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МАТЕМАТИЧЕСКИЕ ОСНОВЫ И ЧИСЛЕННЫЕ МЕТОДЫ МОДЕЛИРОВАНИЯ

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Совершенствование метода парных сравнений для реализации в компьютерных программах, применяемых при оценке качества технических систем

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Представлен усовершенствованный метод парных сравнений, в котором посредством табличных форм систематизированы правила логических выводов при сравнении технических систем и формулы проверочных значений. Для этого сформулированы рациональные правила логических выводов при парном сравнении систем. С целью проверки результатов оценки на непротиворечивость введены понятия количества баллов, набранных одной системой, и коэффициента качества систем, а также разработаны формулы расчетов. Для целей практического использования данного метода при разработке программ для ЭВМ предлагаются формализованные варианты взаимосвязанных таблиц: таблица обработки и систематизации экспертной информации, таблица возможных логических выводов по результатам сравнения заданного количества технических систем и таблица проверочных значений при использовании метода парных сравнений при оценке качества определенного количества технических систем. Таблицы позволяют более рационально организовать процедуры обработки информации и в значительной степени исключить влияние ошибок при вводе данных на результаты оценки качества технических систем. Основной положительный эффект от внедрения усовершенствованного метода парных сравнений состоит в существенном сокращении времени и ресурсов на организацию работы с экспертами, обработку экспертной информации, а также на подготовку и проведение дистанционного опроса экспертов по сети Интернет или локальной вычислительной сети предприятия (организации) за счет рационального использования исходных данных о качестве оцениваемых систем. Предлагаемый усовершенствованный метод реализован в программах для ЭВМ, предназначенных для оценки эффективности и устойчивости больших технических систем.

Ключевые слова: усовершенствованный метод парных сравнений, оценка, проверочные значения, коэффициент качества, таблица, систематизация

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Improvement of the paired comparison method for implementation in computer programs used in assessment of technical systems' quality

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The article describes an improved paired comparison method, which systematizes in tables the rules of logical conclusions and formulas of checking indices for comparison of technical systems. To achieve this goal, the authors formulate rational rules of logical conclusions in making a paired comparison of the systems. In addition, for the purpose of consistency check of the results of the assessment, the authors introduce parameters such as «the number of scores gained by one system» and «systems' quality index»; moreover, they design corresponding calculation formulas. For the purposes of practical application of this method to design computer programs, the authors propose to use formalized variants of interconnected tables: a table for processing and systematization of expert information, a table of possible logical conclusions based on the results of comparison of a set number of technical systems and a table of check values in the paired comparison method used in quality assessment of a definite number of technical systems. These tables allow one to organize procedures of the information processing in a more rational way and to predominantly exclude the influence of mistakes on the results of quality assessment of technical systems at the stage of data input. The main positive effect from the implementation of the paired comparison method is observed in a considerable reduction of time and resources needed to organize experts work, process expert information, and to prepare and conduct distant interviews with experts (on the Internet or a local computer network of an organization). This effect is achieved by a rational use of input data of the quality of the systems to be assessed. The proposed method is applied to computer programs used in assessing the effectiveness and stability of large technical systems.

Keywords: improved paired comparison method, assessment, verification index, quality index, table, systematization

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1. Introduction

Rapid technical development at the beginning of the 21st century has led to a noticeable variety of composition of technical systems (hereinafter called systems) and to an increase in the degree of both the mutual influence of quality characteristics of system elements and their joint influence on functioning of the systems. Thus, nowadays making timely managerial decisions based on a system's quality assessment is of primary importance in the process of the system's maintenance [Билятдинов, Меняйло, 2020, p. 199]. In practice, this is implemented in the necessity to solve a variety of semistructured maintenance problems:

- in the sphere of identification of failures in automated systems;
- when using information systems based on mathematical models in the process of management [Kalimoldayev, Abdildayeva, Mamyrbayev, 2016];
- when assessing sustainable development and safety, including assessment of cyberthreats, of maintained and designed automated systems of management [Baker, Henderson, 2017, p. 51];
- when applying artificial intelligence systems, large data and when improving automated management systems taking into account current trends of development of cyber-physical systems [Baker, Henderson, 2017; Price, Walker, Wiley, 2018; Segal, 2017; Trevino, 2019];
- when choosing the best system for maintenance under certain conditions [Билятдинов, Меняйло, 2020; Билятдинов, Шлянцев, Меняйло, 2020];
- when increasing the effectiveness of systems' maintenance [Билятдинов, Меняйло, 2020, p. 199].

To ensure that managerial decisions within the research area are made, it is rational to continue improvement of the paired comparison method for implementation in computer programs applied to assess the systems' quality when using expert information [Изергин, Таров, 2017; Путивцева и др., 2017; Черкашин, 2020]. The research in this direction and the above-mentioned approach are motivated by the results of recent studies [Calabrese, Osmetti, 2019, p. 1059] and by enhanced requirements for effective and sustainable functioning of systems and mitigation of risks for the systems when making managerial decisions [Pačaiová, Sinay, Nagyová, 2017, p. 288]. This is of particular significance for large technical systems [Билятдинов, Меняйло, 2020, p. 204], [Shafik, Chen, Rashed, 2020] containing automated control systems.

Numerous recent studies are devoted to various issues of the improvement and application of the paired comparison method [Изергин, Таров, 2017; Исаев, 2016; Кривулин, Агеев, 2019; Путивцева и др., 2017; Тихомирова, Сидоренко, 2012; Черкашин, 2020]. The review of these works has allowed the authors to outline the main trends of the research area.

Izergin and Tarov [Изергин, Таров, 2017] describe a methodology which consists in defining a problematic situation and establishing factors that influence the making of rational decisions and the choice of methods ensuring a successful completion of the set task. This approach is supported by the comparative analysis of application of multicriterion methods [Путивцева и др., 2017].

A similar problem is studied in the work [Тихомирова, Сидоренко, 2012] assessing innovative projects. To achieve this objective, the authors concentrate on the choice of a method for formation of criteria' weights necessary for the assessment in the process of expertise. They suggest using a modification of the method of hierarchies' analysis of T. Saati, which considers the specification of its application in the sphere of innovative projects' management. The modification of the method is based on the change of the assessment scale of criteria.

In addition to the review of the article by Tikhomirov and Sidorenko [Тихомирова, Сидоренко, 2012], it is necessary to mention another direction of similar research [Исаев, 2016]: modification of the paired comparison method of Saati based on the use of the alternative assessment scale of superiority. Isaev reveals and demonstrates advantages of the alternative scale over the classical one in the context of the task of setting weights of indistinct cognitive maps.

However, the article by Cherkashin [Черкашин, 2020] outlines the results of the study of the mathematical justification of the scale of judgements based on interconnected observations, paired comparisons of factors, criteria and alternatives, calculations of priorities and their synthesis into final judgements. It is of particular importance that this work demonstrates within what limitations of the procedures of hierarchies' analysis it is possible to calculate priorities and choose a necessary decision if one has the matrix of the paired assessment.

Finally, Krivulin and Ageev [Кривулин, Агеев, 2019] study the problem of assessing alternatives' ratings based on the data of paired comparisons of alternatives in accordance with several criteria and on paired comparisons of the criteria. To achieve this objective, the authors propose a procedure of making decisions on the basis of Chebyshev's approximation in a logarithmic scale of matrices of paired comparisons inversely to symmetrical matrices of single ranks, which define elements of vectors of weights of criteria and alternatives' ratings.

Thus, despite the importance of the reviewed studies, it is still necessary to further improve the program implementation of the method of paired comparison for the purpose of increasing the management effectiveness. Furthermore, the requirement to check upcoming expert information for consistency also motivates the development of the improved method of paired comparison for the assessment of systems' quality during their maintenance (hereinafter called the method). The method is aimed at rational application in computer programs irrespective of the programming language. In practice, the method can have a wider application in assessing the quality of various objects and processes.

2. Objective and essence of the method

The objective of the method is to decrease the labor involved in designing computer programs when applying the paired comparison method, to sufficiently decrease the time needed for processing of expert information, to ensure understandability and simplicity of the program implementation of assessment of systems' quality on the basis of the paired comparison method.

The essence of the method is ensuring automatic filling of the majority of cells of the specifically designed table for processing of expert information (Table 1) with a minimum participation of an expert, which is based on rational rules of logical conclusions in the process of paired comparison of systems and systematization of these rules in Table 2. In order to check the results of assessment for consistency and to counteract input of false information, the method contains concepts of the number of scores gained by one system z (B_z) and systems' quality index (K_z). In addition, checking Table 3 is designed and calculations formulas B_z and K_z are created.

The area of application of the method includes: design of computer programs aimed at processing of expert information, assessment of systems' quality in the process of their maintenance and checking of the results for consistency.

3. Rules of logical conclusions

This section outlines the rules of logical conclusions in the paired comparison of systems for the purpose of the automatic filling of the table comparing systems (Table 1), which uses the information put by an expert (an official).

Rule No. 1. In the case of comparison of a system with itself (R_{nn}), the result of the comparison always equals 1 (one) score, $R_{nn} = 1$, i. e., the program automatically puts «1» in corresponding cells in the diagonal of the table of comparison (Table 1). Rule No 1 is performed automatically by the program without participation of an expert.

Table 1. Table of processing and systematization of expert information in assessing the quality of n number of systems using the paired comparison method

Expert number	Systems				K	Number of scores, B_n	Check
Systems	1	2, . . . , z, . . .	$n-1$	n			
1	2	. . .	n	$n+1$	$n+2$	$n+3$	$n+4$
1	1	R_{1z}	$R_{1(n-1)}$	R_{1n}	K_1	B_1	
2	$2-R_{12}$	Т 2	Т 2	Т 2	K_2	B_2	
3	$2-R_{13}$	Т 2	Т 2	Т 2	K_3	B_3	
2, . . . , z, . . .	$2-R_{1z}$	1	Т 2	Т 2	K_z	B_z	
$n-1$	$2-R_{1(n-1)}$	$R_{(n-1)z} = 2-R_{z(n-1)}$	1	Т 2	$K_{(n-1)}$	$B_{(n-1)}$	
n	$2-R_{1n}$	$R_{nz} = 2-R_{zn}$	$2-R_{(n-1)n}$	1	K_n	B_n	
Total:							
Results of checking data for consistency:							

Comment: «Т 2» means that this cell is filled by the program automatically on the basis of the rules systematized in Table 2.

Rule No. 2. If system ($n-1$) equals system n, both systems get 1 (one) score and the expert puts «1» in a corresponding cell, as a result, the program automatically fills the cell of Table 1, where it is required to put the result of comparison of system n with system ($n-1$), with the same score «1», $R_{(n-1)n} = R_{n(n-1)} = 1$.

Rule No. 3. If system ($n-1$) is better than system n by a chosen indicator of the system's quality, system ($n-1$) gets 2 (two) scores and the expert puts «2» in a corresponding cell, $R_{(n-1)n} = 2$. Then system n gets 0 (zero) scores when compared to system ($n-1$), according to formula (1):

$$R_{n(n-1)} = 2 - R_{(n-1)n}. \quad (1)$$

Accordingly, using formula (1), the program automatically fills the cell of Table 1, where it is required to put the result of the comparison of system n with system ($n-1$), by putting «0» in it, $R_{n(n-1)} = 0$.

Rule No. 4. If system ($n-1$) is worse than system n by a chosen indicator of a system's quality, system ($n-1$) gets 0 (zero) scores and the expert puts «0» in a corresponding cell, $R_{(n-1)n} = 0$. As a result, similarly to rule No. 3, a logical conclusion is made that system n should get 2 (two) scores when compared to system ($n-1$), according to formula (1), i. e., $R_{n(n-1)} = 2$ (Table 2).

Comment: for further program realization of the implementation of the functions of the systems' comparison, it is necessary to draw a possible logical conclusion from Table 2, on the basis of the data received when the expert filled the first line of Table 1 by rules Nos. 1–4 and implementing rules Nos. 5–10 (hereinafter referred to as the rules). The rules are systematized in Table 2.

Rule No. 5. If system ($n-1$) is better than system n ($R_{(n-1)n} = 2$), while system ($n-1$) is equal to system ($n+1$) ($R_{(n-1)(n+1)} = 1$), then system n is worse than system ($n+1$), $R_{n(n+1)} = 0$, formula (2):

$$\text{If } R_{(n-1)n} = 2 \text{ and } R_{(n-1)(n+1)} = 1, \text{ then } R_{n(n+1)} = 0. \quad (2)$$

Table 2. Possible logical conclusions of the results of expert comparison of system n with system $(n + 1)$ ($R_{n(n+1)}$), depending on the results of comparison of system $(n - 1)$ with system n ($R_{(n-1)n}$) and system $(n - 1)$ with system $(n + 1)$ ($R_{(n-1)(n+1)}$)

Results of comparison of system $(n - 1)$ with system $(n + 1)$ ($R_{(n-1)(n+1)}$)	Results of expert comparison of system $(n - 1)$ with system n ($R_{(n-1)n}$)		
	$R_{(n-1)n} = 2$, system $(n - 1)$ is better than system n	$R_{(n-1)n} = 1$, system $(n - 1)$ equals system n	$R_{(n-1)n} = 0$, system $(n - 1)$ is worse than system n
$R_{(n-1)(n+1)} = 2$, system $(n - 1)$ is better than system $(n + 1)$	?*	$R_{n(n+1)} = 2$	$R_{n(n+1)} = 2$
$R_{(n-1)(n+1)} = 1$, system $(n - 1)$ equals system $(n + 1)$	$R_{n(n+1)} = 0$	$R_{n(n+1)} = 1$	$R_{n(n+1)} = 2$
$R_{(n-1)(n+1)} = 0$, system $(n - 1)$ is worse than system $(n + 1)$	$R_{n(n+1)} = 0$	$R_{n(n+1)} = 0$	?*

* Comment: «?» means that it is impossible to make a logical conclusion; the expert has to identify the value of $R_{n(n+1)}$ on one's own.

Rule No. 6. If system $(n - 1)$ is better than system n ($R_{(n-1)n} = 2$), while system $(n - 1)$ is worse than system $(n+1)$ ($R_{(n-1)(n+1)} = 0$), then system n is worse than system $(n+1)$, $R_{n(n+1)} = 0$, formula (3):

$$\text{If } R_{(n-1)n} = 2 \text{ and } R_{(n-1)(n+1)} = 0, \text{ then } R_{n(n+1)} = 0. \tag{3}$$

Rule No. 7. If system $(n - 1)$ equals system n ($R_{(n-1)n} = 1$), while system $(n - 1)$ is better than system $(n + 1)$ ($R_{(n-1)(n+1)} = 2$), then system n is better than system $(n + 1)$, $R_{n(n+1)} = 2$, formula (4):

$$\text{If } R_{(n-1)n} = 1 \text{ and } R_{(n-1)(n+1)} = 2, \text{ then } R_{n(n+1)} = 0. \tag{4}$$

Rule No. 8. If system $(n - 1)$ equals system n ($R_{(n-1)n} = 1$), while system $(n - 1)$ equals system $(n+1)$ ($R_{(n-1)(n+1)} = 1$), then system n equals system $(n + 1)$, $R_{n(n+1)} = 2$.

$$\text{If } R_{(n-1)n} = 1 \text{ and } R_{(n-1)(n+1)} = 1, \text{ then } R_{n(n+1)} = 1. \tag{5}$$

Rule No. 9. If system $(n - 1)$ equals system n ($R_{(n-1)n} = 1$), while system $(n - 1)$ is worse than system $(n + 1)$ ($R_{(n-1)(n+1)} = 0$), then, system n is worse than system $(n + 1)$, $R_{n(n+1)} = 0$.

$$\text{If } R_{(n-1)n} = 1 \text{ and } R_{(n-1)(n+1)} = 0, \text{ then } R_{n(n+1)} = 0. \tag{6}$$

Rule No. 10. If system $(n - 1)$ is worse than system n ($R_{(n-1)n} = 0$), while system $(n - 1)$ is better than system $(n + 1)$ ($R_{(n-1)(n+1)} = 2$), then system n is better than system $(n + 1)$, $R_{n(n+1)} = 2$.

$$\text{If } R_{(n-1)n} = 0 \text{ and } R_{(n-1)(n+1)} = 2, \text{ then } R_{n(n+1)} = 2. \tag{7}$$

Rule No. 11. If system $(n - 1)$ is worse than system n ($R_{(n-1)n} = 0$), while system $(n - 1)$ equals system $(n + 1)$ ($R_{(n-1)(n+1)} = 1$), then system n is better than system $(n + 1)$, $R_{n(n+1)} = 2$.

$$\text{If } R_{(n-1)n} = 0 \text{ and } R_{(n-1)(n+1)} = 1, \text{ then } R_{n(n+1)} = 2. \tag{8}$$

Rule No. 12. It is impossible to draw a logical conclusion without an expert's participation when comparing system n with system $(n + 1)$ ($R_{n(n+1)}$) in two cases (two variants of input data):

- if system $(n-1)$ is better than system n ($R_{(n-1)n} = 2$), while system $(n-1)$ is better than system $(n+1)$ ($R_{(n-1)(n+1)} = 2$), i. e., when $R_{(n-1)n} = 2$ and $R_{(n-1)(n+1)} = 2$;
- if system $(n-1)$ is worse than system n ($R_{(n-1)n} = 0$), while system $(n-1)$ is worse than system $(n+1)$ ($R_{(n-1)(n+1)} = 0$), i. e., when $R_{(n-1)n} = 0$ and $R_{(n-1)(n+1)} = 0$.

In these cases the question mark («?») is put in the corresponding cell of Table 2 (Table 1), and the expert needs to compare system n with system $(n+1)$ on one's own and put the result of this comparison $R_{n(n+1)}$ in the table's cell.

The rules enable a program realization of the automatic implementation of logical conclusions in the real time regime when comparing system n with system $(n+1)$. In other words, they allow one to reasonably and objectively get the value $R_{n(n+1)}$ in the case where reliable input data are received after two paired comparisons of the systems:

- system $(n-1)$ with system n, $R_{(n-1)n}$;
- system $(n-1)$ with system $(n+1)$, $R_{(n-1)(n+1)}$.

Moreover, the analysis of formulas (1)–(8) and Table 2 shows that there are only 7 (seven) possible variants of the results of logical conclusions of the comparison of system n with system $(n+1)$ ($R_{n(n+1)}$) when using initially received input data of the results of comparison of system $(n-1)$ with system n ($R_{(n-1)n}$) and system $(n-1)$ with system $(n+1)$ ($R_{(n-1)(n+1)}$). All these seven variants do not require participation of an expert in the comparison of system n with system $(n+1)$ ($R_{n(n+1)}$).

To summarize, the systemic application of the rules and Table 2 in the paired comparison method (Table 1) considerably decreases the amount of time and resources needed to process information, moreover, it ensures consistency of the results of the quality assessment.

4. Verification of the results of the paired comparison

This section describes the process of verification of the results of the paired comparison of systems (Table 1) for consistency, for the purposes of the rational program realization of the method and/or complex methodology of quality assessment [Билятдинов, Шлянцев, Меняйло, 2020, p. 9], based on this method.

Within the method, the verification is performed by calculating the number of scores gained by one system z (B_z) and indices of the systems' quality (K_z).

It is proposed to use the following formulas (9)–(14) for the calculations:

$$B_z = \sum_{i=1}^{n} R_{zn}, \tag{9}$$

where n is the number of the systems compared, z is the number of one of the systems compared, within the scope of integral numbers from 1 to n:

$$K_z = \frac{B_z}{n^2}. \tag{10}$$

In what follows, the verification of the expert information for consistency and control of the operator's errors (prevention of false information input) in Table 1 is done through the use of formulas (9)–(14) and Table 3.

The verification for consistency is performed within a paired comparison of systems by following the rules and making calculations by formulas (1)–(8) in columns 2–$(n+1)$ of Table 1.

The value of the systems' quality index (K_n) in the column ($n + 2$) of Table 1 is checked for consistency by following the normalization rules, i. e., the sum of values K_n should be equal to 1, otherwise the program will issue an error report. The messages appear at the bottom of the column ($n +$ $+ 2$) of Table 1.

The value of the systems' quality index (K_z) in the column ($n + 2$) of Table 1 is checked for consistency line-by-line by simultaneously fulfilling two conditions:

- the first condition, comparison of K_z of each system with the minimum possible value $K_{z\,\min}$, detected by the formula

$$K_{z\,\min} = \frac{1}{n^2}. \tag{11}$$

  If $K_z < K_{z\,\min}$, then the program issues an error report, in all other cases the values conform to the norm;

- the second condition, the maximum possible $K_{z\,\max}$ is calculated by the formula

$$K_{z\,\max} = \frac{2n-1}{n^2}. \tag{12}$$

  Thus, if $K_z > K_{z\,\max}$, then the program issues an error report, in all other cases the values conform to the norm.

The messages appear in the corresponding cell ($n + 4$) of Table 1.

The examples of values $K_{z\,\min}$ and $K_{z\,\max}$ are given in Table 3.

The value of the sum of scores of one system (B_z) is checked for consistency line-by-line by simultaneously fulfilling two conditions:

The first condition, by comparing B_z with a minimum possible value of the sum of scores of one system z, $B_{z\,\min} = 1$, i. e., system z is worse than all other systems by the chosen characteristic.

Thus, if $B_z < 1$ or $B_z < B_{z\,\min}$, then the program issues an error report, in all other cases the values of B_z conform to the norm.

The second condition, by comparing B_z with a maximum possible value of the sum of scores of one system z:

$$B_{z\,\max} = 1 + 2(n-1). \tag{13}$$

Thus, if $B_z > B_{z\,\max}$, i. e., $B_z > 1 + 2(n-1)$, then the program issues an error report, in all other cases the values of B_z conform to the norm.

The messages with the result of the verification appear in the corresponding cell ($n + 4$) of Table 1.

The examples of values $B_{z\,\max}$ are given in Table 3.

The value of the sum of scores B_n (the value is located in the cell ($n + 1$; $n + 3$) of Table 1) for all compared systems of n number is checked for consistency by fulfilling one condition: the sum of scores of the comparison results should be equal to the check number calculated by the formula

$$B_n = n^2. \tag{14}$$

If $B_n = n^2$, then the value of B_n conforms to the norm, in all other cases the program issues an error report.

The messages with the result of the verification appear in the cell ($n + 1$; $n + 3$) of Table 1. The examples of check values B_n are given in Table 3.

Based on the results of the calculations by formulas (9)–(14), Table 3 systematizes the maximum check values of the systems' quality indices ($K_{z\,\max}$), of the sum of scores for one system ($B_{z\,\max}$) and the maximum values of the sum of scores of all compared systems (B_n) depending on the number of chosen systems (n) (from 2 to 20 in the table, as an example) when using the paired comparison method.

Table 3. Check values in the paired comparison method of 2 to n systems

Number of systems n	Maximum possible values of:		Minimum possible values of:		Check values of the sum of scores of all compared systems (n number), $B_n = n^2$
	the sum of scores of one system, z $B_{z\,max} = 1 + 2(n - 1)$	the system's quality index $K_{z\,max} = \frac{2n-1}{n^2}$	the sum of scores of one system, z $B_{z\,min} = 1$	the system's quality index $K_{z\,min} = \frac{1}{n^2}$	
2	3	0,75	1	0,25	4
3	5	0,55555	1	0,111111	9
4	7	0,4375	1	0,0625	16
5	9	0,36	1	0,04	25
6	11	0,305555	1	0,027778	36
7	13	0,265306	1	0,020408	49
8	15	0,234375	1	0,015625	64
9	17	0,209877	1	0,012346	81
10	19	0,19	1	0,01	100
11	21	0,173554	1	0,008264	121
12	23	0,159722	1	0,006944	144
13	25	0,147929	1	0,005917	169
14	27	0,137755	1	0,005102	196
15	29	0,128889	1	0,004444	225
16	31	0,121094	1	0,003906	256
17	33	0,114187	1	0,00346	289
18	35	0,108025	1	0,003086	324
19	37	0,102493	1	0,00277	361
20	39	0,0975	1	0,0025	400
⋮	⋮	⋮	1	⋮	⋮
n	$B_{z\,max} = 1 + 2(n - 1)$	$K_{z\,max} = \frac{2n-1}{n^2}$	1	$K_{z\,min} = \frac{1}{n^2}$	$B_n = n^2$

5. Conclusion

In practice, the method is used within the complex methodology of technical systems quality assessment in the process of their maintenance [Билятдинов, Шлянцев, Меняйло, 2020, p. 10–11]. The proposed improved method is implemented in two computer programs: «Analysis and assessment of the systems' effectiveness» (Certificate of the state registration of software No 2020610389, 14.01.2020) and «Assessment of systems' stability» (Certificate of the state registration of software No 2020615328, 21.05.2020).

It is worth noting that the main positive effect of the development and application of the method within the complex methodology of quality assessment [Билятдинов, Шлянцев, Меняйло, 2020, p. 12] and the above-mentioned computer programs consists in a considerable reduction of time and resources needed to organize experts' work, to process expert information and prepare and conduct distant interviews with experts (on the Internet or a local computer network of the organization). This effect is achieved by a rational use of input data of the quality of the systems to be assessed.

Additionally, we recommend using Table 3, which contains systematized data of check values in the application of the paired comparison method of 2 to n systems, for the development of computer programs aimed at collecting and processing statistical data. Moreover, it is rational to use this method when preparing technical requirements specifications for design of computer programs aimed at completing a variety of tasks in the sphere of systems' quality assessment, comparison and information processing.

The demonstrated method possesses a certain universality and can be successfully applied not only to assess technical systems in the process of operation, but also to assess the quality of other objects and processes.

Finally, it is obvious that nowadays the effectiveness of systems' management primarily depends on timely managerial decisions made on the basis of systems' quality assessment. The improvement of interactive procedures of quality assessment [Gerami, 2019, p. 37–38] substantiates the possibility of further successful program realization of the method in the real-time mode with the use of statistical and expert information received from internal and external sources.

References

Билятдинов К. З., Меняйло В. В. Методология оценки качества систем в сфере устойчивости больших технических объектов // Век качества. — 2020. — № 2. — С. 198–214.

Biliatdinov K. Z., Meniailo V. V. Metodologiya otsenki kachestva sistem v sfere ustoichivosti bol'shikh tekhnicheskikh ob"ektov [Methodology of systems quality assessment in the sphere of stability of big technical objects] // Vek kachestva [Age of quality]. — 2020. — No. 2. — P. 198–214 (in Russian).

Билятдинов К. З., Шлянцев И. В., Меняйло В. В. Применение структурно-функциональной модели в методе и методике оценки качества систем // Вестник воздушно-космической обороны. — 2020. — Т. 3 (27). — С. 5–13.

Biliatdinov K. Z., Shliantsev I. V., Meniailo V. V. Primenenie strukturno-funktsional'noi modeli v metode i metodike otsenki kachestva sistem [Application of structure functional model in the method and methodology of systems quality assessment] // Vestnik vozdushno-kosmicheskoi oborony [Aerospace defense herald]. — 2020. — Vol. 3 (27). — P. 5–13 (in Russian).

Изергин Н. Д., Таров А. Г. Оценка состояния технических объектов и их классификация методом парных сравнений // Известия Тульского государственного университета. Технические науки. — 2017. — Вып. 5. — С. 164–168.

Izergin N. D., Tarov A. G. Otsenka sostoyaniya tekhnicheskikh ob"ektov i ikh klassifikatsiya metodom parnykh sravnenii [Assessment of condition of technical objects and their classification be the paired comparison method] // Izvestiya Tul'skogo gosudarstvennogo universiteta. Tekhnicheskie nauki [Izvestiya Tula State University. Technical sciences]. — 2017. — Iss. 5. — P. 164–168 (in Russian).

Исаев Р. А. Модифицированный метод парных сравнений для экспертной оценки параметров нечеткой когнитивной модели // Современные информационные технологии и ИТ-образование. — 2016. — Т. 12 (2). — С. 35–42.

Isaev R. A. Modifitsirovannyi metod parnykh sravnenii dlya ekspertnoi otsenki parametrov nechetkoi kognitivnoi modeli [Modified paired comparison method for expert assessment of parameters of a fuzzy cognitive model] // Sovremennye informatsionnye tekhnologii i IT-obrazovanie [Modern Information Technologies and IT-education]. — 2016. — Vol. 12 (2). — P. 35–42 (in Russian).

Кривулин Н. К., Агеев В. А. Методы тропической оптимизации в многокритериальных задачах оценки альтернатив на основе парных сравнений // Вестник Санкт-Петербургского университета. Сер. 10. Прикладная математика. Информатика. Процессы управления. — 2019. — Т. 15, вып. 4. — С. 472–488.

Krivulin N. K., Ageev V. A. Metody tropicheskoi optimizatsii v mnogokriterial'nykh zadachakh otsenki al'ternativ na osnove parnykh sravnenii [Methods of tropical optimization in multicriterion problems of alternatives assessment on the basis of paired comparisons] // Vestnik Sankt-Peterburgskogo universiteta. Seriya 10. Prikladnaya matematika. Informatika. Protsessy upravleniya [Vestnik SPbSU. Applied Mathematics. Computer Science. Control Processes]. — 2019. — Vol. 15 (4). — P. 472–488 (in Russian).

Путивцева Н. П., Пусная О. П., Игрунова С. В., Зайцева Т. В., Нестерова Е. В. Сравнительный анализ применения многокритериальных методов // Научный результат. Информационные технологии. — 2017. — Т. 2, вып. 1. — С. 40–47.

Putivtseva N. P., Pusnaya O. P., Igrunova S. V., Zaitseva T. V., Nesterova E. V. Sravnitel'nyi analiz primeneniya mnogokriterial'nykh metodov [Comparative analysis of the application of multicriterion methods] // Nauchnyi rezul'tat. Informatsionnye tekhnologii [Research result. Information technologies]. — 2017. — Vol. 2 (1). — P. 40–47 (in Russian).

Тихомирова А. Н., Сидоренко Е. В. Модификация метода анализа иерархий Т. Саати для расчета весов критериев при оценке инновационных проектов // Современные проблемы науки и образования. — 2012. — № 2. — URL: http://science-education.ru/ru/article/view?id=6009 (дата обращения: 25.10.2020).

Tihomirova A. N., Sidorenko E. V. Modifikatsiya metoda analiza ierarkhii T. Saati dlya rascheta vesov kriteriev pri otsenke innovatsionnykh proektov [Modification of the method of analysis of hierarchies of T. Saati for calculation of weights of criteria in assessment of innovative projects] // Sovremennye problemy nauki i obrazovaniya [Contemporary problems of science and education]. — 2012. — No. 2. — URL: http://science-education.ru/ru/article/view?id=6009 (accessed: 25.10.2020) (in Russian).

Черкашин А. К. Математические аспекты реализации метода анализа иерархий // Информационные и математические технологии в науке и управлении. — 2020. — № 1 (17). — С. 5–24.

Cherkashin A. K. Matematicheskie aspekty realizatsii metoda analiza ierarkhii [Mathematical aspects of the realization of the method of analysis of hierarchies] // Informatsionnye i matematicheskie tekhnologii v nauke i upravlenii [Information and mathematical technologies in science and management]. — 2020. — Vol. 1 (17). — P. 5–24 (in Russian).

Baker J., Henderson S. The Cyber Data Science Process // The Cyber Defense Review. — 2017. — Vol. 2, no. 2. — P. 47–68.

Calabrese R., Osmetti S. A. A new approach to measure systemic risk: A bivariate copula model for dependent censored data // European Journal of Operational Research. — 2019. — Vol. 279 (3). — P. 1053–1064.

Gerami J. An interactive procedure to improve estimate of value efficiency in DEA // Expert Systems with Applications. — 2019. — No. 137. — P. 29–45.

Kalimoldayev M., Abdildayeva A., Mamyrbayev O. Information system based on the mathematical model of the EPS // Open engineering. — 2016. — Vol. 6, no. 1. — P. 464–469.

Pačaiová H., Sinay J., Nagyová A. Development of GRAM — A risk measurement tool using risk based thinking principles // Measurement: Journal of the International Measurement Confederation. — 2017. — No. 100. — P. 288–296.

Price M., Walker S., Wiley W. The Machine Beneath: Implications of Artificial Intelligence in Strategic Decision making // PRISM. — 2018. — Vol. 7, no. 4. — P. 92–105.

Segal A. Bridging the Cyberspace Gap: Washington and Silicon Valley // PRISM. — 2017. — Vol. 7, no. 2. — P. 66–77.

Shafik M. B., Chen H., Rashed G. Planning and reliability assessment to integrate distributed automation system into distribution networks utilizing binary hybrid PSO and GSA algorithms considering uncertainties // International Transactions on Electrical Energy Systems. — 2020. — Article e12594.

Trevino M. Cyber Physical Systems: The Coming Singularity // PRISM. — 2019. — Vol. 8, no. 3. — P. 2–13.