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Cognitive Fuzzy Logic Modeling of Project Risks

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***Abstract*—In this article, using the fuzzy logic and cognitive modeling apparatus, the general provisions of intelligent support for management activities in projects are presented. In the context of digitalization of the economy the solution proposed is relevant. It can be used in development of a strategy for technical re-equipment and modernization of industrial enterprises. The proposed solution is based on intelligent management methods, along with a project approach. The paper proposes a system model of project technical and technological re-equipment of industrial enterprises (TTRIE). The results of industrial development projects are uncertain. There are always risks that the actual production and commercial performance will deviate for the worse. In most cases, project risk assessments are presented with verbal information. Based on the developed concept, it becomes possible to integrate information support and optimize management in accordance with the project performance criteria, taking into account the target function (strategy) and actual conditions (project risks).**

Keywords*—*fuzzy logic, cognitive modeling, industrial enterprise projects, project risk

I. Introduction

The concept of analysis and risk management of complex systems is one of the main concepts of managing processes and objects of different nature. This concept is also relevant in the context of project activities of industrial enterprises [1]. Its implementation, in the traditional sense, requires the systematic use of available information about the frequency of specific events and the extent of their consequences, which involves the use of methods of probability theory and mathematical statistics.

In some cases, the project is unique. Its development and implementation on an enterprise scale allows to evaluate and manage risk events only on the basis of subjective information or information from which you can not yet obtain statistical characteristics of these events. Therefore, a promising direction for solving project management problems and building risk-based design strategies are methods of formalizing, modeling and analyzing information of a non-statistical nature, and expert knowledge and experience in project management and enterprise business processes [2–4]. A special approach from the position of strategic management is applied to the evaluation of the results of project management of technical and technological re-equipment of industrial enterprises (TTRIE). The goals of technical and technological re-equipment of the existing industrial enterprise are to increase the economic and production and technological potential, increase production capacity and output of competitive products. Achieving the goals is provided by improving the quality of the product, increasing labor productivity, reducing material consumption and production costs [5].

TTRIE project management is the transition from one state of an industrial enterprise to another target state, provided that the task at the project level is performed in the best possible way out of all possible solutions, taking into account the specific current situation. Business expertise gives an idea of the specific situation at the enterprise, determines the need for re-equipment of the enterprise. Based on the results of a business examination, the commercial, engineering, manufacturing, financial and economic activities of an industrial enterprise are evaluated. A comprehensive assessment can be presented quantitatively (points, coefficients, characteristics) and qualitatively (ranking by a set of indicators) [5].

An urgent task that arises when developing the concept of the TTRIE project is the need to assess the future results of the project work performed and the company's development strategy based on a weakly structured situation.

The formalization of knowledge of the problem situation under study on the basis of an expert approach leads to the representation of the regularities of its development in the form of a directed graph [6]. Thus, it is possible to form cognitive maps of the situation object $d_i \in D$, which are represented by a pair (F_i, W_i), where $F_i = \{f_{ij}\}$ are factors that describe the situation d_i; W_i is the adjacency matrix of the graph that reflects knowledge of the situation d_i. Cognitive maps (F_i, W_i) for objects are combined into a cognitive map of a complex situation (F, W), where $F = \cup Fi$ – a set of factors – factors of the situation; W – the adjacency matrix of the digraph, describing a complex situation and including the W_i matrix of individual elements of the situation and the relationship between them. Various ways of setting the strength of cause-and-effect relationships and the values of factors according to expert estimates determine the type of cognitive map [7].

The relevance of cognitive modeling of complex systems is reflected in the main methodological aspects and application software for building cognitive maps of various types [7–10]. Research is underway on the specifics of cognitive modeling in solving applied problems [10–12]. However, the adaptation of modern tools and methods of cognitive modeling to the management of TTRIE projects and their risk assessment is a separate scientific problem.

II. METHODOLOGICAL ASPECTS OF TTRIE PROJECT MANAGEMENT

At the present stage of development of project management of technical and technological re-equipment, there are no standard system solutions for strategic development of industrial enterprises in conditions of uncertainty and risk. The following TTRIE goals are highlighted:

- Replacing worn-out equipment.
- Development of flexible production.
- Increasing the production capacity of equipment.
- Automation of productions.
- Reducing the cost of manufacturing products and production costs.

TTRIE project risks can be classified as: innovative, investment, managerial, and technological. The level of project risk is determined by the coordination of activities with the project goals aimed at changing the technological, organizational and information support of production.

The requirement of the ISO 9001 standard is the presence of a normative model of the company's work that reflects the functional, information, organizational and technological levels. This approach will provide risk management with elements of the internal control standard: environment, goal setting, event identification, risk assessment, risk response, management tools, information and communication, and monitoring [13].

The functional model of an industrial enterprise determines the overall manageability, the ability to execute the production plan, and the level of risks of the production system. The information model consolidates information about objects of production activity, presenting it as structured and unstructured data of all stages of the object's life cycle.

The organizational model reflects the composition, subordination, interaction and distribution of work on the objects of production activity and the production management system, defining the management information in accordance with the authority and responsibility. It is the organization of processes for objects of production activity that determines which risks of production activity are reduced or completely eliminated [14,15].

Modeling at the technological level provides quantitative and qualitative parameters of technological and production processes. The basis for determining the strategic development of an industrial enterprise is being formed. The relationship between the selected levels of an industrial enterprise and the TTRIE project is shown in figure 1.

Each level of industrial enterprise modeling reflects: purchases (input (quantity, quality of raw materials, materials, components,) and output (suppliers, terms, prices)); sales (input (quantity, quality, delivery time of products, product inventory) and output (quantity, quality, delivery time of products)); equipment (input (requirements for the working time Fund) and output (working equipment)); personnel (entry (requirements for staff composition and competence) and exit (number of competent employees)); production process (input (raw materials, materials, components, equipment, employees) and output (products in the required volumes, in the specified time with the specified quality characteristics)).

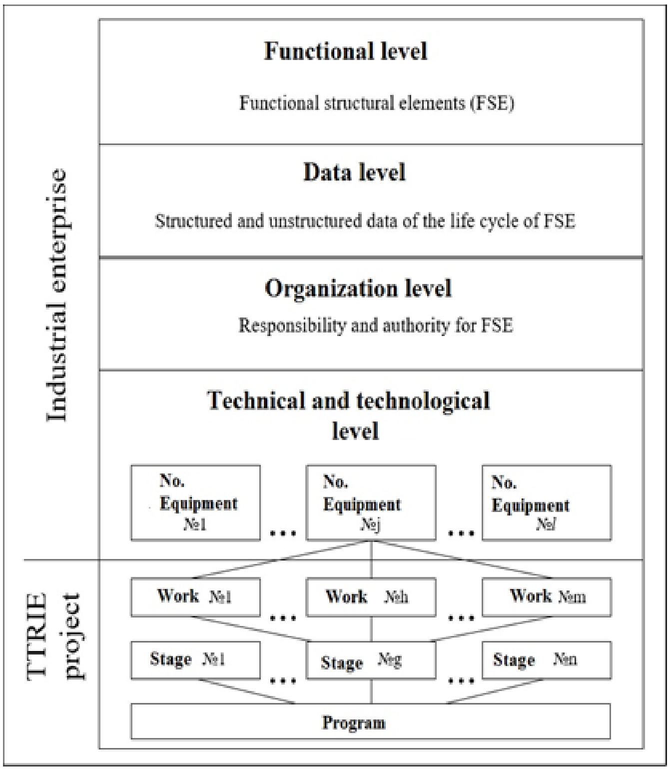

Fig. 1. Relationship between levels of representation of an industrial enterprise and the TTRIE project

The project TTRIE is the development potential of the enterprise. Therefore, the assessment of project risks is embedded in the definition of the project's potential. The system potential is a property that characterizes the system's fitness to achieve goals when functioning [16]. The parameters of the TTRIE project have forecast values. Project risks should be considered as a manifestation of uncertainty and the possibility of obtaining actual values for the worse from the forecast ones. The relationship between production parameters and project risks is shown in table 1.

Based on the factors considered, the potential of objects participating in the TTRIE can be estimated using fuzzy logic. This approach will provide a view of project risks based on quantitative and qualitative indicators.

III. THE SYSTEM MODEL OF THE PROJECT TTRIE

In [17], we consider the system model of the project that defines the tasks of project management, as well as approaches to the classification of projects and project risks. An adapted model for fuzzy cognitive modeling of TTRIE projects taking into account project risks is presented in table 2.

TABLE I. FACTORS AND PROJECT RISKS

Elements	Risk Name	Factors f the TTRIE objects
Personnel	Staff loss risk. Rp	Rp1 – level of time indicators in the staff formation; Rp2 –level of costs in the staff formation; Rp3 – level of staff qualification.
Puchases	Lost risk in selec-tion of unreliable suppliers. Rz	Rz1 – level of time indicators in selections of suppliers, equipment, raw materials, materials, components etc .; Rz2 – level of costs in selections of suppliers, equipment, raw materials, materials, components etc .; Rz3 – quality level of purchase equipment, raw materials, materials, components etc .
Sales	Loss risk in sales. Rs	Rs1 – level of time indicators for the preparation for sales; Rs2 – level of costs for the preparing for sales; Rs3 – level of production volume prepared for sales.
Produc-tion pro-cess	Loss risk of prod-ucts with specified quality characteris-tics. Rpp	Rpp1 – level of time indicators of output products with the specified quality characteristics; Rpp2 – level of product costs with specified quality char-acteristics. Rpp3 – level of product costs with the specified quality characteristics.
Equip-ment	Loss risk in equipment operat-ing. Rf	Rf1 – level of time indicators of equipment operating; Rf2 – level of costs for equipment operating; Rf3 – level of equipment productivity.

Using this system model as the first stage in the development of cognitive maps of TTRIE projects gives the following conditional representation of the Lpr project, for example:

$$Lpr = < Pr1, Ppr1, Ppr2, Ppr3, Sf1, Sf2, Sf3, Sf4, Sf5, Fpr1, Spr2, Tpr5, Zpr1 > \quad (1)$$

The presented model fully characterizes the situation of the TTRIE project under study, reflecting the key features of the management object and the management process. In this example, the draft TTRIE replacement Pr_1, which goal is to increase all levels of potential production Ppr_1, Ppr_2, Ppr_3 (organizational, technical-technological, financial-economic), taking into account all the components of the structural-functional elements of the production, Sf_1, Sf_2, Sf_3, Sf_4, Sf_5, (personnel, procurement, sales, production process, equipment) on pre-investment stage Fpr_1. We consider the possibility of implementing a set of measures to replace the Spr_2 equipment for the entire planning horizon of Tpr_5 from the position of the Zpr_1 investor.

The situation is described by the dynamic cognitive model shown in figure 2.

To build a cognitive map of determining the potential of the studied alternatives, several stages must be implemented.

- Stage 1. Determining the composition of the structure (set of factors) of a fuzzy cognitive model for determining the potential of a TTRIE object. Development of flexible production.
- Stage 2. Determining the agreed relationship of influence (causality) between each pair of factors.

TABLE II. SYSTEM MODEL OF THE TTRIE PROJECT

<table>
<tr><th colspan="6">Object of management (L)</th></tr>
<tr><th colspan="6">TTRIE Project (Pr)</th></tr>
<tr><td>1. Replacement of old equipment</td><td>2. Intro-duction of new tech-nologies (automa-tion of pro-duction, flexible production)</td><td>3. Increase of produc-tion vol-umes</td><td>4. Modernization of production</td><td>5. Intro-duction of energy-saving technology</td><td>6. Introduction of technolo-gies for social prob-lems solving</td></tr>
<tr><th colspan="6">Potential of industrial enterprise object (Ppr)</th></tr>
<tr><td colspan="2">1. Technical and technological level</td><td colspan="2">2. Organization level</td><td colspan="2">3. Financial and economic level</td></tr>
<tr><th colspan="6">Structural and functional elements of an industrial enterprise (Sf)</th></tr>
<tr><td>1. Personnel</td><td>2. Purchases</td><td>3. Sales</td><td colspan="2">4. Production process</td><td>5. Equipment</td></tr>
<tr><th colspan="6">TTRIE Project phases (Fpr)</th></tr>
<tr><td colspan="2">1. Pre-investment</td><td colspan="2">2. Investment</td><td colspan="2">3. Operational</td></tr>
<tr><th colspan="6">Management process (S)</th></tr>
<tr><th colspan="6">Modelling scenario (Spr)</th></tr>
<tr><td colspan="2">1. Lack of management</td><td colspan="2">2. Management with the selected set of activities</td><td colspan="2">3. Search for specific activities</td></tr>
<tr><th colspan="6">Modeling horizon (Tpr)</th></tr>
<tr><td>1. Year</td><td>2. Quarter</td><td>3. Month</td><td colspan="2">4. Day</td><td>5. etc.</td></tr>
<tr><th colspan="6">Subject of management (Zpr)</th></tr>
<tr><td>1. Investor</td><td>2. Customer</td><td>3. Contractor</td><td colspan="2">4. Co-contractor</td><td>5. etc.</td></tr>
</table>

- Stage 3. Formation of fuzzy models of system factors and identified potential of the TTRIE object.
- Stage 4. Determining the degree of importance of the technical and technological level of development of the *Wttu* enterprise, the organizational *Worg* and the financial and economic *Wfe* level for determining the potential γ_i of the TTRIE object of the project, the considered alternative

The hierarchical model describes the situation from the point of view of the management goal, the degree of achievement of which is expressed in terms of the expert's preferences regarding the criteria expressed using their weights and the specific values of the sets represented in a certain scale.

The main research is carried out on the state of the equipment in the TTRIE. this creates a hierarchical model for assessing the situation, which can be used to: 1) a single unit; 2) type of equipment; 3) the production site.

Specific factors that reflect both the technical, organizational, and financial aspects of the process of replacing and or upgrading equipment are significant for each specific object of evaluation. The task of the expert is to determine among the factors of the cognitive model factors that are close in meaning to the main criteria of the hierarchical model. Thus, a subset of $\Phi \subset F$ factors of the cognitive model is determined and their compliance with the selected criteria.

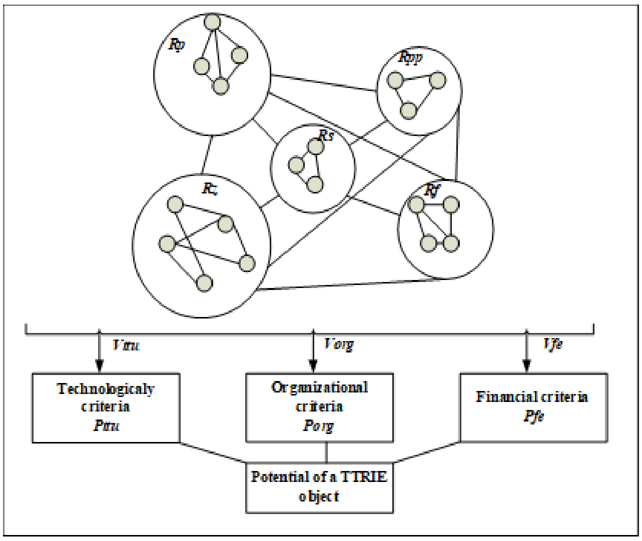

Fig. 2. Hierarchical model for determining the potential of a TTRIE object

For example, for a small business machine-building enterprise, as a result of a comprehensive business examination, objects of technical and technological re-equipment were identified – metal-cutting machines: type "CNC Lathe", type "Universal machine", type "Processing center". Each alternative *Xi* is determined by the amount of costs for the purchased equipment and organizational activities, the time frame for the implementation of works and organizational activities, as well as the requirements for the composition and qualification of personnel.

A fuzzy number (ZFP, ZFO, ZFNO) is calculated for each factor in the model. ZFP has the maximum degree of the membership function 1 when the risk level value is «very high» term τ=T. for the term τ=1, the risk level is practically absent. The membership functions for the remaining ratings take intermediate values. The parameter is represented as a triangular number:

$$ZN = \left(ZFO; \frac{(\tau - 1)(ZFP - ZFNO)}{T - 1}; ZFP\right). \quad (2)$$

To assess the significance of the components of the enterprise's development potential, fuzzy numbers were used, representing statements of the following type: «the significance of technical and technological level decisions», «the significance of organizational level decisions», and «the significance of financial and economic level decisions». In this case, *0<Wtt, Worg, Wfe>1*; *Wtt+ Worg+ Wfe=1*. For a TTRIE object implemented in three variants, we make an assessment, for example, as shown in table 3.

The potential score is represented by the linguistic score T «potential change» = {very high, high, relatively high, high, above average, average, relatively low, low, very low, almost none}. The scale contains 9 triangular terms in the interval [0;1].

The value of the potential of the ttpp object is made by methods of group decision-making. The potential of a TTRIE object is a combination of changes in all components: technical and technological, organizational, and financial.

TABLE III. ALTERNATIVES FOR TTRIE

Potential	Components		
	Technical and technological level, *Pttu*	Organizational level, *Porg*	Financial level, *Pfe*
Significance of the level	*Worg= about 0,23*	*Wttu=about 0,7*	*Wfin = above 0,07*
Alternative 1	*Pttu= relatively low*	*Porg= high*	*Pfin= average*
Alternative 2	*Pttu= average*	*Porg= average*	*Pfin = above the average*
Alternative 3	*Pttu= average*	*Porg= average*	*Pfin= average*

The value of the potential of the ttpp object is made by methods of group decision-making. The potential of a TTRIE object is a combination of changes in all components: technical and technological, organizational, and financial. For example, from table 3 for the organizational level, the increment *Porg= high*. We transform the estimate into a fuzzy number based on the ratio of the importance of the organizational component in this TTRIE project, which is *Wttu=approximately 0.7*. The actual increment at the organizational level is a fuzzy number from the ratio with the «very high» rating.

Similarly, we translate linguistic estimates into a conditional scale, which allows us to determine the increment of the potential of the TTRIE object:

$$\gamma_i^{\,j} = P_{ttu\,i}^{\;\;j} + P_{org\,i}^{\;\;j} + P_{fe\,i}^{\;\;j}, \quad (3)$$

where-the increment of the technical and technological level of potential, the increment of the organizational level of potential, the increment of the financial and economic level of potential, taking into account their significance *Wij*. Taking into account project risks the target function in decision making:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \gamma_i^j x_i^j \rightarrow max. \quad (4)$$

IV. CONCLUSION

In projects of technical and technological re-equipment and modernization of industrial enterprises, the use of cognitive and fuzzy logic modeling methods is proposed. In the development of the digital economy, the methods used form a group of technologies that are designed to process information in an unstructured form [18,19].

The cognitive fuzzy logic model in the system analysis is the basis for developing a knowledge base in the information management system for solving management tasks of TTRIE projects [20]. The approach based on the method of cognitive fuzzy logic modeling expands the possibilities of project risk management by quantifying risk situations, which allows using the model in setting an optimization problem, for example, a dynamic programming problem.

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