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OVERVIEW OF DECISION-MAKING TECHNIQUES USED IN THE DEVELOPMENT OF COMPLEX ENGINEERING SYSTEMS

With the advent of market economy in Russia the role of the decision-making stage in the development of high-technology products significantly rose in significance. The article analyzes the mathematical model of decision-making used in the development of complex engineering systems (CES) that allows identifying the optimal engineering solutions out of a number of alternatives. In order to define the "efficiency" of CES and primary criteria thereof the authors set forth a number of classifications of decision-making techniques along with their main features. They also provide the results of comparative analysis of the best known decision-making techniques, as well those used for evaluation of innovation projects.

Keywords: *system analysis, complex engineering system, decision-making procedure, decision-making techniques, decision-maker, alternative, efficiency, efficiency criteria, comparative analysis.*

1. Introduction and problem definition

The costs of CES-related decision-making are on a constant rise, while the consequences of wrong decisions are getting more and more severe. In the present conditions, experience and intuition do not always ensure the choice of the optimal decision. In this context, scientific decision-making methods started developing rapidly, a new scientific field, the decision-making theory, has emerged. The main purpose of the decision-making theory is to help the decision-maker clarify his or her attitude to the potential consequences of the choice.

The consequences of the choice from a number of alternatives are characterized by the degree of achievement of the goal of the choice and are evaluated by the decision-maker (DM). In complex real-life situations the decision-maker's perception of the goal is usually incomplete and unclear. That a priori does not allow him or her completely analyze the various aspects of the consequences of the compared alternative solutions, identify their importance, develop a cohesive attitude to the alternatives and therefore formulate the selection criterion or the objective function[1]. Therefore, the decision-maker's system of preference is poorly structured [1].

[1] A designer always works with a number of alternative solutions, both while making the decision to participate in a contest, and during the design and development of a weapon system. In rare cases the first solution turns out to be the only correct one. That is an exception though. Qualitative improvements to designs are after all achieved by means of alternative solutions. In order to find those, the designer must show resolution and correctly choose the most optimal and viable alternative (Kalashnikov, M.T. Notes of the weapons designer. Moscow. Voenizdat, 1992. – 300 p. – P. 271).

Mathematical models are developed for the purpose of solving the choice problem. Models enable objective analysis and comparison of alternatives taking into consideration all aspects of consequences, as well as the DM's attitude to those consequences, structuring of the initial task and generation of the selection criterion, or, in most cases, a system of criteria. Thus, the decision-making task becomes multicriterial.

The rapid development of computer and information technologies in the 1990s paved the way for the creation of automated decision support (ADS) systems based on advanced mathematical tools of decision-making theory covering various fields of knowledge and technology. Nevertheless, the problem of application of particular ADS-defining decision-making methods still remains [2-10].

The purpose of this article is to provide an overview of the decision-making methods that can be used in the development of CESs, namely for their performance evaluation. The goal is to demonstrate the significance of the decision-making methods and models involved in the development of new opportunities in technology and CES design; analyze the procedures and mathematical model of decision-making in CES development; introduce the concepts of CES efficiency and primary criteria of efficiency.

2. Mathematical simulation in decision-making as part of development and modernization of complex engineering systems

2.1. Distinctive features of modeling of multicriterial tasks

The distinctive feature of a CES is its multicriteriality, which means that the level of sophistication of a system and the quality of its performance depend on a number of output characteristics. Therefore, the design of a system and comparison of alternative technical solutions should take into consideration the contribution of each of the said characteristics.

Below are the primary considerations that should be taken into account when designing multicriterial decision-making models:

1. The model is designed for the sole purpose of structuring and specification of the preferences of the decision-maker directly involved in the development.
2. The model must by logically consistent.
3. The model must contain the description of all important elements of the decision-making tasks and their properties.
4. The model must enable the use of actual information regarding the task received from experts and the decision-maker.
5. The model must be simple and well-behaved and easily usable by the decision-maker.

A multicriterial model of a decision-making task can be represented in the following generalized form:

$$< t, K, X, S, P, r >, \quad (1)$$

where t is the task definition (type); K is the set of criteria; X is the set of criteria scales; S is the set of solutions; P is the system of preferences of the decision-maker, r is the choice of the final decision.

Practical design inevitably generates alternative engineering solutions. They arise when design is performed by different teams on competitive basis or by a single team. That is why the transition from the design to the development and manufacturing of a system requires the selection of the most preferable alternative. The multicriteriality of a system complicates the decision-making process if one of the alternatives is superior to another in one group of criteria and inferior in another.

The development of a multicriterial decision-making model is characterized by the requirement to request necessary information from people, i.e. the decision-maker and subject matter experts. This feature of the decision-making tasks requires a specific organization of the whole process of multicriterial model development, its evaluation, application of formalized methods of alternatives comparison. The organization of the decision-making process requires special knowledge. Therefore, the development and subsequent evaluation of a multicriterial model involves not only the DM and subject area experts, but also a consultant who specializes in decision-making theory.

Most importantly, the definition and solution of multicriterial tasks must take into consideration a large number of essential circumstances and notions that are difficult to justify mathematically. Therefore, mathematical models intended for solving specific multicriterial tasks must reflect both conceptual considerations that are impossible to properly formalize and formalized task descriptions. Only this comprehensive approach can ensure practically useful results.

2.2. Structure of the model design and application process

The design of multicriterial decision-making models is a complex procedure that includes formalized and non-formalized stages. The process of design and evaluation of a multicriterial model involves three groups of people: the decision-maker, the consultant and the experts.

Fig. 1 shows an example out of a large number of decision making procedures that consists of 13 stages of a discrete multicriterial problem solution. The results of model evaluation allow obtaining ranked sets of allowable solutions coordinated with the specified assumptions and used information. Several versions of a model can be designed. Their advantages and disadvantages can be identified only by comparative analysis and practical application.

Let us examine the structure of the iterative decision-making procedure.

At the first stage, the task is defined, i.e. the required ranking of alternative solutions is specified, the purpose of the research and meaning of the "alternative solution" are defined.

At the second stage, a set of alternative solutions is generated, their applicability for the purpose of the defined goal is verified, the meaning of the term "acceptability" is specified, the solution applicability verification procedure is developed and a set of such alternative solutions is identified.

A the third stage, the possible consequences of the identified alternative solutions are analyzed, the list of indicators characterizing the possible consequences is drawn up, a set of criteria that characterize those consequences in sufficient detail.

At the fourth stage, evaluation scales for the identified set of criteria are developed. The implementation of the third and fourth stage activities is a complex procedure. Those two stages are closely connected to each other.

At the fifth stage, the acceptable alternative solutions are evaluated using the scales of identified criteria.

The general decision rule that ensures the required ranking of alternative solutions can be designed step by step. At the sixth stage, information regarding the decision-maker's preferences is obtained. This information defines the assessment of the impact of various changes in ratings on the general quality (utility, value) of a solution. At the seventh stage, the information is used to generate the respective decision rule. The decision rule is used to compare and rank the alternative solutions (stage 8). The ranking results are analyzed at stage 9.

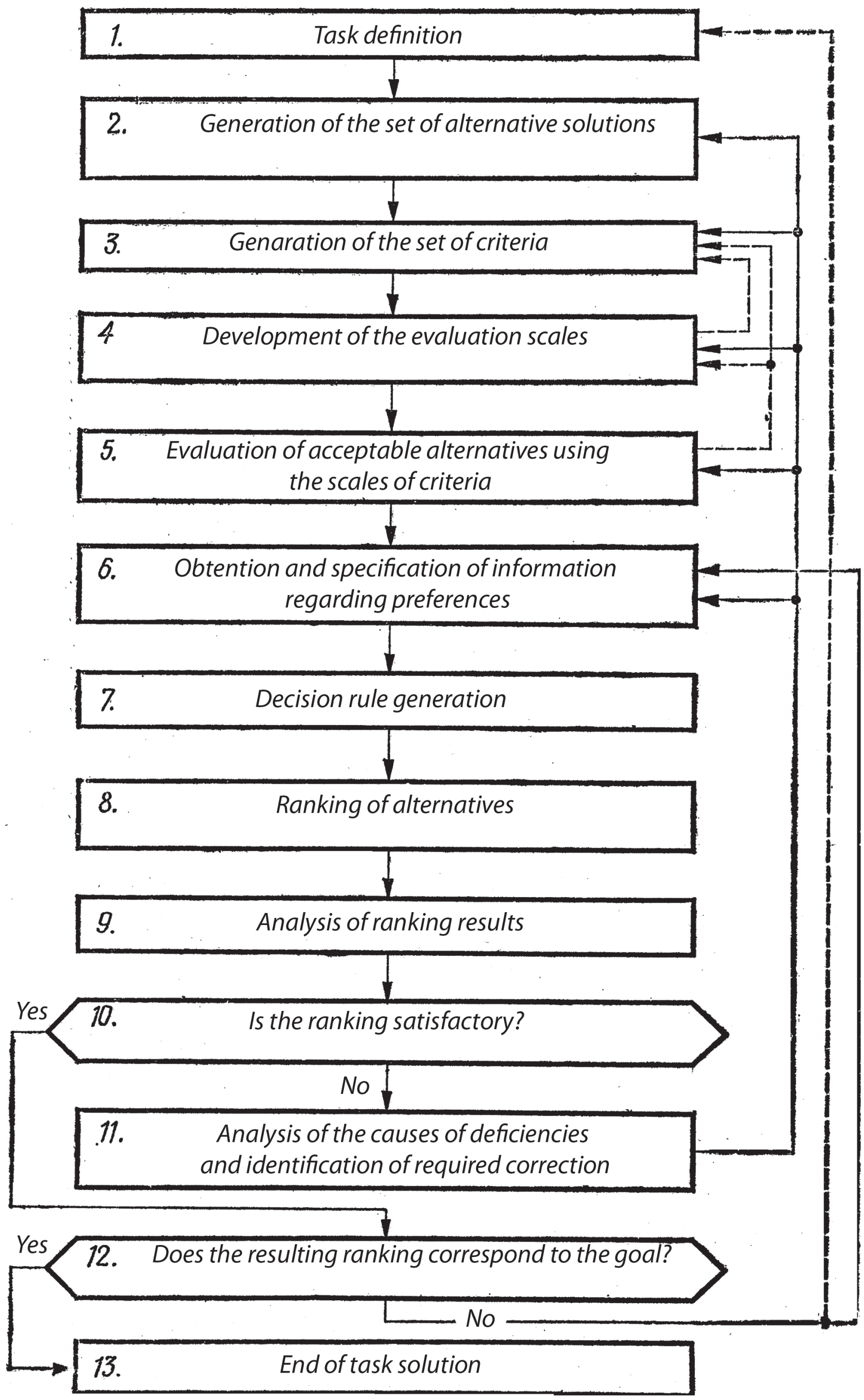

Fig. 1. Structure of the iterative decision-making procedure

If ranking is impossible (stage 10) the causes of the deficiency are examined (stage 11). The possible causes are:

– unconformity of the used information or assumption with intuitive preferences;
– exclusion of an acceptable alternative solution from the analysis;
– incomplete set of criteria used in the model;
– unconformity of criteria scales with the evaluation capability;
– inaccuracies or errors in the evaluation of some of the acceptable alternatives;
– inaccurate definition of an “acceptable alternative”.

Depending on the causes of unsatisfactory ranking, the model is amended and all necessary stages are repeated. If the ranking of alternatives is satisfactory (stage 10), the decision rules that ensure partial ranking of vector evaluations are used upon verification of its compliance with the specified purposes (stage 12).

In case when the ranking of alternatives obtained at a certain stage is considered by the decision-maker as being satisfactory and compliant with the specified purpose, the ranking is accepted as final (stage 13). If the decision-maker acts rationally, he or she must choose the alternative in accordance with the obtained ranking[1].

3. CES efficiency criteria

Finally, by analyzing the available alternative solutions the DM chooses the most efficient one.

Efficiency is the generalized constitutive functional property of a system that implements an operation, is defined by the goal (expected result) and objectively expressed through the degree of goal completion subject to the costs and operation implementation time [12]. The development of decision quality evaluation criterion is one of the primary goals in any object management activity. In order to find the optimal (rational) management (solution), it is required to establish the dependence of the chosen efficiency criterion on the factors affecting its magnitude.

The efficiency criterion W can generally be written as follows [7]:

$$W = F(U, S, C), \qquad (2)$$

where F is a functional; U is a CES control vector:

$$U = (u_1, u_2, \dots, u_n)$$

S is a vector that defines the environment; C is a vector that defines the process (or system).

Vector C can be represented as

$$C = (K, P),$$

where the vector defines the structure of the system, while vector is the parameter vector (or specific numerical characteristics of the system).

The widely known expression (2) can be considered as the mathematical model of a controlled process (system). This model can help find the best (rational) control, structure and parameters specific to the given structure.

The efficiency criterion can be scalar, i.e. be defined by a single number, or vectorial that is defined by a set of numbers. Depending on the nature of the chosen research method and criterion, monocriterial and multicriterial decision-making tasks are usually distinguished.

[1] In order to choose the preferable alternative out of two CES solutions, it suffices to establish a list of partial criteria of the analyzed system ($x_1, x_2, \dots, x_n$) and choose the generalized criterion X (objective function) and establish the analytic dependence of X from the partial criteria $X = F(x_1, x_2, \dots, x_n)$. Then, the value of the generalized criterion X^1 is determined for the system variant 1 and X^2 for the system variant 2. Further, the values of the partial criteria from the designs of the two compared CESs are inserted in the formula of the generalized criterion. The preference is given to the alternative that features the highest generalized criterion value. Generation of generalized criteria on the basis of real connections with partial criteria should help choose the correct preferable alternative (Brakhman, T.R. Multicriteriality and choice of alternative in technology. Moscow. Radio i sviaz, 1984. – 288 p. – P. 56).

The efficiency criteria classification is given in table 1. The choice of an operation's efficiency criterion must always ensure conformity of the goal with the purpose of the operation and the efficiency criteria. In cases when the required result of the operation is defined, the maximum probabilistic guarantee criterion in more consistent with the purpose of the operation than the maximum average result criterion.

Table 1. Efficiency criteria classification

Efficiency criteria		
Suitability criterion	**Optimality criterion**	**Adaptability criterion**
Acceptable result criteria: acceptable guarantee; acceptable guaranteed results, etc.	Maximum result criteria: maximum average result; maximum probable guarantee; maximum guaranteed result, etc.	Selection criteria: freedom of decision-making; self-organization, etc.

It should be noted that the cost-effectiveness criterion is widely used in the analysis of combat deployment of weapon systems [13]. Let us examine the cost-effectiveness ratio of a weapons system for the purpose of the current tasks. Normally, this ratio is expressed in the graph shown in fig. 2.

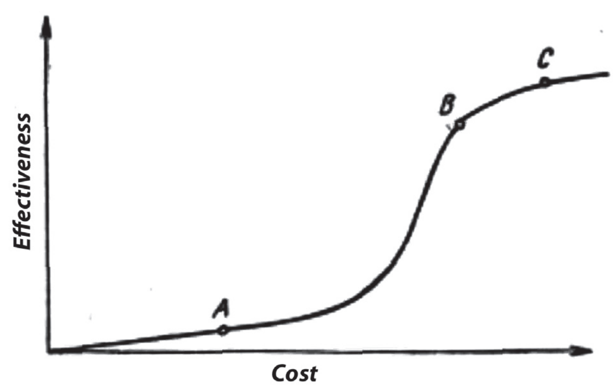

Fig. 2. Standard curve of weapon systems cost-effectiveness ration

If a weapon system can be represented as point A on the graph, then the tasks of the system clearly exceed the budget. In that case either more humble goals should be set, or the whole weapon system should be abandoned, or higher expenditure accepted in order to ensure the development of a weapon system with performance corresponding to point B. If sufficient funding is provided, a system with performance corresponding to point C can be developed as well. However, that would mean that we invest more funds than economically feasible, and we should either look for other weapon systems or set more conservative goals. If, according to the researcher and the person who uses the results of his or her activity, the alternatives identified as the best as the result of model-based analysis, are acceptable, the analysis process concludes. Otherwise, the search for better alternatives should continue or more humble goals should be set.

The introduction of the cost-effectiveness criterion as the relation between the «effectiveness» and «cost» allows the DM to make justified decisions in designing CESs. The popularity of this criterion is due to the fact that it is very simple and clear. The correlation between the effectiveness of a decision taken and the cost of its implementation shows, on the one hand, how much the investments are justified and, on the other hand, the consequences of unjustified cost cutting. However, this philosophy is not as simple as it may initially seem. The dependence of the criterion from the effectiveness is linear, while its dependence from the cost is hyperbolic (fig. 3). [7]. Due to that it gives clear preference to cheap solutions (projects), while in expensive ones it is quite «condescending» to the costs.

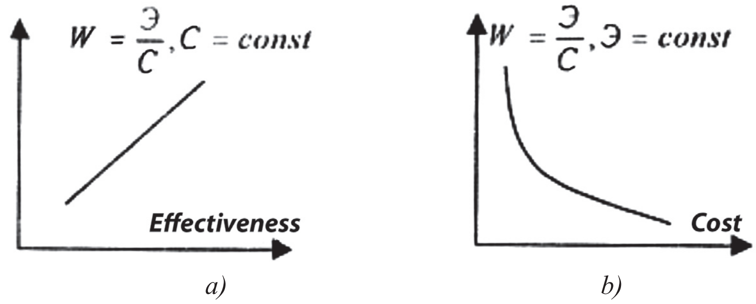

Fig. 3. Dependence of the relation
a – W = (E/C) on the effectiveness (C = const); b – W = (E/C) on the cost (E = const)

One of the advantages of the cost-effectiveness criterion is that it is simple and transparent. Its disadvantage is that the dependence of the criterion from the effectiveness is linear, yet the dependence of the criterion on the cost is hyperbolic.

When using the cost-effectiveness criterion, the user should be fully aware if the criterion corresponds to his or her understanding of the task and address its disadvantages by limiting the application area as: “cost not higher than …”, “effectiveness not lower than …”.

From April 28 to may 3, 2014 in Mexico hosted the First international Congress of advanced science (The First International Congress of Advanced Science devoted to the study of the prospects of development of mankind in the XXI century. During eminent scientists from different countries exchanged the results of their scientific research on the prospects of social development of the society, taking into account the latest achievements of modern science and technology. The Congress was attended by scientists from eight countries: Mexico, Venezuela, Germany, Russia, Brazil, Cuba, China and Norway.

The conference expressed the view that the most important condition for the development of society is correctly selected criteria base the quality of public life.

It was noted that current approaches are based on the concepts of gain and profit, and the sense of the development of society as a whole and its subsystems (up to the individual person) is reduced to achieve maximum profit.

This approach directs economic and other activities on Maxi-optimization profit, but not on the growth of socially useful product. That is the purpose of development of society is not achieving the maximum extent of development of each individual and society as a whole, and extract the maximum profit at all levels of society, sometimes to the detriment of the objective with significant public interest. And this leads to the imbalance of the whole system of social production. In fact, the well-known crises of capitalism are such an imbalance.

Therefore, the highest criterion of efficiency of any production at any level of its hierarchy should be the needs of society.

The efficiency of social production as a whole should be evaluated by the degree of conformity of range and volume needs of the nomenclature and production of all kinds.

In this understanding, criteria such as income, profit or rent-turn profits are purely private and local, auxiliary in nature and may not be used as the main, as is the case today.

Then the sense of the development of society is not confined to race for profit, but to the elimination of appearing natural imbalances, allowing real crisis-free development of society. That is the purpose of development of society is not extracting the most profit, and achievement of the maximum degree of development of society as a whole[1].

[1] Sivkov K. Future for socialism // Military-industrial courier. - 2014. - № 19 (537). - 28 may - 3 June. - 3 p.

4. Classification of decision-making methods

There are a number of decision-making methods and models classifications based on various attributes [14]. In a classification, each of the elements of the expression (1) may serve as its attribute and be characterized by the following properties:

1. By presentation *f*. The presentation of the sets *S* and *K* may be deterministic, probabilistic or undetermined, whereby the decision-making tasks may be divided into tasks under risk and tasks under uncertainty.

2. By saturation of set *K*. A set of choice criteria may contain one or more elements, thus the decision-making tasks may be defined as tasks with scalar or vector criterion (multicriterial decision-making).

3. By system of preferences *P*. Preferences may be defined by one person or a team, subject to which the decision-making tasks can be classified as individual and collective [15].

The individual decision-making methods and models with multiple criteria may be divided in the following main groups:

<u>The first group includes:</u>

– lexicographic methods;
– axiomatic methods of the multicriterial utility theory;
– methods of comparison of multidimensional alternatives (domination methods, compensations, non-comparability thresholds).

<u>The second group includes:</u>

– methods of generalized criterion construction;
– verbal methods;
– methods of the fuzzy sets theory;
– intellectual methods.

The collective decision-making can be divided into the following groups:

<u>The first group includes:</u>

– methods of collective conflict-free decision-making;
– methods of collective selection;
– cooperation methods (expenses and profits distribution).

<u>The second group includes:</u>

– dynamic methods of collective selection in conflict situations;
– problems of allocation;
– collective behavior-shaping methods.

A brief description of the above methods is given in monograph [15]. The utilized classification principle allows for, as we think, a clear definition of four major groups of methods. Three of them pertain to decision-making under certainty, while the fourth one to decision-making under uncertainty.

5. Comparative analysis of decision-making methods in CES design

5.1. Overview of the decision-making methods

Over the past few years, a significant number of scientific papers in decision-making theory have appeared. They deal both with the selection of alternatives in CES design [15, 18-20], and the development of decision-making methods. Among those we can note monograph [15] that details the decision-making methods, including hierarchy analysis methods and analytic network methods, as well as methods based on the fuzzy sets theory, cluster analysis method and combinatorial morphological analysis and synthesis of systems, heuristic methods of search for new solutions, intellectual methods and systems of strategic decision support and methods of the utility theory and game theory. The specificity of system analysis and multicriterial task solving problems is covered in monograph [10] that details the methods of multivector optimization and multivector classification.

The analysis of methodological decision-making theory literature, as well as scientific and technical CES design literature shows that the following decision-making methods can be used for the purpose of selecting primary areas of technology and CES development, namely performance evaluation:

– methods of convolution of vectorial criterion;
– tradeoffs minimization method;
– method of optimization based on the dominant criterion;
– ranking methods (binary relation method, successive tradeoff method);
– weight coefficient method;
– ideal point method;
– ELECTRA method;
– analytic hierarchy method;
– statistical methods of product quality evaluation (correlation analysis and regression analysis);
– spectral method of alternatives ranking;
– analytic hierarchy method;
– method of fuzzy preference relation;
– preference method;
– decision matrix method;
– documentation method;
– test method;
– Pareto method;
– reasoning consistency evaluation method;
– mixed alternative method;
– consensus method;

Table 2. Primary features of the ranking method

Name of the method	Essence of the method	Application area	Advantages of the method	Disadvantages of the method	Notes
Ranking method	While performing the ranking, the expert must arrange the objects (factors) in an order that appears to be the most rational and assign a counting numeral (1, 2, 3, etc.) to each of them.	In practice, this method in its pure form is rarely used. In most cases it is used along with another ranking method that ensures a clearer distinction of the compared objects.	Simplicity Promptness Low cost	Dependence of precision and reliability of ranking on the quantity of objects. Subjective evaluations. The method does not allow identifying the distance from one object to another.	The order scale generated as the result of ranking must meet the requirement of the number of ranks being equal to the number of ranked objects.

– expert evaluation methods (Delphi method, commission method, court method, brainstorming method and its variants, i.e. individual brainstorming, mass brainstorming, written brainstorming, dual brainstorming, reverse brainstorming, idea conference); mutual evaluation and self-evaluation method, complex examination method).

Methods of ordering can be used if:

– the use of probabilistic methods is complicated;

– it is required to identify the most important alternatives or distinctive features out of a total number thereof;

– it is required to compare certain quantitative factors that are very difficult to accurately measure;

– it is required to evaluate certain qualitative factors that are impossible to accurately measure, but it is possible to compare to which extent they possess the said quality ("better", "more important", "more useful"). The primary features of the ranking method are given in table 2.

During the design of new technology or performance evaluation, a DM must always answer the question of applicability of certain decision-making methods. ADS developers face an even more demanding challenge when they choose the mathematical tools of decision-making that are subsequently used in the development of an automated hardware and software system. There are a number of papers that detail the key features of popular decision-making methods and guidelines to their application [5, 7, 16, 21, 22].

5.2. An example comparative analysis of decision-making methods

Monograph [22] gives an overview and comparative analysis of decision-making methods used in performance evaluation of CESs and other objects and recommends studying the weight coefficient method, ideal point method and ELECTRA method. In the Otsenka i Vybor (Assessment and Choice) system an object can be evaluated using the first two methods.

A comparative analysis of various decision-making methods is given in monograph [15]. fig. 4 shows the results of a rational innovative project selection generated using a number of methods: analytic hierarchy method [23], preference relation method, fuzzy method, additive convolution, maximum convolution. It should be noted that innovative projects can be evaluated by a group of experts [24].

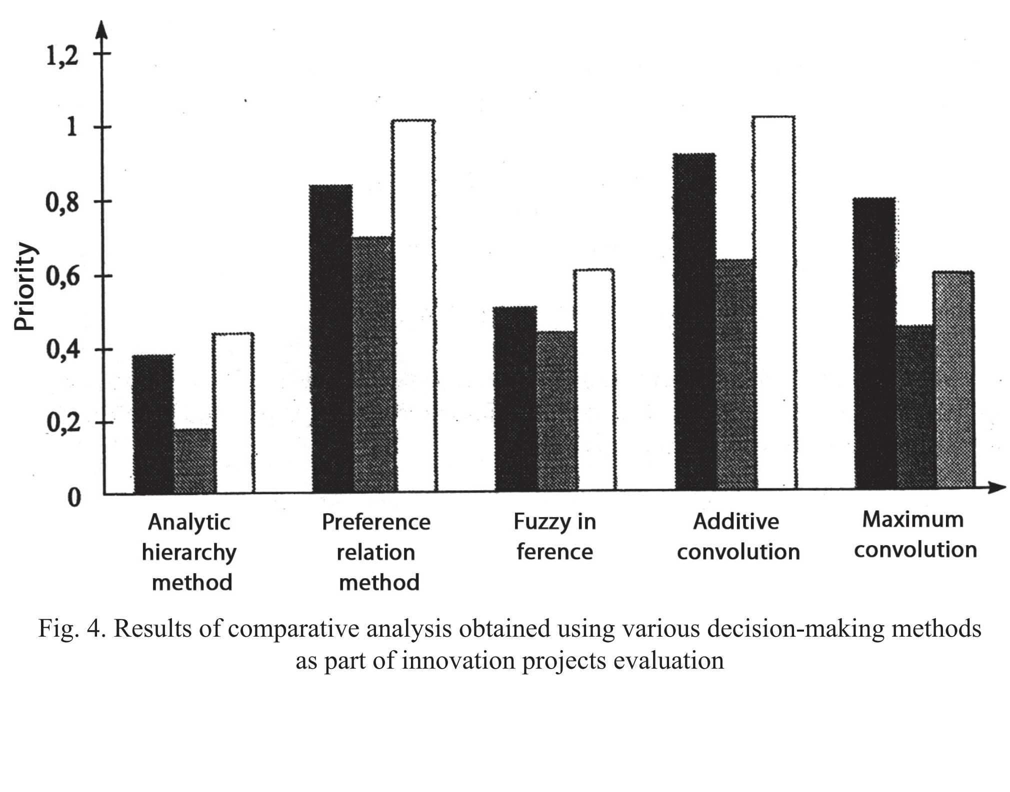

Fig. 4. Results of comparative analysis obtained using various decision-making methods as part of innovation projects evaluation

Despite the fact that the input information is consistent, the results differ. As it is noted in [15], the mismatching results can be explained, on the one hand, by different representations of expert information and different approaches to decision-making, on the other hand. The analytic hierarchy method and the preference relation method are based on the approach that involves pair-wise comparison of objects and standard weight coefficients. The maximum convolution uses the approach that is bases on the assumption that the best alternative is the one with minimum drawbacks according to all criteria. The additive convolution uses the approach when low ratings have equal status compared to the high ones. The fuzzy inference implements the heuristic approach.

The performed analysis shows that:
– each method has its restrictions and the researcher must get acquainted with a method before using it;
– the main problem of multicriterial choice in CES design is the choice of criteria, as well as the possible integral estimations calculation;
– the heuristic approach provides ample opportunities of information representation.

6. Conclusion

1. In the course of the performed research:
– the significance of the decision-making methods and models involved in the development of new opportunities in technology and CES design was demonstrated;
– one of the procedures and the possible mathematical model of decision-making in CES development were analyzed;
– CES effectiveness was defined along with the criteria thereof;
– various types of decision-making methods were examined.
2. An analysis of sources regarding the theory and practice of decision-making has demonstrated that comparative analysis of decision-making methods is an important factor in choosing the rational decision-making method as part of practical activities and is underrepresented in scientific and methodological literature as a CES performance evaluation method.
3. A reliable evaluation of technology performance requires the application of new approaches based on comprehensive modeling and rational use of proven decision-making methods.

References

1. **Optner S.L.** Systems Analysis for Business and Industrial Problem Solving. Moscow. Sov. Radio, 1969. – 216 p.
2. **Lotov A.V., Bushenkov V.A., Kamenev G.K.** Computer and search for balanced tradeoff. The Feasible Goals Method. Moscow. Nauka, 1997. – 240 p.
3. **Trakhtengerts E.A.** Computer support of decision-making. Moscow. Sintek, 1998. – 376 p.
4. **Andreichikov A.V., Andreichikova O.N.** Computer support of invention process (methods, systems, examples of application). Moscow. Machinostroenie, 1998. – 476 p.
5. **Totsenko V.G.** Decision Support Systems and Methods. Algorithmic aspect. – Kiev: Naukova dumka, 2002. – 382 p.
6. **Kostogryzov A.I., Nistartov G.A.** Standardization, mathematical modeling, rational management and certification in the field of system and software engineering. Moscow. Publishing house of VPK and 3 TsNII MO RF, 2004. – 396 p.
7. **Bomas V.V., Sudakov V.A., Afonin K.A.** Support of multicriterial decision-making based on user preferences. SPPR DSB/UTES. Edited by Bomas, V.V. Moscow. Publishing house MAI, 2006. – 172 p.

8. **Semionov S.S.** Performance evaluation of the guidance systems of air-to-surface aircraft weapon systems. Vestnik kompiuternykh i informatsionnykh tekhnologiy. – 2006. – No. 8 – P. 7-11; No. 9 – P. 13-23; No. 10 – P. 12-18.

9. **Lotov A.V., Pospelova I.I.** Multicriterial tasks of decision-making. The Feasible Goals Method. Moscow. MAKS Press, 2008. – 197 p.

10. **Safronov V.V.** Introduction to system analysis: methods of multivector optimization and multivector classification. Saratov. Nauchnaya kniga, 2009. – 329 p.

11. **Gaft M.G.** Decision-making with multiple criteria. Moscow. Znanie, 1979. – 64 p.

12. Technology dependability and efficiency: Reference book. Efficiency of engineering systems / Edited by V. F. Utkin, Yu.V. Kriushkov. Moscow. Machinostroenie, 1988. – 328 p.

13. **Quade E.** Complex system analysis. Edited by Anureev, E.E., Vereshchagin, I.M. Moscow, Sov. radio, 1969. – 520 p.

14. **Larichev O.I.** Theory and methods of decision-making and Chronicle of events in magic lands. Moscow. Logos, 2000. – 296 p.

15. **Andreichikov A.V., Andreichikova O.N.** System analysis of strategic decisions in innovation theory. Mathematical, heuristic and intellectual methods of system analysis and innovation synergy. – Moscow. Knizhny dom LIBROKOM, 2013. – 304 p.

16. **Andreichikov A.V., Andreichikova O.N.** Analysis, synthesis, decision planning in economics. Moscow. Financy i statistika, 2000. – 368 p.

17. **Razumov O.S., Blagodatskikh V.A.** System knowledge: concept, methodology, practice. Moscow. Financy i statistika, 2006. – 400 p.

18. **Dubov Yu.A., Travkin S.I., Yakimets V.N.** Multicriterial models of development and selection of system options. Moscow. Nauka, 1986. – 296 p.

19. **Aizerman M.A., Aleskerov F.T.** Selection of options. Foundations of the theory. Moscow. Nauka, Main office of physics and mathematics literature, 1990. – 237 p.

20. **Berezovsky B.A., Gnedin A.V.** The problem of optimal choice. Moscow. Nauka, 1984. – 196 p.

21. **Mushin E., Muller P.** Methods of engineering decision-making. Moscow. Mir, 1990. – 208 p.

22. **Semionov S.S., Kharchev V.N., Ioffin A.I.** Performance evaluation of weapon systems and hardware. Moscow. Radio i sviaz, 2004. – 552 p.

23. **Saaty, T.** Decision making. Analytic hierarchy method. Moscow. Radio i sviaz, 2003. – 320 p.

24. **Krianev A.V., Tikhomirova A.N., Sidorenko E.V.** Group expert evaluation of innovation projects using the Bayesian approach. Ekonomica i matematicheskie metody. – 2013. – 49 (2). – P. – 134-139.