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A MULTI-CRITERIA APPROACH TO DECISION-MAKING IN TELECOMMUNICATION NETWORK COMPONENTS SELECTION

The problem of decision-making regarding the selection of the optimal composition of telecommunication network components is very urgent. ***The subject*** *of the research in the article is a multi-criteria approach to the selection of telecommunication network components. This approach is related to the evaluation of possible options based on a set of indicators. The set of such indicators is determined by the specifics of a telecommunication network. One of the most dominant devices in telecommunication (mobile) systems is speech codecs. When choosing the appropriate codec configuration, there is a need to make a decision considering a set of contradicting criteria. The use of MCDM (Multiple Criteria Decision Making) methods when making decisions is a promising approach to solving such problems. The current article increases the efficiency of the multi-criteria approach to decision-making in the process of selecting telecommunication network components, in particular, a speech codec. The following* ***methods*** *were used: MARCOS (Measurement Alternatives and Ranking according to COmpromise Solution), entropy, CRITIC (Criteria Importance Through Inter-criteria Correlation) and BWM (Best–Worst method). The following* ***results*** *were obtained. Determining the weight of the criteria by which alternatives are evaluated is one of the key problems that arise when making multi-criteria decisions. Objective methods of entropy, CRITIC, and subjective BWM methods were used to find weighting factors of criteria. Different methods of determining the weights of the criteria give different values. The use of the combined BWM-CRITIC method is proposed, which balances the subjective opinions of experts and assessments made solely based on the decision matrix data. The values of the correlation coefficients showed a close relationship between the weights of the criteria determined by different methods. However, the strongest connection with other methods was shown by the combined BWM-CRITIC method. The MARCOS method was used to rank the alternatives and select the best alternative. A ranking of the set of speech codecs is obtained, which allows for determining the best alternative* ***Conclusion****. A comprehensive approach to the telecommunication network component selection is proposed, namely the multi-criteria BWM-CRITIC-MARCOS model, based on a combination of MCDM methods. The integration of methods into the proposed model provides a systematic approach to the assessment and selection of telecommunication network components.*

Keywords*: telecommunication networks; telecommunication network components; MCDM methods; multicriteria selection; entropy method; CRITIC; BWM; MARCOS.*

Introduction

Modern telecommunication networks (TCN) are complex systems that require substantial financial and organizational costs. Currently, various manufacturers offer a wide range of telecommunication equipment that performs similar functions in telecommunication networks. Therefore, the process of forming an optimal composition of the technical means of a TCN causes considerable difficulty [1]. Considering the high cost of modern telecommunications equipment, the problem of decision-making regarding the selection of the optimal composition of telecommunication network components is important and extremely relevant.

One of the most common types of primary functional transformations in telecommunication (mobile) systems is speech codecs. Such codecs provide signal transmission of speech messages. On the one hand, speech codecs interact with telecommunication endpoints, which requires them to perform the functions of direct and reverse analog-to-digital conversion and efficient (statistical) coding. On the other hand, they interact with digital channel-forming equipment, which requires codecs to perform procedures for eliminating psychoacoustic redundancy, ensuring immunity, and implementation of protection against unauthorized access (encryption).

The most significant transformations of speech messages occur within the limits of elimination of psychoacoustic redundancy (compression). Simultaneously, high quality (intelligibility) of speech messages should be ensured, which is characterized by the parameter of the speech intelligibility index (SII) on a five-point scale. To assess the intelligibility of speech, the control of three basic parameters is provided: optimal volume (automatically provided for digital systems),

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intelligibility, and naturalness of speech messages. The intelligibility and naturalness of speech messages are created based on the articulation tables with the involvement of announcers and articulation teams.

For public telephone networks, the SII ranges from 4 to 5 (speech intelligibility of more than 80 %), and for mobile communication or voice mail, the SII is in the range from 3.5 to 4 (speech intelligibility of 50...80 %) [2].

Speech message compression is implemented based on the algorithms, which are divided into three groups according to the compression principle. Modern speech information codecs are characterized by a combination of elements of the algorithms of all groups [2].

Time-series extrapolation uses the correlation of the elements of the speech message at time intervals of up to 30 msec. Simultaneously, the input signal of the codec is of a polypulse nature. This method of encoding provides the compression of the speech message up to 6..10 times while preserving the naturalness of the speech. Such coding systems are most often used for IP telephony.

The work of the vocoder (voice encoders) is based on imitating the pronunciation of individual sounds. At the output, the pronunciation parameters and parameters for setting the human vocal tract during sound reproduction are generated. The most common in this class are formant vocoders, which currently provide the highest level of compression (more than 100 times) at moderate computing costs while preserving intelligibility and partially preserving the naturalness of speech.

Vector encoding (VQ) of speech messages is based on the transfer of indices of speech elements or parameters of the two previous coding procedures and their recovery using codebooks. It requires the greatest computing costs. VQ hardly affects the quality of speech while reducing the transmission speed by an order of magnitude. It also provides additional protection against unauthorized access.

When choosing an appropriate codec configuration, it is necessary to make a decision considering a set of contradicting criteria: end-user criteria (intelligibility or speech quality); implementation criteria (volume of computing operations and volume of hardware costs); channel criteria (transmission speed and delay). In this situation, there is a need for practical tools for making appropriate decisions. One of the promising approaches is the use of MCDM (Multiple Criteria Decision Making) methods in decision-making [3].

A number of scientific works are devoted to the problem of equipment selection and optimization in the design of information and communication systems and networks. In particular, S. Pidchenko et al. [4, 5] carried out parametric optimization of static and dynamic characteristics of piezo-resonant oscillatory systems of primary measuring transducers of information communication systems. M. Kolisnyk [6] developed a method of selecting communication protocols depending on the selected type of communication template. I. Kononenko and A. Korchakova [7] solved the multi-criteria problem of optimizing the company's projects for the planning period. Simultaneously, the effects of earlier decisions were considered. In the research of A. Zhanasbayeva et al. [1], the selection of network technical equipment was carried out using AHP (Analytic hierarchy process) and ANP (Analytic Network Process) methods. In the article by V. Bezruk et al. [8, 9], the selection of equipment was carried out using methods of fuzzy set theory and the AHP method. In the work of L. Melnikova et al. [10], a heuristic procedure for multi-criteria selection of telecommunication equipment, in particular, a speech codec, was proposed.

MCDM methods ensure the implementation of a process that leads to clear, rational, and justifiable decisions. This led to their rapid and constant development in various fields. MCDM methods are also used in a wide range of scientific research. M.P. Basílio et al. [11] presented a systematic review of the application of MCDM methods for the years 1977–2022.

The process of multi-criteria decision-making consists of the following main stages: identification of alternatives and selection of criteria for evaluating alternatives; determination of the weighting coefficients of each criterion; evaluation of alternatives by each criterion; and application of an algorithm that evaluates alternatives by a set of criteria and provides a recommendation in the form of a ranking of alternatives [12, 13].

The model of the problem of multi-criteria decision-making can be represented as:

$$\langle T, A, C, W, D \rangle$$

where T is the statement of the problem (for example, to choose one alternative that is best in a certain sense or to order a set of alternatives); A is a set of alternatives (must contain at least two alternatives); C – a set of criteria; W is the system of preferences of the decision-maker; D is the method by which alternatives are evaluated.

Let there be a set of m alternatives (Ai, i = 1,2,…,m), each one is characterized by *n* indicators (criteria) (Cj, j = 1,2,…,n), according to which its efficiency is evaluated. Evaluation of alternatives according to all criteria is presented using a decision matrix:

$$X = \left[x_{ij} \right]_{m \times n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, \qquad (1)$$

where x_{ij} is the evaluation of the i-th alternative according to the j-th criterion.

The importance of each criterion is characterized by a weight factor w_j. It is necessary to choose a better alternative.

An important element of the decision-making process is the determination of criteria weights, which is one of the most complex processes in the application of MCDM methods. Many authors, such as G. Odu [3], M. Şahin [14], M. Keshavarz-Ghorabaee [15], A. Krishnan [16], V. Paradowski [12], and Do Duc Trung [17], emphasize the importance of the stage of determining the weighting factors of the criteria. Some of them also note the high sensitivity of decision-making in relation to changes in the weighting factors of the criteria. Therefore, the procedures for determining criteria weights are widely researched and discussed both in theory and in the application of MCDM methods.

Currently, there are a large number of methods for determining the weight of the criteria. The purpose of these methods is to reflect the preferences of interested parties regarding the criteria under consideration [12]. Problems are often characterized by several conflicting (competing) criteria, and there may not be a solution that satisfies all requirements at the same time [13].

According to one of the generally accepted classifications, the methods of assessing the weight of criteria are divided into subjective, objective and integrated (combined) [14, 18].

Subjective methods include: Point allocation method, Ranking method, Analytic hierarchy process (AHP), SMART method (Simple Multi-attribute Ranking Technique), and BWM method (Best–Worst method). The subjective determination of weight is based on the opinion of experts or expert groups representing the views of various stakeholders. However, the subjective determination of criteria weights often takes a long time, especially when there is no agreement among decision-makers on the problem under consideration [3]. One of the important problems of subjective methods is the assessment of the consistency of expert opinions. Additionally, expressing preferences is a mental task for decision-makers, and the accuracy of their preferences decreases as the number of criteria increases [15]. Therefore, when the number of criteria increased, these methods become insufficiently effective.

In terms of objective weighting methods, the preferences of decision-makers do not play a role in determining the weights of the criteria [15]. An objective approach to determining the weight of criteria considers criteria as sources of information. The relative importance of the criteria reflects the amount of information contained in each of them and is related to the contrast intensity of each criterion [19]. Therefore, objective weighting methods ignore the experience of a decision-maker. The most common objective methods are the Entropy method, the CRITIC method (Criteria Importance Through Inter-criteria Correlation), the Standard deviation method, and the Ideal point method.

The integrated weighting approach is based on a combination of subjective and objective weighting methods. Combined methods take advantage of decision-makers' preferences and the information contained in each criterion, thereby reducing the possible bias of one of the weights (subjective or objective). Thus, combined methods can provide more realistic criteria weights [3, 15, 20].

An overview of various methods of determining criteria weights is presented, among others, in works [3, 14, 15, 18, 19, 21]. Despite the large number of methods for determining criteria weights, no method is perfect. If only one method of determining the criteria's weights is used in the decision-making process, the decision made may not be the best. Therefore, to increase the efficiency of decision-making, it is worth determining the weights of the criteria using several different methods [17].

In this study, the objective entropy and CRITIC methods, the subjective BWM method, and the combined BWM-CRITIC method are considered to determine the weights of the codec selection criteria. Codec selection is suggested to be performed using the MARCOS method.

The current article increases the effectiveness of multi-criteria decision-making in the process of choosing telecommunications equipment, in particular, a speech codec.

The article is organized as follows. The second section presents a description of the MCDM methods used in the study. A comprehensive approach to determining the weighting factors of the criteria and a comparative analysis of the applied methods is presented in the third section. In the fourth section, the speech codec is selected based on the MARCOS method. The final section presents conclusions and recommendations for future research.

1. Theoretical basis of research

1.1. MARCOS method

The MARCOS (Measurement Alternatives and Ranking according to COmpromise Solution) method was first proposed in 2020 by Z. Stevic [22]. However, this method has already been used in a number of studies. The stages of implementation of decision-making according to the MARCOS method are as follows.

Stage 1. The construction of a decision matrix (using the formula (1)).

Stage 2. Construction of the extended decision

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matrix (X^*) by adding the ideal alternative (AI) and the anti-ideal alternative (AAI) to the decision matrix constructed during the previous stage.

$$X^* = \begin{pmatrix} x_{aa1} & \dots & x_{aan} \\ x_{11} & \dots & x_{1n} \\ x_{21} & \dots & x_{2n} \\ \dots & \dots & \dots \\ x_{m1} & \dots & x_{mn} \\ x_{a1} & \dots & x_{an} \end{pmatrix}, \qquad (2)$$

where $\left(x_{aa1}, x_{aa2}, ..., x_{aan}\right)$ – values according to the criteria of the anti-ideal alternative (AAI); $\left(x_{a1}, x_{a2}, ..., x_{an}\right)$ – values according to the ideal alternative (AI) criteria.

The ideal alternative has the maximum values for the benefit-criteria (the higher the value, the better) and the minimum values for the cost-criteria (the lower the value, the better). The anti-ideal alternative is formed oppositely: minimum scores for benefit criteria and maximum scores for cost criteria.

Stage 3. Construction of a normalized extended decision matrix according to the formulas:

$$n_{ij} = \frac{x_{ij}}{x_{aj}} \quad \text{for benefit-criteria,}$$

$$n_{ij} = \frac{x_{aj}}{x_{ij}} \quad \text{for cost-criteria.} \qquad (3)$$

Stage 4. Construction of a normalized matrix considering the weights of the criteria:

$$v_{ij} = w_j \cdot n_{ij}, \qquad (4)$$

where w_j – weight factor of the j criterion.

Stage 5. Calculation of the utility level.

Utility levels are calculated for all alternatives based on ideal and anti-ideal solutions:

$$K_i^- = \frac{S_i}{S_{AAI}} \quad \text{and} \quad K_i^+ = \frac{S_i}{S_{AI}}, \qquad (5)$$

where $S_i = \sum_j v_{ij}$, $S_{AAI} = \sum_j x_{aaj}$, $S_{AI} = \sum_j x_{aj}$.

Stage 6. Calculation of positive and negative utility functions:

$$f\left(K_i^-\right) = \frac{K_i^+}{K_i^+ + K_i^-} \quad \text{and} \quad f\left(K_i^+\right) = \frac{K_i^-}{K_i^+ + K_i^-}. \qquad (6)$$

Stage 7. Calculation of general utility functions and ranking of alternatives:

$$f\left(K_i\right) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f\left(K_i^+\right)}{f\left(K_i^+\right)} + \frac{1 - f\left(K_i^-\right)}{f\left(K_i^-\right)}}. \qquad (7)$$

Alternatives are ranked according to utility function values. The bigger the value of $f\left(K_i\right)$, the better.

1.2. Entropy method

Objective methods determine the weights of the criteria using a specific computational process based on a decision matrix. These methods typically use the variation in the scores of the different alternatives for each criterion to determine the weights. It is believed that the greater the spread of evaluations of alternatives according to the criterion, the greater the value of the information contained in the criterion, and the greater the weight of the criterion [14, 17].

The entropy method is one of the most popular objective methods. Determination of weighting coefficients of the criteria by the entropy method is based on the measurement of uncertain information contained in a decision matrix [18]. The smaller the entropy of the criterion, the more valuable information the criterion contains, and therefore is more important.

The algorithm for applying the entropy method consists of the following successive stages [3, 19, 23].

Stage 1. Construction of a normalized decision matrix:

$$Z = \begin{bmatrix} z_{11} & z_{12} & \dots & z_{1n} \\ z_{21} & z_{22} & \dots & z_{2n} \\ \dots & \dots & \dots & \dots \\ z_{m1} & z_{m2} & \dots & z_{mn} \end{bmatrix}, \qquad (8)$$

where $z_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$ for benefit-criteria,

$$z_{ij} = \frac{1/x_{ij}}{\sum_{i=1}^{m} 1/x_{ij}} \quad \text{for cost-criteria.}$$

Stage 2. Construction of an entropy vector:

$$e=(e_1,e_2,...,e_n)\text{ , where } e_j=-\frac{1}{\ln m}\sum_{i=1}^{m} z_{ij}\ln z_{ij}\,. \quad (9)$$

When $z_{ij}=0$ for some i, the value of the expression $z_{ij}\ln z_{ij}$ is regarded as 0.

Stage 3. Construction of a vector of contrast intensities of the criteria:

$$d=(d_1,d_2,...,d_n)\text{, where } d_j=1-e_j\,. \quad (10)$$

Stage 4. Determination of a criteria weight vector:

$$w=(w_1,w_2,...,w_n)\text{, where } w_j=\frac{d_j}{\sum_{j=1}^{n} d_j}\,. \quad (11)$$

1.3. CRITIC method

The CRITIC method provides a broader view of the decision matrix. It considers not only the intensity of the contrast but also the conflict between the criteria. Thus, this method assigns a larger weight to the criterion that has a higher intensity of contrast and a higher degree of conflict with other criteria. This method uses standard deviations of criteria and correlations between criteria [12, 16]. Recently, this method has become popular among many researchers.

The stages of implementation of the determination of criteria weights according to the CRITIC method are as follows [3, 12, 14, 19].

Stage 1. Construction of a normalized decision matrix using equalities:

$$z_{ij}=\frac{x_{ij}-x_j^{min}}{x_j^{max}-x_j^{min}} \quad \text{for benefit-criteria,}$$

$$z_{ij}=\frac{x_j^{max}-x_{ij}}{x_j^{max}-x_j^{min}} \quad \text{for cost-criteria.} \quad (12)$$

Stage 2. The correlation between individual criteria in the normalized matrix as well as the standard deviation of each criterion are calculated. Next, C_j is determined - the amount of information contained in the j-th criterion:

$$C_j=\sigma_j\sum_{i=1}^{m}(1-r_{ij}), \quad (13)$$

where σ_j – is the standard deviation of the j-th criterion, and r_{ij} is the correlation coefficient between the two criteria.

Stage 3. Determination of criteria weights:

$$w_j=\frac{c_j}{\sum_{j=1}^{n} c_j}\,. \quad (14)$$

1.4. BWM method

One of the most popular MCDM methods is the subjective AHP method, which is based on pairwise comparisons of all *n* decision criteria. However, recently, the BWM method, which is a relatively new MCDM method, has been used increasingly more often. Some authors [14, 21] consider this method as an adequate replacement for AHP. Its main advantage is a smaller number of pairwise comparisons compared to AHP [21]. The BWM method was proposed by Rezaei in 2015 [24, 25]. The stages of the application of the method are as follows.

Stage 1. A set of decision-making criteria for the expression $C=\{C_1,C_2,...,C_n\}$ is defined.

Stage 2. The decision maker selects the best and worst from a set of criteria. The best criterion is the most important or most desirable criterion, whereas the worst criterion is the least important or least desirable criterion among others.

Stage 3. The advantages of the best criterion over other criteria were determined. Thus, a vector $A_B=(a_{B1},a_{B2},...,a_{Bn})$ is constructed, where a_{Bj} is the preference of the best criterion over criterion *j*, and its value is an integer in the range from 1 to 9 (where one means equally important and nine means extremely important). Note that $a_{BB}=1$.

Stage 4. Pairwise comparisons of the worst criterion and other criteria were carried out. Thus, a vector $A_W=(a_{1W},a_{2W},...,a_{nW})^T$ is constructed where a_{jW} is the advantage of criterion *j* over the worst criterion, and its value is an integer in the section from 1 to 9. At the same time $a_{WW}=1$.

Stage 5. The search for optimal criteria weights (vector $(\omega_1^*,\omega_2^*,...,\omega_n^*)$) is carried out.

The optimal weight for each criterion is the one where for each pair $\frac{\omega_B}{\omega_j}$ and $\frac{\omega_j}{\omega_W}$ equalities $\frac{\omega_B}{\omega_j}=a_{Bj}$ and $\frac{\omega_j}{\omega_W}=a_{jW}$ are true. To satisfy these conditions for

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all j, it is necessary to find a solution that minimizes the maximum gaps between the obtained weights and the opinion of the decision maker. That is, it is necessary to solve the following optimization problem:

$$\min_j \max \left\{ \left| \frac{\omega_B}{\omega_j} - a_{Bj} \right|, \left| \frac{\omega_j}{\omega_W} - a_{jW} \right| \right\},$$
$$\sum_j \omega_j = 1, \ \ \omega_j \geq 0, \forall j \ . \qquad (15)$$

This model can be rewritten and used to calculate optimal weights and ξ^* as follows:

$$\min \xi,$$
$$\left| \frac{\omega_B}{\omega_j} - a_{Bj} \right| \leq \xi, \qquad j = \overline{1, n},$$
$$\left| \frac{\omega_j}{\omega_W} - a_{jW} \right| \leq \xi, \qquad j = \overline{1, n}, \qquad (16)$$
$$\sum_j \omega_j = 1, \quad \omega_j \geq 0, \ \ j = \overline{1, n}.$$

To verify the reliability of the comparison, the consistency coefficient is checked. The consistency ratio of the model is calculated as follows:

$$CR = \frac{\xi^*}{CI}. \qquad (17)$$

The Consistency Index CI is determined based on a set of fixed values (Table 1). Coefficient of consistency $\mathbf{CR} \in [\mathbf{0}; \mathbf{1}]$. The lower the CR, the more reliable the results. If the CR consistency coefficient does not exceed a fixed threshold (Table 2), the results are acceptable, otherwise, the provided pairwise comparisons must be revised [24 - 26].

1.5. Combined weighting method

The purpose of combined weighting is to combine the weights of criteria obtained using different evaluation methods. The calculation of the combined weight is performed as follows [12, 20]:

$$w_j = \frac{\omega_j^1 \cdot \omega_j^2}{\sum_{j=1}^{n} \omega_j^1 \cdot \omega_j^2}, \quad j = \overline{1, n}, \qquad (18)$$

where $w = (w_1, w_2, ..., w_n)$ – vector of combined weights, $\omega^1 = \left(\omega_1^1, \omega_2^1, ..., \omega_n^1\right)$ – weight vector, determined by the first method, $\omega^2 = \left(\omega_1^2, \omega_2^2, ..., \omega_n^2\right)$ – vector of weights determined by the second method.

2. Research results

During the research, the data of a certain set of typical speech codecs (Table 3) were used [8, 9]. The main technical characteristics of speech codecs that characterize their consumer properties [9], in particular, C_1 – encoding speed, C_2 – speech quality assessment, C_3 – complexity of implementation, and C_4 – total delay, were chosen as criteria.

As mentioned above, the weight values of the criteria have a great influence on determining the importance of alternatives and choosing the best one. Therefore, in our study, the focus is on the weighting of the criteria. In the decision-making process,

Table 1

Consistency Index (CI)

$\mathbf{a_{BW}}$	1	2	3	4	5	6	7	8	9
CI	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Table 2

Consistency coefficient threshold values (CR)

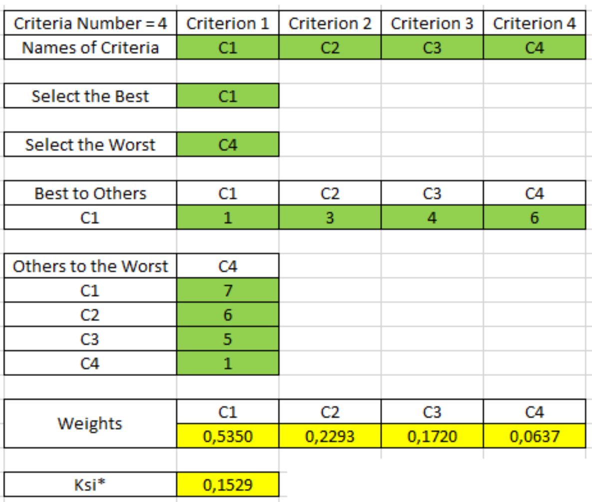
	Number of criteria, *n*						
$\mathbf{a_{BW}}$	3	4	5	6	7	8	9
3	0.2087	0.2087	0. 2087	0. 2087	0. 2087	0. 2087	0. 2087
4	0.1581	0.2352	0.2738	0.2928	0.3102	0.3154	0.3273
5	0.2111	0.2848	0.3019	0.3309	0.3479	0.3611	0.3741
6	0.2164	0.2922	0.3565	0.3924	0.4061	0.4168	0.4225
7	0.2090	0.3313	0.3734	0.3931	0.4035	0.4108	0.4298
8	0.2267	0.3409	0.4029	0.4230	0.4379	0.4543	0.4599
9	0.2122	0.3653	0.4055	0.4225	0.4445	0.4587	0.4747

Table 3

The value of technical characteristics of speech codecs

№	Codec type	Encoding speed	Quality assessment, MOS	Implementation complexity, MIPS	Total delay
1	G.711	64	3.83	11.95	60
2	G.721	32	4.1	7.2	30
3	G.722	48	3.83	11.95	31.5
4	G.722(a)	56	4.5	11.95	31.5
5	G.722(b)	64	4.13	11.95	31.5
6	G.726	24	3.7	9.6	30
7	G.726(a)	32	4.05	9.6	30
8	G.726(b)	40	3.9	9.6	30
9	G.727	24	3.7	9.9	30
10	G.727(a)	24	3.7	9.9	30
11	G.727(b)	40	3.9	9.9	30
12	G.727(c)	16	4	9.9	30
13	G.728	16	4	25.5	30
14	G.728(a)	12.8	4.1	16	30
15	G.729	8	4.05	22.5	35
16	G.729a	8	3.95	10.7	35

different criteria have different levels of importance, and all of them must be considered when building a model of the multi-criteria decision-making problem. Based on the data in Table 1, the Entropy, CRITIC, BWM, and BWM-CRITIC methods were implemented to obtain the weights of each criterion. We used the Excel Solver program (https://bestworstmethod.com/software/) developed by the author of the method to determine the weighting coefficients according to the BWM method. The results of calculating the weighting factors using the specified program are presented in Fig. 1. The values of the criteria weights determined by the Entropy, CRITIC, BWM, and BWM-CRITIC methods are presented in Table 4 and Fig. 2.



Criteria Number = 4	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Names of Criteria	C1	C2	C3	C4
Select the Best	C1			
Select the Worst	C4			
Best to Others	C1	C2	C3	C4
C1	1	3	4	6
Others to the Worst	C4			
C1	7			
C2	6			
C3	5			
C4	1			
Weights	C1	C2	C3	C4
	0,5350	0,2293	0,1720	0,0637
Ksi*	0,1529			

Fig. 1. Weighting coefficients according to the BWM method in Excel Solver

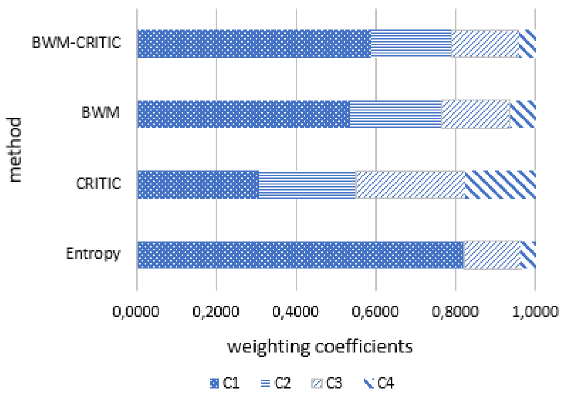


Fig. 2. Weighting coefficients according to Entropy, CRITIC, BWM, and BWM-CRITIC methods

Table 4

Criteria weights obtained by objective, subjective and combined methods

	C_1	C_2	C_3	C_4
Entropy	0.8181	0.0045	0.1409	0.0365
CRITIC	0.3057	0.2437	0.2748	0.1758
BWM	0.5350	0.2293	0.1720	0.0637
BWM-CRITIC	0.5885	0.2011	0.1701	0.0403

As can be seen from Table 4 and Fig. 2, according to all methods, the most important criterion is C_1 (coding speed). The least important criterion is C_4 (total delay). However, there is a significant discrepancy between the Entropy method and other methods in assessing the importance of the C_2 criterion. In particular, according to

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experts, this criterion is the second most important. The CRITIC method defines the C_1 criterion as the most important, and the C_4 criterion as the least important, while the weights of all criteria do not differ significantly.

Objective and subjective weighting methods yielded different weights for the criteria. However, the calculated correlation coefficients show that there is a correlation between these methods. Specifically, the correlation coefficient between Entropy and CRITIC is 0.7251, for Entropy and BWM $r = 0.9269$, and for CRITIC and BWM $r = 0.8281$. However, the strongest connection is between Entropy, CRITIC, BWM, and combined BWM-CRITIC methods. Thus, for Entropy and BWM-CRITIC $r = 0.9495$, for CRITIC and BWM-CRITIC $r = 0.8315$, and for BWM and BWM-CRITIC $r = 0.9975$.

Based on the input data (Table 3), an extended decision matrix was built by adding an ideal alternative (AI) and an anti-ideal alternative (AAI). After that, a normalized extended matrix is constructed according to formula (3). Considering the weights of the criteria obtained by the BWM-CRITIC method, a normalized matrix was constructed considering the weights of the criteria (according to formula (4)). The results are presented in Table 5.

According to formulas (5), (6), (7), utility levels, utility functions, and general utility functions were calculated for each alternative (Table 6).

Table 5

Normalized matrix taking into account the criteria weights

	C_1	C_2	C_3	C_4
AAI	4.708	0.165349	0.048028	0.0806
A_1	0.5885	0.171158	0.102487	0.0403
A_2	1.177	0.183224	0.1701	0.0806
A_3	0.784667	0.171158	0.102487	0.076762
A_4	0.672571	0.2011	0.102487	0.076762
A_5	0.5885	0.184565	0.102487	0.076762
A_6	1.569333	0.165349	0.127575	0.0806
A_7	1.177	0.18099	0.127575	0.0806
A_8	0.9416	0.174287	0.127575	0.0806
A_9	1.569333	0.165349	0.123709	0.0806
A_{10}	1.569333	0.165349	0.123709	0.0806
A_{11}	0.9416	0.174287	0.123709	0.0806
A_{12}	2.354	0.178756	0.123709	0.0806
A_{13}	2.354	0.178756	0.048028	0.0806
A_{14}	2.9425	0.183224	0.076545	0.0806
A_{15}	4.708	0.18099	0.054432	0.069086
A_{16}	4.708	0.176521	0.11446	0.069086
AI	0.5885	0.2011	0.1701	0.0403

Table 6

Selected parameters based on the MARCOS method

	K_i^-	K_i^+	$f(K_i^-)$	$f(K_i^+)$	$f(K_i)$
A_1	0.013429	0.006650	0.331198	0.668802	0.005713
A_2	0.023972	0.011871	0.331198	0.668802	0.010199
A_3	0.016891	0.008365	0.331198	0.668802	0.007186
A_4	0.015668	0.007759	0.331198	0.668802	0.006666
A_5	0.014171	0.007018	0.331198	0.668802	0.006029
A_6	0.028912	0.014317	0.331198	0.668802	0.012300
A_7	0.023306	0.011541	0.331198	0.668802	0.009915
A_8	0.019703	0.009757	0.331198	0.668802	0.008382
A_9	0.028854	0.014289	0.331198	0.668802	0.012275
A_{10}	0.028854	0.014289	0.331198	0.668802	0.012275
A_{11}	0.019646	0.009729	0.331198	0.668802	0.008358
A_{12}	0.040730	0.020170	0.331198	0.668802	0.017328
A_{13}	0.039604	0.019612	0.331198	0.668802	0.016849
A_{14}	0.048852	0.024192	0.331198	0.668802	0.020783
A_{15}	0.074591	0.036938	0.331198	0.668802	0.031733
A_{16}	0.075418	0.037348	0.331198	0.668802	0.032085

3. Discussion

According to the results of the research, objective and subjective methods resulted in different values of criteria weights. It is the combined method that makes it possible to combine these methods and prevent the dominance of a method. Thus, the combined method balances the subjective opinions of experts and assessments made solely based on decision matrix data. Such results indicate a significant advantage of the combined method over others. Therefore, for further research, the criteria weights obtained by the BWM-CRITIC method are to be used.

The ranking of alternatives according to the values of the general utility function $\mathbf{f(K_i)}$ gives the following results: $A_{16} \succ A_{15} \succ A_{14} \succ A_{12} \succ A_{11} \succ A_6 \succ A_9 = A_{10} \succ A_2 \succ A_7 \succ A_8 \succ A_{11} \succ A_3 \succ A_4 \succ A_5 \succ A_1$, this allows to determine the best alternative (Fig. 3). In our study, the best alternative was A_{16}. However, as can be seen from the table. 6 and Fig. 3, the value of the overall utility function for alternative A_{15} is quite close to the corresponding value for alternative A_{16}. This allows the decision maker to have an additional option to make a final decision.

4. Conclusion

A comprehensive approach to the selection of telecommunication network components based on multi-criteria decision-making methods is proposed. The methodology of multi-criteria decision-making allows for structuring complex decision-making problems. This leads to a better understanding of problems, simplifies the decision-making process, and increases its effectiveness.

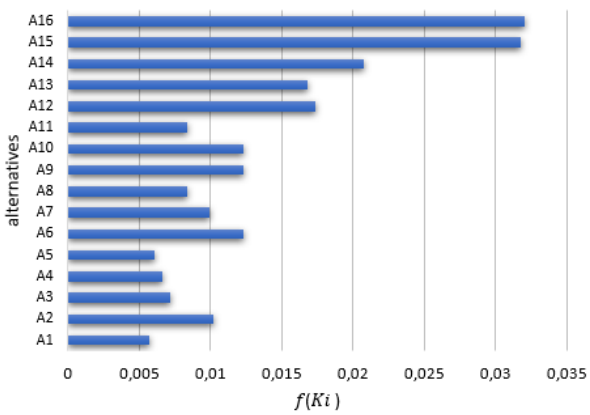

Fig. 3. The value of the general utility function

The ranking of alternatives and the selection of the best alternative were performed using the MARCOS method. Objective methods (entropy and CRITIC) and a subjective method (BWM) were used to determine the weight of the criteria, which is one of the key problems in multi-criteria decision-making. The judgment of decision-makers often depends on knowledge and experience, which can influence the decision-making process to some extent. To overcome the discrepancy in the values of criteria weights due to subjective factors, the authors proposed the use of the combined BWM-CRITIC method.

The values of the correlation coefficients show a close connection between the weights of the criteria determined by different methods. However, the strongest correlation with other methods was shown by the combined BWM-CRITIC method: r = 0.9495 for Entropy and BWM-CRITIC, r = 0.8315 for CRITIC and BWM-CRITIC, r = 0.9975 for BWM and BWM-CRITIC. Thus, the BWM-CRITIC method considers both the objective data of decision matrices and the subjective opinions of experts. Thus, it provides more effective and accurate assessments, which increases the validity of the decisions made.

Using the vector of criteria weights obtained by the BWM-CRITIC method (w = (0.5885; 0.2011; 0.1701; 0.0403)) the alternatives were ranked by the MARCOS method. It was determined that the best alternative in this study was the A_{16} alternative (G.729a codec). Additionally, the study showed that the value of the overall utility function for alternative A_{15} (G.729 codec) is very close to the corresponding value for alternative A_{16}. Therefore, two alternatives can be considered the best.

The multi-criteria BWM-CRITIC-MARCOS model, proposed by the authors, confirms its high efficiency via the obtained results of its implementation in this research. The integration of MCDM methods provides a systematic approach to the evaluation and selection of telecommunication network components depending on the requirements.

In further studies, it is planned to rank the alternatives using other MCDM methods and compare the results.

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БАГАТОКРИТЕРІАЛЬНЕ ПРИЙНЯТТЯ РІШЕНЬ В ПРОЦЕСІ ВИБОРУ КОМПОНЕНТІВ ТЕЛЕКОМУНІКАЦІЙНОЇ МЕРЕЖІ

Сергій Підченко, Оксана Кучерук, Олег Пивовар, Віктор Стецюк, Віктор Мішан

Проблема прийняття рішень щодо вибору оптимального складу компонентів телекомунікаційних мереж є вельми актуальною. **Предметом** дослідження в статті є багатокритеріальний підхід до вибору компонентів телекомунікаційних мереж, який пов'язаний з оцінкою можливих варіантів за набором показників. Набір таких показників визначається специфікою телекомунікаційної мережі. Одними із домінуючих пристроїв в телекомунікаційних (мобільних) системах є кодеки мовних повідомлень. При виборі відповідної конфігурації кодека виникає необхідність прийняття рішення з урахуванням набору критеріїв, які суперечать один одному. Одним із перспективних підходів вирішення таких задач є використання при прийнятті рішень методів MCDM (Multiple Criteria Decision Making). **Мета статті**: підвищення ефективності багатокритеріального прийняття рішень в процесі вибору компонентів телекомунікаційних мереж, зокрема, кодеку мовних повідомлень**.** В досліджені використано **методи:** MARCOS (Measurement Alternatives and Ranking according to COmpromise Solution), ентропії, CRITIC (Criteria Importance Through Inter-criteria Correlation) та BWM (Best–Worst method). Отримано такі **результати**. Визначення ваги критеріїв, за якими оцінюються альтернативи, є однією з ключових проблем, які виникають під час прийняття багатокритеріальних рішень. Для знаходження вагових коефіцієнтів критеріїв застосовано об’єктивні методи ентропії та CRITIC і суб’єктивний метод BWM. Продемонстровано, що різні методи визначення ваг критеріїв дають різні значення. Запропоновано використання комбінованого методу BWM-CRITIC, який врівноважує суб’єктивні думки експертів та оцінки виключно на основі даних матриці рішень. Значення коефіцієнтів кореляції показали тісний зв'язок між вагами критеріїв, визначеними за різними методами. Проте, найсильніший зв'язок з іншими методами дав комбінований метод BWM-CRITIC. Для ранжування альтернатив та вибору кращої альтернативи було використано метод MARCOS. Одержано ранжування набору кодеків мовних повідомлень, яке дозволяє визначити кращу альтернативу. **Висновки**. Запропоновано комплексний підхід до здійснення вибору компонентів телекомунікаційних мереж, а саме багатокритеріальна модель BWM-CRITIC-MARCOS, заснована на поєднанні методів MCDM. Інтеграція методів у запропоновану модель забезпечує системний підхід до оцінки та вибору компонентів телекомунікаційних мереж.

Ключові слова: телекомунікаційні мережі; компоненти телекомунікаційних мереж; методи MCDM; багатокритеріальний вибір; метод ентропії; CRITIC; BWM; MARCOS.

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