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CONSTRUCTION OF A MODEL FOR EVALUATING THE EFFICIENCY OF TECHNOLOGY TRANSFER PROCESS BASED ON A FUZZY LOGIC APPROACH

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The object of research is technology transfer, which covers the mechanism of transfer of technological knowledge and innovations from developers to end users or manufacturers. The problem to be solved is to provide a relevant assessment of the effectiveness of technology transfer by applying modern economic and mathematical models (based on the method of fuzzy logic) to assess the effectiveness of technology transfer under conditions of uncertainty.

The main results obtained: a fuzzy-logical model for evaluating the level of the technology transfer efficiency indicator was built; it is performed according to the following algorithm:

1) the involvement of three components of technology transfer – technological, financial, and marketing as input variables of the model, which are calculated on the basis of statistical and financial reporting data, expert surveys;

2) selection of parameters and type of membership function for three input variables and one output variable (integral indicator) and construction of a system of 27 logical rules;

3) determining the efficiency of technology transfer using Mamdani's fuzzy derivation and checking the adequacy of the model.

A visualization of the "input-output" surface was performed, which determines the maximum value of the TTPE (TechnologyTransferProjectsEfficiency) indicator, which serves as a summary indicator for the success of technology transfer projects and is observed at high levels of model input variables. The indicator T (technical component of technology transfer efficiency), F (financial component of technology transfer efficiency), and M (marketing component of technology transfer efficiency) was introduced.

The scientific results could be applied to determine the optimal ways of technology transfer to industry, to plan strategies for introducing new technological products to the market, taking into account the effectiveness of licensing, partnership, and cooperation processes

Keywords: technology transfer projects, MATLAB environment, fuzzy logic, Mamdani method

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1. Introduction

The relevance of our research is due to the rapid development of technological innovations and the need for their effective integration into industrial production and the social domain, which requires a relevant assessment of the effectiveness of technological innovations, which are carried out, including during the transfer of technologies. Under today's conditions of economic globalization and increased competition, technology transfer is gaining particular importance as it contributes to increasing the competitiveness of countries, regions, and individual enterprises. Technology transfer plays a key role in the commercialization of scientific research, ensuring innovative development of the economy, creating new jobs, as well as solving global social and environmental problems [1].

The importance of technology transfer increases under conditions of rapid scientific and technological progress when it is important not only to generate new knowledge but also to enable its effective implementation in practical activities. However, despite the high potential, technology transfer processes are often accompanied by various barriers and challenges, such as legal restrictions, insufficient funding, which requires detailed study and development of effective mechanisms to overcome them.

The importance of research into the implementation of fuzzy logic tools for assessing the effectiveness of technology transfer is predetermined by several key factors. In today's world where technological progress is incredibly fast, the ability to effectively transfer the latest technologies from scientific laboratories to production lines is critical to support innovative development and enable competitiveness of the national economy. Technology transfer includes not only the physical transfer of new technological solutions but also the transfer of knowledge and skills necessary for their effective application.

Traditional methods for assessing the effectiveness of technology transfer are often not flexible and adaptable enough to take into account all aspects and nuances of this process. Implementing a fuzzy logic toolkit overcomes these limitations, allowing for a more accurate and flexible assessment that takes into account the ambiguities and vagueness that often accompany the technology transfer process. Fuzzy logic based on fuzzy sets allows a better representation of human thinking and decision-making in situations with incomplete information, which makes it ideal for evaluating such complex and multidimensional processes [2].

The relevance of our research is also determined by the need to devise new theoretical approaches and practical tools for analysis, planning, and implementation of technology transfer. In the context of changes in the technological landscape and the constant growth of the importance of innovation, the study of technology transfer opens up new opportunities for industry and government structures in the development and implementation of innovative development strategies. Hence, the relevance of our research topic cannot be overstated given its impact on economic growth, social progress, and environmental security at the national and global levels.

2. Literature review and problem statement

The issue of the development of technology transfer and the use of economic-mathematical apparatus to a certain extent reflects the use of fuzzy logic, and the following scientific and research works deserve the greatest attention.

Thus, in work [3] it is indicated that the viability of technologies depends on innovativeness, cost, compatibility, safety, and environmental suitability. Effective support and management, including regular updates, is key. But they do not identify the basic technological factors that allow interaction, creating strategies for long-term and successful exploitation of technology transfer in various areas of production and service.

Work [4] considers in detail the adaptability to changes and market requirements in the matter of technology transfer. Successful technologies must be adopted by users, taking into account their needs and expectations. Favorable conditions include security and support from industry standards. At the same time, the social and economic context that can influence the decision on technology transfer is not defined.

In work [5] it is argued that the transfer of technologies is often complicated by a number of barriers that limit their effective distribution. The authors do not reveal the evaluative essence of such restrictions and components of technology transfer. Paper [6] determines the effectiveness of technology transfer projects but does not provide methodological flexibility of transfer management and adaptation to changing conditions. In work [7] it is said that the transfer of technologies is often complicated by a number of barriers that limit their effective distribution. Economic constraints, such as high development and implementation costs, can make technology more accessible. Legal restrictions such as patents and copyrights can make legal transfers difficult. Sociocultural differences, including language and social differences, can create barriers to mutual understanding. Inadequate infrastructure and lack of skilled workers can also be important factors inhibiting technology transfer. However, the authors pay little attention to the issue of quantitative analysis of the influence of various factors on the success of the transfer itself.

Paper [8] highlights the main methods of assessing the effectiveness of technology transfer: the FARE (factorrelationship) method and the TOPSIS method, which is one of the powerful methods for making the optimal management decision. At the same time, the author does not specify the organizational conditions of use and applied value.

Study [9] identified advantages for increasing the accuracy and adaptability of evaluation processes, which is critical for the successful integration of new technologies into production and commercial use. But the applied essence of such integration is not defined.

The authors in [10] propose different hierarchical decision-making models for evaluating a research proposal regarding the potential of technology transfer. Such a model fills the gap between the quantitative assessment of technology transfer potential during research and the phases of technology transfer. However, these models do not identify and determine the relative value of the attributes of technology transfer success and do not identify tools that can be used when studying the process of choosing a type of transfer. The ability of the fuzzy logic toolkit to adapt to the ambiguities accompanying the process of technology transfer has already been considered in work [11]. But the authors miss the very evaluation and organizational component of such processes.

Technology transfer has been a common practice in most countries and developing countries. economic transition because they usually do not have their own research and development and industries to produce the necessary technology. Many factors need to be taken into account when transferring technology. Most failures in technology transfer occur due to failure to take these factors into account. At these positions, [12] focuses on the initial (although often forgotten) and important steps of technology transfer. But the author does not take into account the opinion that many factors need to be taken into account when transferring technology.

In work [13] it is noted that the need to evaluate technologies should be formed and determines the factors involved in these steps. Environmental factors, which should be taken into account when assessing process needs and technologies, should also be investigated. However, it is not specified which algorithm determines the input and output variables for technology evaluation.

Study [14] describes an organizational model that serves as a reference for technology transfer processes for developing countries. Many factors in the process of technology transfer are often not recognized, and failure occurs quite often. However, the authors do not specify what an indicator of the efficiency of technology transfer is. In work [15], a general model was built, which provides a guideline and determines the factors to be taken into account in the processes of technology transfer to developing countries. The use of fuzzy logic to support project status assessment is considered. But the features of the calculation and modeling of the technology transfer project are not shown. Paper [16] gives a description of the theory of fuzzy sets, fuzzy logic, and the calculation process. But not enough attention is paid to the issue of building a fuzzy expert system for evaluating the effectiveness of such projects.

Work [17] noted the feasibility of using a fuzzy model for assessing the status of a technology transfer project. The authors indicate that such a model is the result of using FuzzyLogicToolbox. This fuzzy model is based on two main indices, the Schedule Performance Index (SPI) and the Cost Effectiveness Index (CPI), Earned Value Management (EVM). The advantage of the fuzzy model is the possibility of converting the input indices SPI and CPI into linguistic variables, as well as the linguistically estimated general status of the project (output). But the researchers do not indicate at all which approach should simulate risk and uncertainty, which are always associated with technology transfer projects. Therefore, the issues of using the tools of fuzzy logic in the field of transfer have a "small" format of use and are aimed at separate accompanying and auxiliary components. The authors of the reviewed literature do not systematize the most comprehensive assessment of the effectiveness of technology transfer on the basis of the tools of fuzzy logic. All this indicates the expediency and importance of conducting research for the implementation of fuzzy logic tools for assessing the effectiveness of technology transfer under current conditions of economic and industrial relations.

3. The aim and objectives of the study

The purpose of our study is to build a model for objective assessment of the effectiveness of technology transfer based on fuzzy logic. This model aims to account for the ambiguities and uncertainties that often accompany such processes, and to provide a toolkit for quantifying the impact of various factors on transfer success.

To achieve the goal, the following tasks were defined:

– to determine the necessary tools of fuzzy logic for the assessment of technology transfer at the enterprise;

– to develop an integral indicator of the assessment of the efficiency of technology transfer;

– to verify and test the built model for assessing the effectiveness of technology transfer.

4. The study materials and methods

The object of our study is technology transfer, the components of technology transfer, their mutual influence on a complex indicator – the indicator of the efficiency of technology transfer.

Hypothesis: is it appropriate to use fuzzy logic as a tool that allows a comprehensive evaluation of the technology transfer efficiency indicator?

Assumption: each of the components selected for the assessment of the technology transfer process can be determined for each enterprise individually, taking into account the specificity of the enterprise, this is an advantage of the model, but it requires effort and time to collect additional data.

The use of the fuzzy logic tool is due to its significant advantages. Among them: approximation of any multidimensional nonlinear function; suitability when the mathematical model is unknown or difficult to obtain; suitability in the absence of accurate information; application in the formation of decision-making rules. The relative disadvantages of fuzzy logic include laboriousness in structuring the knowledge of experts, exponential increase in the number of rules when the number of input variables increases [18].

Fig. 1 shows the general structure of the constructor of fuzzy logic expert systems as data transformation within the system itself. For the fuzzy logic toolkit, three input variables that affect the target indicator were chosen to determine the evaluation of the integral performance indicator of technology transfer projects (TTPE). The following were selected: the technical (technological) component of the technology transfer efficiency indicator (T), the financial component of the technology transfer efficiency indicator (F), and the marketing component of the technology transfer efficiency indicator (M) [19].

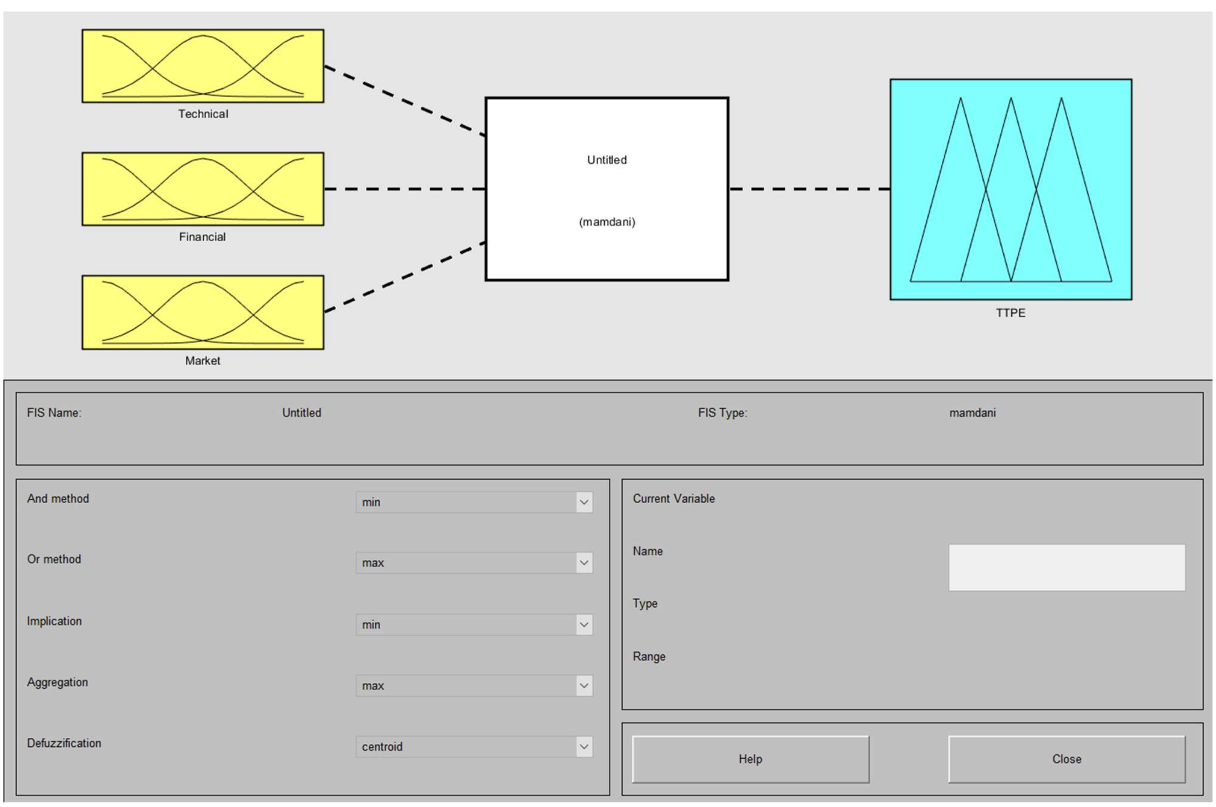

Fig. 1. General structure of the constructor of a fuzzy-logical system

To build a fuzzy expert system, a bell-shaped membership function was chosen, which visually has the appearance of a symmetrical curve and resembles the shape of a bell. The specified function is given by the formula, the parameters of which are interpreted as follows:

$$\mu(x) = \frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}}, \qquad (1)$$

where a is the concentration coefficient of the membership function; b is the coefficient of curvature of the membership function; c is the coordinate of the maximum of the membership function [20].

The next step in building a fuzzy model is the identification of fuzzy logical rules. Given that the number of model inputs (input variables) is equal to ω, and each input has z fuzzy sets (membership functions), the number of fuzzy logic rules can be determined by the following formula:

$$r = z^{\omega}. \qquad (2)$$

Table 1 gives the correlation between the number of fuzzy rules of the model that enable completeness of the model and the input data of the model (input variables) ω, as well as the number of fuzzy sets z at each input.

Table 1

Correlation between the number of fuzzy rules of the model that enable completeness of the model and the input data of the model (input variables) ω, as well as the number of fuzzy sets z at each input

The number of fuzzy z sets at each input	The number of inputs to the ω model (the number of input variables)				
	ω=1	ω=2	ω=3	ω=4	ω=5
z=1	1	1	1	1	1
z=2	2	4	8	16	32
z=3	3	9	27	81	243

The implementation of fuzzy logic tools for evaluating the effectiveness of technology transfer has a significant social effect as it contributes to increasing innovative activity and the ability of enterprises to adapt to the rapidly changing conditions of society. The development and application of this approach allows enterprises to more effectively manage the process of introducing new technologies, create jobs, and implement programs for the socio-economic development of personnel.

5. Result of research on implementing the fuzzy logic model of technology transfer assessment

5. 1. Applying fuzzy logic tools in technology transfer practice

The justification for the implementation of the fuzzy logic toolkit for assessing the effectiveness of technology transfer is based on a number of fundamental principles and concepts that combine the theory of fuzzy sets, logic, and system analysis. Considering technology transfer as a complex multidimensional process, including technical, financial, marketing, and other aspects, requires the application of flexible methodologies for its assessment [21]. The basis of the practical use of fuzzy logic is the concept of fuzzy sets, in which elements can belong to a set with a certain degree, expressed as a number between 0 and 1, which differs from classical logic, in which an element either belongs to a set or not. It allows modeling the fuzziness and uncertainty inherent in human thinking and decision-making and reproducing them in formalized systems.

In the context of assessing the effectiveness of technology transfer, the fuzzy logic approach allows integrating various input data, including quantitative indicators and qualitative assessments of experts, and turning them into clear conclusions about the effectiveness of projects [22]. This is particularly important when there are complex relationships between different aspects of technology transfer, and when data are limited or have a high level of ambiguity. The implementation of the fuzzy logic toolkit in this context is based on the definition of input and output variables, their membership functions, which reflect the degree to which elements belong to certain categories, and a system of rules describing the interaction between these variables. This allows formalizing expert knowledge and experience in the form of fuzzy rules, which are then used to generate conclusions about the effectiveness of technology transfer [23].

The Mamdani method for fuzzy inference provides a mechanism for combining input data using a set of logical rules and subsequently deriving output values. This method is effective for modeling complex systems when it is important to take into account the interrelationships and interactions between different variables. Defuzzification, used at the final stage of fuzzy inference, transforms fuzzy initial values into a clear numerical value, which allows one to obtain a final assessment of the technology transfer project's effectiveness. This is critically important for the practical application of research results as it provides an opportunity to compare different projects and make informed management decisions [24].

5. 2. Model for assessing the efficiency of technology transfer

Fuzzy inference was used to construct the integral indicator of the efficiency of technology transfer projects TTPE (Technology Transfer Projects Efficiency). Three indicators were selected as input variables. The first indicator, Technical (T), is the technical (technological) component of the technology transfer efficiency indicator. The second indicator is Financial (F) – the financial component of the technology transfer efficiency indicator. Markets (M), the marketing component of the technology transfer efficiency indicator was chosen as the third indicator. The output variable was defined as an indicator of the efficiency of TTPE technology transfer projects. Both the input variables and the output variable are transformed into fuzziness by constructing membership functions. The type and parameters of the membership function were substantiated, and a bell-shaped membership function was chosen to estimate the uncertainty of values falling under the normal distribution [25]. The number of fuzzy sets at each input is considered as z=3, the number of input variables as ω=3. The selection of three indicators is the basis of the algorithm for forming an integral indicator for evaluating the effectiveness of the technology transfer project using the fuzzy logic apparatus. To achieve completeness of the model, the number of logical rules was defined as $r=3^3=27$. Mamdani's fuzzy inference was applied to calculate the TTPE technology transfer efficiency indicator. Defuzzification is used to calculate the value of the output variable TTPE-indicator that determines the efficiency of technology transfer projects. A fuzzy expert system was built to assess the efficiency of technology transfer projects [7]. It allows the use of different types of input variables owing to the fuzzy logic methodology, which takes into account the fuzziness of the input variables and the output variable as much as possible.

The modeling of the integral degree of market concentration was performed in the Fuzzy Logic Toolbox software of the MATLAB environment (version R2021A) by the MathWorks firm, which affected the setting and representation of the bell-shaped membership function. The function setting is as follows: μ(*x*)=gbellmf (*x*, [*a b c*]), where *x* is the input variable, *a*, *b*, and *c* are the aforementioned parameters [26].

Fig. 2–5 show the attributes and membership functions for three input variables and one output variable. Fig. 2 shows the input variable *T* (Technical) ("Technical (technological) component of the technology transfer efficiency indicator"). It has three attributes (membership functions): Low corresponds to a low (unsatisfactory) value of the *T* indicator, Medium corresponds to an average (satisfactory) value of the *T* indicator, High corresponds to a high value of the T indicator. This function is chosen as bell-shaped, and its value is formed in the range [0;100]. Low function – low *T* level – has parameters [0.8 4.9 0.0732], Medium function – medium *T* level – has parameters [20.83 2.5 50], High function – high *T* level – has parameters [20.8 2.5 92.39].

Fig. 3 shows the input variable *F* (Financial) ("Financial component of the technology transfer efficiency indicator"). It has three attributes (membership functions): Low corresponds to a low (unsatisfactory) value of the *F* indicator, Medium corresponds to an average (satisfactory) value of the *F* indicator, High corresponds to a high (i.e., normative) value of the *F* indicator. This function is bell-shaped, it is defined in range [0;100]. Low function – low F level – has parameters [20.8 6.946 11.2], Medium function – medium *F* level – has parameters [20.8 4.788 53.5], High function – high *F* level – has parameters [20.8 2.5 95.53].

Fig. 4 shows the input variable *M* (Market) ("Marketing component of the technology transfer efficiency indicator"). It has three attributes (membership functions): Low corresponds to a low (unsatisfactory) value of the *M* indicator, Medium corresponds to an average (satisfactory) value of the *M* indicator, High corresponds to a high value of the *M* indicator. This function is bell-shaped, it is defined in the range [0; 100]. Low function – low M level – has parameters [24.8 2.5 9.087], Medium function – medium *M* level – has parameters [20.8 2.5 55.21], High function – high *M* level – has parameters [17 3.47 94.6].

Fig. 5 shows the original variable TTPE ("Technology transfer efficiency indicator"), it has three attributes (membership functions): Low corresponds to a low (unsatisfactory) value of the TTPE indicator and has parameters [29.3 19.1 26.62]. Medium corresponds to the average (satisfactory) value of the TTPE indicator and has the parameters [18.3 4.55 74.34], High corresponds to the high value of the TTPE indicator and has the parameters [18.1 5.052 110]. This function is bell-shaped and has a range [0; 100] [11]. The assessment of individual components of the overall efficiency is determined by certain services of the enterprise, specialists in analytical work, and is given in points from 0 to 100 (for any specific enterprise where technology transfer takes place). The model takes into account the uncertainty of the constituents in the linguistic terms Low, Middle, High.

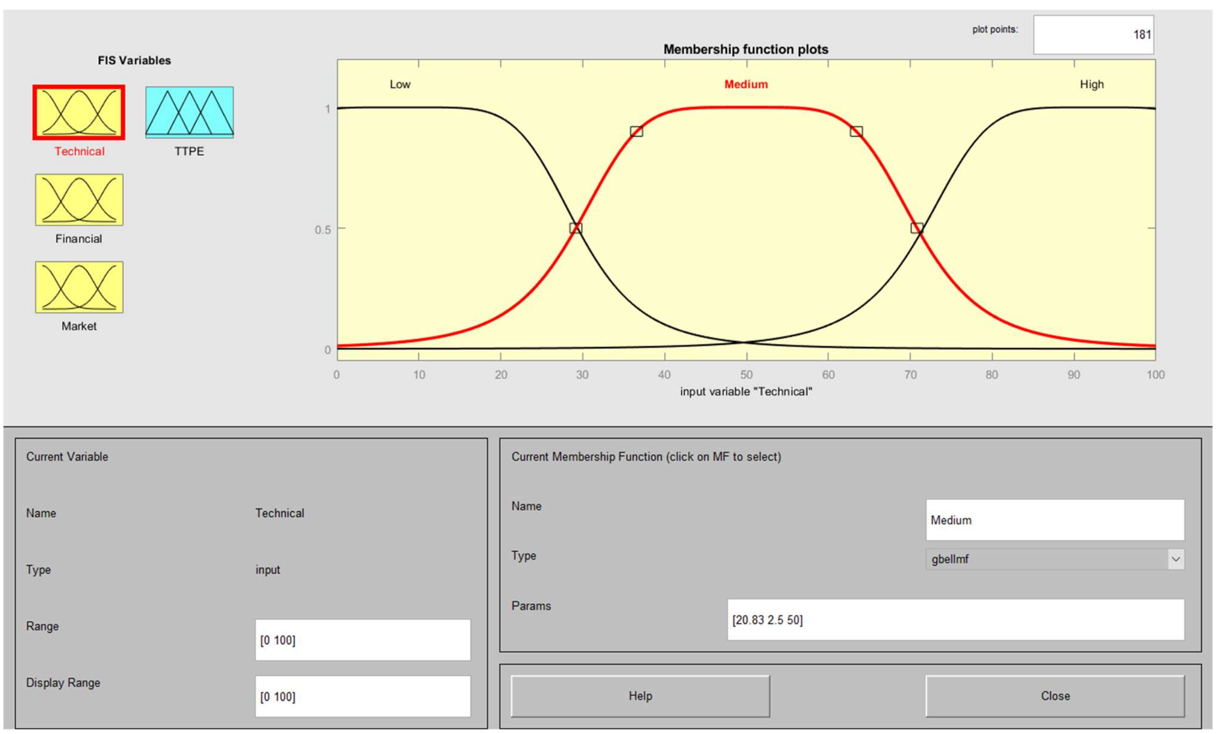

Fig. 2. Membership function for the input linguistic variable *T* (Technical) ("Technical (technological) component of the technology transfer efficiency indicator")

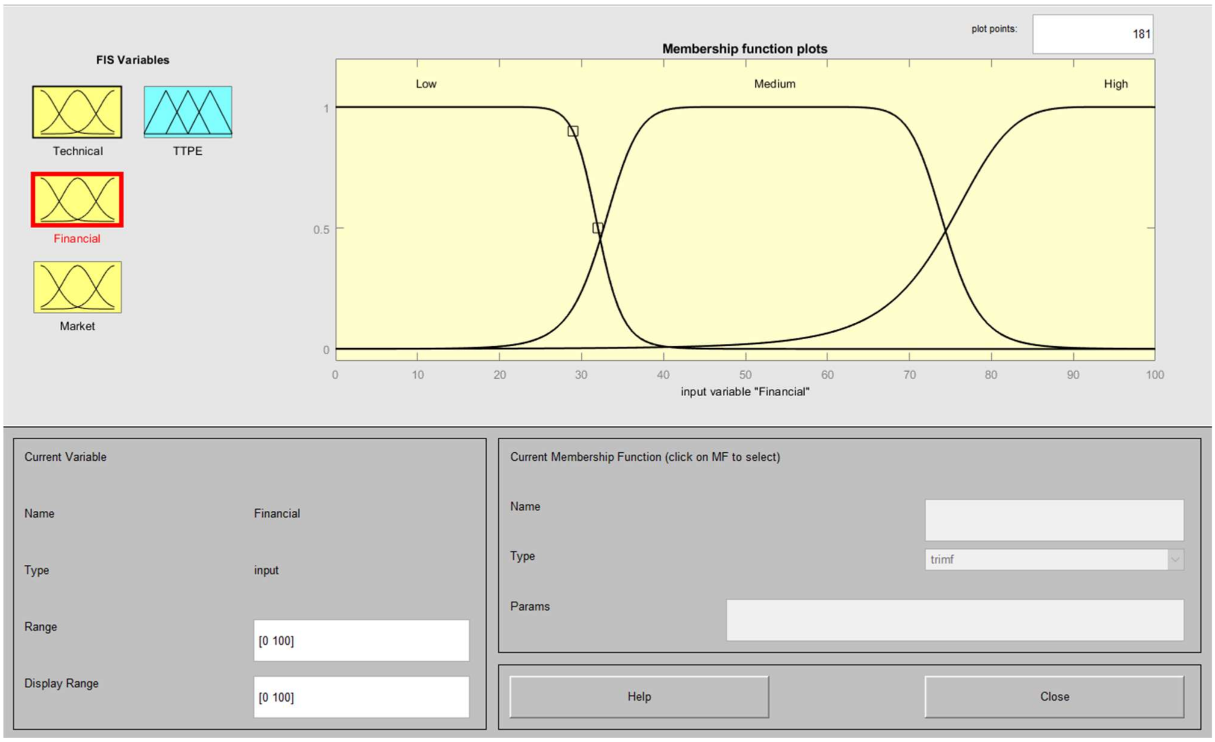

Fig. 3. Membership function for the input linguistic variable F (Financial) ("Financial component of the technology transfer efficiency indicator")

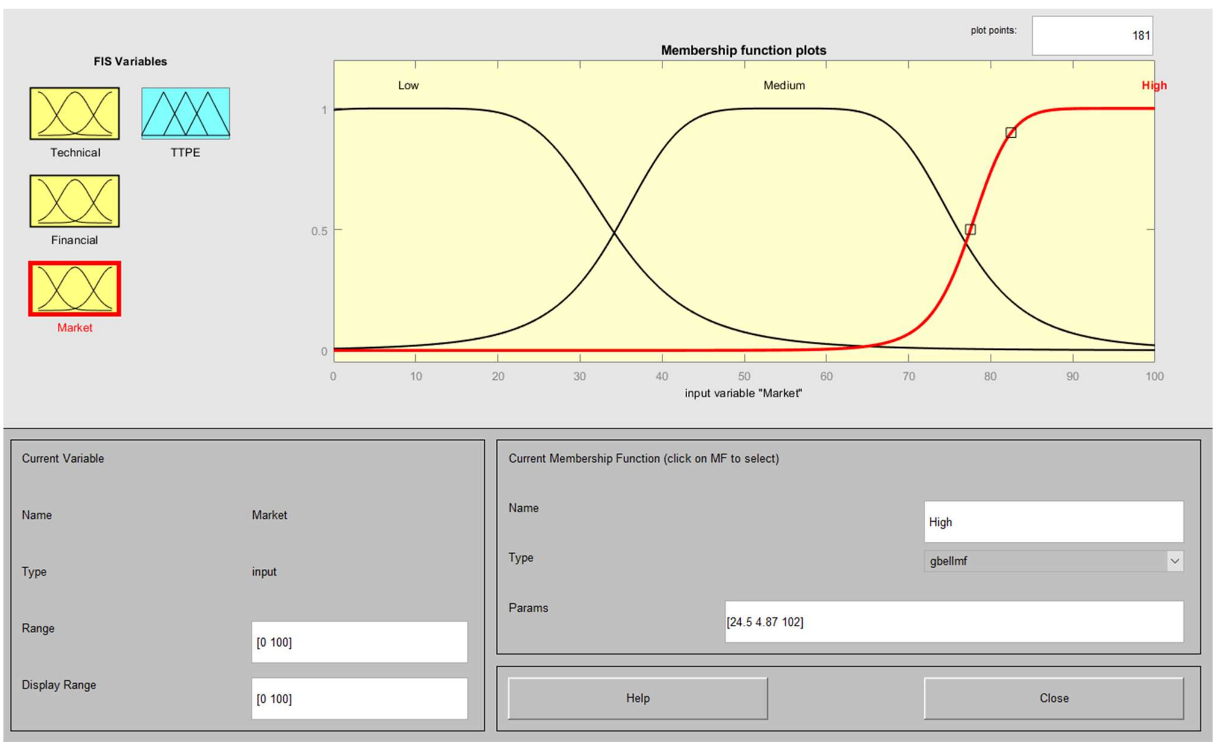

Fig. 4. Membership function for the input linguistic variable M (Market) ("Marketing component of the technology transfer efficiency indicator")

Based on the description of three input and one output variable, 3^3=27 fuzzy rules for output variable inference have been defined.

We describe the rules of fuzzy logic as follows:

– rule 1: If (*T is Low*) and (*F is Low*) and (*M is Low*) then (*TTPE is Low*);

– rule 2: If (*T is Low*) and (*F is Medium*) and (*M is Low*) then (*TTPE is Low*);

– rule 3: If (*T is Low*) and (*F is High*) and (*M is Low*) then (*TTPE is Low*);

– rule 4: If (*T is Medium*) and (*F is Low*) and (*M is Low*) then (*TTPE is Low*);

– rule 5: If (*T is Medium*) and (*F is Medium*) and (*M is Low*) then (*TTPE is Medium*);

– rule 6: If (*T is Medium*) and (*F is High*) and (*M is Low*) then (*TTPE is Medium*);

– rule 7: If (*T is High*) and (*F*) *is Low*) and (*M is Low*) then (*TTPE is Medium*);

– rule 8: If (*T is High*) and (*F is Medium*) and (*M is Low*) then (*TTPE is Medium*);

– rule 9: If (*T is High*) and (*F is High*) and (*M is Low*) then (*TTPE is Medium*);

– rule 10: If (*T is Low*) and (*F is Low*) and (*M is Medium*) then (*TTPE is Low*);

– rule 11: If (*T is Low*) and (*F is Medium*) and (*M is Medium*) then (*TTPE is Medium*);

– rule 12: If (*T is Low*) and (*F is High*) and (*M is Middle*) then (*TTPE is Middle*);

– rule 13: If (*T is Medium*) and (*F is Low*) and (*M is Medium*) then (*TTPE is Medium*);

– rule 14: If (*T is Medium*) and (*F is Medium*) and (*M is Medium*) then (*TTPE is Medium*);

– rule 15: If (*T is Medium*) and (*F is High*) and (*M is Medium*) then (*TTPE is Medium*);

– rule 16: If (*T is High*) and (*F is Low*) and (*M is Medium*) then (*TTPE is Medium*);

– rule 17: If (*T is High*) and (*F is Medium*) and (*M is Medium*) then (*TTPE is High*);

– rule 18: If (*T is High*) and (*F is High*) and (*M is Medium*) then (*TTPE is High*);

– rule 19: If (*T is Low*) and (*F is Low*) and (*M is High*) then (*TTPE is Low*);

– rule 20: If (*T is Low*) and (*F is Medium*) and (*M is High*) then (*TTPE is Medium*);

– rule 21: If (*T is Low*) and (*F is High*) and (*M is High*) then (*TTPE is Medium*);

– rule 22: If (*T is Medium*) and (*F is Low*) and (*M is High*) then (*TTPE is Medium*);

– rule 23: If (*T is Medium*) and (*F is Medium*) and (*M is High*) then (*TTPE is Medium*);

– rule 24: If (*T is Medium*) and (*F is High*) and (*M is High*) then (*TTPE is Medium*);

– rule 25: If (*T is High*) and (*F is Low*) and (*M is High*) then (*TTPE is Medium*);

– rule 26: If (*T is High*) and (*F is Medium*) and (*M is High*) then (*TTPE is High*);

– rule 27: If (*T is High*) and (*F is High*) and (*M is High*) then (*TTPE is High*).

The constructed model of fuzzy inference allows us to evaluate the integral indicator of the efficiency of technology transfer projects depending on three components, namely: on the variable *T*, which is the technological component of the indicated indicator. On the variable *F*, which is the technological component of the efficiency indicator of technology transfer projects, and on the variable *M*, which is the marketing component of the efficiency indicator of technology transfer projects.

5. 3. Verification of the technology transfer evaluation model

The dependence of the output variable TTPE, which is an integral indicator of the efficiency of technology transfer projects, on the input variables *T* and *F* at a fixed value of *M*=50 represents an infinity of TTPE values. Applicate axis – value from 0 to 100 (conditional units, for specific projects it can be expressed in monetary units). Indicators are represented in the form of a response surface built using the SurfaceViewer visualizer (Fig. 6).

The dependence of the output variable TTPE, which is an integral indicator of the efficiency of technology transfer projects, on the input variables *T* and *M* at a fixed value of *F*=50 represents an infinity of TTPE values. They are represented in the form of a response surface built using the SurfaceViewer visualizer (Fig. 7).

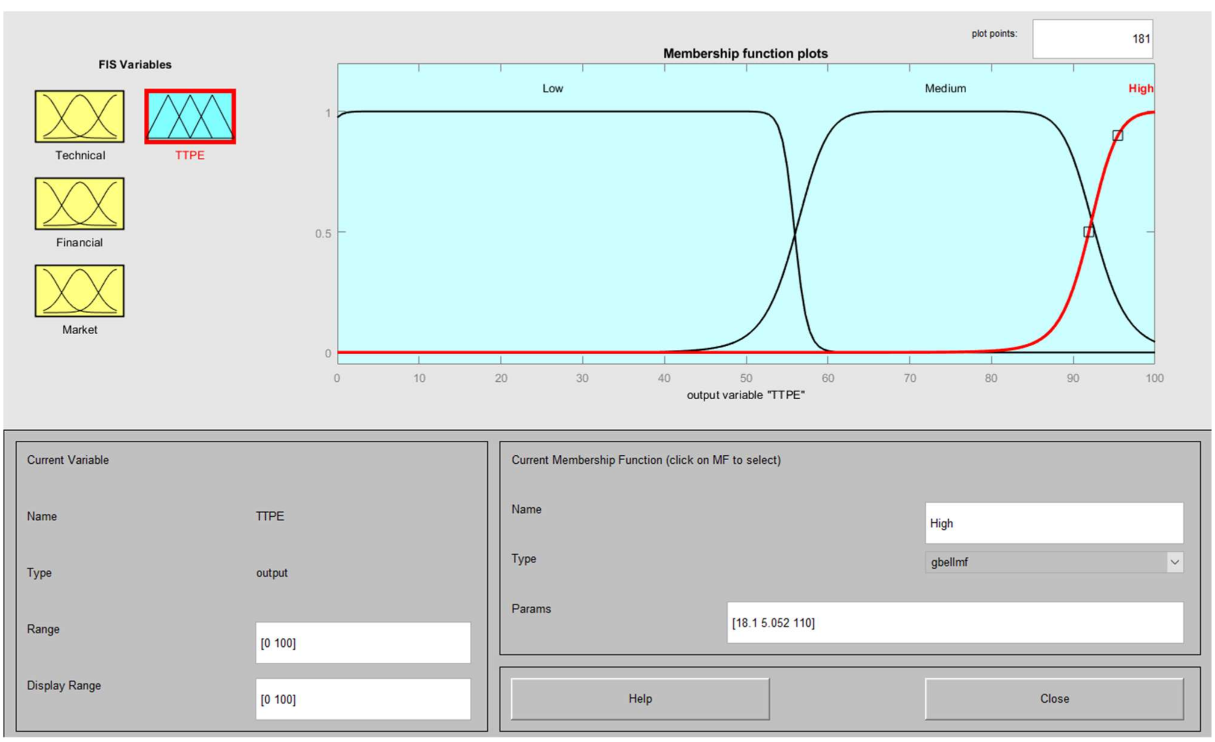

Fig. 5. Membership function for the output linguistic variable “TechnologyTransferProjectsEfficiency”

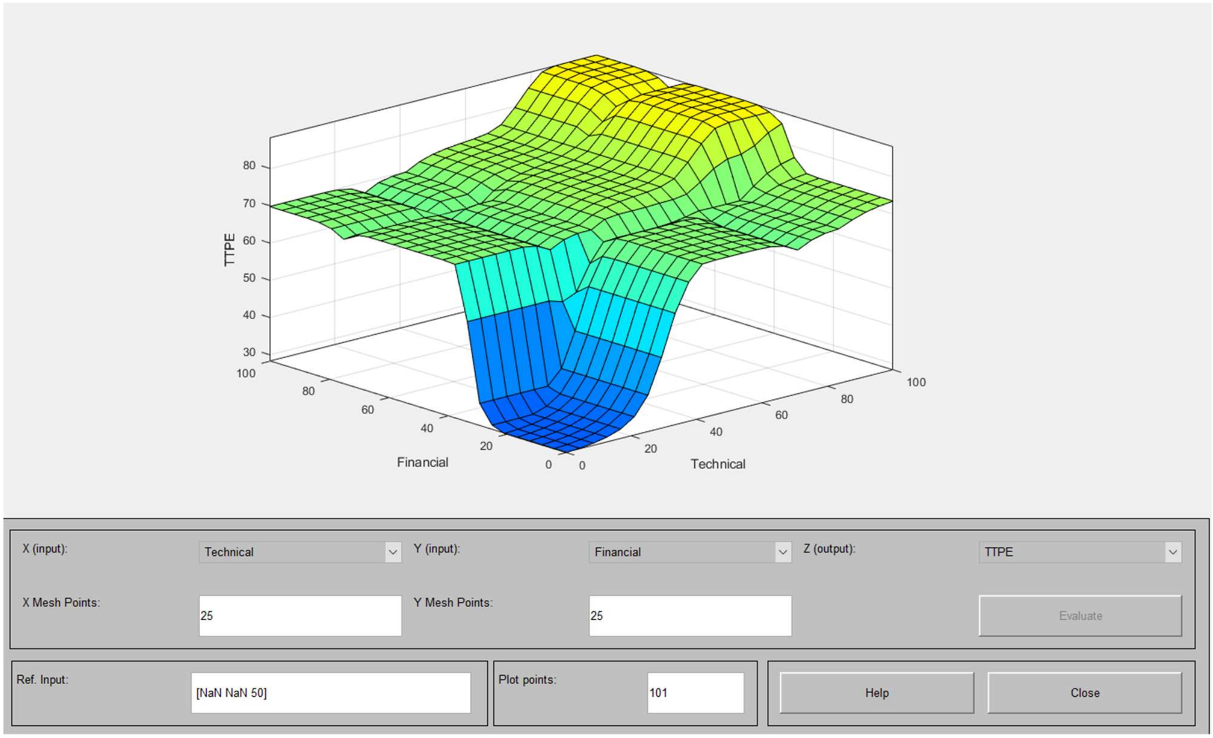

Fig. 6. Dependence of the output variable “Technology Transfer Projects Efficiency”, which is an integral indicator of the efficiency of technology transfer projects, on the input variables *F* and *T* at the level of fixed values of the marketing component of the efficiency indicator of technology transfer projects *M*=50 (constructed by Authors)

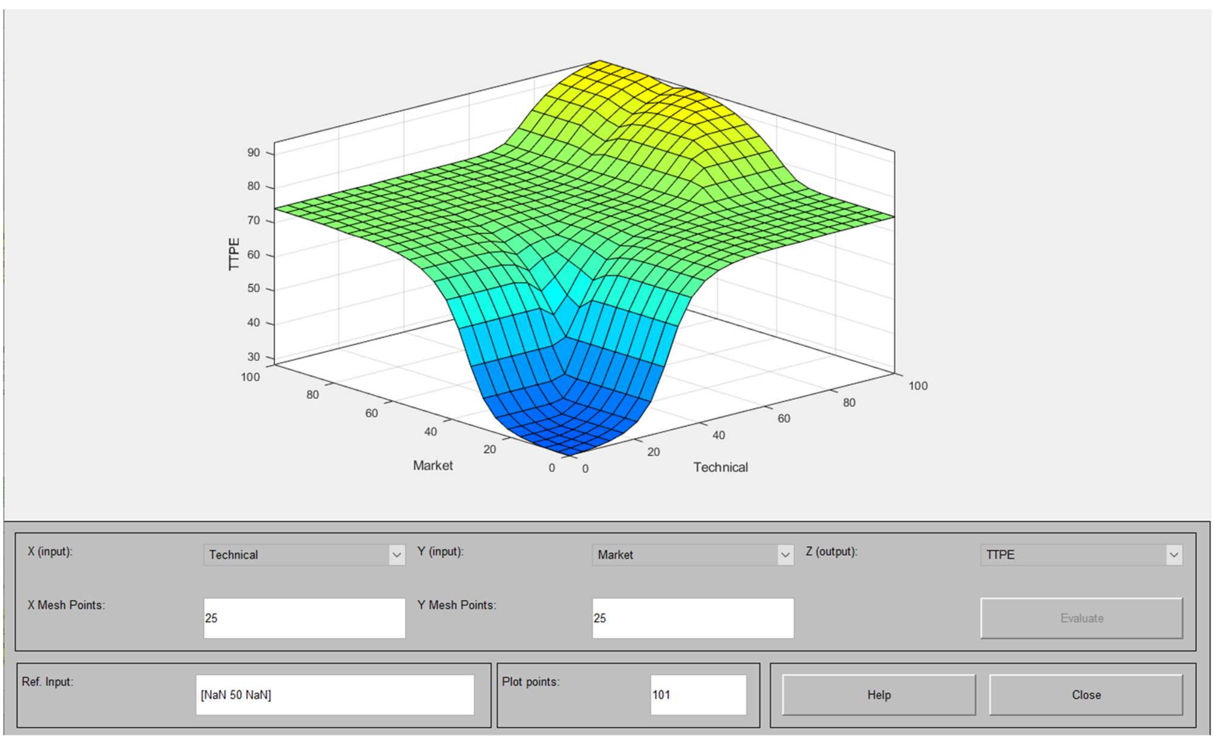

Fig. 7. Dependence of the output variable “TechnologyTransferProjectsEfficiency”, which is an integral indicator of the efficiency of technology transfer projects, on the input variables *M* and *T* at the level of fixed values of the financial component of the efficiency indicator of technology transfer projects *F*=50 (constructed by Authors)

The dependence of the output variable TTPE, which is an integral indicator of the effectiveness of technology transfer projects, on the input variables *F* and *M* at a fixed value of *T*=50 represents an infinity of TTPE values, which are represented in the form of a response surface constructed using the SurfaceViewer visualizer (Fig. 8).

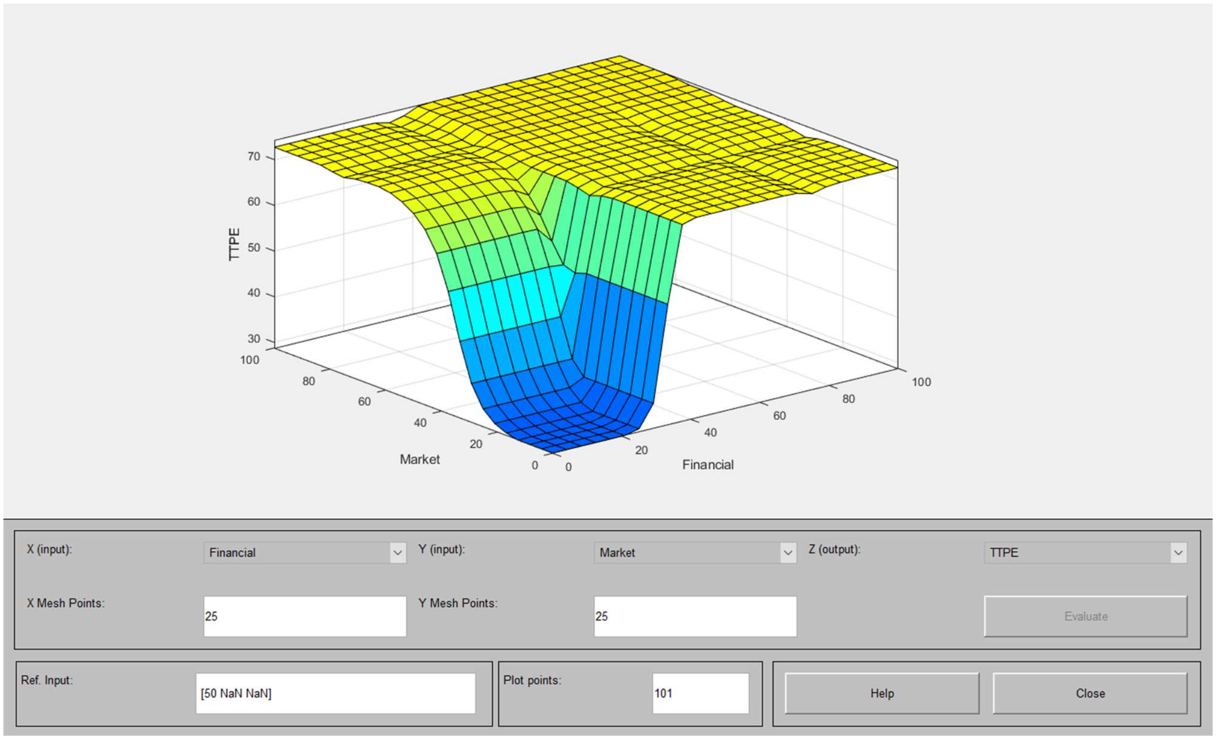

Fig. 8. Dependence of the output variable "TechnologyTransferProjectsEfficiency", which is an integral indicator of the efficiency of technology transfer projects, on the input variables *T* and *F* at the level of fixed values of the technological component of the efficiency indicator of technology transfer projects *T*=50 (constructed by Authors)

Visualization of the "input-output" surface allows us to determine that the output indicator TTPE, which is an integral indicator of the effectiveness of technology transfer projects, reaches its maximum at the maximum values of the input parameters of the model. These parameters are *T* (technological component of the efficiency indicator of technology transfer projects), *F* (financial component of the efficiency indicator of technology transfer projects), and *M* (marketing component of the efficiency indicator of technology transfer projects) [27].

6. Discussion of results of the research on implementing fuzzy logic tools in the process of technology transfer

Our results are represented by an integral indicator of the efficiency of technology transfer projects (Fig. 6–8). The use of fuzzy logic made it possible to model the ambiguity and uncertainty that often accompany the process of technology transfer and provided an opportunity to quantify the impact of these variables on the success of the transfer (Fig. 5).

Thus, the process of technology transfer is multifactorial, but the involvement of more factors (input variables) will exponentially complicate the model and reduce the sensitivity of the influence of each factor (formulas (1), (2), and Table 1). The main drawback of the proposed fuzzy logic model is subjectivity and, hence, a certain inconsistency of experts' opinions, especially when constructing membership functions and logical rules.

The proposed model provides significant advantages for increasing the accuracy and adaptability of evaluation processes, which is critical for the successful integration of new technologies into production and commercial use. The applied value of the study is the ability of the fuzzy logic toolkit to adapt to the ambiguities accompanying the technology transfer process. This means that innovative organizations and institutions can better predict potential risks and identify the most effective strategies to minimize these risks, thereby increasing the overall effectiveness of the transfer process. This, in turn, contributes to a better understanding of the value of technological innovation and its potential to improve productivity and efficiency.

Our explorations in the future will be aimed at improving the fuzzy-logical model for assessing the efficiency of technology transfer and expanding the scope of the proposed model to enterprises in various sectors of the national economy.

7. Conclusions

1. Findings from our study, which focuses on the construction of an integral indicator of technology transfer project performance (TTPE) using fuzzy inference, open up new possibilities for the evaluation and analysis of technology transfer performance. This study demonstrates how the application of fuzzy logic and fuzzy sets can improve the accuracy and adaptability of evaluating complex processes such as technology transfer by integrating various input variables and accounting for their fuzziness. To assess the level of the technology transfer efficiency indicator, the fuzzy set method is more effective compared to linear models due to the fact that it maximally takes into account the uncertainty of the internal and external environment of the enterprise. A fuzzy model practically allows one to involve a significant number of input parameters, both quantitative and qualitative. However, the specific choice of parameters

should be justified by their weight, on the one hand, and the time-consuming nature of data collection necessary to assess the effectiveness of technology transfer, on the other hand.

2. To form an integral indicator of technology transfer efficiency (TTPE), three components are involved – technological, financial, marketing – which to the greatest extent cover the domains of activity of technology transfer subjects. A fuzzy expert system was built based on the use of bell-shaped membership function to evaluate three key input variables: technical (T), financial (F), and marketing (M) components of technology transfer efficiency. Each of these variables is transformed into fuzzy sets using carefully designed membership functions, allowing for the modeling of the uncertainty and ambiguity that often accompany the evaluation of such complex processes. This will not only contribute to a better understanding of the influence of various factors on the success of technology transfer projects but also pave the way for the development of more effective management strategies and the implementation of innovations.

3. The model for assessing the effectiveness of technology transfer has been verified and tested. Using the FuzzyLogicToolbox software in the Matlab environment for modeling demonstrates the practical feasibility and affordability of developing such a model. The result of the built model, which graphically looks like a response surface, is the possibility of obtaining a specific value of the "TechnologyTransferProjectsEfficiency" indicator for any values of the input components – technological, financial, marketing. This forms a toolkit for improving technology transfer under conditions of uncertainty in the internal and external environment.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The manuscript has associated data in the data warehouse.

Use of artificial intelligence

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

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