Multicriteria Decision Support System MOLIP

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Abstract: *The paper discusses a multicriteria decision support system, called MOLIP, which is designed to model and solve linear and linear integer problems of multicriteria optimization. The classification based algorithm, included in the system, is represented. The structure, the functions and the user's interface of the system are described.*
Keywords: *multicriteria optimization, multicriteria decision support systems, interactive algorithms.*

1. Introduction

The decision support systems (DSS) are defined [12] as interactive computer based systems, designed to aid and assist the decision maker (DM) in solving non-formalized or weakly formalized problems. The multicriteria decision support systems (MDSS), are a part of DSS intended to solve multicriteria decision making problems (MDMP). These problems [28] can be divided in two groups: problems of multicriteria optimization (MO) and problems of multicriteria analysis (MA). A finite number of explicitly given constraints defines an infinite number of feasible alternatives in the problems of multicriteria optimization. They are also called multicriteria problems for decision making with continuous alternatives. In multicriteria analysis problems a finite number of alternatives is explicitly set, usually in a tabular form. They are also known as multicriteria problems for decision making with discrete alternatives.

The multicriteria decision support systems developed [30] are classified in three groups: commercial, research or teaching and experimental (for new methods testing). Sometimes it is difficult to make a clear distinction between these groups. Some experimental MDSS can be successfully applied for research and learning purposes. The

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software realization and the documentation of many research or learning MDSS is very well accomplished, but offered free, without any commercial purpose. The status of the multicriteria decision support systems until 1996 is discussed in [30]. More than 40 systems are described which solve problems with continuous alternatives and problems with discrete alternatives as well. New experimental systems [25] or versions of old systems modified to work in Internet environment [13] have been developed in the recent years.

Among the well-known MDSS which solve problems of multicriteria optimization, the systems VIG [7], NIMBUS [11], DIDAS [9], CAMOS [19], LBS [5], DINAS [18], ADBASE [23], MOLP-16 [24], MONP-16 [24], MOIP [25], can be pointed out. Among the systems of multicriteria analysis, the Expert Choice [22], VIMDA [8], ELECTRE III-IV [21], PROMCALC [2], HIVIEW [20], AIM [18] and McView [27] systems are widely spread.

Each MDSS solving problems of multicriteria optimization contains control modules, interface modules and optimization modules. The optimization modules realize different muticriteria and single criterion algorithms. In most of the MDSS developed up to now, basic attention is paid to the interactive multicriteria algorithms. Two types of interactive multicriteria algorithms are included in these MDSS: The first type comprises interactive algorithms of the reference point and of the reference direction [29, 6]. These are MDSS systems such as DIDAS, VIG, CAMOS, DINAS, LBS. The second type of interactive algorithms includes classification based algorithms [1, 15, 16, 12]. These interactive algorithms are built in MDSS systems NIMBUS, MOLP-16, MONP-16, MOIP.

The control modules enable the execution of the optimization and the interface modules in the corresponding operating system. The first MDSS were developed to function in MS DOS operating system, while their next versions, and the new MDSS also, operate under the control of MS Windows operating system. Some MDSS, for example NIMBUS, operate in Internet environment already.

The data concerning the multicriteria problems and DM's preferences are entered with the help of interface modules and the output results are shown in text, numeric and graphic form. Since MDSS are interactive systems, the quality of the interface modules determines to a great extent the quality of MDSS themselves. In the systems developed up to now, the quality of the interface modules is paid the least attention. The new computer and operating systems, the new software languages and the new interactive multicriteria algorithms contribute to the significant progress in the quality of the interface modules and in the realization of a really friendly dialogue between MDSS and the DM.

An experimental MDSS, called MOLIP, is described in this paper. It is designed to solve linear (continuous and integer) problems of multicriteria optimization. The system operates under MS Windows operating system. The optimization modules in the system realize an interactive classification based multicriteria algorithm [26] and two single-objective algorithms. The first single-criterion algorithm [14] is designed to solve linear problems, while the second one – linear integer problems [17]. The interactive multicriteria algorithm allows the DM define not only the aspiration levels at each iteration, as it is in most of the interactive algorithms known up to now, but also set aspiration intervals and aspiration directions of change in the values of the separate criteria. In this way the DM can describe his wishes and preferences with greater precision, flexibility and reliability. This feature of the multicriteria interactive algorithms lies in the basis of the improved interface between the DM and MOLIP system while

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setting the DM's preferences. The other enhancements in the interface are connected with the entry and editing of the input data, with the representation of the current and final output results, with the possibility to return to non-dominated solutions, already found and to search for new solutions in other directions, with the graphical visualization of the process of multicriteria problem solution, with the possibilities to interrupt or restart the computing process, etc.

The paper is organized as follows. The second chapter shows the formal statement of the problems for linear and linear integer MO. The scalarizing problems used are described in the third chapter. The main features of the interactive classification based algorithm are given in the fourth chapter. The structure, the functions and the interface DM-MDSS are described in the fifth chapter.

2. Formal statement of the multicriteria problems

The linear integer problem of MO can be stated as follows:
(1)
$$\text{"max"}\{f_k(x)\}, k \in K,$$
under the conditions
(2)
$$\sum_{j \in N} a_{ij} x_j \leq b_i, i \in M,$$
(3)
$$0 \leq x_j \leq d_j, j \in N,$$
(4)
$$x_j - \text{integers}, j \in N,$$
where $f_k(x)$, $k \in K$, are linear criteria (objective functions), $f_k(x) = \sum_{j \in N} c_j^k x_j$, "max" denotes that all the objective functions should be simultaneously maximized; $x = (x_1, x_2, ..., x_j, ..., x_n)^T$ is the variables vector; $K = \{1, 2, ..., p\}$, $M = \{1, 2, ..., m\}$, and $N = \{1, 2, ..., n\}$ are the sets of the indices of the linear criteria (objective functions), of the linear constraints and of the variables respectively.

Problem (1)-(4) is a linear integer problem of MO. The constraints (2)-(4) define the feasible set of the integer variables alteration, which is denoted by X_1. Problem (1)-(3) is a linear problem of MO (with continuous variables). It can be regarded as a relaxation of the linear integer problem for MO. The feasible set of alteration of the continuous variables is denoted by X_2.

The following definitions are introduced for clarity:

Definition 1. The solution x is called an efficient solution of the linear integer problem of MO or of the linear problem of MO, if there does not exist another solution $\overline{x}$, for which the following inequalities are satisfied:

$$f_k(\overline{x}) \geq f_k(x), k \in K,$$

$$f_k(\overline{x}) > f_k(x) \text{ for at least one index } k \in K.$$

Definition 2. The solution x is called a weak efficient solution of the linear integer problem of MO or of the linear problem of MO, if there does not exist another solution $\overline{x}$ for which the following inequality is satisfied:

$$f_k(\overline{x}) > f_k(x), k \in K.$$

Definition 3. The vector $f(x) = (f_1(x), f_2(x), ..., f_p(x))^T$ is called a (weak) non-dominated solution in the criteria space, if x is a (weak) efficient solution in the variables space.

Definition 4. A close (weak) nondominated solution of the linear integer problem of MO is a feasible solution in the criteria space, obtained after solving an integer scalarizing problem with the help of an approximate (heuristic) algorithm.

Definition 5. A current preferred solution is a (weak) non-dominated solution of the linear integer problem of MO or of the linear problem of MO (or a close (weak) non-dominated solution of the linear integer problem of MO), if it has been selected by the DM at the current iteration. The most preferred solution of the linear integer problem of MO or of the linear problem of MO is a current preferred solution, satisfying the DM's requirements to the greatest extent.

The linear integer problems of MO and the linear problems of MO have not a mathematically well-defined optimal solution. That is why it is necessary to choose this one of the (weak) non-dominated solutions, which is the most appropriate with reference to DM's global preferences. This choice is subjective and it depends on the DM entirely.

3. Classification based scalarizing problems

The DM evaluates at each iteration the current (weak) nondominated solution of the linear integer problem of MO or of MO linear problem, or a near (weak) non-dominated solution of the linear integer problem of MO. In case the DM wants to seek a "better" solution, he/she sets his/her preferences concerning the desired or possible alterations in the values of some or of all the criteria. Depending on these preferences, the set of the criteria can be indirectly classified by the DM into seven or less than seven classes, denoted as: $K^{\geq}$, $K^{=}$, $K^{<}$, $K^{>}$, $K^{\leq}$, $K^{><}$ and K^0. Every criterion $f_k(x)$, $k \in K$, is supposed to belong to one of these classes, as follows:

$k \in K^>$ if the DM wishes improvement of the criterion $f_k(x)$;

$k \in K^{\geq}$ if the DM wants the criterion $f_k(x)$ to be improved by a desired (aspiration) value Δ_k;

$k \in K^<$ if the DM agrees the criterion $f_k(x)$ to be deteriorated;

$k \in K^{\leq}$ if the DM agrees the criterion $f_k(x)$ to be deteriorated by the maximal value δ_k;

$k \in K^{><}$ if the DM wants the value of the criterion $f_k(x)$ to lie in an interval, determined by the current value $f_k(x)$ and within defined limits ($f_k - t_k^- \leq f_k(x) \leq f_k + t_k^+$).

$k \in K^{=}$ in case the DM wishes the current value of the criterion $f_k(x)$ to be preserved;

$k \in K^0$ if the DM is not interested in the criterion $f_k(x)$ and this criterion can be arbitrarily changed.

In order to obtain a solution that is better than the current (weak) non-dominated solution of the linear integer problem of MO, the following Chebyshev's integer scalarizing problem E_1 can be applied on the basis of the implicit criteria classification, done by the DM [26]:

Minimize

(5) $S(x) = \max[\max(\bar{f_k} - f_k(x))/|f_k'| , \quad \max (f_k - f_k(x))/|f_k'|] + r\max(f_k - f_k(x))/|f_k'| ,$

under the constraints

(6) $f_k(x) \geq f_k, \; k \in K^{=} \cup K^>,$

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(7) $$f_k(x) \geq f_k - \delta_k, k \in K^\leq ,$$

(8) $$f_k(x) \geq f_k - t_k^-, k \in K^{><},$$

(9) $$f_k(x) \leq f_k + t_k^+, k \in K^{><},$$

(10) $$x \in X_1,$$

where f_k is the value of the criterion $f_k(x)$ in the current preferred solution, $\overline{f}_k = f_k + \Delta_k$ is the aspiration level of the criterion $f_k(x)$.

f_k' is a scaling coefficient,

$$f_k' = \begin{cases} \varepsilon, \text{if} \left| f_k' \right| \leq \varepsilon, \\ f_{k,} \text{if} \left| f_k' \right| > \varepsilon, \end{cases}$$

where ε is a small positive number, r is an integer number greater than or equal to one ($r = 1, 2, 3, ...$).

In order to obtain a better solution than the current (weak) non-dominated solution of MO linear problem, Chebyshev's continuous scalarizing problem E_2 can be applied, which is obtained from the integer scalarizing problem E_1 replacing constraint (10) by the following constraint:

(11) $$x \in X_2.$$

Since the objective function (5) of the integer-scalarizing problem E_1 is a non-differentiable function, the following equivalent problem [28] of mixed integer programming E_1' can be solved instead of it:

(12) $$\min(\alpha + r\beta)$$

subject to the constraints:

(13) $$\alpha \geq (\overline{f}_k - f_k(x))/|f_k'|, k \in K^\geq,$$

(14) $$\alpha \geq (f_k - f_k(x))/|f_k'|, k \in K^< \cup K^\leq,$$

(15) $$\beta \geq (f_k - f_k(x))/|f_k'|, k \in K^>,$$

(16) $$f_k(x) \geq f_k, \ k \in K^= \cup K^>,$$

(17) $$f_k(x) \geq f_k - \delta_k, k \in K^\leq ,$$

(18) $$f_k(x) \geq f_k - t_k^-, k \in K^{><},$$

(19) $$f_k(x) \leq f_k + t_k^+, k \in K^{><},$$

(20) $$x \in X_1,$$

(21) $$\alpha , \beta - \text{arbitrary}.$$

Problems E_1 and E_1' have similar feasible sets of the variables. The values of their objective functions for their optimal solutions are equal.

Instead of a continuous scalarizing problem E_2 the objective value of which is also a non-differentiable function, an equivalent problem of linear programming E_2' can be solved. It is obtained from problem E_1' replacing constraint (20) by the constraint:

(22) $$x \in X_2.$$

Let us assume that a (weak) non-dominated solution of the linear problem of MO is found, solving scalarizing problem E_2' and that we would like to find a (weak) non-

dominated solution of the linear integer problem of MO, near to a (weak) non-dominated solution of the linear problem of MO. Let us denote the (weak) non-dominated solution of MO linear problem by $\hat{f} = (\hat{f}_1, ..., \hat{f}_p)^T$. In order to find a (weak) non-dominated solution of the linear problem of MO, the following problem [17] of mixed integer programming E_3' can be used:

(23)
$$\min \alpha$$

subject to constraints:

(24)
$$\alpha \geq (\hat{f} - f_k(x))/|f_k'|,$$

(25)
$$x \in X_1,$$

(26)
$$\alpha - \text{arbitrary.}$$

(Weak) non-dominated solutions of MO linear integer problems and of MO linear problems are found with the help of the single criterion problems E_1' and E_2' respectively. If the will is to obtain non-dominated solutions only, problems E_1'' and E_2'' could be solved, which are modifications of problems E_1' and E_2'. Problem E_1'', with the help of which non-dominated solutions of MO linear integer problems are found, has the following form:

(27)
$$\min \left(\alpha + r\beta + \rho \sum_{\substack{k \in K^> \cup K^\geq \cup \\ K^< \cup K^\leq}} y_k \right)$$

under constraints (13)-(21) and additional constraints:

(28)
$$\bar{f}_k - f_k(x)) = y_k, k \in K^\geq,$$

(29)
$$f_k - f_k(x) = y_k, k \in K^> \cup K^< \cup K^\leq,$$

(30)
$$y_k - \text{arbitrary}, \quad k \in K^> \cup K^\geq \cup K^< \cup K^\leq,$$

where ρ is an arbitrarily small positive number.

Problem E_2'', used to find non-dominated solutions of MO linear problems, has the same form as problem E_1'', but constraint (20) is replaced by constraint (22).

4. Classification based interactive algorithm

The interactive algorithm, included in the optimization modules of MOLIP multicriteria decision support system, is developed on the basis of the classification based linear scalarizing problems E_2', E_2'' and also on the basis of the classification based linear integer scalarizing problems E_1', E_1'', E_3'. That is why it is called classification based interactive algorithm. This interactive algorithm enables the solution of MO linear and linear integer problems. The linear scalarizing problems E_2', E_2'', are easy solved (P problems) [4], and the linear integer problems E_1', E_1'', E_3' are hard solved (NP problems) [4]. In connection with this, when solving linear integer problems of MO, especially at the beginning phases of DM's learning, it is possible to use relaxed MO linear problems.

The continuous non-dominated solutions, obtained in the general case, are near to the corresponding integer non-dominated solutions with respect to the criteria values.

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The DM can use these continuous non-dominated solutions for learning and only in separate cases for seeking the closest integer non-dominated solution. In this case the dialogue with the DM during the solution of MO linear integer problems can be considerably improved relating to the time for current solutions obtaining.

The interactive algorithm for solving the MO linear and linear integer problems has the following basic steps:

Step 1. Finding an initial (weak) non-dominated solution of MO linear problem by setting $\underline{f}_k = 1, \bar{f}_k = 2$, $k \in K$, and solving problem E_2'.

Step 2. An inquiry is made to the DM to define the desired alterations in the criteria values compared to the current non-dominated solution, i.e. to define the aspiration levels, the aspiration directions of change and the aspiration intervals of alteration in the values of some or of all the criteria.

Step 3. A question to the DM concerning the type of the solution searched for – weak non-dominated or non-dominated. Solving scalarizing problems E_2' or E_2'' respectively.

Step 4. Representing to the DM of the (weak) non-dominated or non-dominated solution found for evaluation and selection. If he/she approves the solution found as the most preferred solution – STOP; otherwise – go to Step 2.

The main steps of the interactive algorithm when solving linear integer problems of MO, are the following:

Step 1. Finding an initial (weak) non-dominated solution of the linear relaxation of MO integer problem by setting $\underline{f}_k = 1, \bar{f}_k = 2$, $k \in K,$ and solving problem E_2'.

Step 2. A question to the DM concerning the aspiration levels or the aspiration directions of change or the aspiration intervals of alteration in the values of some or of all the criteria with respect to their values in the current preferred solution.

Step 3. In case the DM wants to look for a continuous solution, Step 5 is executed.

Step 4. If the DM wants to seek a near (weak) non-dominated integer solution, Step 6 is executed, if the DM intends to look for a (weak) non-dominated integer solution, Step 7 is executed; otherwise – Step 8.

Step 5. If the DM wants to search for a (weak) non-dominated solution, problem E_2' is solved; otherwise – E_2''. In case the DM does not want to see an integer solution close to the current solution found, Step 2 is executed. Otherwise – problem E_3' is solved. If the DM approves the solution found as the most preferred solution – STOP; otherwise – go to Step 2.

Step 6. The approximate scalarizing problem E_1' is solved. In case the DM confirms the solution found as the most preferred solution – STOP; otherwise – go to Step 2.

Step 7. Scalarizing problem E_1' is solved. In case the DM approves the (weak) non-dominated solution found as the most preferred solution – STOP; otherwise – go to Step 2.

Step 8. Scalarizing problem E_1'' is solved. In case the DM accepts the non-dominated solution obtained as the most preferred solution – STOP; otherwise – go to Step 2.

The interactive algorithm described is oriented towards learning [3] and the DM controls the dialogue, the computing process and the interrupt conditions. Linear single-criterion problems can be solved (problems E_2' and E_2'') at most of the iterations and the

DM does not have to wait too long to obtain and to evaluate new solutions. Integer single criterion problems (problems E_1', E_1'', E_3') are also being solved. They are solved when the DM does not feel comfortable to work with continuous variables or when he/she wants to find an integer solution, close to the current preferred continuous solution.

When the DM solves MO linear problems, he/she obtains and evaluates continuous solutions only. When the DM solves linear integer problems of MO, he/she obtains and evaluates both continuous and integer solutions. Approximate single- criterion scalarizing problems can also be solved while seeking current integer solutions.

The DM operates in the criteria space mainly, because in most of the cases the criteria have physical or economic interpretations and this enables a more realistic evaluation and selection of the solutions.

5. Structure, functions and user's interface

MOLIP multicriteria decision support system 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, saving, linking and executing different types of files. The basic functional possibilities of the control program can be divided in three groups. The first group includes possibilities to use some resources of MS Windows operating system in the program environment. The second group of control program functional facilities includes the possibilities to use some modules in this environment, which realize the following operations:

– creating, modification and saving of files, containing the description of MO linear and linear integer problems;

– interactive solution of the linear and linear integer MO problems which have been entered;

– localization of errors during the entry and solution of MO linear and linear integer problems.

The third group of the control program functional features consists of the possibilities for visualization of important information concerning the DM and the system operation as a whole.

The control program is developed in Multy Document Interface style, which means that it has one basic form, containing the main menu, and all the other forms are its "daughter" forms. Different daughter forms can be simultaneously visualized. In order to communicate with the libraries for dynamic connection of different single-criterion optimization modules, the independent "Csolver" class is applied, which is in fact a data processor. The class contains modules for data input, output data obtaining and execution of the corresponding set ups for the type of the variables and the type of the solution required. It works on the principle of a black box – an optimization problem in a given format and syntaxes is set at its input as a parameter, then syntaxes analysis is implemented, the names and the type of the variables (continuous/integer) are defined, the type of the solution (continuous/integer) is also defined and the optimization problem is transformed into a format required by the corresponding single-criterion optimization module. The information about the solutions obtained is saved in the output points of the class, from where it can be obtained.

Another main class, used by the control program, is "CHistory" class. The purpose of this class is to create a structure, in which the results obtained at every iteration of the interactive algorithm, are saved – the criteria and variables values, the requirements set by the DM and the scalarizing problem used at the current iteration. This enables the interruption and the restarting of the interactive process during each multicriteria problem solution from the place of interruption. The DM has also the possibility to go back and to seek solutions in another direction and with other preferences.

The interface modules realize the dialogue between the DM and MOLIP 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.

The descriptions of the linear and linear integer MO problems the DM wants to solve, are entered, altered and saved with the help of the editing module. The window of the editing program for one test example, denoted by T1 (three criteria, three constraints and four variables) is shown in Fig. 1.

The description of the linear and linear integer MO problems is done in a text form. Each criterion and each constraint is entered or corrected separately in editing
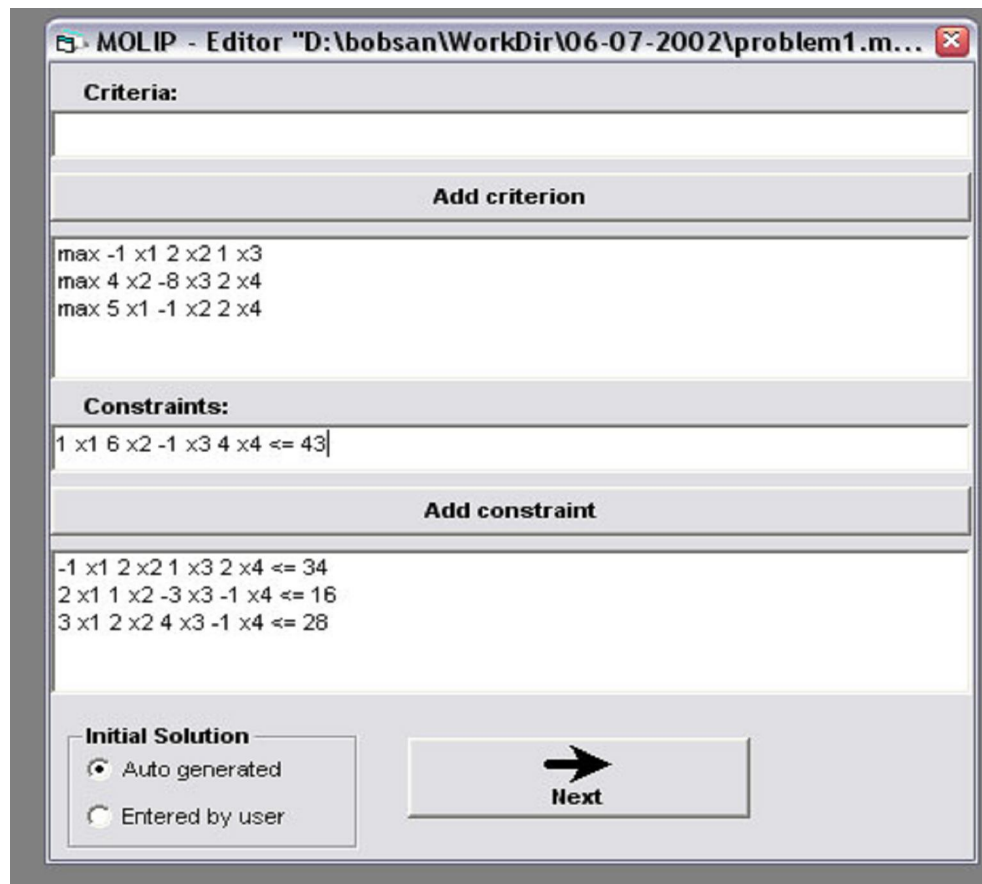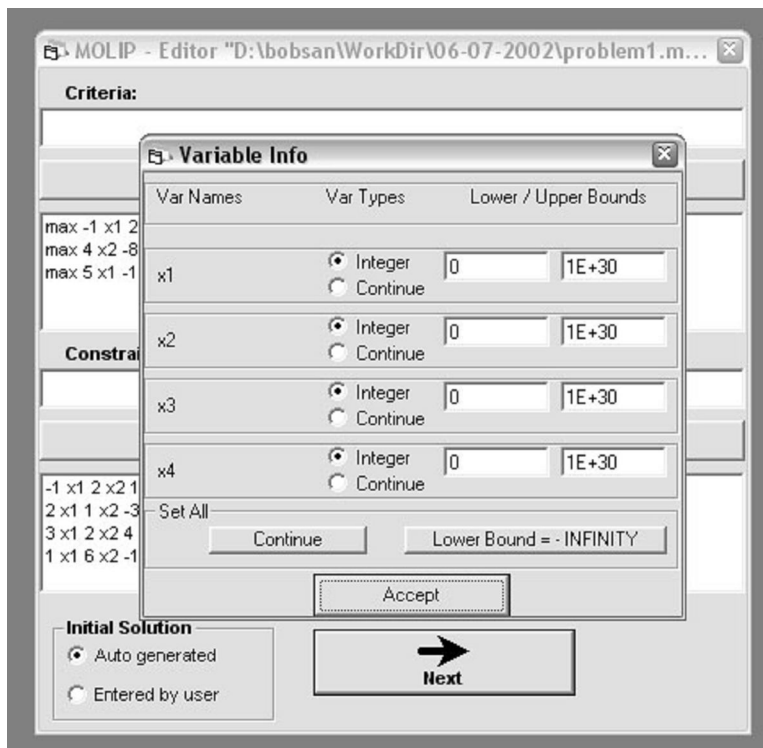

Fig. 1

Fig. 2

text fields, simultaneously realizing a syntaxes check according to editor requirements. After that the criteria and the constraints are saved in separate text fields. After the entry and correction of the criteria and the constraints, the type and the alteration range of a part or of all the variables, is defined. A possible description of the four variables for example T1 is shown in Fig. 2.

The linear and linear integer MO problems are interactively solved with the help of the optimization modules. A better continuous or integer (weak) non-dominated solution or a non-dominated solution is found at defined DM's preferences (automatically at the beginning) with the help of the optimization module, realizing a classification based interactive algorithm. The results from the computations appear in two windows, as shown in Fig. 3.

The left window is selective and it shows detail information about the algorithm operation (the current scalarizing problem construction and its solution with the help of a single-objective linear or integer algorithm). The second window contains the values of the criteria in the new solution found and the type of the scalarizing problem being solved. There are different functional buttons on this window. "Solve" button starts the solution of a new problem. "Info" button is used to show the values of the variables and of some special parameters as well.

The numeric information obtained at different steps of the computing process can move back and forth with the help of "Back" and "Forward" buttons. The DM can see the graphic visualization of the computing process, activating "Graphic" button. The remaining buttons on the first row have additional functions.

The activating of "Solve" button before the computing process defines, if necessary, the type of the new solution - integer or continuous; weak non-dominated, non-dominated or close to a weak non-dominated solution; integer solution, near to a continuous solution.
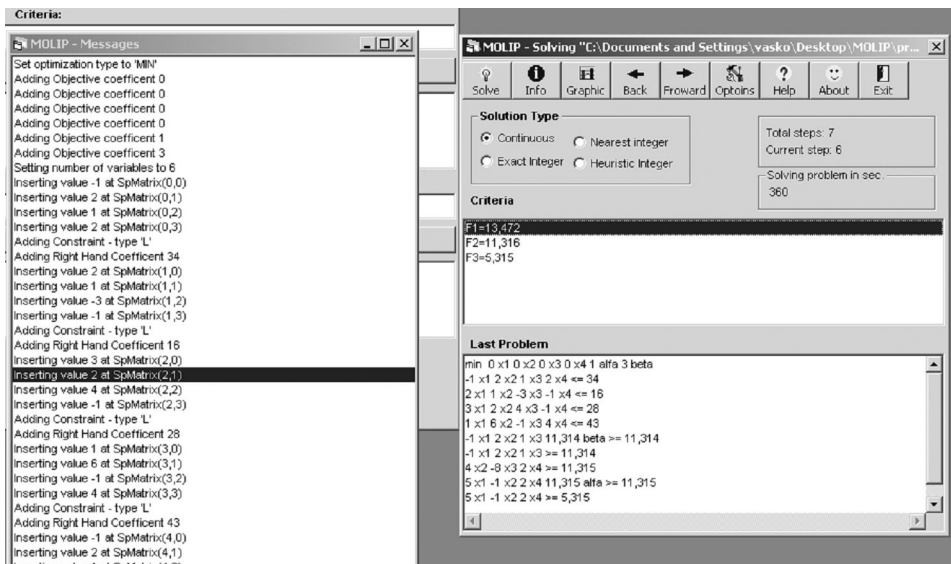
Fig. 3

The selection of new preferences for each criterion is made, marking the desired criterion and clicking twice on the mouse right button. A submenu appears, in which the DM can choose one out of nine possibilities. In Fig. 4 the DM has chosen his preferences for the first two criteria and at the moment he/she has to select his preference for the third criterion.
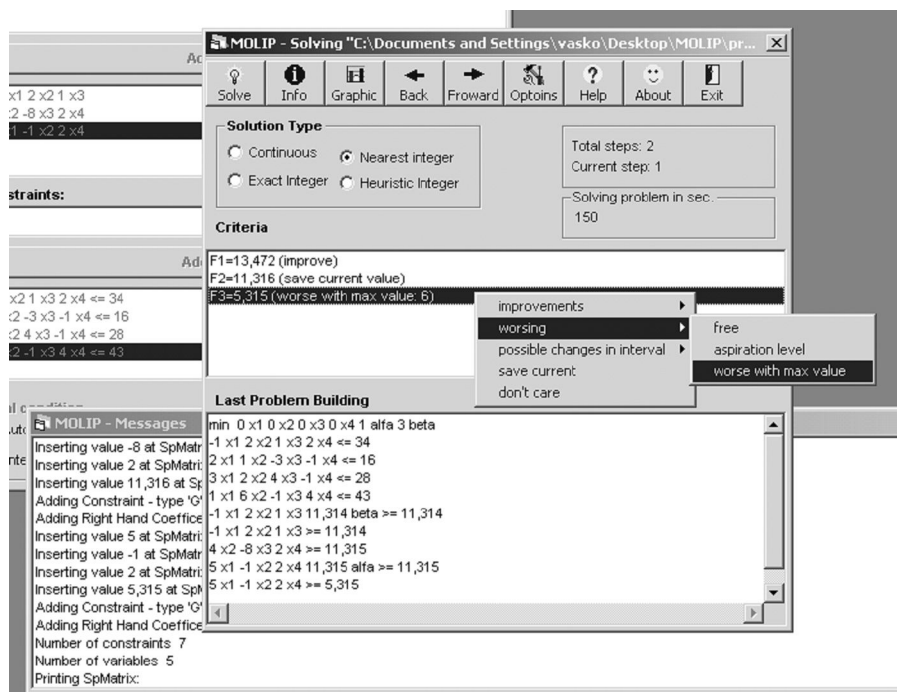

Fig. 4

The linear and linear integer MO problems entered in MOLIP system are saved in files. All the steps of the computing process are also saved in these files during the interactive solution. This enables the interruption of problems solution and after a while their restarting (from the place of interruption), which is particularly important for the linear integer problems, which require significant time for their solution sometimes.

6. Conclusion

The multicriteria decision support system MOLIP is designed to model and solve linear and linear integer problems of multicriteria optimization. The interactive classification based algorithm included in the system offers the DM wide possibilities to set his/her preferences about the quality of the most preferred solution. The user- friendly interface of MOLIP system facilitates the operation of decision making persons of different qualification level relating to the optimization methods and software tools used. MOLIP system can be used for the purposes of education and for experimental and research problems solving as well.

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Система за подпомагане вземането на решения при много критерии MOLIP

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(Р е з ю м е)

Разглежда се система за подпомагане вземането на решения при много критерии MOLIP, предназначена за моделиране и решаване на линейни и целочислени линейни задачи на многокритериалната оптимизация. Представен е класификационно-ориентиран алгоритъм, включен в системата. Описани са структурата, функциите и потребителския интерфейс на системата.