VOL. 10, NO. 16, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MULTI-CRITERIA OPTIMIZATION OF THE OPERATION OF CONTROL SYSTEMS OF MOVING OBJECT UNDER UNCERTAINTY

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ABSTRACT

The articleis devoted to mobile object control system functioning multicriteria optimization in the uncertainty conditions. Complex system work quality is defined by vector criterion. Autonomous navigation productivity function assessment criteria for the position and trajectory management systems are set in the form of fuzzy functions (values). Pareto’s method is applied to optimality assessment. The optimization method on the basis of the complexity principle is considered and approach to the assessment of the received Pareto-optimal fuzzy solutions using usefulness assessment of the received solution is offered. The algorithm of the valuation method of the Pareto-optimal solution taking into account usefulness is developed. Information support is developed for search of the Pareto-optimal solution. The work description with information support is provided.

Keywords: decision-making, optimization, uncertainty, fuzzy interval, solution usefulness estimates, information support, position and trajectory management systems, mobile objects.

1. INTRODUCTION

Any complex systems work quality is defined by many criteria. Criteriaare setfor different basic sets. For multicriteria efficiency functioning determination of position and trajectory, management systems are applied different approaches. Many methodsare based on local criteria ranging by experts. Vector criterion scalarization is ranging methods [1] are applied. These methods are modified for fuzzy local criteria task $\tilde{F}_1, \tilde{F}_2, ..., \tilde{F}_m$ [2].In the conditions of incompleteness of data the relation allows to set criteria rangings $< F, \tilde{Q} >$ (generally fuzzy) on set of criteria *of F*= {*f1*,*f2*, …,*fm*}, $\tilde{Q}$ diagram of the relation [3].

Criteria application is connected with the achievement of goals of functioning of position and trajectory management systems. Optimum system performance is estimatedon a set of criteria values for the input variables area. For multicriteria systems, optimality assessment has well proved Pareto's method [2 6].

This article materials relevance locates the following provisions. Systems functioning Optimization by many criteria is necessary for the solution of tasks in different areas (technical, economic or social). Optimization is connected with search of the managing influences providing best criteria functions values [7]. Actual is algorithm elaboration and information support problem of Pareto-optimal search solution at the task of fuzzy criteria set or using a linguistic variable, or using fuzzy intervals.

2. A SEARCH OF THE FUZZYPARETO-OPTIMAL SOLUTION

Set of fuzzy criteria $\tilde{F}_1, \tilde{F}_2, ..., \tilde{F}_m$ are set either using linguistic variable or fuzzy intervals [2]. At the verbal level fuzzy criterion $\tilde{F}_i$ is set in look:

$$<f_i, T(f_i), X_i, G, M>, \; i = \overline{1,n}, \quad (1)$$

where f_i name i-th of criterion; $T(f_i)$ term set containing fuzzy variables for the description of f_i criterion; X_i - $f_i$criterion definition range; G - syntactic rule; M - semantic rule.

In autonomous navigation and bypass of obstacles characteristic performance criterions can be following [8-10]:

a) The safety indicator (the minimum distance) is the minimum distance between any sensor and any obstacle on all trajectories. This index measures the maximum risk accepted during all mission [11, 12].
b) Movement trajectory length: the trajectory all way length covered with a mobile object from starting point to the purpose [13].
c) Runtime of the task is the time necessary for mission completion. If the mobile object moves at constant linear velocity (V), it gives an idea of time, necessary for completion of mission [14].
d) Trajectory smoothness is a function of the curvature used for assessment of smoothness of the mobile object movement [15].
e) Mission success: successful missions’ numbers in not determined environments with difficult obstacles [16].

VOL. 10, NO. 16, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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At accurate criteria, task $f_i,\ i=\overline{1,m}$ applies themethod of threshold optimization to a search of the Pareto-optimal solution [17, 18-21]. For each criterion *of* f_i set restrictions *of* d_i. By search define the first rank criterion and find its maximum. The maximum values of other criteria define taking into account restriction.

$$f_i(x_i) \geq d_i(x_i), \quad i=\overline{1,m}. \tag{2}$$

The optimization method on the basis of the complexity principle is known [2]. In method the decision-making concept on expanded sets and complexity assessment, and also statements is applied:

- the solution belongs to Pareto's area;
- exists and is the only Pareto-optimal solution of the task

$$f^{(1)}(x_1) \to max, \quad f^{(i)}(x_i) \geq d^{(i)}(x_i), \quad i=\overline{2,m}; \tag{3}$$

- the set of criteria *of* $F=\{f_1, f_2, \ldots, f_m\}$ at the stage of problem definition can be added to any criterion *of* f_{m+1}that defines the completeness of the system of criteria and heuristic nature of their forming;
- the task with restrictions (2)generates *m* of the interfaced problems of threshold optimization with the same restriction that allows to simplify the search of the Pareto-optimal solution due to solution searchprocedure using the minimum complexity principle.

The principle of the minimum complexity [3] is as follows. For tasks with restriction (2) complexity is defined by the complexity of the algorithm. Complexity is estimated for each interfaced task indicator $W_t^k,\ \ k=\overline{1,m}$, where *t* – time of solution, *k* - number of the interfaced task. The predicted time of solution of each interfaced task allows to select task r that will have the smallest indicator $W_{t\,min}^r$. The complexity assessment problem has the approximate solution.

The task with restrictions (2) generates *m* of the threshold optimization interfaced problems. Thus, at worst the analysis of these *m* of options of the received fuzzy Pareto-optimal solutions is necessary.

In the theory of decision-making [17, 18, 21] methods, solutions of tasks in the conditions of incomplete determinacy are proposed (in the terms of risk). On the basis of known provisions, the following approach to the assessment of the received Pareto-optimal fuzzy solutions is offered.

Let's define *i-th* candidate solution of the interfaced problem of threshold optimization as W_i. To set of options $W=<W_1, W_2,\ldots, W_m>$ have compared in the expert way efficiency assessment (numerical or verbal) from set *of* $E=<E_1, E_2,\ldots, W_h>$. Experts set compliance $<W,E, Q>$, *Q* – the diagram of this compliance (see Table-1).

Table-1. The compliance diagram "option assessment."

W	**E**			
	E_1	E_2	…	E_h
W_1	$\tilde{z}_{11}$	$\tilde{z}_{12}$		$\tilde{z}_{1h}$
W_2	$\tilde{z}_{21}$	$\tilde{z}_{22}$		$\tilde{z}_{2h}$
…	…	…	…	…
W_m	$\tilde{z}_{m1}$	$\tilde{z}_{m2}$	…	$\tilde{z}_{mh}$

By experts, it is set at the intersection of line i and column j, $\tilde{z}_{ij}=<\underline{z}_{ij},\overline{z}_{ij},\alpha_{z_{ij}},\beta_{z_{ij}}>$ usefulness fuzzy assessment i of candidate solution of the interfaced task to E_j efficiency value.

At making a decision on the final choice of candidate solution *of* W_i by experts considered the possible system status, determined by ordered set *of* $S=<S_1, S_2,\ldots,S_d>$. Statuses*of Sj* are defined by a fuzzy number $\tilde{p}_j=<p_j,\alpha_{p_j},\beta_{p_j}>$ on rating scale (0, 1). Experts have defined a set of estimates of system status in the form of fuzzy points $\tilde{p}_l^s=<p_l^s,\alpha_{p_l^s},\beta_{p_l^s}>$.

Degree of accessory of the best, from the point of view of the expert, option of the Pareto-optimal solution is determined in the form of fuzzy interval by formula:

VOL. 10, NO. 16, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

$$\max_{W_i}\left[\sum_{j=1}^{h}\sum_{l=1}^{d}\tilde{z}_{ij}\otimes\tilde{p}_j\otimes\tilde{p}_l^s\right]=\max_{W_i\in W}\tilde{E}(W_i(x)), \qquad (4)$$

where⊗- triangular norm (T-norm), which we will accept, as the logical product it agrees with Zadie.

If the system status and external environment cannot be evaluated previously, definition of degree of accessory of the best option of the Pareto-optimal fuzzy solution on formula is offered (for the example of Wald's criterion [18,19]):

$$\max_{W_i\in W}\ \min_{S_l\in S} x=\sum_{j=1}^{h}\tilde{z}_{ij}\otimes\tilde{p}_j,\ \ i=\overline{1,m},\ \ l=\overline{1,d}\ . \qquad (5)$$

The assessment (5) will allow defining option of the most effective at the worst system status and external environment of the Pareto-optimal fuzzy solution.

As an analog, it is possible to take criterion of Sevidzh [2] for assessment of the best option of the Pareto-optimal fuzzy solution. Let's define the fuzzy intervals matrix defining assessment of usefulness of the selected option of the Pareto-optimal fuzzy solution:

$$U=\left|\tilde{u}_{il}\right|,\ \ \tilde{u}_{il}=\sum_{j=1}^{h}\tilde{z}_{ij}\otimes\tilde{p}_j,\ \ i=\overline{1,m},\ \ l=\overline{1,d} \qquad (6)$$

The assessment of usefulness is executed on the basic great number *of X*, $x_i \in X$, $x_i \in [0, 1]$. In each *l* column such fuzzy interval is defined $\tilde{u}_l^{max}$, that $\tilde{u}_l^{max}=\max_i \tilde{u}_{il}$, $\tilde{u}_{il}=<\underline{u_{il}},\overline{u_{il}},\alpha_{u_{il}},\beta_{u_{il}}>$. The greatest value is selected from the analysis of upper modal values $\overline{u_{il}}$ and right coefficients of illegibility $\beta_{u_{il}}$. Maximum, it is considered fuzzy interval, at which greatest value $\overline{u_{il}}$. At fuzzy intervals coincidence, the preference will be given to fuzzy interval with great value $\beta_{u_{il}}$. The value $\tilde{u}_l^{max}$ is defined as the greatest usefulness of the selected options of the Pareto-optimal fuzzy solution.

At Sevidzh criterion application, the concept of regret is entered. That value is equal to the change of result usefulness at this system status concerning the best possible status. For usefulness assessment in the aspect of the analog criterion of Sevidzh, we will create a matrix of "regrets."

$$U_C=\left|\tilde{u}_{ilc}\right|,\ \ \tilde{u}_{ilc}=\tilde{u}_{il}\simeq\tilde{u}_l^{max},\ \ i=\overline{1,m},\ \ l=\overline{1,d} \qquad (7)$$

The final decision on Pareto-optimal fuzzy solution options choice is defined from condition

$$\min_{S_l} x\ \ \max_i \tilde{u}_{ilc},\ \ \tilde{u}_{ilc}=<\underline{u_{ilc}},\overline{u_{ilc}},\alpha_{u_{ilc}},\beta_{u_{ilc}}> \qquad (8)$$

To develop theoretical recommendations, which estimates what (4) (8)should be applied, it is not possible owing to lack of any formalization therefore check has to go empirical way using the corresponding information support. The algorithm of the valuation method of the Pareto-optimal solution taking into account usefulness is shown in Figure-1.

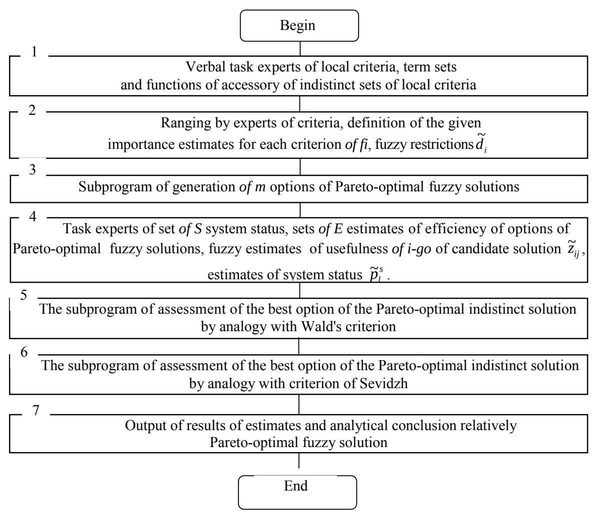

Figure-1. The valuation method algorithm of the Pareto-optimal solution taking into account usefulness.

The subprogram of a generation of *m* of options of Pareto-optimal fuzzy solutions implements the following rules of optimization.

The fuzzy criterion is maximized $\tilde{f}_1(x_1)$ taking into account restriction $\tilde{f}_1^{max}(x_1)\tilde{\geq}\tilde{d}_1$. Then the maximum for the fuzzy criterion is defined $\tilde{f}_2(x_1)$ taking into account restriction $\tilde{f}_2^{max}(x_2)\tilde{\geq}\tilde{d}_2$. If restriction condition $\tilde{f}_2^{max}(x_2)\tilde{\geq}\tilde{d}_2$ it is not executed, criterion maximum $\tilde{f}_1^{max}$ worsens on concession value $\tilde{\Delta}_{f^{(1)}}=<\underline{f^{(1)}},\overline{f^{(1)}},\alpha_{f^{(1)}},\beta_{f^{(1)}}>$. Then this procedure is executed consistently for other criteria $\tilde{f}_3(x_3),\tilde{f}_4(x_4),...,\tilde{f}_m(x_m)$. The W_1 option of the

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Pareto-optimal fuzzy solution will be as a result received.

The W_2 option of the Pareto-optimal fuzzy solution will be received if in the beginning maximizing fuzzy criterion is executed $\widetilde{f}_2(x_2)$ taking into account restriction $\widetilde{f}_2^{max}(x_2) \tilde{\geq} \widetilde{d}_2$, and then will be executed maximizing fuzzy criteria $\widetilde{f}_1(x_1), \widetilde{f}_3(x_3),..., \widetilde{f}_m(x_m)$.

The W_3 fuzzy solution option will be received at initial maximizing fuzzy criterion and the subsequent maximizing fuzzy criteria $\widetilde{f}_1(x_1), \widetilde{f}_2(x_2), \widetilde{f}_4(x_4),..., \widetilde{f}_m(x_m)$, etc.

3. INFORMATION SUPPORT FOR THE SEARCH OF THE PARETO-OPTIMAL SOLUTION [2]

The Pareto optimum tab provides the functionality for search of the Pareto-optimal solution. Its look is given in Figure-2.

The program window, in this case, shares in some areas. The first area contains the list of criteria. To the right of the list of criteria, there are fields where fuzzy intervals optimum and critical values for the criterion selected from the list are entered. This information is used it is necessary for a search of the solution therefore it is necessary to fill them for each criterion in the list and to do it rather precisely. Below the list of criteriais located, the parameter list for which optimization is made.

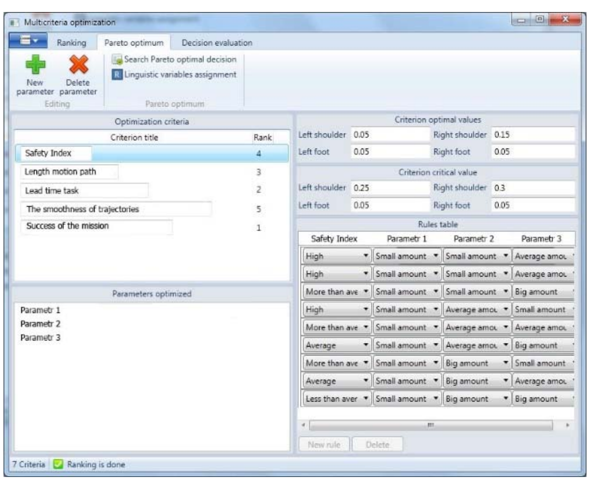

Figure-2. Type of the Ranging tab.

The right lower part of the programwindowis occupied by look-up table of values of parameters of the selected criterion value. The table is the base of fuzzy rules whereas input variables it is possible to consider the optimized parameters, and a day off - the selected criterion. The rule can be added clicking of the "Add" button under the table to the table. The rule can be deleted, having selected the necessary rule and having clicked "to Delete". When adding in the table the rule is empty and does not contain any statements.

Criteria and parameters are linguistic variables, and their values - fuzzy variables, available to choice in the Table. They can be set in the Linguistic variables assignment window that opens by clicking the corresponding button on tape. The type of window is given in Figure-3. Fuzzy variables can be added and deleted, their names are editable.

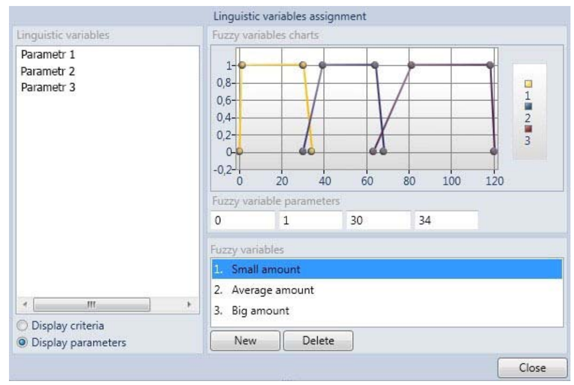

Figure-3. Linguistic variables task window.

After introduction of parameters, optimum and critical intervals for criteria, and also fillings of a full rule base for each of criteria the program runs for search of solution and presents it in the form of the following window shown in Figure-4.

In the right part of window the parameter list for which best values are found, at the left - graphic display of optimum in the form of fuzzy interval with the coordinates of points of interval designated on horizontal axis is located.

For assessment of the Pareto-optimal solution taking into account usefulness the Decision evaluation tab serves. When this tab is active, the application window looks as is shown in Figure-5.

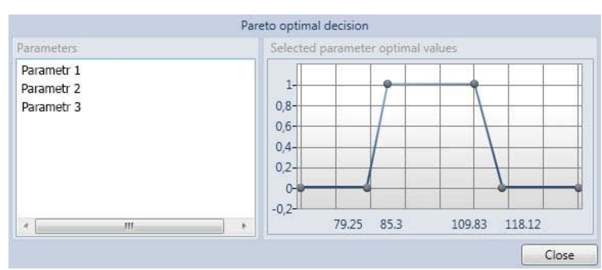

Figure-4. Window of search result of the Pareto-optimal solution.

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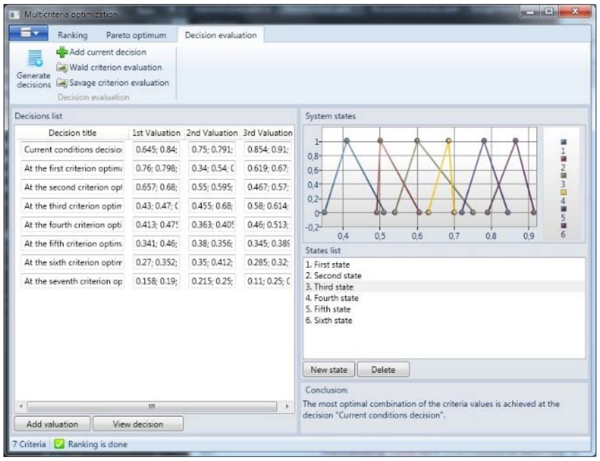

Figure-5. Type of the solution assessment tab.

In the interface, three parts are selected: the list of solutions, data on system status and output about the choice of the best of the present solutions. The list of solutions occupies the left half of window and contains expert estimates of the efficiency of these solutions. Lines are added to the list by clicking or the Generate decisions buttons on tape, or the Add the Current Solution buttons. When clicking the Generate Solutions button the solutions received in aspiration to maximize each of criteria are added to the list (the quantity of the added solutions corresponds to the amount of criteria). When clicking the Add current decision button, the only solution received with the purpose to have the maximum benefit in a combination of values of criteria according to their priorities is added.

It is possible to look at any of solutions, having used the View decision button under the table. The solution is displayed in the form of fuzzy intervals of values for parameters and intervals of values of the criteria reached this status of parameters.

The list of system status with graphic display of these statuses in the form of triangular functions of accessory is in the right part of the window. The diagram displaying system status is interactive. Statuses can be added, deleted, and their names are editable.

The output about choice of the best of solutions is in the right lower part of window and is accepted after assessment of all solutions and input of system status on clicking of the button of "Wald criterion valuation" or the Wald criterion valuation button.

4. CONCLUSIONS

In the modified methodof fuzzy threshold optimization search of the Pareto-optimal solution is carried out after definition of fuzzy criterion of the first rank, finding of its maximum and determination of the maximum values of other criteria taking into account the introduced fuzzy restrictions. The method is developed for assessment of the efficiency of the found solutions using expert estimates. At estimates can be applied as analogs, Wald, Gurvits, Laplace's known criteria Sevidzh, which look it is modified taking into account task of parameters in the form of fuzzy intervals. The algorithm of the valuation method of the Pareto-optimal solution is developed for position and trajectory management systems by mobile objects taking into account usefulness.

Information support is developed for search of the Pareto-optimal solution and complex assessment of the efficiency of functioning of position and trajectory management systems by mobile objects. The main interface windows are given. The application of information support for complex assessment of efficiency of functioning of system allowing to receive at verbal determination of key parameters of functioning of management systems mobile objects the decision about quality of work of management systems as mobile objects is considered.

Materials of the articleare prepared within the execution of research work No. 213.01-07-2014/02PChVG of the Southern Federal University.

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