ПРИЧОРНОМОРСЬКИЙ НАУКОВО-ДОСЛІДНИЙ ІНСТИТУТ
ЕКОНОМІКИ ТА ІННОВАЦІЙ

# ІНФРАСТРУКТУРА РИНКУ

*Електронний науково-практичний журнал*

**Випуск 87**

Видавничий дім
«Гельветика»
2025

*Magazine.* Available at: https://hotelsmag.com/news/how-geo-location-technology-can-drive-hotel-development-and-transactions.

8. Olson K. (2025) How Marriott Uses Maps to Transform Global Risk Management – *Esri Blog*. Available at: https://www.esri.com/about/newsroom/blog/video-marriotts-advanced-gis-tools-ensure-guest-safety-and-environmental-responsibility.

9. Malook J. (2025) Role of GIS in Tourism Management: Mapping the Future of Sustainable Travel. *AI Geo 360 Blog*. Available at: https://aigeo360.com/role-of-gis-in-tourism-management.

*Стаття надійшла: 15.10.2025*
*Стаття прийнята: 28.10.2025*
*Стаття опублікована: 24.11.2025*

# РОЗДІЛ 7. МАТЕМАТИЧНІ МЕТОДИ, МОДЕЛІ ТА ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ В ЕКОНОМІЦІ

## GENERALIZATION OF DIRECTIONS OF USE OF FUZZY SETS FOR SOLVING TYPICAL PROBLEMS OF ECONOMIC ENTERPRISE

## УЗАГАЛЬНЕННЯ НАПРЯМКІВ ВИКОРИСТАННЯ НЕЧІТКИХ МНОЖИН ДЛЯ ВИРІШЕННЯ ТИПОВИХ ЗАДАЧ ЕКОНОМІЧНОГО ПІДПРИЄМСТВА

UDC 65.012.123:330

DOI: https://doi.org/10.32782/infrastruct87-21

**Minienkova Olena**[1]
Candidate of Economic Sciences, Docent, Associate Professor at the Department of Higher Mathematics and Economic and Mathematical Methods, Simon Kuznets Kharkiv National University of Economics

**Мінєнкова О.В.**
Харківський національний університет імені Семена Кузнеця

*Decision-making methods in fuzzy models allow convenient and fairly objective evaluation of alternatives according to individual criteria. The difference of these methods from others is that adding new alternatives does not change the ranking order of previous options. The article summarizes the use of fuzzy set theory for solving problems of an economic enterprise. The basic concepts of fuzzy logic and the possibility of its use in decision-making are considered. Various methods of decision-making based on fuzzy set theory are analyzed. The main problem of multi-criteria choice using fuzzy models is identified, namely, the idea of the relationships between the criteria and the methods of calculating overall estimates. Methods based on different approaches give different results. The article discusses each approach with its own characteristics and limitations, which you need to know about before applying.*

**Keywords:** *decision-making problems, fuzzy sets, multi-criteria choice, uncertainty, fuzzy methods, enterprise.*

*Прийняття рішень – це одна з найпоширеніших задач у будь-якій галузі. Щоб розглянути рішення, потрібно обрати одну або кілька кращих варіантів з певного набору. Для того щоб здійснити такий вибір, слід чітко поставити мету та визначити критерії, якими буде оцінений кожен з варіантів. Вибір способу вирішення цієї задачі залежить від того, яка інформація доступна – її кількість і якість. Методи прийняття рішень у нечітких моделях дозволяють зручно і досить об'єктивно оцінювати альтернативи за окремими критеріями. Відмінність цих методів від інших полягає в тому, що додавання нових альтернатив не змінює порядок ранжування попередніх варіантів. У статті узагальнено використання теорії нечітких множин для розв'язання задач економічного підприємства. Розглянуто основні поняття нечіткої логіки та можливості її використання у прийнятті рішень. Проаналізовано різні методи прийняття рішень на основі теорії нечітких множин. Більшість методів прийняття рішень, які мають нечіткість, показують слабку стійкість результатів до початкових даних. Евристичний підхід дає найбільш широкі можливості для подання інформації. Дослідження різних методів показало, що найбільш стійким є метод, який заснований на правилах. Виявлено головну проблему багатокритерійного вибору з використанням нечітких моделей, а саме – уявлення про взаємозв'язки між критеріями та способи обчислення загальних оцінок. Аналіз нечітких методів прийняття рішень дозволяє визначити вимоги до подальших розробок у цій галузі. Це включає розвиток теоретичних підходів для описання складних взаємовідносин між критеріями, більш широке застосування інтелектуальних методів, побудованих на нечіткій логіці, а також розвиток комбінованих методів прийняття рішень, що використовують нечіткі уявлення. Методи, які базуються на різних підходах, дають різні результати. У статті розглянуто різні підходи, кожен з яких зі своїми особливостями та обмеженнями. Необхідно знати про них, перш ніж застосовувати певний метод для прийняття рішень. Сьогоднішня проблема полягає в тому, щоб обрати правильний метод або програму, які допоможуть у прийнятті рішень. В статті проведено порівняльний аналіз різних методів і розробка рекомендацій по їх застосуванню.*

**Ключові слова:** *задачі прийняття рішень, нечіткі множини, багатокритеріальний вибір, невизначеність, нечіткі методи, підприємство.*

**Statement of the problem.** The decision-making problem is one of the most common in any field. Its solution comes down to choosing one or more best alternatives from a set. In order to make such a choice, it is necessary to clearly define the goal and criteria by which a set of alternatives will be evaluated. The choice of a method for solving such a problem depends on the quantity and quality of available information. In the field of decision-making, many different methods have been developed based on this theory. One of the difficult problems today is choosing the right method or software to support the decision-making process. Therefore, comparing different methods and creating advice on their use becomes especially important.

[1] ORCID: https://orcid.org/0000-0002-3381-6060

**Analysis of recent research and publications.** One of such tools is the theory of fuzzy sets, proposed by L. Zade [4, 5]. The study of this approach was carried out by R.E. Bellman [5], T.L. Saaty [3], Y.P. Zaichenko, O.I. Larichev, A.V. Matviychuk [1], O.P. Rotshtein [2] and many other scientists. In modern conditions, the use of fuzzy set theory for making managerial decisions requires detailing.

**Setting the task.** The purpose of the study is to analyze various decision-making methods based on fuzzy set theory, as well as identify the features of each of them in order to provide recommendations for their use.

**Presentation of the main research material.** The data needed to make an informed choice can be divided into four categories: information about alternatives, information about selection criteria, information about preferences, and information about the task environment.

In its development, the theory of decision-making went through three stages. At the first stage, a descriptive approach was developed, which was aimed at describing the process of choosing decisions by a person. Thanks to this, it was possible to clearly determine what a person can and cannot do when solving a choice problem. At the second stage, a normative approach to decision-making was developed. However, these theories did not find practical application. At the third stage, a prescriptive approach was developed. It does not guarantee the optimal solution in any situation, but ensures the choice of a consistent and consistent solution. This approach places serious demands on a person to master the methods and techniques of the theory of decision-making, and also gives practical recommendations for the implementation of these solutions [4].

Decision-making tasks can be classified according to various characteristics that characterize the quantity and quality of available information, for example:

• Decision-making problems under conditions of certainty. These include problems for which there is sufficient and reliable quantitative information. In this case, mathematical programming methods are used, the essence of which is to find optimal solutions based on a mathematical model of a real object.

• Problems under risk. They arise when possible outcomes can be described by some probability distribution. To construct a probability distribution, it is necessary to either have statistical data at one's disposal or to involve expert knowledge. Usually, methods of univariate and multivariate utility theory are used to solve problems of this type.

• Problems under uncertainty. These problems occur when the information needed for decision-making is imprecise, incomplete, non-quantitative, and formal models of the system are either very complex or absent. In such cases, expert knowledge is usually involved in solving the problem. In contrast to the approach taken in expert systems, for solving decision-making problems, expert knowledge is usually expressed in the form of some quantitative data, which are called preferences.

Let's take a closer look at the tasks of the third type. So there are many methods and approaches to decision-making that make it possible to take into account multi-criteria and uncertainty. Decision-making tasks can be classified by the type of information about the advantages of many criteria and about the consequences of alternatives into qualitative, quantitative and mixed. In connection with this classification, there are different methods of decision-making:

1. Lack of information on benefits; quantitative and/or interval information on effects; qualitative information on benefits and quantitative information on effects.

✓ Methods with discretization of uncertainty.

✓ Stochastic dominance.

✓ Methods of decision-making under risk and uncertainty based on global criteria.

✓ Hierarchy analysis method.

✓ Methods of fuzzy set theory.

2. Quality information about the benefits and consequences.

✓ Methods of practical application of solutions.

✓ Methods for selecting statistically reliable solutions.

3. Quantitative information about benefits and consequences.

✓ Indifference curve methods for decision making under risk and uncertainty.

✓ Decision tree methods.

✓ Decomposition methods of expected utility theory.

Among these methods, the most promising are the decomposition methods of the theory of expected utility, the method of analysis of hierarchies and the theory of fuzzy sets. They are the ones that best satisfy the requirements of universality, accounting for multi-criteria choice under conditions of uncertainty, and simplicity of preparation and processing of expert information.

Decomposition methods of the theory of expected utility have become the most widespread among the groups of axiomatic methods of decision-making under risk and uncertainty. The main idea of this theory is to obtain quantitative estimates of the utility of possible outcomes that are the consequences of decision-making processes. In the future, based on these estimates, the best possible outcome can be chosen. To obtain utility estimates, it is necessary to have information about the preferences of the person responsible for the decision. The decision can be reduced to a process that includes five stages: preliminary analysis, structural analysis, uncertainty analysis, utility analysis and optimization procedures.

The method of analysis of hierarchies involves the decomposition of the problem into simpler components and the processing of the thoughts of the decision-maker. As a result, the relative importance of the studied alternatives for all criteria in the hierarchy is determined. The relative importance is expressed numerically in the form of priority vectors. The values of the vectors obtained in this way are estimates in the scale of relations and correspond to the so-called hard estimates [4].

Elements of fuzzy set theory can be successfully applied to decision-making under uncertainty. The founder of fuzzy set theory, L. Zadeh, predicted the broad applied significance of his theory in 1965, writing the following on this subject: "In fact, fuzziness may be the key to understanding a person's ability to cope with tasks that are too difficult to solve on a computer."

Let us consider the basic elements of fuzzy set theory [1]. Let$U$ – a complete set that includes all objects of a certain class. Fuzzy subset $F$ plurals$U$, which we will call a fuzzy set in the following, is determined by the membership function $\mu_F(u)$, $u \in U$ This function displays the elements $u_i$ plurals$U$ to the set $F$ of real numbers in the interval [0,1], which indicate the degree of membership of each element in the fuzzy set $F$.

If the complete set$U$ consists of a finite number of elements $u_i$, $i$ = 1,2,...,$n$ then a fuzzy set$F$ can be presented in the following form:

$$F = \mu_F(u_1)/u_1 + \mu_F(u_2)/u_2 + ... + \mu_F(u_n)/u_n,$$

Fuzzy sets are widely used to formalize linguistic knowledge. Using the apparatus of fuzzy set theory, it is possible to solve many problems even in the absence of complete quantitative information.

*Operations on fuzzy sets:*

The addition operation can be represented as follows:

$$\overline{F} = \sum_{i=1}^{n} \left(1 - \mu_F\left(u_i\right)\right)/u_i, \quad \mu_{\overline{F}} = 1 - \mu_F\left(u\right).$$

The merge operation will look like this:

$$F \cup G = \sum_{i=1}^{n} \left(\mu_F\left(u_i\right) \vee \mu_G\left(u_i\right)\right)/u_i, \quad \mu_{F \cup G} = \mu_F\left(u\right) \vee \mu_G\left(u\right).$$

The intersection operation is calculated as follows:

$$F \cap G = \sum_{i=1}^{n} \left(\mu_F\left(u_i\right) \wedge \mu_G\left(u_i\right)\right)/u_i, \quad \mu_{F \cup G} = \mu_F\left(u\right) \wedge \mu_G\left(u\right).$$

Symbol ∨ denotes taking the maximum, and the symbol ∧ taking the minimum.

By a vague relation$R$ between the full plural$U$ and others in full plural$V$ is called a subset of the direct Cartesian product$U \times V$, defined as follows:

$$R = \sum_{i=1}^{l} \sum_{j=1}^{m} \mu_R\left(u_i, v_j\right)/\left(u_i, v_j\right),$$

where $U = \{u_1, u_2, ... u_l\}$, $V = \{v_1, v_2, ... v_m\}$,

*Properties of fuzzy relations:*

1. Merging relationships $(R \cup S)(u,v) = R(u,v) \vee S(u,v), \quad u \in U, v \in V.$
2. Intersection of relationships $(R \cap S)(u,v) = R(u,v) \wedge S(u,v), \quad u \in U, v \in V.$
3. Switching on operation $(R \subseteq S) \leftrightarrow R(u,v) \leq S(u,v), \quad u \in U, v \in V.$
4. Idempotence property $R \cap R = R$, $R \cup R = R$.
5. Commutatively $R \cap S = S \cap R$, $R \cup S = S \cup R$.
6. Associativity $R \cap (S \cap Q) = (R \cap S) \cap Q$, $R \cup (S \cup Q) = (R \cup S) \cup Q$.
7. Distributive $R \cap (S \cup Q) = (R \cap S) \cup (R \cap Q)$, $R \cup (S \cap Q) = (R \cup S) \cap (R \cup Q)$.
8. Reflexivity

If $\mu_R(u, u) = 1$, relationship $R$ – reflection.
If $\mu_R(u, u) < 1$, relationship $R$ – weak reflection.
If $\mu_R(u, u) = 0$, relationship $R$ – anti-reflective.
If $\mu_R(u, u) > 0$, relationship $R$ – slightly anti-reflective.

9. Symmetry $\mu_R(u,v) = \mu_R(v, u)$; $u,v \in U$
10. Transitivity $\mu_R(u,v) \geq \mu_R(u,z) \wedge \mu_R(z,v)$; $u,v,z \in U$.

Elements of fuzzy set theory are successfully used for decision-making. Expert assessments of alternative options by criteria can be represented as fuzzy sets or numbers expressed using a membership function. There are many methods for ordering fuzzy numbers, which differ from each other by the method of convolution and construction of fuzzy relations. The latter can be defined as preference relations between objects. Let us consider one of the mathematical formulations of decision-making problems based on fuzzy set theory.

In this case, the criteria define some concepts, and the evaluations of the alternatives are the degrees of compliance with these concepts. Let there be a set of alternatives $A = \{a_1, a_2, ... a_m\}$ and many criteria $C = \{C_1, C_2, ... C_m\}$, while the evaluations of alternatives for each ith criterion are represented by fuzzy sets:

$$C_i = \left\{\mu_{C_i}\left(a_1\right)/a_1, \mu_{C_i}\left(a_2\right)/a_2, ..., \mu_{C_i}\left(a_m\right)/a_m\right\}.$$

The rule for selecting the best alternative can be represented as the intersection of fuzzy sets corresponding to the criteria:

$$D = C_1 \cap C_2 \cap ... \cap C_n.$$

The intersection operation corresponds to taking the minimum:

$$\mu_D\left(a_j\right) = \min_{i=1,...,n} \mu_{C_i}\left(a_j\right), j = 1,...,m.$$

The alternative is considered better $a^*$, which has the highest membership function value $\mu_D\left(a^*\right) = \max_{j=1,...,m} \mu_D\left(a_j\right)$.

Let us consider a decision-making method that involves constructing a set of non-dominant alternatives based on a fuzzy preference relation [5].

The problem statement in short form is presented as follows. Let the set of alternatives be given *A* and each alternative is characterized by several quality criteria with numbers $j = i,...,m$ Information on pairwise comparison of alternatives for each quality criterion *j* presented in the form of a preference ratio $R_j$. You need to choose the best alternative from a set $\{A, R_1, \dots R_m\}$.

Definition 1. Fuzzy relation*R* in the plural *A* is called a fuzzy subset of the Cartesian product characterized by the membership function $\mu_R : A \times A \rightarrow [0,1]$ Value $\mu_R (a,b)$.of this function is understood as the degree of fulfillment of the relation $a \wedge b$.

Definition 2. The fuzzy preference relation on *A* is any fuzzy reflection relation given on this set, the membership function of which is calculated as follows:

$$\mu_{R^s}(a,b) = \begin{cases} \mu_R(a,b) - \mu_R(b,a), & \mu_R(a,b) \geq \mu_R(b,a); \\ 0, & \mu_R(a,b) < \mu_R(b,a). \end{cases}$$

Definition 3. Let *A* – many alternatives and $\mu_R$ – a fuzzy preference relation is given on it. A fuzzy subset of non-dominant alternatives of the set $(A, \mu_R)$ is described by the membership function

$$\mu_R^{нд} = 1 - \sup_{a,b \in A}\left(\mu_{R^s}(b,a) - \mu_{R^s}(a,b)\right), \ a \in A.$$

Definition 4. Clearly non-dominant alternatives are those for which $\mu_R^{нд} = 1$, and many such alternatives

$$A_R^{чнд} = \{a|, a \in A, \mu_R^{нд} = 1\}$$

Definition 5. The carrier of a fuzzy set *B* with a membership function $\mu_B(a)$ there is a plural

The procedure for solving the selection problem is performed in several steps.

1. A fuzzy relation is constructed, which is the intersection of the initial preference relations:

$$\mu_{Q_1}(a,b) = \min\left(\mu_{R_1}(a,b),...,\mu_{R_m}(a,b)\right),$$

and a fuzzy subset of non-dominant alternatives on the set is defined $(A, \mu_{Q_1})$:

$$\mu_{Q_1}^{нд}(a) = 1 - \sup_{b \in A}\left(\mu_{Q_1}(b,a) - \mu_{Q_1}(a,b)\right).$$

2. A vague relationship is being built $Q_2$:

$$\mu_{Q_2}(a,b) = \sum_{j=1}^{m} w_j \mu_{R_j}(a,b)$$

and a fuzzy subset of non-dominated alternatives in the set is defined $(A, \mu_{Q_2})$:

$$\mu_{Q_2}^{нд}(a) = 1 - \sup_{b \in A}\left(\mu_{Q_2}(b,a) - \mu_{Q_2}(a,b)\right).$$

This function orders the alternatives by their degreenon-dominance. Numbers $w_j$ in the above convolution are the coefficients of the relative importance of these criteria, for which the following conditions are met:

$$\sum_{j=1}^{m} w_j = 1, \ w_j \geq 0, \ j = \overline{1,m}.$$

3. Finding the intersection of sets $\mu_{Q_1}^{нд}$ and $\mu_{Q_2}^{нд}$:

$$\mu^{нд}(a) = \min\left(\mu_{Q_1}^{нд}(a), \mu_{Q_2}^{нд}(a)\right).$$

4. Choosing an alternative from a set is considered rational

$$A^{нд} = \left\{a' \mid a' \in A, \mu^{нд}(a') = \sup_{a \in A} \mu^{нд}(a)\right\}.$$

The most rational alternative from the set $A^{нд}$ is the one that has the maximum degree of non-domination.

Let us consider a method of multi-criteria selection of alternatives based on a compositional rule of aggregation of a description of alternatives with information about the preferences of the decision-maker, which are given in the form of fuzzy constraints [4].

Let*U* – many elements, *A* – its fuzzy subset, the degree of membership of the elements to which is a number from the unit interval [0,1]. Subsets $A_j$ are the values of the linguistic variable *X*.

Suppose that a set of decisions is characterized by a set of criteria $x_1, x_2,...,x_p$, i.e. linguistic variables defined on the basis sets $u_1, u_2,...,u_p$ respectively. For example, the variable $x_1$ "quality of management" can have the value LOW, and the variable $x_2$ "value" – the value of GOOD and so on. A set of several criteria with corresponding values characterizes the decision maker's representation of the satisfac- toryness of an alternative. Variable *S* "satisfaction" is also linguistic. Example of a statement:

$d_1$: "If $x_1$ = LOW and $x_2$ = OK, then *S* = HIGH.

In the general case, the expression $d_i$ has the form:

$d_i$: "If $x_1 = A_{1i}$ and $x_2 = A_{2i}$ and … $x_p = A_{pi}$, then $S = B_i$".

Let us denote the intersection $(x_1 = A_{1i} \cap x_2 = A_{2i} \cap \dots x_p = A_{pi})$ through $x = A_i$. The operation of intersection of fuzzy sets corresponds to finding the minimum of their membership functions:

$$\mu_{A_i}(v) = \min_{v \in V}\left(\mu_{A_{i1}}(u_1), \mu_{A_{i2}}(u_2), ..., \mu_{A_{ip}}(u_p)\right).$$

Here $V = U_1 \times U_2 \times ... \times U_p$; $v = (u_1, u_2,...,u_p)$; $\mu_{A_{ij}}(u_j)$ – element membership value $u_j$ fuzzy plural $A_{ij}$ .Then the expression can be written as: $d_i$: "If, then $S = B_i$".

To give commonality to thoughts, we denote the base sets *U* and *V* through *W*. Then $A_i$ is a fuzzy subset, while $B_i$ – fuzzy subset of the unit interval *I*.

To represent the rules, the implication operation is used, for which various methods of fuzzy implementation have been proposed. The Lukasiewicz fuzzy implication has the form:

$$\mu_H(w,i) = \min_{w \in W}\left(1, \left(1 - \mu_A(w) + \mu_B(i)\right)\right),$$

Where *H* – fuzzy subset of $W \times I$, $w \in W$, $i \in I$

In a similar way, I express $d_1, d_2,...,d_q$ will turn into plurals $H_1, H_2,...,H_q$. Their intersection is the set $D = H_1 \cap H_2 \cap \dots \cap H_q$. And for everyone

$$\mu_D(w,i) = \min_{w\in W}\left(\mu_{H_i}(w,i)\right), j = \overline{1,q}.$$

Satisfiability of an alternative described by a fuzzy subset $A$ with $W$, is determined based on the compositional input rule: $G = A \circ D$, where $G$ – fuzzy subset of the interval $I$.

Then $\mu_G(i) = \min_{w\in W}\left(\min \mu_A(w)\mu_D(w,i)\right)$.

The comparison of alternatives is based on point estimates. For a fuzzy set $C \subset I$ we define a – level set ($\alpha \in [0,1]$):

For everyone $C_\alpha$ you can calculate the average number of elements - $M(C_\alpha)$:

for a set of n elements $M(C_\alpha) = \sum_{j=1}^{n} i_j / n; \quad i_j \in C_\alpha$;

for $C_\alpha = \{a \le i \le b\} \quad M(C_\alpha) = \frac{a+b}{2}$;

for

$$C_\alpha = \bigcup_{j=1}^{n}\{a_j \le i \le b_j\} \quad M(C_\alpha) = \frac{\sum_{j=1}^{n}\frac{a_j+b_j}{2}(a_j-b_j)}{\sum_{j=1}^{n}(a_j-b_j)};$$

at $0 \le a_1 \le b_1 \le a_2 \le b_2 \le ... \le a_n \le b_n \le 1$.

Then the point value for the set $C$ can be written as

$$F(C) = \frac{1}{\alpha_{\max}}\int_0^{\alpha_{\max}} M(C_\alpha)\, d\alpha,$$

where $\alpha_{\max}$ – maximum value in the set $C$.

When choosing alternatives, the satisfaction of each of them is found and the corresponding exact score is calculated. The alternative with the highest value is considered the best.

Let us consider multi-criteria selection of alternatives based on additive convolution. In this method [3], expert preferences are represented using fuzzy numbers with triangular membership functions.

Let there be many alternatives $A = \{a_1, a_2,...,a_m\}$ and many criteria $C = \{c_1, c_2,...,c_m\}$, while the evaluation of the jth alternative according to the ith criterion is represented by a fuzzy number $R_{ij}$, and the relative importance of the ith criterion is given by the coefficient $\alpha_i$, i=1,2,...,$n$. If the coefficients $a_i$ normative, then the weighted score of the jth alternative is calculated by the formula

$$R_j = \sum_{i=1}^{n}\alpha_i R_{ij}.$$

If the membership functions $\mu_{R_{ij}}(r_{ij})$ and $\mu_{\alpha_i}(\alpha_i)$ have a triangular shape, then for them, as for a fuzzy number $X$, top $X^*$, as well as the left $X'$ and rights $X''$. The limits are determined by the following relations:

$$\forall\delta : \mu(X') = 0; \mu(X'-\delta) = 0; \mu(X'+\delta) \ne 0;$$

$$\forall\delta : \mu(X'') = 0; \mu(X''-\delta) \ne 0; \mu(X''+\delta) = 0; \mu(X^*) = 1.$$

Weighted evaluation of the jth alternative $R_i$ is the result of a linear combination of fuzzy numbers and will also have a triangular membership function. The vertex and boundaries of a fuzzy number obtained as a result of addition or multiplication operations can be calculated as follows: $Z' = X' \times Y'$; $Z'' = X'' \times Y''$; $Z^* = X^* \times Y^*$.

Ranking of alternatives using the obtained weighted scores is possible based on their fuzzy composition:

$$\mu_J(j) = \sup_{r_1,r_2,...,r_m; r_k \ge r_j}\ \min_{j=1,...,m}\mu_{R_j}(r_j)$$

Here $\mu_J(j)$- a fuzzy set of alternatives corresponding to the concept of "best alternative". The best alternative is considered to be the one with the greatest value $\mu_J(j)$.

Another method of ranking alternatives on a set of linguistic vector scores. Given a set of alternatives $A = \{a_1, a_2,...,a_m\}$ and the set of corresponding results $S = \{s_1, s_2,...,s_m\}$. Every result $s_j$ characterized by an alternative $a_i$ and a vector of linguistic evaluations on a set of criteria $K = \{K_1, K_2,...,K_n\}$. The set of linguistic vector estimates of the results $K = \{K(s_1), K(s_2),...,K(s_m)\}$ can be ordered by introducing a membership function of a fuzzy order relation $\mu \ge$: K × K → [0, 1] For the ith criterion, we denote $\mu^i \ge (K_i(s_j), K_i(s_k))$ through $\mu^i \ge (s_j, s_k)$ The value of this function can be found by the formula

$$\mu^i \ge (s_j,s_k) = 1 - \mu^i < (s_j,s_k) = \mu^i > (s_j,s_k) + \\ + \mu^i = (s_j,s_k).$$

Degree of truth $\mu< (s_j, s_k)$ unclear statement $s_j < s_k$ can be found as the probability that the exact value $s_j$ will be less than the exact value $s_k$ Assuming that the outcomes are independent random variables, the relation $\mu < (s_j, s_k)$ can be represented as:

$$\mu < (s_j,s_k) = \sum_{i=1}^{n-1}\left(v_{si}(x_i)\left(1 - w_{sk}(x_{i+1})\right)\right)$$

where $v_s(x)$ – the probability that as the exact value of a fuzzy number the value used $x$; $w_s(x)$ – the probability that as an exact value the value used $y<x$;

$$v_s(x) = \mu_s(x) / \sum_{y\in S}\mu_s(y); \quad w_s(x) = \mu_s(x) / \sum_{y\in S, y<x} v_s(y).$$

Vector estimates can be ordered based on the membership function $\mu \ge (K(s_j), K(s_k)) = \underset{i\in n}{\times}\ \mu^i \ge (s_j,s_k)$ where × – denotes a generalized operation symbol.

Since among the many alternatives and outcomes there isone-to-one correspondence, the membership function of a fuzzy preference relation on a set of alternatives can be represented as: $\mu^F \ge (a_j, a_k)$= $\mu \ge (K(s_j), K(s_k))$.

Solving the problem using this method includes the following main steps:

- ✓ Calculating membership functions $\mu<$;
- ✓ Fuzzy order constructions $\mu \ge$;
- ✓ Minimizing the ratio $\mu \ge$;

Determining the preference relations on a set of alternatives and identifying the best alternative. To do this, the preference relation between the alternative is calculated $a_j$ and the rest of all alternatives, whose membership function is as follows:

$$\mu^F \geq \left(a_j;\left\{a_k\right\},k \in I_j\right) = \underset{k \in I_j}{\times} \mu_{\geq jk}, j \in m,$$

where $I_j$ – a set of alternative indices with which the jth alternative can be compared. The solution to the ranking problem can be described by the relations:

$$r_i < r_l \Leftrightarrow \mu^F \geq (a_j;\{a_k\},k \in I_j) > \mu^F \geq (a_l;\{a_k\},k \in I_l)$$
$$r_i < r_l \Leftrightarrow \mu^F \geq (a_j;\{a_k\},k \in I_j) = \mu^F \geq (a_l;\{a_k\},k \in I_l)$$

where $r_i$ – rank of the alternative.

The most preferred alternative has the lowest rank.

Thus, we can say that the theory of fuzzy sets has gained wide popularity and has received practical application in many fields. In the field of decision-making, a wide range of different methods have been developed based on this theory. The difficult problem today is the choice of an appropriate method or software to support decision-making processes. Therefore, the comparative analysis of different methods and the development of recommendations for their application are of particular relevance.

The method of analysis of hierarchies and the method of preference relations is based on a rationally weighted approach based on pairwise comparisons of objects and normalized weight coefficients. Maximum convolution and linguistic vector estimation are implementations of a pessimistic approach that ignores the good sides of alternatives, when the alternative with minimal disadvantages on all criteria is considered the best. Additive convolution assumes an optimistic approach, when low scores on criteria have the same status compared to high ones. Fuzzy rule-based inference implements a heuristic approach[4].

**Conclusions.** Decision-making methods based on fuzzy models allow convenient and fairly objective evaluation of alternatives by individual criteria. Unlike other methods, adding new alternatives does not change the order of previously ranked sets. When evaluating alternatives by criteria, linguistic evaluation is possible based on point estimates using the membership function of the criteria.

The main problemmulti-criteria choice using fuzzy models is the representation of information about the relationships between criteria and ways to calculate their integral estimates. Methods based on different approaches give different results. Each approach has its own limitations and features, and the user must get an idea of them before applying one or another method of decision-making. The heuristic approach provides the widest possibilities for representing information.

Most fuzzy decision-making methods show poor robustness of results with respect to initial data. A study of the considered methods showed that the rule-based method has the greatest robustness.

The analysis of fuzzy decision-making methods allows us to formulate requirements for further developments in this area. These include the development of theoretical approaches to describing complex relationships between criteria, the wider application of intellectual methods based on fuzzy logic, and the development of combined decision-making methods using fuzzy representations.

**REFERENCES:**

1. Matviichuk A. V. (2007) Modeliuvannia ekonomichnykh protsesiv iz zastosuvanniam metodiv nechitkoi lohiky [Modeling of economic processes using fuzzy logic methods]. KNEU, 264 p.
2. Rotshtein A., Mityushkin Y. (2001) Fuzzy knowledge bases extraction from experimental data by using a genetic algorithm. *Cybern. Syst. Anal.*, vol. 4, pp. 45–53.
3. Saaty T. L. (1980) Multicriteria Decision Making: The Analytic Hierarchy Process.McGraw-Hill, New York.
4. Zadeh L. (1965) Fuzzy sets. *Inform. Control*, no. 8, pp. 338 – 353.
5. Zadeh L., Bellman R. (1970) Decision-making in a fuzzy environment. *Management Science*, vol. 17, no. 4, pp. 141 – 164.
6. Mudi R.K., Pal N.R. (2000) A self-tuning fuzzy PI controller. F*uzzy sets and systems*, no. 115, pp. 327 – 378.
7. Hguen H.T., Sugeno M., Tong R., Yager R.R. (1995) Theoretical aspects of fuzzy control. New York, John Wiley & Sons, 359 p.
8. Zimmerman H.J. (1991) Fuzzy Set Theory and Its Applications. Kluwer, Dordrecht, 1991. 315 p.

**БІБЛІОГРАФІЧНИЙ СПИСОК:**

1. Матвійчук А.В. Моделювання економічних процесів із застосуванням методів нечіткої логіки. Київ: КНЕУ. 2007. С. 264.
2. Rotshtein A., Mityushkin Y. Fuzzy knowledge bases extraction from experimental data by using a genetic algorithm. *Cybern. Syst. Anal.* 2001. Vol. 4. P. 45–53.
3. Saaty T. L. Multicriteria Decision Making: The Analytic Hierarchy Process. McGraw-Hill, New York, 1980.
4. Zadeh L. Fuzzy sets. *Inform. Control.* 1965. № 8. P. 338–353.
5. Zadeh L., Bellman R. Decision-making in a fuzzy environment. *Management Science*. 1970. Vol. 17. № 4. P. 141–164.
6. Mudi R.K., Pal N.R. A self-tuning fuzzy PI. *Fuzzy sets and systems*. 2000. № 115. P. 327–378.
7. Hguen H.T., Sugeno M., Tong R., Yager R.R. Theoretical aspects of fuzzy control, 1995. P 359.
8. Zimmerman H. J. Fuzzy Set Theory and Its Applications. Kluwer, Dordrecht, 1991. P. 315.

*Стаття надійшла: 13.10.2025*
*Стаття прийнята: 24.10.2025*
*Стаття опублікована: 24.11.2025*

## РОЗДІЛ 5. РОЗВИТОК ПРОДУКТИВНИХ СИЛ І РЕГІОНАЛЬНА ЕКОНОМІКА



## РОЗДІЛ 6. ЕКОНОМІКА ПРИРОДОКОРИСТУВАННЯ ТА ОХОРОНИ НАВКОЛИШНЬОГО СЕРЕДОВИЩА



## РОЗДІЛ 7. МАТЕМАТИЧНІ МЕТОДИ, МОДЕЛІ ТА ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ В ЕКОНОМІЦІ



## РОЗДІЛ 8. МЕНЕДЖМЕНТ



## РОЗДІЛ 9. МАРКЕТИНГ

Наукове видання

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Адреса редакції: вул. Інглезі 6/1, оф. 135,
м. Одеса, Україна, 65101
Телефон: +38 (093) 120-27-72
Вебсайт журналу: www.market-infr.od.ua
E-mail редакції: journal@market-infr.od.ua