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DECISION SUPPORT SYSTEM FOR SOLVING MULTICRITERIA PROBLEMS IN THE ANALYSIS OF COMPLEX SYSTEMS

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Abstract. *The paper describes a decision support system for solving multicriteria problems during the analysis of complex systems, in the case where a finite set of alternatives whose characteristics are given in tabular form is considered. It is based on the analysis of the phasing of such studies whose results determine the requirements for the types of problems to be solved with its use and the list of methods that are expedient to implement. The considered decision support system is designed to solve problems under certainty, as well as stochastic and non-stochastic uncertainty. In accordance with the main stages of the analysis of complex systems, it implements a number of multicriteria methods that allow assessment of relationships between the factors associated with its operation, determine the importance of the indicators that characterize it, generate a priority series of the considered alternatives, or form the kernel of alternatives that are promising for further research.*

Keywords: *alternative, multicriteria decision making, kernel generation method, ranking method.*

INTRODUCTION

Today, the main approach to the analysis of any systems is the systematic approach. Its feature is that, on the one hand, the system under study is considered as a set of interconnected elements, and on the other hand, it is considered as a component of a higher-level system.

It should be noted that the main advantages of a systematic approach are manifested in the study of complex systems characterized by a sufficiently large number of indicators considered, the complexity (impossibility) to provide an analytical (formula-based) description of the relationships between these indicators, the disproportion in units of measurement of those indicators characterizing various properties of the system, and the conflictness of criteria which must be satisfied during the creation of a system with characteristics that ensure acceptability for use in practice.

Applying the systematic approach means the analysis of a significant number of factors, taking into account their influence on the functioning of the system under study. In other words, the multicriteriality of analysis is its integral feature and provides for the use of the corresponding methodological apparatus implemented in the form of software for computer technology, in particular decision support systems. Therefore, in our opinion, the development of decision support systems that can be used for multicriteria optimization of complex systems is an urgent scientific task.

ANALYSIS OF MODERN DECISION SUPPORT SYSTEMS

Decision support systems (DSS) are known to be interactive computer systems designed to help researchers to solve unstructured or weakly structured problems [1]. Multicriteria DSS are a type of DSS designed to solve problems

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typical for multicriteria optimization where it is necessary to analyze a finite set of alternatives whose characteristics are set in tabular form. They usually consist of three main parts: control module, interface module, and calculation module. The control module provides the order of circulation and processing of information in accordance with the conditions defined by the user. The interface module provides user interaction with DSS, namely input and output of source data, determination of calculation conditions, presentation of the results in a convenient form, etc. The calculation module is designed to perform operations and calculations directly related to multicriteria optimization, in particular, to carry out calculations using a certain method (methods).

Conventionally, all DSS can be divided into two groups: general-purpose and problem-oriented systems. General-purpose DSS contain only the components necessary for the implementation of multicriteria optimization, i.e., their source data is only a list of alternatives and characteristics of the considered indicators. Problem-oriented DSS contain additional software that is specific to a particular field of research, in particular, models of typical systems that can be used to obtain their characteristics when forming a variety of alternatives, for example, in land use [2], business planning [3], financial management [4], etc.

Currently, there are more than 40 DSS [1] designed for multicriteria optimization. A detailed analysis of the most common DSS is given in [2, 5]. In addition, it is noted in [2] that for various reasons (lack of developer support, a very specific focus, etc.), a fairly small number of DSS, in particular, Criterium DecisionPlus, Expert Choice, and Decision Lab, were most widely used. Typically, such systems use a very narrow list of multicriteria methods. For example, Criterium DecisionPlus software is based on a multicriteria utility theory and hierarchy analysis method (HAM), Expert Choice tool and DSS from [4] is based on HAM, Decision Lab software is based on PROMETHEE I and PROMETHEE II methods, DSS from [3] implements the methods of the ELECTRE group, and the DSS prototype from [5] implements the methods of HAM, MOORA, TOPSIS, SAW, and ELECTRE. In other words, the common problem of modern DSS is that they are focused on the implementation of a certain set of methods, and not on providing the user with complete multicriteria optimization methodology.

A consequence of this approach is that the use of DSS, which is based, for example, on the methods of the ELECTRE group, provides a comparison of alternatives according to the criteria inherent in ELECTRE. However, no one can guarantee that the same results will be obtained using the DSS based on the methods of the PROMETHEE group. For example, in [6], selection of a rational technology for processing hazardous waste based on ranking of eight alternatives according to the ELECTRE method was considered and it was concluded that one of the alternatives within the framework of the method cannot be comparable with others; therefore, it is not included in the obtained priority series. However, calculations for the same problem using the TODIM method, based on the prospect theory, indicate that under certain conditions this alternative takes third place in the priority series, i.e., it is quite competitive. This example clearly demonstrates that the constraints imposed by tools on the procedure for comparing alternatives can entail certain unrecognized risks. Therefore, in order to ensure the validity of the results of multicriteria optimization of complex systems, it is advisable to develop a DSS focused not on a specific group of optimization methods, but on the implementation of a certain research methodology, i.e., aimed at providing the researcher with tools whose composition corresponds to the features of the research stages.

GENERAL APPROACH TO DEVELOP A DECISION SUPPORT SYSTEM

In general, the idea of a systematic approach can be illustrated by the diagram presented in Fig. 1, which shows that a sufficiently large number of factors must be taken into account during the analysis of a complex system.

In general, when conducting a research, depending on the characteristics of the data that characterize the system-of-interest, it is necessary to solve several types of problems.

According to [7], these data (depending on how they are presented) can be divided into three groups: deterministic, probabilistic, and undefined.

The term “output-determinacy” provides that the data are fully defined. Therefore, problems where such data are used are called problems of decision-making under determinacy.

The term “probabilistic input data” provides that their uncertainty is associated with some processes of a random nature, which are a prerequisite for various risks. Therefore, problems that use such data are called risk-based decision-making problems.

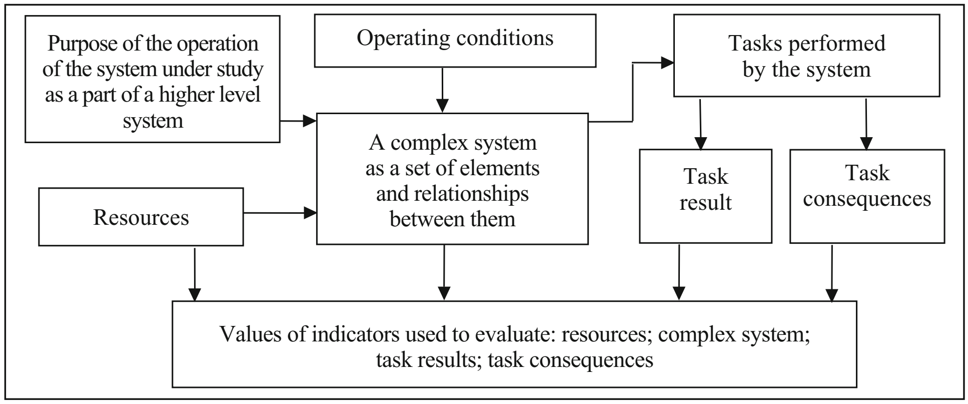

Fig. 1 Schematic representation of the idea of a system approach.

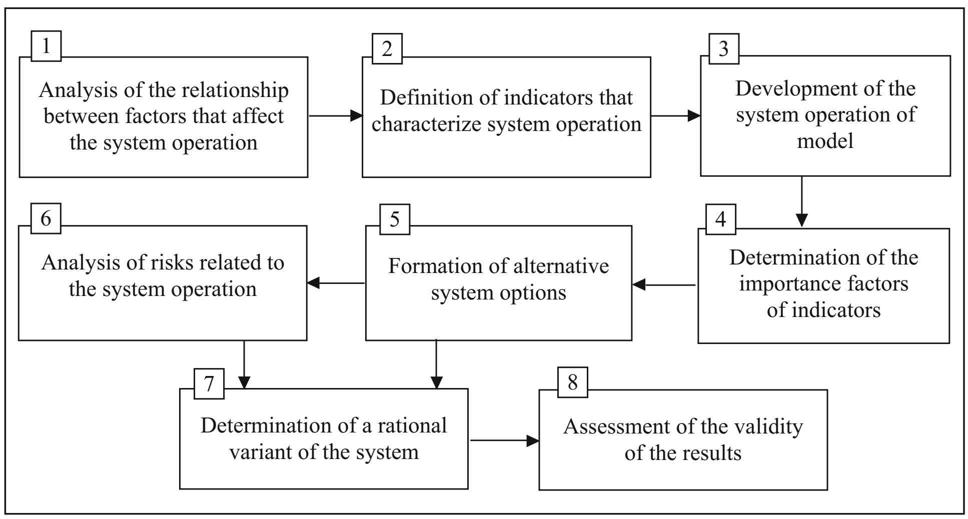

Fig. 2 Main stages of research on multicriteria optimization of complex systems.

The term "undefined input data" provides that their uncertainty is not related to processes of random nature, i.e., it cannot be described by the apparatus of probability theory and mathematical statistics. The uncertainty of this data can come from different sources [8], and problems of processing such data are called problems of decision-making under uncertainty.

According to [9], non-stochastic uncertainty is divided into two groups: uncertainty due to insufficient knowledge of the system and uncertainty due to the properties of the system. The latter cannot be eliminated by conducting additional analysis. To account for the uncertainty caused by insufficient knowledge of the system, a fuzzy logic apparatus is usually used. Moreover, the level of expert knowledge about the system under study can be formalized using membership functions of particular type and their parameters. As the level of knowledge about the system increases, membership functions and their parameters can be specified. To take into account the uncertainty caused by the properties of the system, which cannot be eliminated by additional analysis, the apparatus of the grey system theory is used. Moreover, the system, the available information about which is exhaustive and reliable, is white. A system that is completely missing information is black. All other systems are considered to be gray. Therefore, the DSS for solving multicriteria problems should provide the ability to process data of all these types.

Usually, the purpose of studying a complex system is to determine its rational option from the list of alternatives that will provide the necessary (acceptable, appropriate) results of its operation according to some criteria. Analysis of the main stages of study of such systems (Fig. 2) indicates that stages 2, 3, and 5 associated with the development of a model of its operation are actually specific for each system.

Other stages are quite universal, i.e., they are performed for different systems. Thus, the DSS, which will allow one to make analysis at these stages, will also be universal.

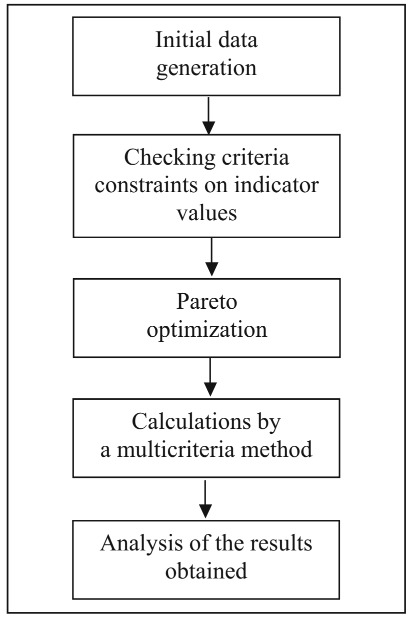

Fig. 3 Typical calculation scheme for a specific multicriteria method.

For studies of the first stage, depending on the volume and nature of the available information, factor analysis is usually used [10] if there is numerous data on system operation, or the DEMATEL method [11], if such data are not available and experts should be involved to identify relationships between the factors. The following methods are usually used to study the fourth stage associated with determining the coefficients of importance of indicators: HAM [12], entropy [13], critical distance [14], and CRITIC [15] methods. At the sixth stage, when determining the risks associated with system operation, risk theory methods are usually applied based on the criteria of Bayes, Laplace, Wald, Hodge–Lehman, Savage, Hurwitz [16]. The determination of the rational version of the system, which is performed at the seventh stage, can be carried out using several approaches.

If it is necessary to involve experts to compare alternatives, the HAM method can be used, and if there are quantitative and ordinal characteristics of alternatives, the EVAMIX method should be used. If there are quantitative characteristics of alternatives, the determination of a rational version of the system can be carried out using a variety of optimization methods, for example, with the approaches given in [17], and the validity of the results obtained at the eighth stage can be evaluated, for example, using the methodology given in [18]. In [18], it was also shown that the validity of the results substantially depends on the completeness of comparison of alternatives by various criteria, which is determined by the number and characteristics of the methods used at the seventh stage.

A typical calculation scheme for a specific multicriteria method is shown in Fig. 3. Moreover, depending on the method used, it is possible to obtain a priority series of the considered alternatives or some kernel that contains one (best) alternative or several disparate ones. Moreover, the diagram shown in Fig. 3 clearly indicates that the developed DSS should ensure verification of the criteria constraints that are imposed on the values of indicators, formation of a Pareto-effective set of alternatives, as well as the implementation of calculations using multicriteria methods.

When choosing a number of methods that should ensure a complete comparison of alternatives, in our opinion, it is advisable to focus on the methods that are now most widely used in the analysis of complex systems, namely, ELECTRE II, SAW, WASPAS, Harrington, PROMETHEE II, TOPSIS, TODIM, VIKOR, MOORA, COPRAS, OCRA, and GRA. Moreover, the completeness of comparison is ensured not only due to the number of methods, but also due to the variety of conceptual approaches that are based on them. In particular, Harrington's method is based on the evaluation of the desirability function, TODIM is based on the prospect theory, and GRA is based on the grey system theory.

The above reasoning is, in fact, a system of requirements for the DSS being developed considering the types of problems to be solved and the methods used.

TABLE 1. Typical Dependencies that Normalize the Initial Values of Indicators

Dependencies for Indicators that Require Maximization	Dependencies for Indicators that Require Minimization	Note
$e_{ij} = E_{ij} / \sum_i E_{ij}$	$r_{ij} = 1 / E_{ij},\ e_{ij} = r_{ij} / \sum_i r_{ij}$	All indicators will need maximization after normalization
$e_{ij} = \dfrac{E_{ij} - \min\limits_{i=1,\ldots,n} (E_{ij})}{\max\limits_{i=1,\ldots,n} (E_{ij}) - \min\limits_{i=1,\ldots,n} (E_{ij})}$	$e_{ij} = \dfrac{\max\limits_{i=1,\ldots,n} (E_{ij}) - E_{ij}}{\max\limits_{i=1,\ldots,n} (E_{ij}) - \min\limits_{i=1,\ldots,n} (E_{ij})}$	
$e_{ij} = E_{ij} / \max\limits_{i=1,\ldots,n} (E_{ij})$	$e_{ij} = \min\limits_{i=1,\ldots,n} (E_{ij}) / E_{ij}$	
$e_{ij} = \dfrac{E_{ij}}{\sum_{i=1}^{n} E_{ij}}$	$p_{ij}^1 = \dfrac{E_{ij}}{\sum_{i=1}^{n} E_{ij}},\ p_{ij}^2 = \dfrac{\min\limits_{1,\ldots,n} p_{ij}^1}{p_{ij}^1},$ $e_{ij} = p_{ij}^2 / \sum_{i=1}^{n} p_{ij}^2$	
$e_{ij} = \dfrac{E_{ij} - E_{jcp}}{S_j},\ E_{jcp} = \dfrac{1}{n} \sum_{i=1}^{n} E_{ij},\ S_j = \left[\dfrac{1}{n} \sum_{i=1}^{n} (E_{ij} - E_{jcp})^2 \right]^{1/2}$		—
$e_{ij} = E_{ij} / \sqrt{\sum_i E_{ij}^2}$		—
$e_{ij} = E_{ij} / \sum_i E_{ij}$		—

FUNCTIONAL STRUCTURE OF THE DSS BEING DEVELOPED

A DSS that satisfies these requirements has been developed in the Delphi environment with the following considerations.

An analysis of the described methods for multicriteria comparison of alternatives showed that most of them have a typical structure. In this case, normalization of the initial values of indicators is actually an independent stage of calculations, which can be implemented independently of the stages directly related to the comparison procedure. Therefore, several methods of normalization were implemented in DSS (Table 1), and it was also possible to interactively form (if necessary) dependencies for normalization in the form of a graph of the dependence "the natural value of the indicator — its desirability for the decision maker."

Therefore, combining various methods of normalization with criteria for comparing alternatives, it is possible to provide additional opportunities for the completeness of their comparison. The analysis of fuzzy and gray analogs of the above methods for multicriteria comparison of alternatives showed that most often their modification consists in replacing operations with clear numbers with their corresponding analogs for fuzzy or gray numbers. The implementation of this approach provides the possibility of using these methods to solve decision-making problems under uncertainty.

Based on the results of the implementation of these provisions, a DSS was developed with the functional structure shown in Fig. 4.

The sequence of actions in the case of its use may be, for example, as follows. First of all, the initial data are prepared in accordance with the selected method of multicriteria comparison and the type of problem being solved. These data can be entered in an interactive way, from a file of a special structure or test cases, selected from literary sources and implemented in software.

In general, the initial data contain an attribute of the type of initial data (unfuzzy, fuzzy, gray), values of indicators by which comparisons will be made, optimization attributes (to the maximum or minimum) and an attribute of the type of methods that will be applied. The last feature makes it possible to bring fuzzy or gray data into unfuzzy and use

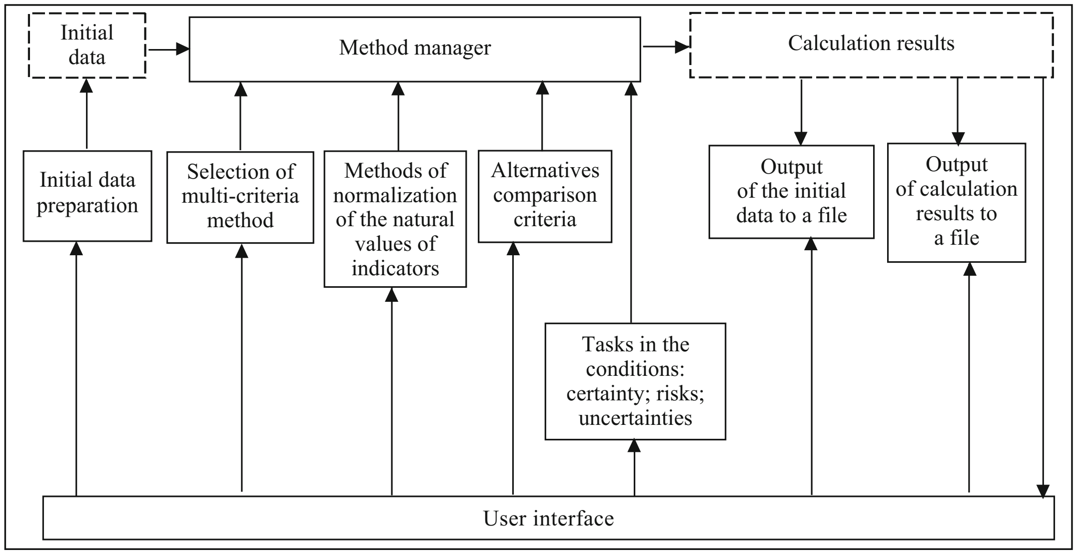

Fig. 4. Functional structure of the developed DSS.

unfuzzy methods for calculations, i.e., those designed to solve problems under of certainty. For the first time, the prepared initial data can be output to a file to ensure the possibility of their use in the future for repeated calculations. At the next stages, calculations are carried out using appropriate methods. In this case, you can choose one of the individual methods (factor analysis, DEMATEL, one of the methods for determining the importance factors of indicators, Pareto, checking for criteria constraints) or the method of multicriteria comparison of alternatives. For multicriteria comparison, one of the normalization methods shown in Table 1 should be determined, or a desirability function should be generated in an interactive way. In addition, it is necessary to choose a method in accordance with the comparison criteria of which the core of alternatives or their priority series will be formed. Additionally, it is possible to perform batch calculations, where for the selected normalization method, calculations are performed sequentially by all methods without additional commands. The calculation results are output to a text file, which can be viewed using DSS tools or regular text editors. For the convenience of using the calculation results in the preparation of reporting materials, the data that can be presented in tables is organized in this file so that it can be easily turned into a table using the standard tools of the Microsoft Office Word editor (Table → Convert to Table → Separator → Other → “:”)

CONCLUSIONS

The article describes a DSS designed to solve multicriteria optimization problems in the analysis of complex systems, focused on providing researchers with appropriate tools taking into account the characteristics of individual stages of studies.

The direction of further development of the study is expanding the list of implemented methods and functional capabilities of the software by providing opportunities to assess the stability of the results and clustering of alternatives.

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