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# СИСТЕМНИЙ АНАЛІЗ

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## SYSTEM ANALYSIS

UDC 331.5.021:510.22

DOI <https://doi.org/10.32782/tnv-tech.2026.3.24>

### FUZZY MODELING OF LABOR MARKET ADAPTATION STRATEGIES TO ARTIFICIAL INTELLIGENCE EXPANSION

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*This study develops a conceptual algorithm for the strategic management of labor market adaptation, viewed as a complex socio-economic system undergoing non-linear digital transformation. A systemic approach is implemented to synthesize a decision-support framework that bridges the gap between autonomous AI evolution and human capital management. The author applied a modified Bellman-Zadeh decision-making scheme, which allows for integrating additional objectives and constraints into a single weighted aggregation model. The developed model integrates conflicting systemic parameters-including labor productivity as a performance metric, social stability as a system constraint, and budget availability as a resource limit-into a unified analytical framework. The findings confirm the systemic hypothesis that a synergistic configuration of human-machine interaction yields higher global efficiency than isolated automation or rigid administrative restrictions. The internal consistency of the expert-knowledge base is mathematically verified through a consistency ratio analysis, ensuring the structural integrity of the weight coefficients. The scientific novelty lies in the transition from static planning to an adaptive modeling paradigm. The study proposes a roadmap for the systemic expansion of the algorithm through the integration of dynamic feedback loops, such as personnel psychological readiness and tax-induced investment variability in the IT sector. This architectural flexibility allows the model to maintain high predictive accuracy amidst the stochastic fluctuations of Ukraine's digital economy. The proposed framework serves as a scalable computational foundation for optimizing the evolution of labor market structures in the era of pervasive artificial intelligence.*

**Key words:** labor market, artificial intelligence, fuzzy modeling, Bellman-Zadeh model, systems analysis, strategic management.

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**Дебела І. М. Нечітке моделювання стратегій адаптації ринку праці до експансії штучного інтелекту**

У статті розглядається актуальна науково-практична задача моделювання стратегій адаптації національного ринку праці до викликів, зумовлених масовим впровадженням технологій штучного інтелекту. Об'єктом дослідження є процеси трансформації зайнятості під впливом цифровізації, предметом – математичний інструментарій обґрунтування управлінських рішень у цій сфері. Мета роботи полягає у розробці концептуального алгоритму вибору оптимальних стратегій адаптації ринку праці на основі методів системного аналізу та теорії нечітких множин. Автором застосовано модифіковану схему прийняття рішень Беллмана-Заде, яка дозволяє інтегрувати суперечливі цілі та обмеження в єдину модель зваженого агрегування. Запропонований підхід враховує нелінійний характер впливу ШІ на економічні системи та базується на актуальних прогностичних сценаріях розвитку економіки України на 2025 – 2027 рр. За результатами моделювання ідентифіковано три базові стратегії: інтенсивне перенавчання, гібридна модель взаємодії та нормативне обмеження. Верифікацію результатів проведено за допомогою розрахунку відношення узгодженості експертних суджень та побудови пелюсткових діаграм порівняльних профілів стратегій. Наукова новизна полягає в переході від статичного планування до адаптивної парадигми моделювання. Сформульовано рекомендації щодо подальшого розширення набору можливих рішень шляхом інтеграції в модель додаткових динамічних параметрів, таких як індекс психологічної готовності персоналу до цифрових змін та мінливість податкового навантаження в ІТ-секторі. Це підвищить адаптивність запропонованого алгоритму до нелінійних коливань в економічній системі України. Запропонований фреймворк слугує масштабованою обчислювальною основою для оптимізації еволюції структур ринку праці в епоху повсюдного штучного інтелекту.

**Ключові слова:** ринок праці, штучний інтелект, нечітке моделювання, модель Беллмана-Заде, системний аналіз, стратегічне управління.

**Formulation of the problem.** Modern socio-economic systems are complex high-level active systems whose internal goals may conflict with external management factors. In current realities, such factors include global technological shocks caused by the widespread integration of artificial intelligence (AI). This creates a situation of critical uncertainty, where traditional deterministic models are unable to adequately describe the complex processes of labor market transformation and the dynamics of human capital development. The problem stems from the need for a strategic choice between alternative scenarios to ensure socioeconomic stability under conditions where information regarding the consequences of digitalization is subjective, imprecise, or lacks unambiguous quantitative assessments. Given that the reaction of active market actors to the implementation of intelligent systems is often unpredictable, there is an urgent need to employ methods of systems analysis and fuzzy set theory. This approach enables coordinated decision-making as a rational compromise between the strategic goals of the system and actual resource and time constraints.

**Analysis of recent research and publications.** The problem of decision-making in complex socio-economic systems under uncertainty has been a subject of profound scientific research over the last decades. The fundamental principles of modeling systems with fuzzy logic were established in the works of L. Zadeh and further developed by R. Yager [1-4], who demonstrated the superiority of fuzzy models over traditional logical systems in describing human reasoning processes.

The methodology of multicriteria analysis, based on subjective judgments and the use of the pairwise comparison scale, is substantiated in detail in the works of T. Saaty [5]. His approach allows for the transformation of qualitative characteristics and hierarchical structures into numerical priority vectors, which is critically important for assessing such intangible factors as social risks and technological shocks. Research by Nobel laureate D. Acemoglu [6] confirms that the implementation of AI necessitates a fundamentally new analysis of labor operations. In his work, he mathematically substantiates

that the impact of AI on productivity may be limited, as a significant portion of tasks are «non-routine» and require human judgment. These elements are most effectively formalized through the framework of fuzzy set theory. According to the World Economic Forum report [7], large-scale structural changes and the transformation of approximately 92 million jobs necessitate the development of effective algorithms for selecting reskilling strategies. The works of E. Brynjolfsson, D. Li, and L. Raymond [8] highlight the «skill compression» effect, which acts as a significant constraint in personnel management optimization models. Given the assessments by PwC Ukraine [9] regarding the rapid digitalization of the domestic market, the systemic optimization of labor resource adaptation strategies using fuzzy logic inference methods becomes highly relevant, which determines the direction of this research.

**Formulation of the purpose of the article.** The purpose of the research is to develop a conceptual algorithm for selecting optimal scenarios for labor market adaptation to digital transformation, utilizing a systems analysis approach. The achievement of this goal involved solving the following tasks:

1. Choice Modeling: to adapt the Bellman-Zadeh fuzzy scheme for evaluating labor market adaptation strategies in response to the expansion of artificial intelligence.
2. Scenario Analysis: to substantiate the selection and formalize the parameters of three core adaptation strategies:
  - Reskilling (intensive retraining) strategy;
  - Human-AI Collaboration (hybrid human-machine interaction) strategy;
  - Regulatory Limitation of automation strategy.
3. Verification: to ensure the reliability of the simulation results, the consistency ratio of the pairwise comparison matrices was calculated.

**Presentation of the main material.** The justification of labor market adaptation strategies in response to the expansion of artificial intelligence occurs under conditions of vague goals and constraints, which necessitates the use of multi-criteria analysis. The proposed approach is based on a modification of the Bellman-Zadeh fuzzy decision-making scheme, adapted by the author [10, 11] specifically for active socio-economic systems. The modeling process assumes that the choice of the optimal scenario  $a^*$  from the set of available alternatives  $A = \{a_1, a_2, \dots, a_n\}$  is determined as the result of the intersection of fuzzy goals  $G$  and constraints  $C$ . This intersection forms a fuzzy decision set  $D = G \cap C$ , whose membership function represents the degree of suitability of each strategy, taking into account all specified conditions. In the context of labor market transformation, goals reflect the desired indicators of socioeconomic stability, while constraints characterize resource, time, and technological barriers. Functionally, this is represented by the minimization operator (1), which enables finding a strategic option that, in the worst-case scenario, satisfies the system's requirements at the maximum possible level:

$$\mu_D(a) = \min_{i,j} \{ \mu_{G_i}(a), \mu_{C_j}(a) \}, i = 1 \div n; j = 1 \div m \quad (1)$$

At the same time, the specifics of the current digitalization stage dictate the need for a differentiated approach to criteria evaluation, as certain factors exert a dominant influence on adaptation processes. To address this, a weighted aggregation model is applied, where the priority of each criterion is determined by a corresponding weight coefficient. Unlike the classical approach, the proposed transition to a weighted additive model (2) allows for incorporating the hierarchical structure of goals and implementing a mechanism for partial compensation of criteria values.

$$\mu_D(a) = \sum_{i=1}^n w_i \mu_{G_i}(a) + \sum_{j=1}^m v_j \mu_{C_j}(a), \quad (2)$$

where  $w_i, v_j$  – normalized weight coefficients obtained on the basis of expert estimates according to the method of T. Saati [5]. The optimal strategy is considered to be one that satisfies the condition:

$$a^* = \arg \max_{a \in A} \mu_D(a), \quad (3)$$

where  $A$  is the set of available labor market adaptation alternatives.

The determination of weight coefficients  $w_i, v_j$ , as well as the values of the criteria membership functions, is carried out based on expert judgments. A detailed description of the ranking procedure for qualitative characteristics and the algorithm for calculating the priority vector was presented by the author in [11]. The information base for forming expert assessments consisted of analytical data from the Inflation Report of the National Bank of Ukraine [12] and operational labor market reviews by the Ministry of Economy of Ukraine [13]. In light of the limited access to comprehensive statistical reporting under martial law, the parameterization of fuzzy sets in this study was conducted based on a synthesis of the aforementioned reports and labor market development forecast scenarios for 2025 – 2026. Specifically, the recorded labor shortage (ranging from 20-30% in critical sectors) and stringent budget constraints determined the priority of time and resource availability criteria. The declared deficit of financial resources formed the basis for the parameters of constraint  $C_1$ , while the critical lack of skilled personnel necessitated the high significance of goal  $G_2$  regarding the preservation and adaptation of human capital.

Three strategies were selected for evaluation:

$a_1$  – Intensive Reskilling strategy;

$a_2$  – Human-AI Collaboration (hybrid human-machine interaction) strategy;

$a_3$  – Regulatory Limitation of automation strategy.

Based on the construction of pairwise comparison matrices, the weight coefficients for goals ( $w_i$ ) and constraints ( $v_j$ ) were determined, with priority given to labor productivity and the preservation of human capital (Table 1)

The parameterization of membership functions was carried out on a scale from 0 to 1 (where 1 corresponds to the maximum degree of criterion satisfaction) based on a synthesis of expert survey results and analytical data [12, 13]. The assessment reconciliation procedure was performed using the algorithm described in [11], which allowed for minimizing subjectivism in the formation of the fuzzy knowledge base.

Table 1

**Parameterization of membership functions and strategy evaluation results**

Selection criteria	Weight ( $w, v$ )	$a_1$ (Reskilling)	$a_2$ (Hybrid interaction)	$a_3$ (Automation limits)
Goals (G)				
$G_1$ – Labor productivity	0,35	0,80	0,95	0,40
$G_2$ – Social stability	0,25	0,60	0,80	0,90
Constraints (C)				
$C_1$ : Budget availability	0,20	0,40	0,70	0,80
$C_2$ : Speed of implementation	0,20	0,50	0,85	0,30
Result $\mu_D(a)$	1,00	0,61	0,85	0,59

Source: Compiled and calculated by the author.

The highest priority (0,35) was assigned to labor productivity ( $G_1$ ), as the efficiency of existing resource utilization becomes critical under conditions of labor shortages. Specifically, the high rating of strategy  $a_2$  regarding criterion  $G_1$  (0,95) is driven by the synergistic effect of AI-tool integration. Conversely, the low rating for  $a_3$  (0,40) reflects the deceleration of technological progress due to regulatory constraints. This aligns with the 2026 digitalization forecast scenarios concerning the necessity for rapid labor market adaptation [13].

The final strategy rating  $\mu_D(a)$  was calculated as a weighted sum using formula (2). As the calculation results indicate, the most rational scenario is strategy  $a_2$  ( $\mu_D(a) = 0,85$ ). This is explained by the high compensatory capacity of the model: a significant increase in productivity and moderate costs for integrating AI as an assistant (0,70) offset the risks associated with the technological transition.

To visualize the multi-criteria evaluation and provide a clear comparison of strategy profiles, a radar chart (Fig. 1) was constructed. The graphical representation of the results confirms that strategy  $a_2$  (Human-AI Collaboration) forms the most balanced and extensive contour. It demonstrates superiority over alternatives across the combined parameters of productivity and implementation speed, while maintaining a high level of social stability. This makes it the optimal choice under the conditions of the current labor market transformation.

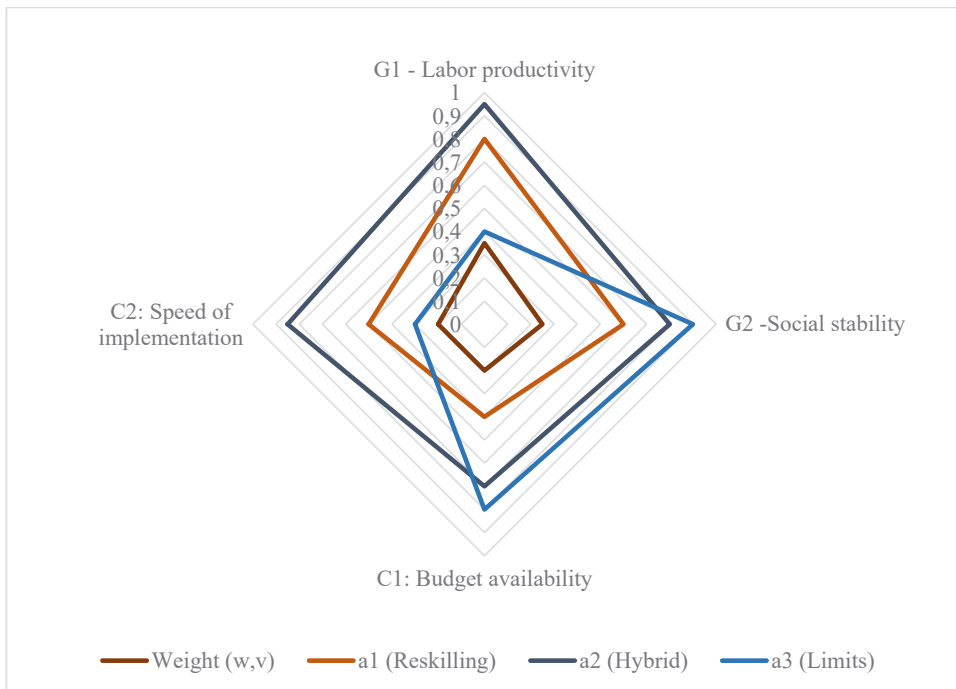


Figure 1. Comparative evaluation of labor market adaptation strategies based on a multi-criteria fuzzy model

Source: Compiled and calculated by the author

To verify the obtained data, the consistency ratio of the pairwise comparison matrices was calculated. The resulting value of  $CR = 0,076 < 0,1$  confirms the logical consistency of expert judgments, the adequacy of the selected weight coefficients, and the reliability of the final strategy ranking.

**Conclusions.** The study implements a systems approach to addressing labor market adaptation amidst the expansion of Artificial Intelligence. The application of a modified Bellman-Zadeh fuzzy model enabled the formalization of the decision-making process, integrating conflicting economic and social criteria into a unified analytical system. Based on the calculated membership function values, Strategy  $a_2$  (Hybrid interaction) was identified as the most rational scenario with a score of 0,85<sup>7</sup>. This confirms the hypothesis that the synergy between human capital and AI ensures maximum labor productivity while maintaining a high level of social stability. Visualization via radar charts confirmed the resilience of the selected strategy and its superiority over alternative scenarios (such as intensive reskilling or administrative constraints) across a set of resource and time parameters.

The scientific value of this work lies in the potential for further expanding the set of possible solutions by integrating additional dynamic parameters into the model. Specifically, future research should focus on incorporating an index of personnel psychological readiness for digital change to better assess resistance to innovation, as well as accounting for tax burden variability in the IT sector, which directly influences the investment attractiveness of automation. Such an expansion will enhance the predictive accuracy of the algorithm amidst the non-linear transformation of Ukraine's digital economy.

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*Дата першого надходження статті до видання: 11.03.2026*

*Дата прийняття статті до друку після рецензування: 14.04.2026*

*Дата публікації (оприлюднення) статті: 28.05.2026*