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MULTI-CRITERIA MODEL FOR SELECTION OF OPTICAL LINEAR TERMINALS BASED ON FUZZY TOPSIS METHOD

Optical networks are an integral part of modern telecommunication systems. Huge traffic and ever-increasing requirements for data transmission capacity and quality encourage the wider use of modern optical technologies in telecommunications. The rational choice of equipment for the design of optical networks is an urgent task at present. The ***subject*** *of this study is the process of selecting optical line terminals, which is associated with the evaluation of possible options by a set of indicators. The OLT (optical line terminal) in PON technology implements the function of organizing subscriber lines and is also a node equipment - an L4 switch that combines the functions of routing (IP), traffic fragmentation (VLAN), switching (MAC), quality of service (QoS), and some necessary network service functions. The optimal structuring of PON access networks demands a judicious selection of software and hardware, guided by their tactical and technical characteristics, in view of the substantial information load they entail. One of the effective approaches to solving such problems is the use of MCDM (Multiple Criteria Decision Making) methods.* ***Purpose****: to construct a TOPSIS model of the optimal choice of optical linear terminals in the conditions of unclear information for different cases of aggregation of evaluations of decision makers.* ***Task:*** *to formalize the process of selecting optical linear terminals; develop a multi-criteria mathematical model for the effective selection of optical line terminals.* ***Methods*** *used in the study: The fuzzy TOPSIS method, four methods of aggregating the opinions of decision makers. The following* ***results*** *were obtained. Alternatives and criteria for their evaluation are defined. On the basis of interviews with decision makers, evaluations of the degree of importance of the criteria and alternatives to the criteria were determined. Linguistic changes were used to describe decision-makers' evaluations, which were interpreted as triangular fuzzy numbers. During this study, four methods of aggregating the evaluations of decision makers were used. A fuzzy TOPSIS model for selecting an optical line terminal is constructed. The ranking of the selected optical line terminals is obtained and the best alternative is determined. The results of modeling with different methods of aggregating assessments of decision makers are compared.* ***Conclusions****. The use of the Fuzzy TOPSIS method for optimal selection of optical linear terminals is proposed. The influence of the methods of aggregation of evaluations of decision-makers is analyzed.*

Keywords*: optical network; optical line terminal; MCDM methods; multicriteria selection; triangular fuzzy numbers; Fuzzy TOPSIS method.*

1. Introduction

1.1. Motivation

The societal consumption of information has exhibited exponential growth in recent decades and is anticipated to persist in the near future. The ever-increasing traffic transmitted by telecommunication networks leads to enormous technical and economic challenges that engineers must confront when designing both transport and access networks [1].

Optical communication is one of the most promising technologies capable of addressing the escalating demands of the telecommunications market due to a sharp increase in the frequency resources of transmission channels [2]. Currently, optical communications are the dominant technology for cable channels within transport networks that operate with powerful homogeneous digital data streams. Regarding cable access networks catering directly to subscribers, the market is still dominated by copper wire technologies that use well-developed and cost-effective means of information exchange. However, numerous subscribers have recently found copper technologies insufficient, primarily because of the necessity of expanding the bandwidth. The adoption of optical transport technologies for subscriber access is not feasible because of the increased cost and complexity associated with deploying individual optical channels.

A compromise solution to the problem of introducing optical technologies into the practice of access networks involves leveraging Passive Optical Network (PON) technology. Its concept involves utilizing purely optical methods to combine and separate individual channels without relying on complex electronic equipment to facilitate multiple access. This makes it possible to connect a significant number of densely located subscribers

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via optical transmission lines while minimizing capital expenditures. From the provider's point of view, PON technology entails constructing a tree topology for the subscriber network based on optical splitters, where information is transmitted from the optical line terminal (OLT) to the user terminals (Optical Network Unit (ONU) or Optical Network Terminal (ONT) in PON terminology).

The interaction between OLT and ONU in the forward and reverse traffic channels is carried out via a single optical fiber at different wavelengths using passive frequency division technology of the shared WDM optical line resource. The information flow for individual subscriber channels is structured similarly, allowing the allocation of distinct shared channels for specific transmissions, such as television. Thus, from an economic perspective, PON optical technology has approached the conventional "copper" solutions commonly employed for the "last mile" problem. Passive access technology has proven to be so successful that it is also used in metro transport networks [3].

Like any advanced subscriber access technology, PON technology is developing dynamically. At present, the most appropriate option is to use GPON (Gigabit PON) and GEPON (Gigabit Ethernet PON), which offer a subscriber traffic channel capacity in the range of tens of gigabauds over distances spanning tens of kilometers. Due to its powerful bandwidth, simple, and cost-effective nature, PON technology can serve as a local transport technology for constructing remote networks (rural networks) with low spatial concentration of ONUs. Therefore, some small data transmission operators are actively interested in its implementation.

The widespread adoption of PON technology is actively facilitated by the following advantages: conservation of optical fibers in optical cables; elimination of power supply for solitaries; reduction in the number of OLT optical emitters; simplicity in connecting subscribers; dynamic control over subscriber bandwidth and emitter power levels; and ease of network maintenance. However, the main challenge still hindering the development of PON is the cost of line and subscriber equipment (OLT and ONU).

From the perspective of network technologies, the OLT in PON technology not only fulfills the role of organizing subscriber lines but also serves as node equipment, functioning as an L4 level switch. It combines various functions, including routing (IP), traffic fragmentation (VLAN), switching (MAC), ensuring quality of service (QoS), and several essential service network functions. The extensive information load on the tactical and technical characteristics of software and hardware emphasizes the necessity for providers to rationally select optical line terminals. This choice is essential for the efficient organization of PON access networks and their seamless interaction with higher-level transport networks. Therefore, the need to develop a methodology for rational equipment selection has become a pressing task, especially given the growing integration of optical technologies into residential subscriber networks.

The growing complexity of the world around us and the multitude of decision-making challenges render it increasingly difficult to make sound decisions. Complex problems in science, engineering, or management are usually characterized by several criteria that are not always quantifiable and usually conflict or interact with each other. The problem of selecting optical line terminals is one of them.

Decision-making processes in solving such problems require the support of methods and tools that have ready-made procedures for reducing uncertainty, resolving conflicts, and limiting the number of unknowns. In this situation, we can use Multiple Criteria Decision Making (MCDM) methods, which have ready-made algorithms that allow us to organize possible solutions and choose the best option [4].

1.2. State of the art

Currently, multicriteria decision-making methods are of great importance, have become quite popular, and are widely used in solving real-world decision-making problems in various industries. Multi-criteria decision-making is a methodological tool for solving complex engineering problems. Most problems in the design of telecommunication networks can be modeled as an MCDM problem, where it is necessary to evaluate several criteria and choose the most appropriate solution for design engineers according to their preferences and requirements.

The problem of making rational equipment choices in the design of telecommunication networks is currently highly relevant and has been explored by A. Zhanasbayeva et al. [5], V. Bezruk et al. [6], L. Melnikova et al. [7], G. Gaivoronska and B. Rybalov [8], M. Kolisnyk [9], Pidchenko S. et al. [10].

However, in real-life decision making, in many cases, the actual situation cannot be described in a clear and deterministic way, i.e., by providing clear quantitative assessments of all criteria and alternatives, because human judgment is often fuzzy and cannot evaluate certain preferences with a precise numerical value. In addition, the data used in the decision-making process may be incomplete or unclear. In such circumstances, classical decision-making methods lose their relevance [11, 12].

A more realistic approach is to use linguistic variables instead of numerical values to evaluate criteria and alternatives. Linguistic expressions, such as "important", "very important", "not very important", "low", "medium", "high", etc., are a natural reflection of the judgment of decision makers. To work with data and information containing uncertainties, the best tool is fuzzy set theory, which was proposed by Zadeh (1965) as a tool for modeling complex systems. The use of fuzzy set theory allows the inclusion of information that cannot be quantified or incomplete information in a decision-making model. The theory of fuzzy sets provides a mathematical tool for capturing the uncertainty associated with linguistic variables and helps to measure the ambiguity of concepts associated with human subjective judgment [13].

The theory of fuzzy sets is currently applied to problems in engineering, business, medicine, and natural sciences. MCDM is one of the fields in which fuzzy set theory has found wide application. The combination of MCDM and fuzzy set theory has led to a new theory of decision making, which is now known as Fuzzy Multi-Criteria Decision Making (FMCDM). The development and application of fuzzy MCDM methods have increased significantly over the past two to three decades [12, 14].

One of the most common FMCDM methods is the Fuzzy TOPSIS (FTOPSIS) method. The classic TOPSIS method (Techinque for Order Preference by Similarity to Ideal Solution) was developed by C.L. Hwang and K. Yoon in 1981. The idea behind the method is to choose the alternative that is closest to the positive ideal solution (PIS) and farthest from the negative ideal solution (NIS) [15]. Positive and negative ideal solutions are artificial alternatives that are determined by the decision maker; therefore, PIS is the ideal solution for all criteria and NIS is the solution that has the worst performance for all criteria [16].

In 2000, Chen proposed an extension of the TOPSIS method to fuzzy numbers. Accordingly, in the Fuzzy TOPSIS method, the alternative that is closest to the fuzzy positive ideal solution (FPIS) and farthest from the fuzzy negative ideal solution (FNIS) is selected as the optimal solution [13].

In recent years, the Fuzzy TOPSIS method has been used in a significant number of studies. In particular, FTOPSIS has been used to select a supplier [17], software [18], for personnel selection [19], website quality assessment [20], and IoT application selection [21].

1.3. Objectives and the approach

The purpose of the article: construction of the TOPSIS model of the optimal choice of optical linear terminals in the conditions of unclear information for different cases of aggregation of evaluations of decision-makers.

The material of this article is organized as follows. The second chapter presents a description of the research methodology (the concept and properties of triangular fuzzy numbers; the Fuzzy TOPSIS method algorithm; methods of aggregating experts' assessments). In the third section, a fuzzy TOPSIS model is built for the selection of an optical linear terminal, and the simulation results are compared for different cases of aggregation of the judgments of decision makers. The results of this study are discussed in the fourth chapter. The final section presents conclusions and recommendations for future research.

2. The theoretical basis of the research

The goal of the multi-criteria decision-making process is to evaluate and rank available alternatives based on a selected set of criteria. Thus, the main stages of the multi-criteria decision-making process are as follows: (1) identification of alternatives and criteria for evaluating alternatives; (2) determination of the importance of each criterion (determination of weight coefficients of criteria); (3) evaluation of alternatives according to each criterion; (4) evaluation of alternatives according to a set of criteria, ranking of alternatives and making a decision based on the results of the ranking [10].

2.1. Fuzzy numbers

The FMCDM method use linguistic variables that can be represented by fuzzy numbers to assess the importance of criteria and evaluate alternatives. The most commonly used fuzzy numbers are triangular and trapezoidal.

A fuzzy set $\tilde{A}$ on a universal set U is a set of ordered pairs:

$$\tilde{A} = \left\{ \left\langle x, \mu_{\tilde{A}}(x) \right\rangle \middle| x \in U \right\}, \quad (1)$$

where $\mu_{\tilde{A}} : U \to [0,1]$ – membership function [4].

A membership function is a mathematical function that defines the degree to which the elements of a set U belong to a fuzzy set $\tilde{A}$. The more the argument x corresponds to a fuzzy set $\tilde{A}$, the greater the value of $\mu_{\tilde{A}}(x)$. A fuzzy number is a special form of a fuzzy set on the real number set R.

A fuzzy number is a fuzzy set given on the set of real numbers $\tilde{A}$ that has a normal and convex membership function, i.e:

a) $\sup_{x \in R} \mu_{\tilde{A}}(x) = 1$;

b) for any $x \le y \le z$ the inequality is satisfied $\mu_{\tilde{A}}(y) \ge \min\{\mu_{\tilde{A}}(x), \mu_{\tilde{A}}(z)\}$.

A triangular fuzzy number is a fuzzy number $\tilde{A}$ represented by a triple of real numbers $\langle a, b, c \rangle$, where

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$a \le b \le c$, whose membership function is defined as follows [13]:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, \text{ if } \ x < a \text{ or } x > c, \\ \frac{x-a}{b-a}, \text{ if } \ a \le x \le b, \\ \frac{c-x}{c-b}, \text{ if } \ b < x \le c. \end{cases} \quad (2)$$

Thus, each triangular fuzzy number can be represented by an ordered triple of real numbers: $\tilde{A} = (a, b, c)$, where b is the modal value, and the values a and c represent the lower and upper bounds of the number $\tilde{A}$ and determine the so-called degree of fuzziness of the number.

Triangular fuzzy number $\tilde{A} = (a, b, c)$ for which $0 \le a \le b \le c$ is called a positive triangular fuzzy number. Algebraic operations with two positive triangular fuzzy numbers $\tilde{A}_1 = (a_1, b_1, c_1)$ and $\tilde{A}_2 = (a_2, b_2, c_2)$ [13, 4]:

- Addition of fuzzy numbers (+):

$$\tilde{A}_1 (+) \tilde{A}_2 = (a_1, b_1, c_1)(+)(a_2, b_2, c_2) = \\ = (a_1 + a_2, b_1 + b_2, c_1 + c_2); \quad (3)$$

- Multiplication of fuzzy numbers ($*$):

$$\tilde{A}_1 (*) \tilde{A}_2 = (a_1, b_1, c_1)(*)(a_2, b_2, c_2) = \\ = (a_1 \cdot a_2, b_1 \cdot b_2, c_1 \cdot c_2); \quad (4)$$

- Multiplication of real number k and fuzzy number ($*$):

$$k(*)\tilde{A}_1 = (k, k, k)(*)(a_1, b_1, c_1) = \\ = (k \cdot a_1, k \cdot b_1, k \cdot c_1) \quad \text{for } k > 0; \quad (5)$$

- Subtraction of fuzzy numbers ($-$):

$$\tilde{A}_1 (-) \tilde{A}_2 = (a_1, b_1, c_1)(-)(a_2, b_2, c_2) = \\ = (a_1 - a_2, b_1 - b_2, c_1 - c_2); \quad (6)$$

- Division of fuzzy numbers (/):

$$\tilde{A}_1 (/) \tilde{A}_2 = (a_1, b_1, c_1)(/)(a_2, b_2, c_2) = \\ = \left(\frac{a_1}{c_2}, \frac{b_1}{b_2}, \frac{c_1}{a_2} \right) \quad \text{for } a_2 > 0; \quad (7)$$

- Reciprocal of a fuzzy number:

$$\tilde{A}_1^{-1} = (a_1, b_1, c_1)^{-1} = \left(\frac{1}{c_1}, \frac{1}{b_1}, \frac{1}{a_1} \right) \text{ for } a_1 > 0. \quad (8)$$

The distance between two triangular fuzzy numbers $\tilde{A}_1 = (a_1, b_1, c_1)$ and $\tilde{A}_2 = (a_2, b_2, c_2)$ is defined as follows

$$d(\tilde{A}_1, \tilde{A}_2) = \\ = \sqrt{\frac{1}{3}\left[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2 \right]}. \quad (9)$$

2.2. Fuzzy TOPSIS method

Any MCDM problem with m alternatives evaluated according to n criteria can be represented by a decision matrix

$$X = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{matrix} C_1 & C_2 & \cdots & C_n \\ \left[\begin{matrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{matrix}\right] \end{matrix}, \quad (10)$$

and $W = (w_1, w_2, ..., w_n)$,

where $A_i \ (i = 1, 2, ..., m)$ – alternatives, $C_j \ (j = 1, 2, ..., n)$ – criteria, x_{ij} – evaluation of the i-th alternative according to the j-th criterion, W – vector of criteria weighting coefficients.

Accordingly, the FMCDM problem is represented by the fuzzy decision matrix:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \quad (11)$$

where $\tilde{x}_{ij}$ – linguistic variables described by triangular fuzzy numbers $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$.

The weights of the criteria are usually also represented by linguistic variables, which are described by triangular fuzzy numbers:

$$\tilde{W} = (\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_n), \qquad (12)$$

where $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$.

The algorithm of the Fuzzy TOPSIS method consists of the following steps [4, 13].

Step 1. Construction of a fuzzy decision matrix.

Step 2. Construction of a normalized fuzzy decision matrix

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n}, \qquad (13)$$

where

$$\tilde{r}_{ij} = \begin{cases} \left(\dfrac{a_{\tilde{x}_{ij}}}{\max\limits_i c_{\tilde{x}_{ij}}}, \dfrac{b_{\tilde{x}_{ij}}}{\max\limits_i c_{\tilde{x}_{ij}}}, \dfrac{c_{\tilde{x}_{ij}}}{\max\limits_i c_{\tilde{x}_{ij}}} \right) & \text{for benefit criterion} \\ \left(\dfrac{\min\limits_i a_{\tilde{x}_{ij}}}{c_{\tilde{x}_{ij}}}, \dfrac{\min\limits_i a_{\tilde{x}_{ij}}}{b_{\tilde{x}_{ij}}}, \dfrac{\min\limits_i a_{\tilde{x}_{ij}}}{a_{\tilde{x}_{ij}}} \right) & \text{for cost criterion} \end{cases}$$

Step 3. Building a weighted normalized fuzzy matrix

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n}, \qquad (14)$$

where $\tilde{v}_{ij} = \tilde{r}_{ij} (*) \tilde{w}_j$.

Operation $(*)$ is performed according to equation (4).

Step 4. Determining the fuzzy ideal positive decision $\tilde{A}^+$ (ideal) and the fuzzy ideal negative decision $\tilde{A}^-$ (anti-ideal):

$$\tilde{A}^+ = (\tilde{v}_1^+, \tilde{v}_2^+, ..., \tilde{v}_n^+) = \left(\max_i \tilde{v}_{i1}, \max_i \tilde{v}_{i2}, ..., \max_i \tilde{v}_{in} \right), \qquad (15)$$

where $\max\limits_i \tilde{v}_{ij} = \left(\max\limits_i a_{\tilde{v}_{ij}}, \max\limits_i b_{\tilde{v}_{ij}}, \max\limits_i c_{\tilde{v}_{ij}} \right)$.

$$\tilde{A}^- = (\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_n^-) = \left(\min_i \tilde{v}_{i1}, \min_i \tilde{v}_{i2}, ..., \min_i \tilde{v}_{in} \right), \qquad (16)$$

where $\min\limits_i \tilde{v}_{ij} = \left(\min\limits_i a_{\tilde{v}_{ij}}, \min\limits_i b_{\tilde{v}_{ij}}, \min\limits_i c_{\tilde{v}_{ij}} \right)$.

Step 5. Calculate the distance from each alternative to the ideal $\tilde{A}^+$ and anti-ideal $\tilde{A}^-$ according to formula (7):

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+) \quad \text{and} \quad d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-). \qquad (17)$$

Step 6. Calculate the integral index (the coefficient of proximity to the ideal positive solution $\tilde{A}^+$) for each alternative A_i:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}. \qquad (18)$$

Step 7. Ranking of alternatives by the integral indicator CC_i. The best alternative corresponds to the largest one.

The growing complexity of the problems that arise in the management of complex systems, including telecommunications, leads to the fact that decisions are made not by one person, but by a group of experts or decision makers. Therefore, when using multicriteria decision-making (FMCDM) methods, it is necessary to aggregate the opinions of experts (or decision makers).

The assessment of the degree of importance of the criteria and the evaluation of alternatives according to the criteria are carried out using linguistic variables that can be represented by triangular fuzzy numbers [11], as shown in Tables 1 and 2.

Table 1

Linguistic terms for weights of criteria [11]

Linguistic terms	Fuzzy number
Very small (VS)	(0,0,0.1)
Fairly small (FS)	(0,0.1,0.3)
Small (S)	(0.1,0.3,0.5)
Middle (M)	(0.3,0.5,0.7)
Big (B)	(0.5,0.7,0.9)
Fairly big (FB)	(0.7,0.9,1)
Very big (VB)	(0.9,1,1)

Table 2

Linguistic terms for alternatives [22]

Linguistic terms	Fuzzy number
Very poor (VP)	(1,1,3)
Poor (P)	(1,3,5)
Fair (F)	(3,5,7)
Good (G)	(5,7,9)
Very good (VG)	(7,9,9)

To aggregate expert opinions, the concepts of geometric mean, arithmetic mean, or other ideas are usually used to help determine aggregate estimates of the weights

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of criteria and alternatives by criteria. Scientists, in particular, Chen, Kacprzak [4], Nãdãban [14], proposed different approaches to aggregating expert opinions. Thus, D. Kacprzak in his work [4] identified four approaches to determining the aggregate opinion of experts.

If the assessment of the *k*-th expert is represented by a triangular fuzzy number $\tilde{x}_{ij}^k = \left(a_{ij}^k, b_{ij}^k, c_{ij}^k\right)$, then according to [4], the aggregate opinion of experts can be defined as:

- arithmetic mean:

$$\tilde{x}_{ij} = \frac{1}{K}\sum_{k=1}^{K}\tilde{x}_{ij}^k = \left(\frac{1}{K}\sum_{k=1}^{K}a_{ij}^k, \frac{1}{K}\sum_{k=1}^{K}b_{ij}^k, \frac{1}{K}\sum_{k=1}^{K}c_{ij}^k\right); \quad (19)$$

- modified arithmetic mean:

$$\tilde{x}_{ij} = \left(\min_k a_{ij}^k, \frac{1}{K}\sum_{k=1}^{K}b_{ij}^k, \max_k c_{ij}^k\right); \quad (20)$$

- geometric mean:

$$\tilde{x}_{ij} = \left(\prod_{k=1}^{K}\tilde{x}_{ij}^k\right)^{\frac{1}{K}} = \left(\left(\prod_{k=1}^{K}a_{ij}^k\right)^{\frac{1}{K}}, \left(\prod_{k=1}^{K}b_{ij}^k\right)^{\frac{1}{K}}, \left(\prod_{k=1}^{K}c_{ij}^k\right)^{\frac{1}{K}}\right); \quad (21)$$

- modified geometric mean:

$$\tilde{x}_{ij} = \left(\min_k a_{ij}^k, \left(\prod_{k=1}^{K}b_{ij}^k\right)^{\frac{1}{K}}, \max_k c_{ij}^k\right). \quad (22)$$

3. Research results

This study used data on the characteristics of optical line terminals provided by representatives of the Khmelnytsky branch of Ukrtelecom JSC. The following optical line terminals were identified as alternatives: A_1 - BDCOM P3600-04 optical line terminal; A_2 - BDCOM GP3600-08B optical line terminal; A_3 - BDCOM GP3600-16B optical line terminal; A_4 - BDCOM P3600-16E optical line terminal; A_5 - BDCOM P3600-08E optical line terminal.

The following characteristics of optical line terminals were chosen as selection criteria: C_1 - number of PON ports; C_2 - backplane bandwidth; C_3 - MAC address table; C_4 - IPv4 routing table; C_5 - IPv6 routing table; C_6 - AC power supply; C_7 - weight; C_8 - Uplink interfaces; C_9 - types of supported PON modules.

Based on the interviews with the decision makers (DM_1, DM_2, DM_3), the importance of the criteria and the scores of the alternatives by criteria were determined. The assessment was performed using linguistic variables, as shown in Tables 1 and 2. The results are presented in Tables 3 and 4.

Using Tables 1 and 2, the importance ratings of the criteria and the scores of the alternatives by criteria made by the decision makers were converted into triangular fuzzy numbers (Tables 5 and 6).

To further apply the Fuzzy TOPSIS method, the opinions of decision makers were aggregated using (20). Thus, a fuzzy decision matrix and a vector of weighting coefficients were formed (Table 7).

In the next step, the fuzzy decision matrix was normalized according to (13). Then, considering the weights of the criteria, the weighted normalized fuzzy matrix and the fuzzy ideal positive decision $\tilde{A}^+$ and ideal negative decision $\tilde{A}^-$ were determined (according to (14) - (16)). Next, the distances from each alternative to the ideal $\tilde{A}^+$ and anti-ideal $\tilde{A}^-$ were calculated using (17). The calculation of the integral index for each alternative Ai, according to (18), allows us to create a ranking of alternatives. The following ranking was obtained: $A_3 \succ A_2 \succ A_5 \succ A_4 \succ A_1$. Thus, the best alternative is alternative A_3.

However, as mentioned above, the aggregation of decision makers' opinions can be done in different ways (according to formulas (19) - (22)). In the first stage, we used a modified arithmetic mean to aggregate the opinions of decision makers.

Table 3

Assessment of the importance of the criteria by decision makers

Criteria	DM_1	DM_2	DM_3
C_1	B	VB	FB
C_2	M	VB	FB
C_3	M	B	FB
C_4	FB	B	FB
C_5	FB	B	B
C_6	S	S	VS
C_7	VS	VS	VS
C_8	VB	B	VB
C_9	FB	FB	B

Table 4

Evaluation of alternatives using criteria by decision makers

Alternatives	decision makers	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	DM_1	F	G	F	F	G	F	G	G	F
	DM_2	F	G	F	F	F	G	G	F	G
	DM_3	F	G	P	VG	VG	VG	VG	G	F
A_2	DM_1	F	F	VG	VG	VG	G	G	VG	VG
	DM_2	G	G	VG	VG	VG	VG	G	VG	VG
	DM_3	G	G	VG	VG	VG	VG	VG	VG	VG
A_3	DM_1	VG	G	VG	G	G	VG	G	VG	VG
	DM_2	VG	G	VG	VG	VG	VG	G	VG	VG
	DM_3	VG	G	VG	VG	VG	VG	VG	VG	VG
A_4	DM_1	VG	VG	G	G	F	VG	G	F	G
	DM_2	VG	VG	G	G	G	G	VG	G	G
	DM_3	VG	VG	F	VG	VG	VG	VG	G	F
A_5	DM_1	G	VG	G	VG	VG	G	G	G	G
	DM_2	G	VG	G	G	G	G	VG	G	G
	DM_3	G	G	F	VG	VG	VG	VG	G	F

Table 5

Criteria importance scores expressed as triangular fuzzy numbers

Criteria	DM_1	DM_2	DM_3
C_1	(0.5; 0.7; 0.9)	(0.9; 1; 1)	(0.7; 0.9; 1)
C_2	(0.3; 0.5; 0.7)	(0.9; 1; 1)	(0.7; 0.9; 1)
C_3	(0.3; 0.5; 0.7)	(0.5; 0.7; 0.9)	(0.7; 0.9; 1)
C_4	(0.7; 0.9; 1)	(0.5; 0.7; 0.9)	(0.7; 0.9; 1)
C_5	(0.7; 0.9; 1)	(0.5; 0.7; 0.9)	(0.5; 0.7; 0.9)
C_6	(0.1; 0.3; 0.5)	(0.1; 0.3; 0.5)	(0; 0; 0.1)
C_7	(0; 0; 0.1)	(0; 0; 0.1)	(0; 0; 0.1)
C_8	(0.9; 1; 1)	(0.5; 0.7; 0.9)	(0.9; 1; 1)
C_9	(0.7; 0.9; 1)	(0.7; 0.9; 1)	(0.5; 0.7; 0.9)

Table 6

Evaluation of alternatives using criteria expressed as triangular fuzzy numbers

Alternatives	decision makers	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	DM_1	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)
	DM_2	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)
	DM_3	(3,5,7)	(5,7,9)	(1,3,5)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(3,5,7)
A_2	DM_1	(3,5,7)	(3,5,7)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(5,7,9)	(7,9,9)	(7,9,9)
	DM_2	(5,7,9)	(5,7,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)
	DM_3	(5,7,9)	(5,7,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)
A_3	DM_1	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)
	DM_2	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)
	DM_3	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)
A_4	DM_1	(7,9,9)	(7,9,9)	(5,7,9)	(5,7,9)	(3,5,7)	(7,9,9)	(5,7,9)	(3,5,7)	(5,7,9)
	DM_2	(7,9,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)
	DM_3	(7,9,9)	(7,9,9)	(3,5,7)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(3,5,7)
A_5	DM_1	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
	DM_2	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)
	DM_3	(5,7,9)	(5,7,9)	(3,5,7)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(3,5,7)

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Table 7

Fuzzy decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	(3,5,7)	(5,7,9)	(1, 4.3, 7)	(3, 6.3, 9)	(3,7, 9)	(3,7, 9)	(5, 7.7, 9)	(3, 6.3, 9)	(3, 5.7, 9)
A_2	(3, 6.3, 9)	(3, 6.3, 9)	(7,9,9)	(7,9,9)	(7,9,9)	(5, 8.3, 9)	(5, 7.7, 9)	(7, 9, 9)	(7, 9, 9)
A_3	(7,9,9)	(5,7,9)	(7,9,9)	(5, 8.3, 9)	(5, 8.3, 9)	(7,9,9)	(5, 7.7, 9)	(7,9,9)	(7, 9, 9)
A_4	(7,9,9)	(7,9,9)	(3, 6.3, 9)	(5, 7.7, 9)	(3,7, 9)	(5, 8.3, 9)	(5, 8.3, 9)	(3, 6.3, 9)	(3, 6.3, 9)
A_5	(5,7,9)	(5, 8.3, 9)	(3, 6.3, 9)	(5, 8.3, 9)	(5, 8.3, 9)	(5, 7.7, 9)	(5, 8.3, 9)	(5,7,9)	(3, 6.3, 9)
W	(0.5,0.87,1)	(0.3,0.8,1)	(0.3,0.7,1)	(0.5,0.83,1)	(0.5,0.77,1)	(0,0.2,0.5)	(0,0,0.1)	(0.5,0.9,1)	(0.5,0.83,1)

Table 8

Results of ranking alternatives using the Fuzzy TOPSIS method, using different aggregation methods

	CCi (AM)	rank	CCi (MAM)	rank	CCi (GM)	rank	CCi (MGM)	rank
A_1	0.04	5	0.03	5	0.04	5	0.03	5
A_2	0.76	2	0.77	2	0.77	2	0.78	2
A_3	0.86	1	0.83	1	0.87	1	0.83	1
A_4	0.52	4	0.48	4	0.52	4	0.48	4
A_5	0.53	3	0.49	3	0.54	3	0.5	3

Therefore, in the next stage of the study, we determined the ranking of alternatives using the Fuzzy TOPSIS method and other methods of aggregating the opinions of decision makers (arithmetic mean, geometric mean, and modified geometric mean). The results are presented in Table 8. Regardless of the method of aggregation, the ratings obtained are the same and the best alternative is alternative A_3.

4. Discussion

One of the most important issues that must be resolved when designing telecommunication networks is the choice of telecommunication equipment that meets the requirements of the network. As indicators (criteria) for selecting appropriate equipment, the technical characteristics determined by the specifics of the network are used. However, the presence of several selection criteria leads to an increase in the amount of information needed to evaluate the importance of the criteria and compare alternatives according to the specified criteria.

In real-life decision making, a person’s preference model is fuzzy and subjective. Therefore, the decision maker cannot express his/her preferences using precise numerical values. In addition, most solutions involve the work of a group of experts or specialists. However, in a group of decision-makers, each of them can specialize in different issues, have different knowledge, skills, and experience. That is, there is a need to aggregate their opinions.

The results of the study showed that the use of the fuzzy MCDM method allowed decision makers to express their subjective judgments using linguistic terms, which facilitated the process of assessing the importance of the criteria and evaluating alternatives according to the criteria.

Linguistic evaluations of decision makers were transformed into triangular fuzzy numbers and a fuzzy decision matrix was formed. To aggregate the opinions of decision-makers, a modified arithmetic mean was initially used. Then the Fuzzy TOPSIS method was used. According to the results of this study, the best alternative is alternative A_3.

In the next phase of the study, a better alternative was identified using other approaches to the aggregation of decision makers’ ratings. As the results of this study showed, the value of the integral indicator of some alternatives varies slightly with different methods of aggregation. Thus, the difference between the integral indicators CC_3 and CC_2 (for alternatives A_3 and A_2) is 0.1 when using the arithmetic mean and geometric mean for aggregating opinions. When using the modified arithmetic mean and modified geometric mean, this difference is 0.06 and 0.05, respectively.

Thus, if the alternatives are very similar in terms of characteristics, the method of aggregation may affect the result. Therefore, when building a decision-making model (with the participation of a group of decision-makers), it is necessary to consider different approaches to the aggregation of assessments of decision-makers.

5. Conclusion

Given the high cost of modern telecommunications equipment, the rational choice of optical line terminals by providers is a decision-making task that considers a set of criteria that contradict each other.

This article proposes a fuzzy TOPSIS model for choosing an optical linear terminal by considering a set of criteria.

The ambiguity of human judgment in assessing the importance of criteria and evaluating alternatives by criteria creates certain problems for decision makers. The use of fuzzy logic allows processing of imprecise and uncertain information, providing a more complete and accurate assessment of alternatives and evaluation of the importance of criteria. The main advantage of fuzzy decision making is that it provides a structure with more flexibility to solve problems that arise due to lack of information.

The fuzzy TOPSIS method is the best tool to solve the problem in an environment of uncertain and imprecise data. This method allows you to present the evaluation of the criteria and the alternative in a descriptive (linguistic) form, which facilitates the decision-making process.

This study showed that the TOPSIS fuzzy method provides a comprehensive and reliable alternative evaluation system, which increases the efficiency of the optical line terminal selection process.

A model of the optimal choice of optical linear terminals has been developed. The following stages of modeling are defined: formalization of assessments of decision makers using linguistic variables; their interpretation by triangular fuzzy numbers; aggregation of evaluations of decision makers by arithmetic mean, modified arithmetic mean, geometric mean, and modified geometric mean; application of the Fuzzy TOPSIS method for ranking alternatives (optical linear terminals) and selecting the best alternative based on a set of criteria.

The following rating of the optical linear terminals was obtained: $A_3 \succ A_2 \succ A_5 \succ A_4 \succ A_1$. Thus, the best alternative, regardless of the aggregation method, is alternative A_3 (BDCOM GP3600-16B optical line terminal).

In further research, it is planned to use trapezoidal fuzzy numbers to interpret linguistic variables and compare the simulation results with those obtained in this study.

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Conflict of Interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data Availability

The manuscript contains no associated data.

Use of Artificial Intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current study.

All the authors have read and agreed to the published version of this manuscript.

References

1. Marom, D. M., Miyamoto, Y., Neilson, D. T., & Tomkos, I. Optical Switching in Future Fiber-Optic Networks Utilizing Spectral and Spatial Degrees of Freedom. *Proceedings of the IEEE*, 2022, vol. 110, no. 11, pp.1835-1852. DOI: 10.1109/JPROC.2022.3207576.

2. Hall, M. N., Foerster, K., Schmid, S., & Durairajan, R. A Survey of Reconfigurable Optical Networks. *Optical Switching and Networking*, 2021, vol. 41, 100621. DOI: 10.1016/j.osn.2021.100621.

3. Ullah, R., Ullah, S., Almadhor, A., Alwageed, H. S., Al-Atawi, A. A., Ren, J., & Chen, S. A High-Capacity Optical Metro Access Network: Efficiently Recovering Fiber Failures with Robust Switching and Centralized Optical Line Terminal. *Sensors*, 2024, vol. 24, iss. 4, article no. 1074. DOI: 10.3390/s24041074.

4. Kacprzak, D. Podwójna rozmyta metoda TOPSIS wspomagająca podejmowanie decyzji grupowych [Dual fuzzy TOPSIS method supporting group decision making]. *Przegląd statystyczny – Statistical review*, 2019, vol. LXVI, no. 1, pp. 27-50. DOI: 10.5604/01.3001.0013.8363 (In Polish).

5. Zhanasbayeva, A., Tokhmetov, A., Amirova, A. Methods for substantiating decisions on the choice of the composition of telecommunications equipment. *Journal of Theoretical and Applied Information Technology*, 2021, vol. 99, no 22, pp. 5582-5591. Available at:

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

http://www.jatit.org/volumes/Vol99No22/31Vol99No22.pdf (accessed 12.12.2023).

6. Bezruk, V., Chebotareva, D., & Skoryk, Y. Multicriteria selection of the optimal design options of telecommunication facilities. *IAPGOS*, 2018, no. 4, pp. 16–19. DOI: 10.5604/01.3001.0012.8014.

7. Melnikova, L. I., Linnyk, O. V., Kryvoshapka, N. V., & Barsuk V. A. Zastosuvannia evrystychnoi protsedury bahatokryterialnoi optymizatsii do vyboru varianta movnoho kodeku v IP-merezhi [Application of the European procedure of multi-criteria optimization to the choice of the language codec option in the IP network]. *Problemy telekomunikatsii*, 2020, no. 1 (26), pp. 23-32. DOI: 10.30837/pt.2020.1.02. (In Ukrainian).

8. Gayvoronska, G., & Rybalov, B. Zadacha vybora kommutatsionnogo elementa dlya opticheskoy telekommunikatsionnoy seti [Problem of choice of switching element for optical telecommunication network]. *International Journal «Information Models and Analyses»,* 2016, vol. 5, iss. 1, pp. 78-99. (In Russian). Available at: http://www.foibg.com/ijima/vol05/ijima-fv5-vol5.htm (accessed 12.12.2023).

9. Kolisnyk, M. Vulnerability analysis and method of selection of communication protocols for information transfer in internet of things systems. *Radioelektronni i komp'uterni sistemi – Radioelectronic and computer systems*, 2021, no. 1(97), pp. 133-149. DOI: 10.32620/reks.2021.1.12.

10. Pidchenko, S., Kucheruk, O., Pyvovar, O., Stetsiuk, V., & Mishan, V. A multi-criteria approach to decision-making in telecommunication network components selection. *Radioelektronni i komp'uterni sistemi – Radioelectronic and computer systems*, 2023, no. 1(105), pp. 155-165. DOI: 10.32620/reks.2023.1.13.

11. Tubis, A., & Werbińska-Wojciechowska, S. Fuzzy TOPSIS in selecting logistic handling operator: case study from Poland. *Transport*, 2023, no. 38, iss. 1, pp. 12–30. DOI: 10.3846/transport.2023.17074.

12. Antucheviciene, J., Kala, Z., Marzouk, M., & Vaidogas, E. R. Solving Civil Engineering Problems by Means of Fuzzy and Stochastic MCDM Methods: Current State and Future Research. *Mathematical Problems in Engineering*, 2015, vol. 2015, article no. 362579. DOI: 10.1155/2015/362579.

13. Petrović, G., Mihajlović, J., Ćojbašić, Ž., Madić, M., & Marinković, D. Comparison of three fuzzy mcdm methods for solving the supplier selection problem. *Facta universitatis Series: Mechanical Engineering*, 2019, vol. 17, no. 3, pp. 455-469. DOI: 10.22190/FUME190420039P.

14. Nădăban, S., Dzitac, S., & Dzitac, I. Fuzzy TOPSIS: A General View. *Procedia Computer Science*, 2016, no. 91, pp. 823-831. DOI: 10.1016/j.procs.2016.07.088.

15. Halicka, K. Technology Selection Using the TOPSIS Method. *Foresight and STI Governance*, 2020, vol. 14, no. 1, pp. 85-96. DOI: 10.17323/2500-2597.2020.1.85.96.

16. Pidchenko, S., Kucheruk, O., & Pyvovar, O. Vybir telekomunikatsiinoho obladnannia v systemakh peredachi movnykh povidomlen [Selection of telecommunication equipment in voice message transmission systems]. *Visnyk Khmelnytskoho natsionalnoho universytetu. Seriia: Tekhnichni nauky – Herald of Khmelnytskyi national university, Technical sciences*, 2023, Vol.5(327), Part 2, pp. 192-199. DOI: 10.31891/2307-5732-2023-327-5-192-199. (In Ukrainian).

17. Sun, H., Zhang, B., & Ni, W. A Hybrid Model Based on SEM and Fuzzy TOPSIS for Supplier Selection. *Mathematics*, 2022, no. 10, article no. 3505. DOI: 10.3390/math10193505.

18. Salimov, V. H. O. Application of TOPSIS Method with Trapezoidal Fuzzy Numbers. *Science Review*, 2021, no. 1(36). DOI: 10.31435/rsglobal_sr/30012021/7377.

19. Aliyeva, K. Multifactor Personnel Selection by the Fuzzy TOPSIS Method. *13th International Conference on Theory and Application of Fuzzy Systems and Soft Computing — ICAFS-2018. Advances in Intelligent Systems and Computing*, 2019, vol. 896, pp. 478-483. DOI: 10.1007/978-3-030-04164-9_64.

20. Jefmański, B. Rozmyta metoda TOPSIS jako narzędzie identyfikacji determinant jakości usług i produktów [The fuzzy TOPSIS method as a tool for identifying determinants of the quality of services and products]. *Handel wewnętrzny – Internal trade*, 2013, no. 5(346), pp. 28-41. Available at: http://cejsh.icm.edu.pl/cejsh/element/bwmeta1.element.desklight-61006eb1-8df7-4f2b-b15f-85dd6191301f (accessed 12.12.2023) (In Polish).

21. Alojaiman, B. A Multi-Criteria Decision-Making Process for the Selection of an Efficient and Reliable IoT Application. *Processes*, 2023, no. 11, article no. 1313. DOI: 10.3390/pr11051313.

22. Zulqarnain, M., & Dayan, F. Choose Best Criteria for Decision Making Via Fuzzy Topsis Method. *Mathematics and Computer Science*, 2017, no. 2(6), pp. 113-119. DOI: 10.11648/j.mcs.20170206.14.

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БАГАТОКРИТЕРІАЛЬНА МОДЕЛЬ ДЛЯ ВИБОРУ ОПТИЧНИХ ЛІНІЙНИХ ТЕРМІНАЛІВ НА ОСНОВІ МЕТОДУ FUZZY TOPSIS

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Оптичні мережі є невід'ємною частиною сучасних телекомунікаційних систем. Величезний трафік, а також постійно зростаючі вимоги до пропускної здатності та якості передачі даних спонукають до ширшого використання сучасних оптичних технологій у телекомунікаціях. Раціональний вибір устаткування при проектуванні оптичних мереж є актуальним завданням на даний час. **Предметом** дослідження в статті є процес вибору оптичних лінійних терміналів, який пов'язаний з оцінкою можливих варіантів за набором показників. OLT (оптичний лінійний термінал) в технології PON реалізує функцію організації абонентських ліній, а також є вузловим устаткуванням – комутатором рівня L4, що об’єднує функції маршрутизації (IP), фрагментації трафіку (VLAN), комутації (MAC), якості зв’язку (QoS) та ряду необхідних сервісних мережевих функцій. Таке високе інформаційне навантаження на програмно-апаратні тактико-технічні характеристики обумовлюють необхідність їх раціонального вибору для потреб ефективної організації PON мереж доступу. Одним з ефективних підходів до вирішення таких задач є використання методів MCDM (Multiple Criteria Decision Making). **Мета** статті**:** побудова моделі TOPSIS оптимального вибору оптичних лінійних терміналів в умовах нечіткої інформації для різних випадків агрегації оцінок осіб, що приймають рішення. **Завдання**: формалізувати процес вибору оптичних лінійних терміналів; розробити багатокритеріальну математичну модель для ефективного вибору оптичних лінійних терміналів. В дослідженні використано **методи**: метод Fuzzy TOPSIS, чотири способи агрегації думок осіб, що приймають рішення. Отримано **такі результати**. Визначено альтернативи та критерії їх оцінювання. На основі проведених інтерв'ю з особами, що приймають рішення визначено оцінки ступеня важливості критеріїв та оцінки альтернатив за критеріями. Для опису думок осіб, що приймають рішення, було використано лінгвістичні змінні, які інтерпретувались трикутними нечіткими числами. В ході дослідження використано чотири способи агрегації оцінок осіб, що приймають рішення. Побудовано нечітку модель TOPSIS для вибору оптичного лінійного терміналу. Одержано ранжування обраних оптичних лінійних терміналів та визначено кращу альтернативу. Порівняно результати моделювання при різних способах агрегації оцінок осіб, що приймають рішення. **Висновки**. Запропоновано використання методу Fuzzy TOPSIS для оптимального вибору оптичних лінійних терміналів. Проаналізовано вплив способів агрегації оцінок осіб, що приймають рішення.

Ключові слова: оптичні мережі, оптичний лінійний термінал, методи MCDM, багатокритеріальний вибір, трикутні нечіткі числа, метод Fuzzy TOPSIS.

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