supplied by the DM. The information, that the DM sets, reflects his/her global preferences concerning the quality of the alternative sought.

The multicriteria optimization problem has the following form:

\[
\text{"max" } \{f_1(x), f_2(x), \ldots, f_p(x)\}
\]

under the constraints:

\[
g_j(x) \leq b_j, \ j = 1, m, \\
x \in \mathbb{R}^n,
\]

where:

- \( p \geq 2 \);
- \( \mathbb{R}^n \) is the n-dimensional space;
- \( x = (x_1, x_2, \ldots, x_n)^T \) is the variables vector;
- \( f(x) = (f_1(x), \ldots, f_p(x))^T \) is the vector of the criteria (the objective functions);
- \( g_j(x), \ j = 1, m \) are functions of the problem constraints;
- \( b_j, \ j = 1, m \) are the right sides of the problem constraints;
- “max” denotes that the criteria (the objective functions) are simultaneously maximized.

The functions of the problem constraints define the feasible set of the variables. This set will be denoted as \( X, X \subset \mathbb{R}^n \). \( f(X) = Z \) denotes the image of the set \( X \) in the criteria space \( \mathbb{R}^p \), \( Z \subset \mathbb{R}^p \). \( Z \) is called a feasible set in the criteria space.

A linear multicriteria problem with three criteria, four constraints and four variables is formulated as follows:

\[
\text{max } f_1(x) = 5x_1 - x_2 + 2x_4
\]
\[
\begin{align*}
\text{max } f_2(x) &= -x_1 + 2x_2 + x_3 \\
\text{max } f_3(x) &= 4x_2 - 8x_3 + 2x_4
\end{align*}
\]
under the constraints:
\[
\begin{align*}
-x_1 + 2x_2 + x_3 + 2x_4 &\leq 34 \\
2x_1 + x_2 - 3x_3 - x_4 &\leq 16 \\
3x_1 + 2x_2 + 4x_3 - x_4 &\leq 28 \\
x_1 + 6x_2 - x_3 + 4x_4 &\leq 43 \\
x_i &\geq 0, \; i = 1, 4
\end{align*}
\]

Many real problems in management practice can be formulated as multicriteria optimization problems. Depending on the type of the criteria and of the constraints, as well as on the variables type, the multicriteria optimization problems can be divided into linear, non-linear, network and other problems.

Very frequently the multicriteria optimization problems are solved using scalarization. Scalarization is by itself transformation of the multicriteria optimization problem into one or a set of single criterion optimization problems (called scalarizing problems) with real objective functions, depending usually on one or several parameters.

The algorithms developed up to now for solving multicriteria optimization problems, may be grouped in four classes. This classification is based on the place and the time, when the information is set and obtained by the DM. The classes of problems are the following: algorithms that do not require information by the DM, apriori algorithms, aposteriori algorithms and interactive algorithms.

One of the most developed and widespread algorithms for solving multicriteria optimization problems are the interactive algorithms. This is 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 multicriteria 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.

Each one of the interactive algorithms developed up to now for solving different classes of multicriteria optimization problems has its advantages and shortcomings, connected mainly with the way and type of the information derived by the DM, which is reflecting his/her global and local preferences, the type and ways of solution of the scalarizing problems, and also with the type of the information given by the DM.

The software systems developed to aid the multicriteria optimization problems solution can be divided into two groups: software systems of general purpose and problem-oriented software systems.

The software systems of general purpose serve to aid the solution of different multicriteria optimization problems by different DMs. Usually one algorithm is realized in them to solve the multicriteria problems. This is due to the following reasons:

- the different algorithms are intended to solve different types of multicriteria optimization problems (linear, non-linear, discrete, continuous, network, etc.); 
- different types of procedures are used in the different algorithms to derive and set information by and to the DM, which causes considerable difficulties in the realization of user-friendly interface modules; 
- different strategies are used in the different algorithms that learn the DM and different ways to decrease the time for scalarizing problems solution; 
- usually the developers of the software systems are interested in the realization of their own algorithm.
The problem-oriented software systems are included in other information-control systems and serve to aid the solution of one or several types of various multicriteria optimization problems and most frequently simplified user’s interface modules are implemented in them. Hence, more than one algorithm for solving the multicriteria optimization problems is realized in some of these systems.

MKO-2 software system is designed to aid the solution of linear and linear integer multicriteria optimization problems. 12 known scalarization problems of different type, based on a generalized scalarizing problem, are generated in the system, and the corresponding 12 interactive algorithms. Depending on the type of information about the DM’s preferences at searching new decisions, these algorithms may be separated in five groups (Table 1). The system is characterized by an user-friendly interface, connected with the input data entry, entering in the beginning or at any iteration various types of information about the decision maker’s preferences, choice of different interactive solving algorithms, the presentation of the output results obtained in a digital and graphical form, and their archivation, the possibilities to interrupt the process of multicriteria problem solution and to restart it in another direction, etc.

<table>
<thead>
<tr>
<th>Type of preference information, specified by the DM</th>
<th>Interactive algorithm</th>
</tr>
</thead>
</table>
| Weighting factor (priority) for every criterion | 1) Chebyshev algorithm  
2) Weighting algorithm |
| Select one of the criteria for optimization and transform the rest of them into constraints, setting a lower limit for each. | 1) $\varepsilon$ – constraint algorithm |
| Aspiration level for every criterion | 1) STEM algorithm  
2) STOM algorithm  
3) Reference point algorithm RP  
4) GUESS algorithm  
5) Modified reference point algorithm MRP |
| Aspiration level for every criterion and parameter to define the reference direction | 1) Reference direction algorithm VIG  
2) Reference direction algorithm RD2 |
| Desired or acceptable levels, directions and intervals for every criterion | 1) Classification-based algorithm NIMBUS  
2) Classification-based algorithm DALDI |

2. Structure and functions of the main modules of MKO-2 system

MKO-2 system consists of three main modules: a control module, optimization modules and interface modules.

The control module is an integrated software environment for creating, processing and storing of files associated with the system (with “*.mlp” extension), as well as for linking and execution of different types of software modules.

The basic functional possibilities of the control module may be separated into three groups. The first group includes the possibilities to use the standard for MS Windows applications menus and system functions – *File, Settings, Edit, View, Window, Help* and others in the system own environment.

The second group of functional possibilities includes the control of the interaction between the modules realizing:
- the creating, modification and storing of “*.mlp” files associated with the system, which contain input data and data for the intermediate and final results from the solution of the linear and linear integer multicriteria optimization problems;
- interactive solution of the multicriteria optimization problems entered;
The third group of functional possibilities of the control module consists in the possibilities to visualize significant information about the DM and the operation of MKO-2 system as a whole.

The control module is designed in Multy Document Interface style. There is one main form (window), containing the main menu, and all the other forms (windows) are its “daughter” forms. Several “daughter” forms can be visualized at one and the same time. In order to accomplish communication with the libraries for dynamic linking of different single criterion optimization modules, the independent “CSolver” class is used, which is a data processor. It includes modules for input data entry, for output data obtaining and for different setups of the type of the variables and the type of the solution required. It works after the black box principle—an optimization problem in certain format and syntax is set at its input as a parameter, syntactic analysis is done, the names and the type of the variables (continuous/integer) are defined, the type of the solution (continuous/integer) is also determined and the optimization problem is transformed in a format, required by the corresponding single criterion optimization module. The information about the solutions obtained is recorded at the output points of the class, where from it can be obtained.

The other main class, used by the control module, is the “CHistory” class. Its purpose is to create a structure, in which the results obtained at each iteration of the interactive algorithm—the values of the criteria and variables, the preferences set by the DM and the scalarizing problem used at this iteration. This enables the interruption and restarting of the interactive process of solving each problem of the multicriteria optimization from the place of its interruption. The DM has also the possibility to go backward and to search for solutions in another direction with other preferences.

The interface modules guarantee the dialogue between the DM and the system during the input and correction of the input data of the problems being solved, during the interactive process of their solution and also during the digital and graphical visualization of the main parameters of this process. With the help of the editing module, the descriptions of the criteria, of the constraints, as well as the type and bounds of alteration of the variables are entered, changed or preserved. Another interface module realizes two types of graphic presentation of the information about the values of the criteria at different steps and the possibilities to compare them. Dynamic information is supplied about the purpose and the way of use of the fields and radio buttons.

The optimization modules realize 12 interactive algorithms of multicriteria optimization, as well as two algorithms of linear and linear integer single criterion optimization.

3. System requirements

MKO-2 system can be installed on computers meeting the following minimal requirements:

- Pentium 200MMX processor or quicker (recommended);
- 32 MB RAM or more (64 MB RAM recommended);
- 32-bit MS Windows operation system (98, NT 4.0, 2000, X);
- 10 MB of free disk space for optimal productivity;
- XVGA display (1024x768 resolution recommended, or higher).

4. Installation and uninstallation

In order to install MKO-2 system, the following operations have to be executed:

- Start Windows;
- Insert the disk in the CD-ROM device;
- The installation program has to be self-started. If the CD-ROM device or Windows version does not support the option Automatic starting, RUN command is selected in the Start menu of Windows;
- Enter x:\MKO1Setup.exe, where x is the letter assigned to the CD-ROM device;
- Press OK button;
- Follow the instructions, given by the installation program, in order to continue with the installation process;
- When the installation is completed, restart the computer.

In order to uninstall MKO-2 system from the computer, open Control Panel and choose Add/Remove Programs, select MKO-2 in the list and follow the instructions which appear in the window opened.

5. Operation with MKO-2 system

5.1. Introduction

MKO-2 system operates in MS Windows environment. It can be added to the Programs group and/or a Desktop icon, from where it is started. When starting it, “MKO-2 Main window” is opened (Fig. 1), containing a band with six main menus – File, Settings, Edit, View, Window and Help and a second band with quick access icons – New, Open, Save, Print, Settings and Graphic.

With the help of “New” command, a window is opened for a new problem, its data being stored by the system in a file with “.mlp” extension. The storing is accomplished by commands “Save” or “Save as”. In case the data about the problem, contained in this file, are not entirely entered or the process of this problem solution is not started, the window “MKO-2 Editor” is opened with the help of “Open” command. Otherwise, the window “MKO-2 Solver” is opened.

5.2. Entry of the data of the multicriteria problem

The entry and correction of the criteria and constraints of the problem is completed in two separate fields of “MKO-2 Editor” window (Fig. 2). Every criterion and every constraint is entered separately in the corresponding text fields for input and edition. Syntactic check is done after their adding to the already entered criteria or constraints. The syntax accepted is similar to the mathematical record of this class of optimization problems. For each criterion the name of the
criterion is entered at first, followed by the equality sign. In case the name of the criterion is not specified, the name $F_i$ is automatically assigned to it, where $i$ is a number, indicating the sequence of the criteria input. After that the type of the optimum sought is written – “min” or “max”. Later on a digital coefficient with its sign is entered, followed by the name of the variable it concerns. The variables names can be arbitrary strings of letters and digits. 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 variables is defined by any of the symbols “<”, “<=” or “=”. By double clicking on an already entered constraint or criterion, they are transferred again to the editing field, if some corrections are necessary.

![MKO-2 Editor](image)

**Fig. 2**

Fig. 2 shows a screen of a linear integer multicriteria problem with three criteria, four constraints and four variables, described in chapter 1. In “MKO-2 Editor” window, the window “Variable Info” is opened with the help of Next button (Fig. 3), in which information is given about the type and the bounds of variables alteration. All the variables are of Integer type by default, with Lower Bound = 0 and Upper Bound = 1E + 24, which is accepted $\infty$. With the help of the two buttons Continue and Lower Bound = - INFINITY, the information about all the criteria can be automatically altered. The closing of “Variable Info” window and the storing of the corrections made is done pressing Accept button, after that “MKO-2 Solving” window appears.
In order to generate an initial feasible solution, the DM is offered two possibilities (Fig. 2). By the radio buttons group *Initial Solution, either Auto generated or Entered by user* is activated. In case the button for automatic generation (*Auto generated*) is activated, by the button the main window “MKO-2 Solving” of MKO-2 system is opened and the generated initial continuous solution is indicated. If the radio button *Entered by user* is activated, after pressing the button a window for setting the initial values of the criteria is opened and by the button these values are stored and “MKO-2 Solving” window is opened.

**5.3. Solving of multicriteria problems**

The solving of linear and linear integer multicriteria problems is realized with the help of 12 “MKO-2 Solving” windows, intended to work with the 12 interactive algorithms. Solving of linear and linear integer multi criteria problems is carried out with the help of 12 “MKO-2 Solving” windows, intended to work with the 12 interactive algorithms. The “MKO-2 Solving” window, shown in Fig. 6 is intended to work with a classification-based interactive algorithm, and in Fig.7 – for work with the reference point interactive algorithm. Every windows “MKO-2 Solving” is divided into several zones. In its upper part the band with the buttons is located, in which the main functions of the process of interactive solution of linear and linear integer multicriteria optimization problems are realized. These are the buttons:

- **Solve** – for starting optimization modules of MKO-2 system to find a new current solution by solving the scalarizing problem generated at this iteration;
- **Info** – for visualization of the variables values for the current solution in a separate window (Fig. 8);
- **Back** and **Forward** – buttons for navigation; they provide the DM the possibility to go backward to previous iterations or to go forward to next iterations and to review the current solutions found. In case the DM decides, he/she can alter the preferences set by him/her relating to the alteration of the criteria at any of the iterations and to start the process of a better solution search from there on;
- **Var Opt.** – opens a window, in which information about the type and bounds of the variables alteration is given (Fig. 3).
- **Preference information type.** – defines the type of the decision maker’s preferences at searching for new solutions (Fig. 4) and selection of a algorithm, oriented to such type of
preferences (Fig. 5). If the DM is troubled with the choice of a algorithm, one is automatically
selected representative for the given group of algorithms. The DM’s choice of his/her preferences
and the respective algorithm is done at the first iteration. The choice may be changed at each
iteration or over arbitrary number of iterations.

Fig. 4

Fig. 5

Fig. 6
Below the buttons band in “MKO-2 Solving” window, the radio buttons for selection of the type of the solution searched for are found: continuous, integer, the closest integer, as well as a weak Pareto optimal (weak non-dominated) or a Pareto optimal (non-dominated) solution. Below them information is given about the number of the iteration currently considered and the total number of executed iterations.

Two text fields follow, indicated in Fig. 6, which are for the window, corresponding to the classification oriented interactive algorithm DALDI. In the first field the values of the criteria obtained at the current iteration, are successively output. It is also a working field for setting DM’s preferences in the search for a next solution. When clicking on each one of the criteria with the mouse right button, a context menu is opened, where the DM defines the desired alteration in the values of this criterion for the next iteration. In case the selection is connected with the necessity to enter a certain value, MKO-2 system opens an additional dialogue window and waits for the input of the corresponding digital information.

In the second text field the scalarizing problem is visualized, during the solution of which the respective solution at the current iteration is found. This information could be useful for beginners and for persons working in the field of multicriteria optimization.

For the remaining 11 algorithms these two fields are of similar appearance.

When solving multicriteria optimization problems, it is important to provide information not only about the last solution found, but also about the solutions found at previous iterations. It is important that the DM could “testify” how he/she has reached the last solution.
Hence, the information about the interactive process of the multicriteria optimization problem solving, comprising not only the problem input data, the solutions obtained at each iteration, the preferences set by the DM for a new search and the scalarizing problems constructed, stored in “*.mlp” files associated with MKO-2 system serve not only to restart an interrupted solution process, but also for documentation. When turning back to “MKO-2 Editor” window and pressing Next button the information about the problem solution is lost.

6. Setups
The system setups of MKO-2 can be altered with the help of “Settings” menu, comprising three commands – “Global Variables”, “Language” and “File association”.

6.1. Language
The system interface can be used in two languages – Bulgarian and English. The language selected is indicated by the corresponding radio button.

6.2. Global variables
The global variables are service variables, used by the system. Their alteration requires very good knowledge of the algorithms used.

6.3. File association
By pressing the button “File association”, the working file is assigned an “*.mlp” extension.

7. View
With the help of “View” menu, additional information connected with the problem solved can be visualized.
7.1. Advisor

The "Advisor" command supplies help information about the visual components of MKO-2 system. After the selection of this option, "Advisor window" is opened and by the cursor movement on any visual element in this window of the system, an explanatory text appears.

7.2. Messages

Choosing "Messages" command, the window "Messages" is opened (Fig. 6). All the modules of MKO-2 system output service information about their operation in this window. The window content can be deleted or stored in a file by a context menu.

7.3. Graphics

Choosing "Graphic" command enables the visualization of two types of graphical information about the process of problem solution. For this purpose a window with two types of graphic is opened (Fig. 10).
With the help of the upper bar-graphic, visual comparison can be made of the solutions found at two iterations, selected in the fields below it for iterations selection. The lower graphic can trace visually the alteration of the values of the separate criteria at different iterations of the interactive process of search for a better solution. With the help of the selection buttons, the initial and the final iteration of the iterations interval are defined, in which the values of all the criteria are traced.

8. Help
After the selection of “Help” menu, a window of an Internet browser can be opened, which displays “User’s Manual” or information obtained by the system developers.

9. Printing
The printing of short or detail information about the problem currently solved is done with the help of “Print” command. A form is opened for selecting the information to be printed. The general view of the form is given in Fig. 11. Printing of information about the current step may be selected, or of all the intermediate steps of the process of multicriteria problem solution, also information about the separate scalarizing problems may be printed, about the criteria, the constraints, about the type and kind of the variables, as well as about the finite time for problem solution. Requirements about the quality of printing can also be set, the number of copies and the character style.

![Fig. 11](image_url)
10. Terms dictionary

Criteria – alterable or evaluable properties of the problems/processes discussed, which describe them to a great extent in the context of the problem considered. Synonyms: attributes, parameters, characteristics, factors, components and others.

Alternatives – a set of resources, strategies, projects, offers, policies, credits, products, inventions, designs, portfolios, etc. that must be evaluated in accordance with the criteria given with the purpose to select the best one.

Dominated alternatives – those alternatives, for which at least one other alternative exists, which is better than them with respect to all the criteria simultaneously.

Weak Pareto optimal or weak non-dominated alternatives – those alternatives, for which there do not exist other alternatives better than them in relation to all the criteria simultaneously.

Pareto optimal or non-dominated alternatives – those alternatives, for which there do not exist other alternatives better than or equal to them with regard to all the criteria simultaneously and at least for one criterion they are strictly better.

DM – a decision making person – in order to choose one alternative, additional information is needed, which is set by the person evaluating and selecting an alternative.

Interactive algorithm – the search for a better alternative is done in several steps. At each step the DM is presented the closest to his preferences alternative found and if it does not satisfy him/her, the DM defines again his/her preferences and passes to a new step.

Currently preferred alternative – the alternative selected by the DM at the current step.

Optimal solution – the best solution of a single criterion optimization problem.

Scalarizing problem – a single criterion optimization problem, the optimal solution of which is a weak Pareto or a Pareto optimal solution of the multicriteria problem.

Associated level – the criterion value, which has to be achieved according to the DM.