UDC 004.9: 519.81 DOI: https://doi.org/10.30837/ITSSI.2020.14.013

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COMBINED METHOD OF RANKING OPTIONS IN PROJECT DECISION SUPPORT SYSTEMS

The **subject** of research in the article is the process of ranking options in project decision support systems. The **goal** of the work is to create a method for ranking options to improve the efficiency of decision support systems by coordinating the interaction between automatic and interactive procedures of computer-aided design systems. The following **tasks** are solved in the article: review and analysis of the current state of the problem of ranking options in design decision support systems; decomposition of the problem of project decision support; development of a combined method of ranking options, which combines the procedures of technologies of ordinalistic and cardinalistic ordering; development of a method of minimax selection of options from a set of effective for the procedure of expert evaluation. The following **methods** are used: systems theory, utility theory, optimization and operations research. **Results.** As a result of the analysis of the modern methodology of decision support, the existence of the problem of correct reduction of subsets of effective design options for ranking, taking into account factors that are difficult to formalize, knowledge and experience of the decision maker (DM), has been established. The decomposition of the problem of supporting the making of design decisions into the tasks of determining the goal of designing an object, forming a universal set of design decisions, identifying sets of admissible and effective decisions, ranking and choosing the best design option for decision makers has been performed. A combined method for ranking options has been developed, which combines the procedures of ordinalistic and cardinalistic ordering technologies and allows you to correctly reduce subsets of effective design solutions for ranking decision makers. A method of minimax selection of options from a set of effective ones for the expert evaluation procedure of decision makers has been developed, which allows improving the quality of the assessment. **Conclusions.** The developed method expands the methodological foundations of automation of processes for supporting multi-criteria design decisions, allows for the correct reduction of the set of effective alternatives for the final choice, taking into account factors that are difficult to formalize, knowledge and experience of decision makers. The practical use of the results obtained due to the proposed procedure for determining the set of effective solutions will reduce the time and capacitive complexity of decision support, and due to the use of the maximin procedure for selecting options in the synthesis of the estimation model – to improve the quality of design solutions.

Keywords: design automation; multicriteria evaluation; effective solutions; comparative identification; project decision support; utility theory.

Introduction

Increasing the requirements for the functional characteristics of anthropogenic objects, which are operated in various spheres of human activity, leads to the complexity of technologies and means of their design [1]. Within the methodology of the system approach to obtain effective and sustainable design solutions, it is advisable to jointly solve the problems of structural, parametric and technological optimization of objects at all major stages of their life cycles [2]. However, most of these problems are combinatorial in nature and are solved by a set of functional and cost indicators in terms of incomplete definition of goals and data [3-4].

The most complex objects of design and management are organizational and technical systems, which are characterized by significant structural complexity and contain, along with traditional technical components, active (organizational) elements [5]. In territorially distributed technical and organizational-technical objects (service systems, logistics, telecommunications, monitoring, etc.) cost and functional characteristics are significantly dependent on their topology (territorial organization) [6-7]. The processes of design, development planning or reengineering of such objects are even more complex due to the fact that they include in addition to the above traditional synthesis problems the problem of their topological optimization [8-10]. This leads to the need to generate and analyze super-powerful sets of alternatives. However, the vast majority of decisions generated using automatic procedures are inefficient, and the choice of the implementation of the design object is made by the decision maker (DM), who is able to analyze and make a choice among only a few options [11].

At the same time, it is often not possible to substantiate a single scalar criterion for assessing efficiency, which would fully characterize the alternatives. Based on this, DM evaluates the effectiveness of the alternative as a whole based on the analysis of some set of contradictory criteria, each of which characterizes some of its partial properties [12-14]. Evaluation of the effectiveness of alternatives is traditionally carried out using the theory of utility. The decision-making process for choosing the best project option is carried out using the methods of individual or collective expert evaluation [15-17]. The above raises problems of coordination of interaction between automatic and interactive design procedures of computer-aided design systems. One of them is the problem of forming and correctly reducing the set of effective alternatives for the final choice, taking into account factors that are difficult to formalize, knowledge and experience of DM.

Analysis of the problem and methods of its solution

In the first stages of formalization, the essence of the problem of project decision-making can be represented by the logical expression "necessary s^o" or formally $< -, s^o >$ (where s^o is the optimal project decision) [18]. In this case, the decision-making situation d (formally $< d, - >$) is usually not defined clearly enough. To move to the decision-making task of the form, the problem is decomposed into a set of auxiliary problems of the form: "given $<d,->$, necessary $<d,s^o>$", i.e. $<<d,->,<d,s^o>>$, or "given $<-,s^o>$, necessary $<d,s^o>$", ie $<<-,s^o>,<d,s^o>>$.

In the subsequent stages, the problem of making design decisions can be presented as a system Pr, consisting of the set of tasks [19]:

$$Pr =< Tasks, Rels >,\ Tasks = \{ Task_i \},\ i = \overline{1,6}, \qquad (1)$$

where $Tasks$ – the set of tasks obtained as a result of decomposition of the problem; $Rels$ – the set of relationships between tasks that determine the scheme of their relationships on input and output data; $Task_1$ – goal setting; $Task_2$ – formation of a universal set of design solutions S^U; $Task_3$ – selection of a set of valid solutions $S \subseteq S^U$; $Task_4$ – selection of a subset of effective solutions $S^E \subset S \subset S^U$; $Task_5$ –decisions $s \in S^E$ ranking; $Task_6$ – choosing the best design solution $s^o \in S^E$.

The task of determining the goal $Task_1$ is to establish the set and importance of indicators (partial criteria) of effectiveness $k_i(s)$, $i = \overline{1,m}$, which adequately characterize the design solutions [6, 20]. It determines the relationship between functional $k_j(s) \in Q(s)$ and costly $k_l(s) \in C(s)$ characteristics $k_i(s)$, $i = \overline{1,m}$ of the design solutions. The generalized functional effect $\overline{Q}(s)$ of the object S in the general case is a non-decreasing function of the amount of resources to achieve it (cost) $\overline{Q}(s) = F[\overline{C}(s)]$ (where $\overline{Q}(s)$ and $\overline{C}(s)$ are generalized scalar estimates of the effect and costs S; F is an operator that reflects the strategy of resource use, which is determined by the construction option of the S object).

The problem of determining the universal set of design solutions S^U ($Task_2$) is combinatorial in nature and can have computational complexity from $O[2^n]$ to $O[n!]$. Its solution is carried out based on the specifics of the projected object and the design task. In practice, methods of directed search are widely used, which allow to significantly reduce the set of alternative solutions that are generated and analyzed in the process of designing objects [21].

The problem of determining the set of admissible solutions $S \subseteq S^U$ ($Task_3$) is to remove from the universal set S^U of a subset of solutions $\overline{S}$ that do not satisfy the constraint of the problem to be solved $S = S^U \setminus \overline{S}$ [6]:

$$k_j(s) \overset{\geq}{\leq} k_j^* \ \ \forall k_j(s) \in Q(s),\ k_l(s) \leq k_l^* \ \ \forall k_l(s) \in Q(s). \qquad (2)$$

The task of selecting a subset of effective design solutions $S^E \subset S$ ($Task_4$) is to remove from the admissible set $S \subset S^U$ of subsets of inefficient solutions $\overline{S}^E \subset S$. Thus the variant of the design decision $s^E \in S^E$ is called effective if on a set S of admissible design decisions there is no decision $s \in S$ for which inequalities would be fair [22]:

$$k_i(s) \geq k_i(s^E),\ \text{if}\ k_i(s) \to max, \qquad (3)$$

$$k_i(s) \leq k_i(s^E),\ \text{if}\ k_i(s) \to min \qquad (4)$$

and at least one of them was strict.

Depending on the features of the problem, methods are used to solve it: discrete choice, weight [23], pairwise comparisons, Carlin, Hermeyer [22], evolutionary search [24-26].

Methods of discrete choice and pairwise comparisons allow to correctly select subsets of effective solutions, but have a relatively high time complexity.

A subset of effective variants $S^E \subset S$ by the Carlin method is found by combining solutions s_i^o and $i = \overline{1,m}$ that optimize each of the partial criteria by solving a set of parametric programming problems [22, 27]:

$$s_i^o = arg\,\max_{s \in S} \{ P(s) = \sum_{i=1}^{m} \lambda_i \xi_i(s) \}, \qquad (5)$$

$$\lambda_i \in \Lambda = \{ \lambda_i : \lambda_i > 0 \ \ \forall i = \overline{1,m},\ \ \sum_{i=1}^{m} \lambda_i = 1 \}, \qquad (6)$$

where $\xi_i(s)$ – the value of the utility function (normalized value) of the i-th partial criterion; λ_i – weighting factor of the i-th partial criterion.

The subset of effective design solutions $S^E \subset S$ by the Hermeyer method is determined by combining options s_i^o, $i = \overline{1,m}$ that optimize each of the local criteria by solving a set of parametric programming problems [22-27]:

$$s_i^o = arg\,\max_{s \in S} \{ P(s) = \min_{i} \lambda_i \xi_i(s) \}, \qquad (7)$$

$$\lambda_i \in \Lambda = \{ \lambda_i : \lambda_i > 0 \ \ \forall i = \overline{1,m},\ \ \sum_{i=1}^{m} \lambda_i = 1. \qquad (8)$$

To reduce the time complexity of the methods of pairwise comparisons, Carlin and Hermeyer use procedures for selecting subsets of suboptimal Pareto solutions S' for which the condition is satisfied $S^E \subseteq S' \subseteq S$ [28]. They are implemented by the methods of "sector" or "segment" and provide for a set of acceptable solutions $S = \{ s \}$ to pre-determine the best options for each of the partial criteria k_i^+, $i = \overline{1,m}$. Hyperplanes are drawn through the points k_i^+, $i = \overline{1,m}$ lying on the boundary of the set of admissible solutions $S = \{ s \}$ in the area of partial criteria. Hyperplanes will divide variants into subsets that fall into a sector $S_1' \supseteq S^E$ or segment $S_2' \supseteq S^E$, respectively, and those that are inefficient in the sense of (3)-(4):

$$S = S_1' \bigcup \overline{S}^E, \quad S_1' \bigcap \overline{S}^E = \varnothing; \tag{9}$$

$$S = S_2' \bigcup \overline{S}^E, \quad S_2' \bigcap \overline{S}^E = \varnothing. \tag{10}$$

Among evolution, the most popular method is based on a genetic algorithm with non-dominant sorting NSGA-II [29]. It is used to determine the Pareto front on acceptable sets of ultra-large size and has the ability to give convergence to the front and a good distribution of solutions across the front. To accelerate the rate of convergence of genetic algorithms to the Pareto front, a method of reducing the number of target functions based on the principal components method is used [30].

The ranking of solutions ($Task_5$) and the choice of the best design solution $s^o \in S^E$ ($Task_6$) is based on the paradigm of utility maximization within the framework of ordinalistic or cardinalistic approaches [23]. When using the ordinalistic approach, the ordering of a small set of effective solutions $s \in S^E$ is carried out by DM. When using the cardinalistic approach, a generalized efficiency criterion $P(s)$ is formed; it is used for scalar evaluation and selection of the best design solution:

$$s^o = \arg\max_{s \in S^E} P(s). \tag{11}$$

At the same time, in both approaches, it is considered that each of the design solutions is assigned a value of some of its value $P(s)$, which determines their order [19]:

$$\begin{aligned} &\forall s, v \in S: \; s \sim v \leftrightarrow P(s) = P(v); \\ &s \succ v \leftrightarrow P(s) > P(v); \\ &s \succsim v \leftrightarrow P(s) \geq P(v). \end{aligned} \tag{12}$$

To solve these problems, methods of comparative identification [11, 19] or expert collective assessment [31-35] are used, which give quite satisfactory results on a set of effective low-power solutions. In this case, the model of generalized utility based on the Kolmogorov-Gabor polynomial is used as a universal one [11, 19, 36].

Research results

According to the results of the review of the current state of the problem of project decision support, it is established that:

- most design tasks are multi-criteria and have a combinatorial nature;
- the process of solving them involves the generation and automatic analysis of huge numbers of design solutions;
- the vast majority of solutions generated in the design process are ineffective according to Pareto;
- methods of allocating subsets of effective solutions have a high time and capacitive complexity and, based on the peculiarities of design tasks, give subsets of enormous power;
- evaluation of the effectiveness of design solutions is traditionally carried out using the theory of utility;
- the process of making a final decision is carried out using the methods of expert evaluation, in the process of which only a small number of project decisions can be analyzed.

There is a need to correctly reduce subsets of effective design solutions for ranking, taking into account factors that are difficult to formalize, knowledge and experience of DM.

The aim is to develop a combined method of ranking options in project decision support systems, which will be based on the procedures of ordinalistic and cardinalistic ordering.

As a result of decomposition of the problem of obtaining stable and effective system solutions for complex design objects at the l-th (lower) level, we will highlight the tasks [6]: $Task_1^l$ – definition of the principles of object construction; $Task_2^l$ – choice of object structure; $Task_3^l$ – determination of the topology of elements and connections; $Task_4^l$ – choice of operating technology; $Task_5^l$ – determination of parameters of elements and connections; $Task_6^l$ – evaluation of efficiency and selection of design solutions.

The scheme of system optimization of the object on the selected set of tasks can be presented in the form of a tuple [37]:

$$SysOptS = \; < Tasks, InDat, Res, DesDec, ProcDec >, \tag{13}$$

where: $Tasks = < Task_i^l >$, $i = \overline{1,6}$ – an ordered set of tasks; $InDat$ – set of input data tasks; Res is a set of task constraints; $DesDec$ is a set of design optimization solutions; $ProcDec$ – a decisive procedure that assigns a non-empty subset $\{ DesDec_i^2 \}$, $i = \overline{1,6}$ to each pair $< InDat_i^2, Res_i^2 >$.

The number of design solutions $Card(S^U)$ increases nonlinearly with increasing dimension of the problem (the number of partial criteria for evaluating solutions m, the number of elements of the design object n, the number of types of elements, the number of possible locations of elements, etc.). It is known that the power of a set of effective solutions is much less than the power of a set of acceptable solutions $Card(S^E) << Card(S)$.

Table 1 shows examples of increasing the capacity of the universal set of acceptable $Card(S^U)$, subsets of effective design solutions $Card(S^E)$ and reducing the relative capacity of the subset of effective solutions $\delta S = Card(S^E) / Card(S^U)$ in the task of structural and topological optimization of a three-level centralized object on four indicators ($m = 4$).

Table 1. *Estimation of capacities of sets of admissible and effective design decisions*

n	15	20	25	30	35	40
$Card\ (S^U)$	$3{,}27\cdot 10^4$	$1{,}04\cdot 10^6$	$3{,}35\cdot 10^7$	$1{,}07\cdot 10^9$	$3{,}44\cdot 10^{10}$	$1{,}09\cdot 10^{12}$
$Card\ (S^E)$	$7{,}53\cdot 10^2$	$9{,}12\cdot 10^3$	$5{,}7\cdot 10^4$	$1{,}18\cdot 10^6$	$2{,}06\cdot 10^7$	$8{,}79\cdot 10^7$
δS	0,023	0,0087	0,0017	0,0011	0,0006	0,00008

To solve the problem of ranking solutions from the sets $S = \{s\}$ acceptable in design automation systems, a combined expert-machine method is proposed. It involves the sequential implementation of the following stages: selection on the set of allowable subsets of effective options $S^E \subseteq S$, $Card(S^E) << Card(S)$; determining the preferences of experts on the importance of different properties of options $s \in S^E$, which are assessed by partial criteria $k_i(s)$, $i = \overline{1,m}$; parametric synthesis of the generalized utility function $P(s)$; ranking of options using the synthesized generalized utility function $P(s) > P(v) \leftrightarrow s \succ v\ \forall s,v \in S^E$; selection on a subset S^E of a subset of some of the most effective options $S' \subseteq S^E$, $card(S') << card(S^E)$; determining the ranks of a subset of the most effective options.

Taking into account the limitations of the problem and the use of directed search methods can significantly reduce the set of acceptable solutions S relative to the universal set of solutions S^U, which leads to a corresponding reduction of the subset of effective solutions S^E. However, in practice, the allocation of a subset of effective solutions $S^E \subset S$, storage and processing of information about it is quite problematic.

Based on this, it is proposed not to select a subset S^E of the set of acceptable solutions, but to form it in the process of generating options. This allows not only to significantly reduce the amount of memory to store the characteristics of options for a set of indicators $k_i(s)$, $i = \overline{1,m}$, but also the computer time to install a subset of effective solutions.

It is proposed to determine the advantages of DM by parametric synthesis of the generalized utility function of solution variants based on the Kolmogorov-Gabor polynomial. [11, 19]:

$$P(s) = \sum_{i=1}^{m} \lambda_i \xi_i(s) + \sum_{i=1}^{m} \sum_{j=i}^{m} \lambda_{ij} \xi_i(s) \xi_j(s) + \\ + \sum_{i=1}^{m} \sum_{j=i}^{m} \sum_{l=j}^{m} \lambda_{ijl} \xi_i(s) \xi_j(s) \xi_l(s) + \ldots , \qquad (14)$$

$$\xi_i(s) = \bar{k}_i(s) = \frac{k_i(s) - k_i^-}{k_i^+ - k_i^-}, \quad i = \overline{1,m}, \qquad (15)$$

where $P(s)$ – generalized scalar assessment of the effectiveness of the solution $s \in S^E$; m – number of partial criteria; λ_i, λ_{ij}, λ_{ijl} – coefficients of importance of criteria $k_i(s)$, $i = \overline{1,m}$ and product of criteria $k_i(s)$, $k_j(s)$, $k_l(s)$; $0 < \xi_i(s) < 1$, $i = \overline{1,m}$ – the value of the utility function of the partial criterion $k_i(s)$, $i = \overline{1,m}$ for a solution *s*; $k_i(s)$, k_i^+, k_i^- – accordingly, the value of the partial criterion for the solution s, the best and worst value of the criterion $k_i(s)$, $i = \overline{1,m}$.

Function (15) requires a minimum number of machine operations to calculate its values among common functions [20]. For a more accurate nonlinear (*S*- and *Z*-shaped) approximation of estimates of the usefulness of the values of partial criteria, it is proposed to use a universal gluing function, which is the best in terms of the complex indicator "accuracy-complexity" among the common [38]:

$$\xi(s) = \begin{cases} \bar{a}(b_1+1)\left(1-\left(b_1 / \left(b_1 + \dfrac{\bar{k}(s)}{\bar{k}_a}\right)\right)\right), 0 \le \bar{k}(s) \le \bar{k}_a; \\ \bar{a} + (1-\bar{a})(b_2+1) \times \times \left(1-\left(b_2 / \left(b_2 + \dfrac{\bar{k}(s)-\bar{k}_a}{1-\bar{k}_a}\right)\right)\right), \bar{k}_a < \bar{k}(s) \le 1, \end{cases} \qquad (16)$$

where $\xi(s) = \bar{k}(s)$; $\bar{k}_a, \bar{a}$ – normalized values of the coordinates of the gluing point, $0 \le \bar{k}_a \le 1$, $0 \le \bar{a} \le 1$; b_1, b_2 – coefficients that determine the type of dependence on the initial and final segments of the function.

The value k_i^-, $i = \overline{1,m}$ for (15) should be determined on the whole set of admissible solutions $S = \{s\}$. Their definition only on a subset of effective S^E leads to the fact that the worst values of the utility functions of partial criteria $\xi_i(s)$, $i = \overline{1,m}$ (15) and (16) will be equal to 0 [11]. In this case, the property of universality of the model constructed on the basis of the Kolmogorov-Gabor polynomial (14) disappears and it is transformed into the classical additive model.

The number of summonds N in model (14) is determined by the required accuracy of restoring the benefits of DM. To determine the parameters of model (14) we will use the technology of comparative identification [11, 36].

The unreasonable choice of solutions for the parametric synthesis of model (14) reduces the accuracy of determining the advantages of DM, which is given by the values of the weight coefficients, λ_i, λ_{ij}, λ_{ijl},…. To increase the accuracy of identifying the advantages of DM, we select among the effective subset of a given number of the best options $S' \subseteq S^E$ by criterion:

$$s' = \arg \max_{s \in S^E} \min_{1 \le i \le m} \xi_i(s). \tag{17}$$

DM on the basis of requirements to the design decision and subjective estimations forms the binary relation of strict advantage on pairs of options [39]:

$$R(S') = \left\{ <s,v>: \ s,v \in S', \ s \succ v \right\}. \tag{18}$$

Given the possibility of scalar estimation of solutions (14), for relation (18) we make a system of inequalities:

$$P(\lambda,s) > P(\lambda,v), \ s,v \in R(S'), \tag{19}$$

where λ – the desired vector of parameters of the generalized utility model (14).

Let's enter the notation:

$$\xi_1(x)\cdot\xi_1(x) = \xi_{m+1}(x), \ \lambda_{1,1} = \lambda_{m+1}, \ \xi_1(x)\cdot\xi_2(x) = \xi_{m+2}(x),$$
$$\lambda_{1,2} = \lambda_{m+2}, \ \ldots . \tag{20}$$

The maximum number of terms of model (14) is $N = C^n_{m+n} - 1$ (where n is the given degree of the polynomial). Taking into account the accepted notation (20), model (14) can be presented in the classical additive form:

$$P(\lambda,s) = \sum_{i=1}^{N} \lambda_i \, \xi_i(s). \tag{21}$$

Then the problem of parametric synthesis of the generalized utility function (21) is reduced to determining the vector of weight coefficients $[\lambda_i]$, $i = \overline{1,N}$, which satisfies the formed system of inequalities and normalizing conditions:

$$\sum_{i=1}^{N} \lambda_i = 1, \ \lambda_i \ge 0, \ \ i = \overline{1,N}. \tag{22}$$

Taking into account (21) we present a system of inequalities (19) and equations (22), in the form:

$$\eta_j(\lambda) \equiv \sum_{i=1}^{N} \lambda_i \, \xi_i(s) - \sum_{i=1}^{N} \lambda_i \, \xi_i(v) > 0, \ \ <s,v> \in R(S'),$$
$$j = \overline{1,n'}, \tag{23}$$
$$\eta_{n_S+1}(\lambda) \equiv \sum_{i=1}^{N} \lambda_i = 1, \ \lambda_i \ge 0, \ i = \overline{1,N},$$

where $n' = Card \ R(S')$ – the power of the set of the established ratio of strict advantage (19).

The first part of the system (23) are homogeneous inequalities defining the set of planes that pass through the origin, and the second part acts as a normalizing condition and defines the cutting plane.

The obtained system of inequalities and equations (23) can have innumerable solutions or be incompatible (if there are contradictions in the advantages of DM). The problem of determining stable estimates of the vector of weights of model (21) can be reduced to finding the Chebyshev point [11, 19, 39].

Let's introduce an additional variable λ_{N+1} in the system of constraints (23) and require that the conditions $\eta_j(\lambda) \le \lambda_{N+1}$, $j = \overline{1,n'}$ are satisfied. Then the search for the Chebyshev point of system (23) is reduced to solving the problem:

$$\lambda_{N+1} \to \min;$$
$$\begin{cases} \eta_j(\lambda) + \lambda_{N+1} > 0, \quad j = \overline{1,n'}, \\ \eta_{n'+1}(\lambda) \equiv \sum\limits_{i=1}^{N} \lambda_i = 1, \quad \lambda_i \ge 0, \quad i = \overline{1,N}. \end{cases} \tag{24}$$

If the system of inequalities (24) is compatible, then the indicator variable is

$$r = \min_{\lambda} \max_{j} \eta_j(\lambda) \le 0, \tag{25}$$

and the obtained solution λ^o will be as resistant as possible to possible shifts of the constraint planes (variations of DM advantages). If the system of constraints (24) is incompatible, then $r > 0$. In this case, for the system of DM advantages, given by the binary relation $R(S')$ (18), there is no vector of weight coefficients of partial criteria $[\lambda_i]$ that satisfies the conditions (24).

At the next stage, the values of the generalized utility function $P(\lambda^o,s)$ (21) are calculated for all effective variants $s \in S^E$ with the set values of weight coefficients $[\lambda_i^o]$, $i = \overline{1,N}$. This allows the ranking of the whole set of effective options using the values of the synthesized generalized utility function.

At the last stage, based on the quantitative evaluation of options $P(\lambda^o,s)$, $s \in S^E$, a subset $S^o \in S^E$ of a given number n^o of the best options is selected. With $Card(S^o) << Card(S^E)$. After that, DM, using the methods of expert evaluation or lexicographic optimization, makes the final choice of the best option $s^o \in S^o$.

Conclusions

In the process of analyzing the problem of project decision support, it was found that most design tasks are multi-criteria and combinatorial, and the final decision-making processes are carried out using expert evaluation methods by analyzing only a small number of options. In practice, this leads to the problem of correctly reducing subsets of effective design solutions for ranking, taking into account factors that are difficult to formalize, knowledge and experience of DM. As a result of decomposition of the problem of support of design decisions the tasks of definition of the purpose of designing of object, formation of universal set of design decisions, allocation of sets of admissible and effective decisions, ranking and a choice of the best design decision are allocated.

To coordinate the interaction between automatic and interactive design procedures of automated design and control systems, a combined method of ranking options is proposed, which combines the procedures of ordinalistic and cardinalistic ordering technologies. It involves the sequential implementation of the stages of formation of a subset of effective options, determining the preferences of experts on the importance of individual properties of options, which are evaluated by partial criteria, parametric synthesis of generalized utility function, ranking options using synthesized generalized utility function, selection of subsets of multiple options and several ranks of the options selected in this way. Parametric synthesis of the generalized utility function, built on the basis of the Kolmogorov-Gabor polynomial, is proposed to be carried out using the method of comparative identification on a set of alternatives with maximum values of indicators.

The developed method expands the methodological principles of automation of support processes for multi-criteria design solutions, allows to correctly reduce the set of effective alternatives for the final choice, taking into account factors that are difficult to formalize, knowledge and experience of DM. The practical use of the obtained results due to the proposed procedure for determining the set of effective decisions will reduce the time and capacity complexity of decision support, and through the use of maximum selection in the synthesis of the evaluation model that is to improve the quality of design decisions.

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Received 22.11.2020

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КОМБІНОВАНИЙ МЕТОД РАНЖУВАННЯ ВАРІАНТІВ У СИСТЕМАХ ПІДТРИМКИ ПРИЙНЯТТЯ ПРОЄКТНИХ РІШЕНЬ

Предметом дослідження в статті є процес ранжування варіантів у системах підтримки прийняття проєктних рішень. **Мета** роботи – створення методу ранжування варіантів для підвищення ефективності систем підтримки прийняття рішень за рахунок узгодження взаємодії між автоматичними й інтерактивними процедурами систем автоматизованого проєктування. У статті вирішуються наступні **завдання**: огляд і аналіз сучасного стану проблеми ранжування варіантів у системах підтримки прийняття проєктних рішень; декомпозиція проблеми підтримки прийняття проєктних рішень; розробка комбінованого методу ранжування варіантів, який об'єднує процедури технологій ординалістичного та кардиналістичного впорядкування; розробка методу мінімаксного вибору варіантів з множини ефективних для процедури експертного оцінювання. Використовуються такі **методи**: теорії систем, теорії корисності, оптимізації та дослідження операцій. Результати. За результатами аналізу сучасної методології підтримки прийняття рішень встановлено існування проблеми коректного скорочення підмножин ефективних проєктних варіантів для ранжування з урахуванням факторів, що важко піддаються формалізації, знань і досвіду особи, що приймає рішення (ОПР). Виконана декомпозиція проблеми підтримки прийняття проєктних рішень на задачі визначення мети проєктування об'єкта, формування універсальної множини проєктних рішень, виділення множин допустимих та ефективних рішень, ранжування та вибору ОПР найкращого проєктного варіанту. Розроблено комбінований метод ранжування варіантів, який об'єднує процедури технологій ординалістичного та кардиналістичного впорядкування та дозволяє коректно скорочувати підмножин ефективних проєктних рішень для ранжування ОПР. Розроблено метод мінімаксного вибору варіантів з множини ефективних для процедури експертного оцінювання особою, що приймає рішення, який дозволяє підвищувати якість оцінювання. **Висновки.** Розроблений метод розширює методологічні засади автоматизації процесів підтримки багатокритеріальних проєктних рішень, дозволяє здійснювати коректне скорочення множини ефективних альтернатив для остаточного вибору з урахуванням факторів, що важко піддаються формалізації, знань і досвіду ОПР. Практичне використання отриманих результатів за рахунок запропонованої процедури визначення множини ефективних рішень дозволить скорочувати часову й ємнісну складності підтримки прийняття рішень, а за рахунок використання максимінного відбору варіантів при синтезі моделі оцінювання – підвищити якість проєктних рішень.

Ключові слова: автоматизація проєктування; багатокритеріальне оцінювання; ефективні рішення; компараторна ідентифікація; підтримка прийняття проєктних рішень; теорія корисності.

КОМБИНИРОВАННЫЙ МЕТОД РАНЖИРОВАНИЯ ВАРИАНТОВ В СИСТЕМАХ ПОДДЕРЖКИ ПРИНЯТИЯ ПРОЕКТНЫХ РЕШЕНИЙ

Предметом исследования в статье является процесс ранжирования вариантов в системах поддержки принятия проектных решений. **Цель** работы – создание метода ранжирования вариантов для повышения эффективности систем поддержки принятия решений за счет согласования взаимодействия между автоматическими и интерактивными процедурами систем автоматизированного проектирования. В статье решаются следующие **задачи:** обзор и анализ современного состояния проблемы ранжирование вариантов в системах поддержки принятия проектных решений; декомпозиция проблемы поддержки принятия проектных решений; разработка комбинированного метода ранжирования вариантов, который объединяет процедуры технологий ординалистичного и кардиналистичного упорядочения; разработка метода минимаксного выбора вариантов из множества эффективных для процедуры экспертного оценивания. Используются такие методы: теории систем, теории полезности, оптимизации и исследования операций. **Результаты.** В результате анализа современной методологии поддержки принятия решений установлено существование проблемы корректного сокращения подмножеств эффективных проектных вариантов для ранжирования с учетом факторов, трудно поддающихся формализации, знаний и опыта лица, принимающего решения (ЛПР). Выполнена декомпозиция проблемы поддержки принятия проектных решений на задачи определения цели проектирования объекта, формирования универсального множества проектных решений, выделения множеств допустимых и эффективных решений, ранжирования и выбора ЛПР лучшего проектного варианта. Разработан комбинированный метод ранжирования вариантов, который объединяет процедуры технологий ординалистичного и кардиналистичного упорядочения и позволяет корректно сокращать подмножества эффективных проектных решений для ранжирования ЛПР. Разработан метод минимаксного выбора вариантов из множества эффективных для процедуры экспертного оценивания ЛПР, который позволяет повысить качество оценивания. **Выводы.** Разработанный метод расширяет методологические основы автоматизации процессов поддержки многокритериальных проектных решений, позволяет осуществлять корректное сокращение множества эффективных альтернатив для окончательного выбора с учетом факторов, трудно поддающихся формализации, знаний и опыта ЛПР. Практическое использование полученных результатов за счет предложенной процедуры определения множества эффективных решений позволит сокращать временную и емкостную сложности поддержки принятия решений, а за счет использования максиминной процедуры отбора вариантов при синтезе модели оценивания – повысить качество проектных решений.

Ключевые слова: автоматизация проектирования; многокритериальная оценка; эффективные решения; компараторна идентификация; поддержка принятия проектных решений; теория полезности.

Бібліографічні описи / Bibliographic descriptions

Безкоровайний В. В. Комбінований метод ранжування варіантів у системах підтримки прийняття проєктних рішень. *Сучасний стан наукових досліджень та технологій в промисловості*. 2020. № 4 (14). С. 13–20. DOI: https://doi.org/10.30837/ITSSI.2020.14.013

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Сучасний стан наукових досліджень та технологій в промисловості. 2020. № 4 (14) *ISSN 2522-9818 (print)*
ISSN 2524-2296 (online)

UDC 519.722:004.415.26 DOI: https://doi.org/10.30837/ITSSI.2020.13.021

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EXPERIMENTAL STUDIES OF A MODEL FOR OPTIMIZING THE PORTFOLIO OF A PROJECT-ORIENTED ORGANIZATION BASED ON THE ENTROPY CONCEPT

The **subject** of the research is the optimization of the composition of the project portfolio based on the entropy concept. The **aim** of the study is to experimentally test the model for optimizing the portfolio of a project-oriented organization and substantiate its applicability in practice in management processes to ensure their effectiveness. Research **objectives:** forming a model taking into account the accepted value of the organization; formation of initial data on the organization and alternative projects; portfolio optimization by model and interpretation of results. Research **methods**: system analysis, functional analysis, operations research. **Results.** A model has been developed for forming a portfolio structure from projects of two categories – operational and development; the optimization criterion is to minimize the discrepancy between the desired and actually provided value of the organization. The restrictions take into account the maximum allowable energy limit and the minimum allowable value limit. As a result of the study, the applicability and adequacy of the model for optimizing the portfolio structure of a project-oriented organization were substantiated. The model makes it possible to obtain solutions on the optimal structure of a portfolio of projects in terms of its value under given resource constraints (in the form of a share of total energy and output energy) and energy entropy. The studies substantiated the possibility of adjusting the model in terms of the optimization criterion (maximizing value, minimizing energy entropy) and adding restrictions on the maximum permissible border of information entropy and energy efficiency. **Conclusions.** The model under consideration is characterized by wide practical application, taking into account its possible adjustment without changing the basic essence, taking into account the specifics of a particular field of activity or organization. The practical use of the main indicators of the entropy concept - information entropy, temperature, energy entropy, which characterize the state of organizations, allowing to identify hidden problems before they are reflected on the traditional indicators of organizational performance is demonstrated. Taking this into account, the structure of the project portfolio is being formed within the framework of the considered approach.

Keywords: project; portfolio; model; energy entropy; information entropy; energy efficiency.

Introduction

The specificity of project-oriented organizations is that their current activities and development are carried out through projects [1]. The effectiveness of project-oriented management is justified both in theoretical studies [2] and in applied works related to specific types of activities (for example, [3]).

The project portfolio of these organizations forms the final result, which, in the context of modern project management methodology, represents the value of the organization [4, 5], which can be calculated both in the form of economic indicators and in the form of indicators characterizing, for example, the market status of the organization.

The allocation of the organization's resources between portfolio projects and the formation of its optimal structure allows the organization to build its current activities and development in such a way as to maximize value under certain resource constraints and the desired state.

The entropy concept of managing organizations [6-11] puts forward new requirements that must be taken into account in the processes of optimizing a portfolio of projects in order to ensure not only economic efficiency, but also the sustainability of the organization [12] in the context of information and energy entropy.

Analysis of recent research and publications

A significant number of works are devoted to the problem of forming the optimal composition of portfolios of project-oriented organizations [13-20]. International standards for project portfolio management [13] set a certain benchmark for theoretical research.

Most of the works, for example [14, 15], focus on ensuring the achievement of the strategic goals of organizations, which is the essence of the core value of portfolios. In some works (in particular, [16]), the dynamics of the state of the organization is taken into account and the portfolio of projects is also considered in the form of a dynamic structure. In [17], approaches were proposed to the formation of a portfolio taking into account risks.

Thus, it can be argued that the instrumental basis for the formation of the optimal composition of project portfolios in the form of models and methods has been sufficiently developed in modern research.

Nevertheless, as mentioned above, the new entropic concept of managing organizations, which assesses their state by means of energy entropy [10-12], forms a new approach to optimizing the composition of the project portfolio. In particular, ensuring high economic performance without a corresponding increase in control over the external environment (controlled part of the external environment) [11], which is expressed in a gradual decrease in information entropy, as well as an increase in the efficiency of the use of total energy (resources), will not lead the organization to the required stable state. in a modern turbulent environment.

In [12], on the basis of the entropy concept of management of organizations, a model was developed that allows one to determine the optimal composition of a project portfolio that meets the requirement of balance in terms of the value-entropy ratio. Justification of the reliability and practical applicability of this model is impossible without appropriate experimental studies, which is the essence of this study.

Thus, the aim of this study is to experimentally test