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ESTIMATING THE PROPERTIES OF TECHNOLOGICAL SYSTEMS BASED ON FUZZY SETS

The subject of the research in the article is the process of evaluating the properties of technological systems at the stages of their design and reengineering. The **goal** – to improve the efficiency of procedures for multi-criteria evaluation of options for constructing technological systems using the apparatus of fuzzy sets. **Objectives**: to search for new or modification of known functions of belonging to fuzzy sets "the best variant of building a technological system" by particular criteria in the direction of reducing the complexity of procedures for calculating their values; perform a comparative analysis of the temporal complexity and accuracy of approximation of the preferences of the decision maker with the help of monotonic membership functions; give recommendations on the practical use of monotonous membership functions in decision support systems. Common scientific **methods** are used, such as: decision making, utility theory, fuzzy sets and identification. The following results are obtained. The article presents the model of preferences of the decision-maker developed by the authors for evaluating individual properties of technological systems using the membership function of fuzzy sets, which allows to realize both linear and nonlinear (convex, concave, S-shaped and Z-shaped) criteria. The carried out experimental research has revealed its advantages in terms of accuracy and time complexity in comparison with the functions of Gauss, Harrington, logistic function, gluing of power functions and their modifications. Methods are proposed that reduce the time complexity of procedures for calculating the values of membership functions. **Conclusions**. As a result of the analysis of known membership functions for fuzzy sets, it has been established that they do not adequately reflect the preferences of the decision-maker for the characteristics of systems close to extreme values and have a relatively high computational complexity. The proposed membership function and its calculation method make it possible to increase the adequacy of multifactorial estimation models and significantly reduce the time complexity of procedures for calculating its values. Practical use of the proposed membership function in the support systems for the adoption of design and management solutions will make it possible to obtain solutions of the problems of multifactor estimation and choice of a much larger dimension or with less expenditure of computing resources practically without loss of accuracy.

Keywords: technological system, quality criteria, multicriteria optimization, fuzzy set, membership function.

Introduction

Modern technological systems are difficult complexes of functionally interconnected means of technological equipment, items of production and actors for conducting specified technological processes or operations under regulated production conditions. Their efficiency is largely determined by decisions made in the process of their designing or reengineering [1].

Processes of designing and reengineering of technological systems assume the solution of a set of interrelated problems of structural, topological and parametric optimization. These tasks belong to the NP-complex class and are solved in conditions of incomplete information according to a set of functional and cost indicators (particular criteria of efficiency). The best solution from a set of efficient ones can be selected by a decision-maker only in the simplest situations [2]. Otherwise, to automate the procedures for estimating project solutions, additional information about the utility of different values of formalized properties of decisions is necessary (particular criteria) [3].

Analysis of the current state of the problem

The methodology of solving tasks of optimization of technological systems as well other anthropogenic systems is based on the theory of multicriteria optimization [4–6]. It is based on mathematical models and methods of utility theory. Two main approaches to estimating the quality of system variants are used, that is the ordinal and cardinal ones.

Within the ordinal approach a decision-maker establishes the procedure "better-worse" on the subset $X=\{x\}$ of admissible $X \subseteq X^*$ or efficient variants $X \subseteq X^C$ for developing the system; for example, a decision maker can determine the binary relations of strict preference $R_S(X)$, the preference-indifference relation $R_{NS}(X)$ or equivalence $R_E(X)$:

$$R_S(X)=\{<x_i,x_j>:\ x_i,x_j \in X,\ x_i \succ x_j\};$$

$$R_S^O(X): x_k \succ x_l \succ ... \succ x_n; \qquad (1)$$

$$R_{NS}(X)=\{<x_i,x_j>:\ x_i,x_j \in X,\ x_i \tilde{\succ} x_j\};$$

$$R_{NS}^O(X): x_k \tilde{\succ} x_l \tilde{\succ} ... \tilde{\succ} x_n; \qquad (2)$$

$$R_E(X)=\{<x_i,x_j>:\ x_i,x_j \in X,\ x_i \sim x_j\};$$

$$R_E^O(X): x_k \sim x_l \sim ... \sim x_n. \qquad (3)$$

Within the cardinal approach, preferences are determined by attributing some value $P(x)$, that is interpreted as its utility or value, to each of the alternatives $x \in X$. The utility function that is common according to a set of indicators $P(x)$ determines the appropriate order (preferences of a decision maker) $R(X)$ (1), (2) or (3). The value of the argument $x^o \in X$, corresponding to the maximum of general utility function $P(x)$, corresponds to the best variant of the technological system development.

The pattern for solving the task of multicriteria selection within the cardinal approach is presented as:

$$S \to A \to Opt\ G \to x^0, \qquad (4)$$

where S is the situation of multicriteria selection; A is the axiomatics of multicriteria selection, which is a set of axioms that determine the pattern of compromise (the principle of ordering solutions); $Opt\,G$ is compromise pattern $P(x)$); x^0 is the best variant for developing a technological system [3].

A decision-maker or a group of experts determine the principle of ordering decisions A grounding on heuristic considerations. Currently, the apparatus of fuzzy sets theory is used to develop a scalar estimation on a set of partial criteria $k_i(x)$, $i=\overline{1,m}$ (where m is a number of partial criteria), representing the most important properties of the technological system [3, 7]. In this case, the fuzzy set adjective "the best variant of developing a technological system" is used as the general utility function $P(x)$.

The fuzzy set adjective "the best variant of developing a technological system" can be represented as a set of ordered pairs:

$$"The\ best\ variant\ of\ developing\ a\ technological\ system" = \{<x, P(x)>\},$$

where $x \in X$ is a variant of system development; $P(x)$ is a degree of the fuzzy set adjective "the best variant of developing a technological system".

The most universal function among the ones for multifactor estimation is the function developed on the basis of the Kolmogorov-Gabor polynomial [3]:

$$P(x)=\sum_{i=1}^{m}\lambda_i\xi_i(x)+\sum_{i=1}^{m}\sum_{j=i}^{m}\lambda_{ij}\xi_i(x)\xi_i(x)+ +\sum_{i=1}^{m}\sum_{j=i}^{m}\sum_{l=j}^{m}\lambda_{ijl}\xi_i(x)\xi_j(x)\xi_l(x)+\ldots, \quad (5)$$

where $\lambda_i, \lambda_{ij}, \lambda_{ijl}$ – weight coefficients of partial criteria and their products; $\xi_i(x), \xi_j(x), \xi_l(x)$ – utility functions of partial criteria $k_i(x), k_j(x),..., k_l(x)$.

The utility functions of partial criteria $\xi_i(x), \xi_j(x), \xi_l(x)$ in this case are considered as the fuzzy set adjective "the best variant of developing a technological system" according to particular criteria $k_i(x), k_j(x),..., k_l(x)$. They map $\xi_i : k_i(x) \rightarrow E^1$, $i=\overline{1,m}$, and should be universal and well-adapted to considering the peculiarities of specific situations of multicriteria selection [3]: they should be monotonous and dimensionless; have a common change interval (from 0 to 1); be invariant to the extremum of a particular criterion (min or max); enable implementing both linear and non-linear dependencies on the characteristics of options for developing systems.

In the practice of multicriteria optimization the mostly wide-spread functions are membership functions [3, 8–10]:

$$\xi_i(x) \equiv \xi_i(k_i(x)) = \left(\frac{k_i(x)-k_i^-}{k_i^+-k_i^-}\right)^{\alpha_i}, \quad (6)$$

where $k_i(x)$, k_i^+, k_i^- is the value of the i-th partial criterion for the variant x, the best and worst values of the i-th criterion, $i=\overline{1,m}$; α_i is a parameter determining the variant of the dependence ($\alpha_i = 1$is linear, $0<\alpha_i<1$ is concave, $\alpha_i>1$ is convex).

The disadvantage of the function (6) is the impossibility of implementing S- and Z-shaped dependencies on the values of the particular criterion, which more adequately represent the situations of making project optimization solutions. In particular, power functions sewing from [7] and [11], the Gaussian function, the Harrington function, the logistic function, and their modifications do not have such drawback [12].

The experimental study of the utility functions of particular criteria used in practice [12] showed that: the procedures for selecting their parameters have a linear or quadratic time complexity with respect to a number of approximation nodes and take from several hundredths to tens of seconds; power functions sewing from [11] has several times greater accuracy of approximation of a decision maker's estimations than other functions.

The main disadvantage of these functions is a various degree of approximation of their values to the boundary values (0 and 1) with the approximation of the normalized values of the particular criterion to the extremal values $k_i^+=1$, $k_i^-=0$, $i=\overline{1,m}$. This reduces their capability to differentiate the utility of different values of the particular criterion. To avoid this disadvantage the ordinates $k_i(x)$, $i=\overline{1,m}$ should be scaled, which, in turn, increases the computation time of the membership function $\xi_i(x)$, $i=\overline{1,m}$.

The conducted analysis and the review of literature sources on the topic of the study [1–12] showed that nowadays there remain some unexplored problems of evaluating the time complexity of procedures for calculating the values of utility functions of partial criteria. Their preliminary analysis shows that the computation time basing on them can differ by several times. Taking into account the fact that the tasks of structural, topological and parametric optimization of technological systems suggest, in the worst case, the analysis of the variants of the 2^n order (where n is a variable that determines a number of structural elements, variants of topologies or parameters of the technological system), the search for new functions or the modification of available ones are required in order to reduce the complexity of calculating their values.

The goal and objectives of the study

The goal of the research is to increase the efficiency of multicriteria estimation of the properties of technological systems at the stages of their designing and reengineering using the apparatus of fuzzy sets.

To achieve this goal, it is necessary:

- to search new monotonous fuzzy set adjectives "the best variant of developing a technological system" or their modification according to particular criteria for reducing the complexity of their values calculation;

- to make a comparative analysis of time complexity and accuracy of approximation of a decision maker's preferences for available and suggested monotonous membership functions;

- to give recommendations about the practical use of monotonous fuzzy set adjectives "the best variant of developing a technological system" according to private criteria.

Study materials

Dependencies representing the change in the utility of the values of certain technological properties, like other anthropogenic systems, on the values of their criterion estimates are monotonous: S-shaped for particular criteria $k_i(x) \to max$ and Z-shaped for particular criteria $k_j(x) \to min$, $i, j \in [1,...,m]$ (where m is a number of partial criteria). In this case, by normalizing the values of particular criteria (regardless their type), all membership functions can be reduced to *S*-type [3]:

$$\bar{k}(x) = \frac{k(x) - k^-}{k^+ - k^-},\; i = \overline{1,m}, \quad (7)$$

where $k(x)$, k^+, k^- – the value of the particular criterion for the variant *x*, the best and worst values of the criterion $k(x)$.

Power functions sewing from [7] and functions (6) [11], the Gaussian function, the Harrington functions, logistic function, and their modifications belong to the utility functions of partial criteria (as a fuzzy set adjective "the best variant"), that describe a decision-maker's estimations in the most accurate way and are widely accepted in practice [12].

Let us represent the listed functions using the normalization of the form (6):

- the Gaussian function [12]:

$$\xi(x) = exp\left[-\frac{(\bar{k}(x) - 1)^2}{c}\right], \quad (8)$$

where $c > 0$ is the parameter, defining specific type of dependencies;

- the logistics function [12]:

$$\xi(x) = \frac{1}{1 + exp\left[-\frac{(\bar{k}(x) - a)}{b}\right]}, \quad (9)$$

where a is the abscissa of the inflection point; b is the parameter, defining the type of dependencies;

- the Harington function [12]:

$$\xi(x) = exp\left\{-exp\left[(g \cdot \bar{k}(x) - a)\right]\right\}, \quad (10)$$

where g is the parameter of nonlinearity; a / g determines the inflection point;

- the modified Gaussian function [12]:

$$\xi(x) = exp\left[-\frac{(\bar{k}(x) - 1)^{2\cdot\alpha}}{c}\right], \quad (11)$$

where $c > 0$ is the parameter defining the form of dependence; α is the parameter determining the type of nonlinearity;

- power functions sewing [11]:

$$\xi(x) = \begin{cases} \bar{a} \cdot \left(\frac{\bar{k}(x)}{\bar{k}_a}\right)^{\alpha_1}, & 0 \le \bar{k}(x) \le \bar{k}_a; \\ \bar{a} + (1 - \bar{a}) \cdot \left(\frac{\bar{k}(x) - \bar{k}_a}{1 - \bar{k}_a}\right)^{\alpha_2}, & \bar{k}_a < \bar{k}(x) \le 1, \end{cases} \quad (12)$$

where $\bar{k}_a$, $\bar{a}$ – are normalized values of the coordinates of the point of sewing function, $0 \le \bar{k}_a \le 1$, $0 \le \bar{a} \le 1$; α_1, α_2 – are the coefficients that determine the form of the dependence on the initial and final segments of the function;

- power functions sewing based on the function [7]:

$$\xi(x) = \begin{cases} 2^{p-1} \cdot \left[\bar{k}(x)\right]^p, & 0 \le \bar{k}(x) \le 0.5; \\ 1 - 2^{p-1} \cdot \left[\frac{0.5 - \bar{k}(x)}{0.5}\right]^p, & 0.5 < \bar{k}(x) \le 1, \end{cases} \quad (13)$$

where p is the parameter defining the form of dependence.

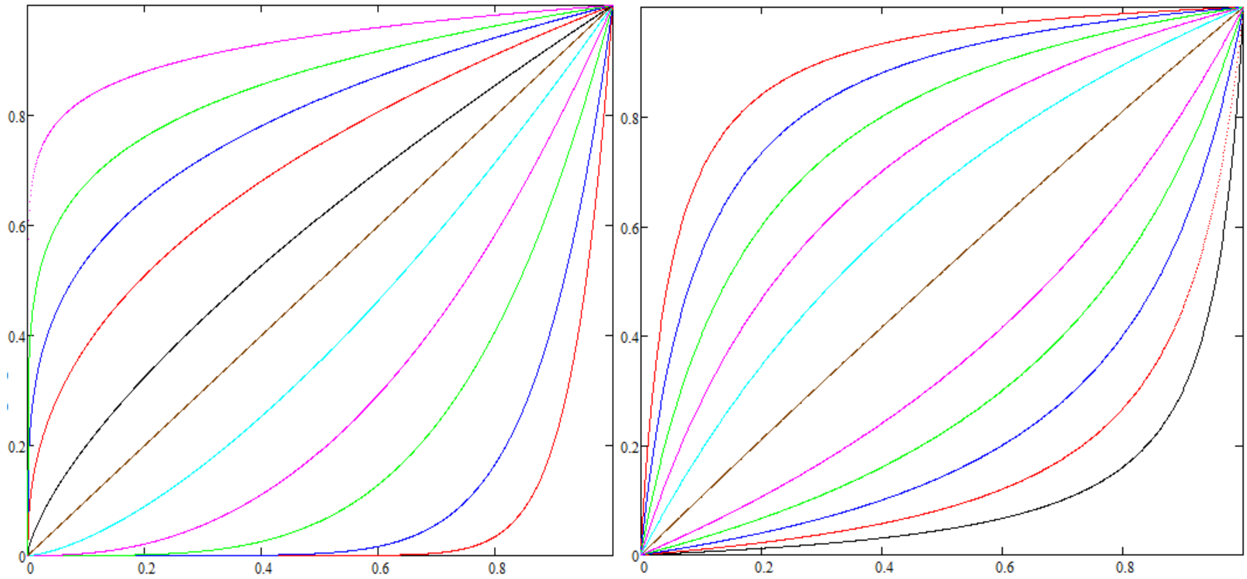
Functions (8) –(13) greatly change their values at the entrance to the dead bands (when the partial characteristics of the system approach to the worst and best values, i.e., $\bar{k}(x) \to 0$ and $\bar{k}(x) \to 1$. This can lead to significant errors in determining the properties of technological systems according to specific criteria and have a significant effect on the error in calculating the quality of options for their development as a whole $P(x)$ (5).

To overcome these drawbacks, sewing function (12) should be modified by using fractional-linear functions instead of power functions:

$$\xi(x) = \begin{cases} \bar{a} \cdot (b_1 + 1) \cdot \left(1 - \left(b_1 / \left(b_1 + \frac{\bar{k}(x)}{\bar{k}_a}\right)\right)\right), & 0 \le \bar{k}(x) \le \bar{k}_a; \\ \bar{a} + (1 - \bar{a}) \cdot (b_2 + 1) \cdot \left(1 - \left(b_2 / \left(b_2 + \frac{\bar{k}(x) - \bar{k}_a}{1 - \bar{k}_a}\right)\right)\right), & \bar{k}_a < \bar{k}(x) \le 1, \end{cases} \quad (14)$$

where b_1, b_2 are the coefficients that determine the form of the dependence on the initial and final segments of the function.

The suggested modification of sewing function (14) substantially reduces the dead band of membership function, thereby widening the region of the estimation model adequacy (fig. 1).



a – function (12) *b* – function (14)

Fig. 1. The components of sewing the utility functions of particular criteria for different values of α_1, α_2 and b_1, b_2 parameters

To reduce a number of operations that are required while calculating the values of function $\xi(x)$, it is suggested to use a single preliminary calculation of their parts that do not change when the values of the particular criterion change $\bar{k}(x)$.

The values of the functions (8) - (14) transformed to reduce the computation time are represented as:

- the Gaussian function (8):

$$\xi(x) = exp\left[z \cdot (\bar{k}(x) - 1)^2\right], \qquad (16)$$

where $z = -1/c$;

- the logistics function (9):

$$\xi(x) = \frac{1}{1 + exp\left[z_1 - z_2 \cdot \bar{k}(x)\right]}, \qquad (17)$$

where $z_1 = a/b$; $z_2 = 1/b$;

- the Harrington function (10):

$$\xi(x) = exp\left\{-exp\left[(a - g \cdot \bar{k}(x))\right]\right\}, \qquad (18)$$

where g – is the nonlinearity parameter; a/g – determines the inflection point;

- the modified Gaussian function (11):

$$\xi(x) = exp\left[z_1(\bar{k}(x) - 1)^{z_2}\right], \qquad (19)$$

where $z = -1/c$; $z_2 = 2 \cdot \alpha$;

- power functions sewing (12):

$$\xi(x) = \begin{cases} z_1 \cdot [\bar{k}(x)]^{\alpha_1}, & 0 \le \bar{k}(x) \le \bar{k}_a; \\ \bar{a} + z_2 \cdot [\bar{k}(x) - \bar{k}_a]^{\alpha_2}, & \bar{k}_a < \bar{k}(x) \le 1, \end{cases} \qquad (20)$$

where $z_1 = \bar{a} \cdot \left(\frac{1}{\bar{k}_a}\right)^{\alpha_1}$, $z_2 = (1 - \bar{a}) \cdot \left(\frac{1}{1 - \bar{k}_a}\right)^{\alpha 2}$;

- power functions sewing (13) based on the function [7]:

$$\xi(x) = \begin{cases} z \cdot \left[\bar{k}(x)\right]^p, & 0 \le \bar{k}(x) \le 0.5; \\ 1 - z \cdot \left[\frac{0.5 - \bar{k}(x)}{0.5}\right]^p, & 0.5 < \bar{k}(x) \le 1, \end{cases} \qquad (21)$$

where $z = 2^{p-1}$;

- the suggested modification of sewing function (14):

$$\xi(x) = \begin{cases} z_{11} - \frac{z_{12}}{z_{13} + \bar{k}(x)}, & 0 \le \bar{k}(x) \le \bar{k}_a; \\ z_{21} - \frac{z_{22}}{z_{23} + \bar{k}(x)}, & \bar{k}_a < \bar{k}(x) \le 1, \end{cases} \qquad (22)$$

where $z_{11} = a \cdot (b_1 + 1)$; $z_{12} = b_1 \cdot z_{11} \cdot \bar{k}_a$; $z_{13} = b_1 \cdot \bar{k}_a$; $z_{21} = b_2 \cdot (1 - \bar{a}) + 1$; $z_{22} = (z_{21} - 1) \cdot (b_2 + 1) \cdot (1 - \bar{k}_a)$; $z_{22} = b_2 \cdot (1 - \bar{k}_a) - \bar{k}_a$.

The results of the study

The software was developed and the series of experiments were carried out for a comparative analysis of the accuracy of approximation of a decision maker's preferences and the time complexity of calculating the values of utility functions of particular criteria $\xi(x)$ (8) – (14).

The values of the particular criterion $\bar{k}(x_i)$ and the corresponding values of their significance $\tilde{\xi}(x_i),\ i=\overline{1,20}$ were developed while simulating the work of experts using a random number generator. The selection of the best values of the parameters of the functions q was carried out by the method of the golden section according to the criterion of the least squares:

$$K=\sum_{i=1}^{20}\left[\xi(x_i,q)-\xi(x_i)\right]^2\rightarrow\min_{q\subseteq Q}, \qquad (15)$$

where Q – set of admissible values of the parameters of the functions (8) – (14).

The average time for calculating the value of the original functions was estimated (8) – (14) t_{1c}; as well as the average time for calculating the value of the transformed functions (16) – (22) the average error in approximating a decision maker's preferences K_c (15); the maximum error of one decision maker's estimation, the value K_{max} according to the series of experiments (tab. 1).

Table 1. **Results of the experimental study of functions**

Function type	t_{1c}, Ns	t_{2c}, Ns	K_c	K_{max}
Gauss (8)	2.523	2.23	1.83101	0.34394
Logistic (9)	2.471	2.361	0.08763	0.02251
Harrington (10)	4.658	4.611	0.07969	0.01285
Modified Gaussian (11)	7.74	7.501	0.40765	0.09471
Gluing (12)	5.739	5.431	0.03707	0.00655
Gluing (13)	0.876	0.722	1.02613	0.25744
Proposed function (14)	0.786	0.624	0.04151	0.01131

The results of the experiments justified that the accuracy of approximating a decision maker's preferences using sewing function (12) and the suggested modification (14) is several times higher than with the help of other functions. At the same time, all functions except for the Gaussian function (8) and power functions sewing (13) have an error of approximation of preferences according to the maximum error K_{max}, that is satisfactory for practice.

A much shorter time for calculating the values is required for the suggested modification of sewing function (14) and power functions sewing (13). At the same time, according to this indicator, they are 1.15–12.02 times higher than all other membership functions.

The suggested method for simplifying the algorithms for calculating the functions (8) – (14) made it possible to reduce the time for estimating by 1.01–25.96% more.

A number of compromises according to the accuracy of approximation of a decision maker's preferences the calculation time include sewing function (12) and the suggested modifications (14). The suggested modification of sewing function (14) is the most efficient function according to the complex parameter "accuracy – computational complexity".

Conclusions

The analysis of the problem of estimating the properties of technological systems in the process of their multicriteria optimization resulted in the study of available monotonous fuzzy set adjectives "the best variant".

It was established experimentally that power functions sewing (12) has much higher accuracy of approximation of expert estimates in comparison with the Gaussian function, the Harrington function, the logistic function and sewing function from (13) among the functions that are used in decision making support systems and enable implementing S (Z)-like dependencies on the values of particular criteria.

In this case, the available membership functions greatly change their values when the system's partial characteristics approach to the worst and best values, which can lead to significant errors in determining the properties of technological systems according to specific indicators and, consequently, to the error of their complex multicriteria estimation. To use the methods of solving combinatorial tasks of structural, topological, and parametric optimization of technological systems, membership functions with little time complexity are required.

To overcome the mentioned drawbacks, the modification (14) of sewing function (12) is suggested by using fractional-linear functions instead of power functions. The suggested modification of the membership function significantly reduces the dead band practically without any loss of accuracy, thereby increasing the adequacy of the model of multifactor estimation and the selection of design solutions. In this case, the time for calculating the values of the suggested modification of the function is 8.7 times less than for the basic sewing function.

Its practical use in decision making support systems of design and management solutions enables solving multifactor estimation tasks practically without any loss of accuracy and selecting solutions of much larger dimension with less computational resources.

Directions for further research in this area can be the development of mathematical models, methods and software tools for selecting the parameters of the fuzzy set adjective "the best variant of developing a technological system" according both to specific indicators and to a set of quality indicators simultaneously.

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ОЦІНКА ВЛАСТИВОСТЕЙ ТЕХНОЛОГІЧНИХ СИСТЕМ ІЗ ВИКОРИСТАННЯМ НЕЧІТКИХ МНОЖИН

Предметом дослідження в статті є процес оцінки властивостей технологічних систем на етапах їхнього проектування та реінжинірингу. **Мета** – підвищення ефективності процедур багатокритеріальної оцінки варіантів побудови технологічних систем з використанням апарату нечітких множин. **Завдання:** провести пошук нових чи внесення змін до відомих функцій приналежності нечітких множин «кращий варіант побудови технологічної системи» за частковими критеріями в напрямку зниження складності процедур обчислення їх значень; виконати порівняльний аналіз часової складності та точності апроксимації переваг особи, що приймає рішення, за допомогою монотонних функцій приналежності; дати рекомендації щодо практичного використання монотонних функцій приналежності в системах підтримки прийняття рішень. Використовуються загальнонаукові **методи**: прийняття рішень, теорії корисності, нечітких множин, ідентифікації. Отримані такі **результати**. У статті подана розроблена авторами модель переваг особи, що приймає рішення, для оцінки окремих властивостей технологічних систем з використанням функції приналежності нечітким множинам, що дозволяє реалізувати як лінійні, так і нелінійні (опуклі, увігнуті, S-образні і Z-образні) залежно від значень часткових критеріїв. Проведене експериментальне дослідження виявило її переваги за показниками точності та часової складності в порівнянні з функціями Гауса, Харрінгтона, логістичною функцією, склейками ступеневих функцій і їх модифікаціями. Запропоновано прийоми, що знижують часову складність процедур обчислення значень функцій приналежності. **Висновки.** У результаті аналізу відомих функцій приналежності нечітких множин встановлено, що вони недостатньо адекватно відображають переваги особи, що приймає рішення, для характеристик систем близьких до екстремальних значень і мають відносно високу обчислювальну складність. Запропонована функція приналежності та спосіб її обчислення дозволяють підвищити адекватність моделей багатофакторного оцінювання та суттєво знизити часову складність процедур обчислення її значень. Практичне використання запропонованої функції приналежності в системах підтримки прийняття проектних і управлінських рішень дозволить практично без втрати точності отримувати розв'язки задач багатофакторного оцінювання та вибору набагато більшої розмірності або з меншими витратами обчислювальних ресурсів.

Ключові слова: технологічна система, критерії якості, багатокритеріальна оптимізація, нечітка множина, функція приналежності.

ОЦЕНКА СВОЙСТВ ТЕХНОЛОГИЧЕСКИХ СИСТЕМ С ИСПОЛЬЗОВАНИЕМ НЕЧЕТКИХ МНОЖЕСТВ

Предметом исследования в статье является процесс оценки свойств технологических систем на этапах их проектирования и реинжиниринга. **Цель** – повышение эффективности процедур многокритериальной оценки вариантов построения технологических систем с использованием аппарата нечетких множеств. **Задачи:** провести поиск новых или модификацию известных функций принадлежности нечетким множествам «лучший вариант построения технологической системы» по частным критериям в направлении снижения сложности процедур вычисления их значений; выполнить сравнительный анализ временной сложности и точности аппроксимации предпочтений лица, принимающего решения, с помощью монотонных функций принадлежности; дать рекомендации по практическому использованию монотонных функций принадлежности в системах поддержки принятия решений. Используются общенаучные **методы:** принятия решений, теории полезности, нечетких множеств, идентификации. Получены следующие **результаты.** В статье представлена разработанная авторами модель предпочтений лица, принимающего решения, для оценки отдельных свойств технологических систем с использованием функции принадлежности нечетким множествам, позволяющая реализовать как линейные, так и нелинейные (выпуклые, вогнутые, S-образные и Z-образные) зависимости от значений частных критериев. Проведенное экспериментальное исследование выявило ее преимущества по показателям точности и временной сложности в сравнении с функциями Гаусса, Харрингтона, логистической функцией, склейками степенных функций и их модификациями. Предложены приемы, снижающие временную сложность процедур вычисления значений функций принадлежности. **Выводы.** В результате анализа известных функций принадлежности нечетким множествам установлено, что они недостаточно адекватно отображают предпочтения лица, принимающего решения, для характеристик систем близких к экстремальным значениям и имеют относительно высокую вычислительную сложность. Предложенная функция принадлежности и способ ее вычисления позволяют повысить адекватность моделей многофакторного оценивания и существенно снизить временную сложность процедур вычисления ее значений. Практическое использование предложенной функции принадлежности в системах поддержки принятия проектных и управленческих решений позволит практически без потери точности получать решения задач многофакторного оценивания и выбора гораздо большей размерности или с меньшими затратами вычислительных ресурсов.

Ключевые слова: технологическая система, критерии качества, многокритериальная оптимизация, нечеткое множество, функция принадлежности.

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