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Fuzzy Decision Support for Selecting Innovation Projects in University-Based Flexible Manufacturing Systems

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ABSTRACT This paper addresses the problem of developing an integrated corporate management system for innovation and flexible manufacturing within a university environment, aimed at ensuring effective interaction between science, innovation and production at HEI. This paper proposes an innovation-transfer subsystem that integrates research laboratories, engineering centers, a business incubator and a flexible manufacturing system (FMS) into a unified digital management framework. A structural and functional model of corporate governance is proposed, including strategic, managerial and operational levels to coordinate the processes of innovation generation, technology transfer and commercialization. In addition, the role of a digital platform as a key tool for integrating and synchronizing information flows among all participants of the innovation and production ecosystem is substantiated. The principles of adaptive resource management and flexibility of production processes under dynamically changing conditions are also considered. The proposed approach is based on fuzzy logic, enabling the formalization of expert knowledge and decision-making under uncertainty. A fuzzy rule-based knowledge base is developed and an algorithm for selecting the optimal project based on resource availability, project status and investment attractiveness is implemented.

KEYWORDS fuzzy decision-making; innovation ecosystems; flexible manufacturing system; HEI; Industry 4.0; digital platform; Mamdani inference; technology transfer.

I. INTRODUCTION

A. PROBLEM STATEMENT AND RELEVANCE

RAPID development of digital technologies and automated production processes [9, 13] requires the effective integration of scientific research, education, and production. Universities are serving as centers for generating innovation and technology that must be quickly transformed into production solutions. Modern universities are becoming hubs not only for education and research, but also for industrial development, creating innovative ecosystems that include startups, technology parks, and flexible manufacturing systems.

Creating a global innovation ecosystem at a university, for its productive functioning and the rapid transition from a startup idea and its prototype to a real production system, requires the implementation of new structures for innovation and production associations and new approaches to their management. Corporate management systems (CMS) used at universities follow a classic model of interaction between educational, research, and innovation structures. Therefore, to fully utilize traditional CMS, it is necessary to strengthen this system with an innovation transfer subsystem (ITS), which can serve for integration into a flexible manufacturing system (FMS). The implementation of the ITS at HEI will enable the university to perform the following system-wide functions:

- accelerate the implementation of scientific research in industry;
- develop the competencies of students and researchers in applied projects;
- strengthen collaboration with industrial partners;
- directly and productively implement the stages from project ideation to implementation and serial production.

The integration of universities, industry, and innovation systems has attracted considerable attention in recent years. Universities are increasingly viewed as active participants in regional and national innovation ecosystems, facilitating the commercialization of scientific research, supporting entrepreneurship, and economic development [1]. However, despite the growing body of research in this area, there is still a lack of integrated approaches that combine innovation transfer mechanisms with flexible manufacturing systems within a unified corporate management framework.

The novelty of this study lies in the development of an integrated corporate management model that combines innovation transfer processes, flexible manufacturing systems, and fuzzy decision-making methods within a unified digital environment. This gap motivates the development of integrated corporate management models that combine innovation transfer mechanisms with flexible manufacturing systems.

The Triple Helix model proposed in [1, 2] provides a theoretical framework for understanding the interactions between univers ities, industry, and government institutions. This model emphasizes the role of universities as knowledge creators and drivers of innovation. The primary strength of the Triple Helix model is its comprehensive explanation of institutional interactions within innovation ecosystems. A limitation, however, is the lack of practical guidance for designing internal corporate governance structures that integrate research and production processes.

Works [3, 4] extended this approach by analyzing the contribution of universities to regional economic growth and technological development. These studies demonstrate that universities play a key role in shaping entrepreneurial ecosystems and developing technology clusters. The advantage of these studies lies in the use of empirical and econometric methods to quantify the impact of academic innovation. However, their limitation lies in the insufficient elaboration of organizational mechanisms and operational management within universities.

The concept of open innovation, proposed in [5, 6], emphasizes the use of external knowledge sources and partnerships to accelerate innovation processes. This approach is widely applied in university-industry collaborations, improving technology transfer and the commercialization of research developments. The strength of the concept lies in its practical focus on external interactions, while its limitation is that it is primarily oriented toward the corporate sector and pays less attention to the internal management of universities and integration with industrial systems.

A number of studies focus on academic entrepreneurship and technology transfer mechanisms [6, 7]. These works provide a detailed analysis of how universities create technology transfer offices and interact with industrial partners to commercialize research. Their advantage is a comprehensive mapping of institutional practices, while a limitation is the lack of integration with digital manufacturing platforms or flexible manufacturing systems.

Work [8] analyzed the development of university innovation ecosystems and management practices that ensure effective interaction between research laboratories, start-ups, and industrial partners. In addition, it highlighted the role of digital platforms in coordination, project management, and technology transfer [9].

The main strength of these studies is the recognition of digital tools as key elements of innovation management. A limitation is the insufficient analysis of the integration of these processes with operational ones.

B. THE MAIN RESEARCH TASKS OF THE PAPER

1. Develop the concept and structure of an innovation transfer subsystem that ensures the integration of research laboratories, engineering centers, a business incubator, and a flexible manufacturing system.

2. Develop a structural and functional model of corporate governance, including strategic, managerial, and operational levels of interaction.

3. Formalize the key parameters of the innovation production system and develop a mathematical model for assessing project effectiveness, taking into account resource constraints.

4. Develop a decision-making model based on fuzzy logic (the Mamdani algorithm), including the creation of a database of fuzzy production rules.

5. Implement an algorithm for selecting the optimal innovation project for implementation in a flexible manufacturing system.

6. Conduct modeling and evaluate the effectiveness of the proposed approach using alternative projects as examples. To substantiate the practical applicability of the developed system for improving the efficiency of innovation management and accelerating technology transfer.

II. THE STRUCTURE OF A UNIVERSITY INNOVATIVE AND FLEXIBLE PRODUCTION SYSTEM: ANALYSIS AND OPERATING PRINCIPLES

Modern universities are key hubs for the integration of scientific research, innovation, and production processes. The development of an innovative production infrastructure requires the creation of unified corporate management systems capable of ensuring the effective coordination of all stages—from the generation of a scientific idea to the industrial implementation and commercialization of finished products. This integration allows the university not only to generate scientific results but also to quickly transform them into technologically mature and commercially viable products [9, 10]. Following the principle of integrating innovative projects developed at the university directly into the FMS, a structural framework for integrating the university innovative and flexible production system through ITS was proposed in [11]. The proposed framework includes research centers (R&D centers), specialized innovation centers, a business incubator, and FMS, ensuring synergistic interaction between science, innovation, and production.

The R&D centers are equipped with modern laboratory and production equipment, enabling them to conduct cutting-edge experimental research, test prototypes, and develop innovative technical solutions. They serve as the core of the university's research activities and form the foundation for applied projects and industrial implementation. The R&D center establishes specialized innovation centers working in the following areas:

- mechatronics and robotics;
- mechanics and materials science;
- automation of industrial processes;
- transport technology;
- energy supply and alternative energy sources.

Each center develops applied projects and prototypes, ensuring that solutions are ready for industrial implementation [12]. This organization allows for the concentration of expertise in narrow areas while simultaneously conducting parallel development in several areas. The R&D center provides systemic support for startups, including business model development, commercialization support, and interaction with industrial partners and investors. The business incubator is a key link between research and development and the release of innovative products, i.e., the FMS. The FMS functions as an adaptable production unit, capable of quickly reconfiguring to produce innovative products developed in the research centers and innovation centers [13, 14]. The primary

function of the FMS is to bring prototypes to the mass production stage and release finished startup products ready for commercialization.

The university innovation and production system is based on the following key principles:

1. Integration of science and production: Research and prototypes from research centers are directly linked to the FMS's production tasks, ensuring a continuous technological cycle.

2. Specialization and parallel development: Innovation centers, each with its own focus, allow for the simultaneous implementation of several projects in different technological fields, increasing efficiency and speed of implementation.

3. Startup support: The business incubator provides the full path from idea and prototype to commercially viable product, supporting the entrepreneurial activity of students and researchers [15].

4. Flexibility and adaptability of production: The ITS is capable of quickly reconfiguring to accommodate new projects and scaling production as market demands change.

5. Digital coordination: Using an integrated digital platform enables project management, resource tracking, data exchange, and control of the entire process from development to production.

Based on the key operating principles of the innovation and production system, a conceptual framework for integrating all components of the university-based innovation and production system (using Sumgayit State University as an example) is being developed (Figure 1). This framework represents an architectural model in which the innovation and ITS is the fundamental core, ensuring the integrated operation of the innovation and flexible production system. A digital control platform ensures the efficiency of the operation.

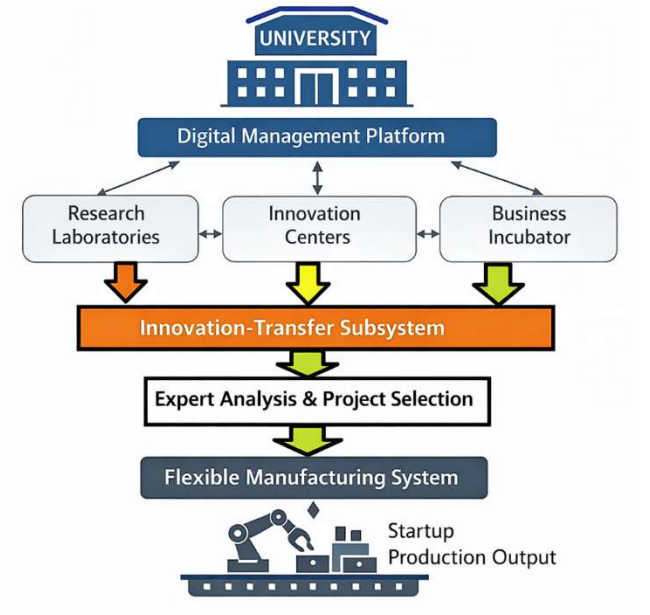


Figure 1. Conceptual diagram of the integration of all components of the study, innovation and production system based on the university

The corporate governance architecture for the university innovative and flexible production system, presented in Figure 1, is justified by the need to bridge the gap between the research stages, innovative design, and industrial implementation. Unlike traditional models, where these processes operate in a fragmented manner, the proposed structure ensures their integration within a single digital management platform.

The key element of the system is the innovation-transfer subsystem, which acts as an intelligent integrator, aligning information flows and coordinating interactions between scientific, innovative, and entrepreneurial structures. The introduction of this element allows for the formalization of the process of transition from a scientific idea to serial production, significantly increasing the efficiency of technology transfer.

The scientific contribution of this study lies in the formalization of an integrated model for coordinating university research, innovation, technology transfer, and flexible manufacturing processes within a unified digital management system. The proposed model includes a subsystem for transferring innovations from a flexible manufacturing system and allows for a formal representation of a mechanism for evaluating innovative projects under conditions of resource constraints and uncertainty [16, 17]. Mamdani's fuzzy inference approach is used to represent linguistic assessments of resource availability, project implementation status, and investment attractiveness, and to transform these criteria into an integrated project performance indicator. The proposed approach provides a formal decision-making mechanism that can be implemented as a software prototype and subsequently tested in real-world university-industry interactions, as well as in flexible manufacturing settings.

An additional innovation is the formalization of the innovation project selection procedure using fuzzy inference (the Mamdani algorithm), which allows for the consideration of uncertainty in initial data and improves the validity of decisions [18-20].

Thus, the proposed framework creates a holistic innovation and production ecosystem that ensures the accelerated commercialization of scientific developments and adaptive management of production processes.

III. CORPORATE GOVERNANCE MODEL FOR THE UNIVERSITY INNOVATION AND PRODUCTION SYSTEM

As Figure 1 shows, the innovation and production system is a complex, multifunctional, multi-tiered system, where research and development centers, scientific centers, and a business incubator interact with the flexible production system via an innovation transfer subsystem. The ITS is an intelligent software-server toolkit that incorporates expert knowledge bases based on fuzzy rules, multi-level analysis, and decision-making for selecting an innovative project for its serial production in the FMS. When selecting a project for serial production in the FMS, a comprehensive review of technical, engineering, functional, innovative, and economic indicators is required. Therefore, to ensure reliable, effective, and productive interaction between the subsystems of the innovation and production structures, we will consider developing a corporate governance model for the university innovation and production system through the ITS. Corporate governance can be formalized as a three-tier management system, including strategic, managerial, and operational levels, with a digital decision support platform [21].

ITS formalizes for corporate governance between innovative structures and the FMS as N separate research laboratories, M engineering and design innovation centers, a startup business incubator L, and flexible manufacturing modules K, which are part of the FMS. In accordance with the

indicators of these structures (*N, M, L, K*) and the parameters that depend on them, we write the following set [22]:

$$(R_i(t);\ S_k(t);\ I_l(t));\ P_j(t)), \tag{1}$$

where $R_i(t)$ is the resource load on the *i*-th laboratory at time *t* (man-hours, equipment), $\forall\ i \in \{N_i\},\ i=1,n$; $S_k(t)$ is the implementation status of the *k*-th innovative project, $\forall\ k \in \{M_k\},\ k=1,n$; $I_l(t)$ is the investment attracted to the *l*-th startup, $\forall\ l \in \{L_l\},\ l=1,n$; $P_j(t)$ is the production capacity of the *j*-th flexible manufacturing module (FMM) of the FMS at time *t*, where $\forall\ j \in \{K_j\}, j=1,n$.

In accordance with the objective set in this article, the goal of the proposed ITS is to use this toolkit to maximize the effect of technology transfer to one of the FMM production modules and the commercialization of innovations, taking into account the resource and production capacity constraints.

To model the process of expert analysis and selection of projects for industrial implementation and their serial production, we will write a function for the efficiency of using the proposed ITS toolkit, based on the maximum importance of laboratory testing, production in the innovation center, commercialization in business incubation, and, ultimately, the need for serial production in a particular FMM of the FMS. The expression representing these conditions can be written as:

$$\max U(t) = \sum_{i=1}^{N} \vartheta_i R_i(t) + \sum_{k=1}^{M} \alpha_k S_k(t) + \sum_{l=1}^{L} \beta_l I_l(t), \tag{2}$$

where ϑ_i, α_k, β_l are respectively weighting coefficients reflecting the strategic importance of scientific research projects in *N* individual research laboratories; the importance of innovative activity in *M* specialized innovation centers; the importance of commercialization of *L* startups in the incubation center, depending on the need for industrial production of innovative projects in the FMM FMS.

In this case, we establish resource constraints for each structure of the innovation and production system. These expressions can then be written as follows [23]:

For the research center

$$\sum_{i=1}^{N} \vartheta_i R_i(t) \le R_{\max}, \tag{3}$$

where R_{max} is the total available resource (man-hours, computer workstations for simulation, laboratory equipment for testing).

For the innovation center

$$\sum_{k=1}^{M} \alpha_k S_k(t) \le S_{\max}, \tag{4}$$

where S_{max} is the total available resource (man-hours, assembly equipment-machines and 3D printers).

For business incubation center

$$\sum_{l=1}^{L} \beta_l I_l(t) \le I_{\max}, \tag{5}$$

where I_{max} is the total available resource (man-hours, financial calculation systems, commercialization, business).

When selecting a project for serial production in the FMS FMM, taking into account (3), (4) and (5), it is also necessary to establish limitations on the production capacity of the FMS in the form of [24]:

$$0 \le P_j(t) \le P_j^{\max},\ j = \overline{1,K}, \tag{6}$$

Taking into account the balance of resources between projects and the FMS, the conditional expression can be written as follows:

$$\max U(t) = \sum_{i=1}^{N} \vartheta_i R_i(t) + \sum_{k=1}^{M} \alpha_k S_k(t) + \sum_{l=1}^{L} \beta_l I_l(t) \le (R_{total} + S_{total} + I_{total}), \tag{7}$$

Fuzzy modeling can be used to optimally allocate resources between projects, laboratories, innovation structures, and production modules of the FMS system, manage them, and select projects for serial production within the FMS system. Since classical deterministic models are insufficient under the conditions of high uncertainty typical of innovation activities (incomplete data, expert-based assessments [25], and a dynamic environment), the use of fuzzy logic is therefore proposed, allowing for the formalization of qualitative and linguistic assessments.

Formalization of fuzzy parameters of the ITS for the effective selection of a project for the purpose of their serial production in the production module of the FMS is carried out by entering the main parameters of the research object in fuzzy form:

$$\widetilde{R}_i(t),\ \widetilde{S}_k(t),\ \widetilde{I}_l(t), \tag{8}$$

where $\widetilde{R}_i(t)$ - fuzzy estimate of the resource load of the *i*-th research laboratory; $\widetilde{S}_k(t)$ – fuzzy status of the implementation of the *k*-th project of the innovation center; $\widetilde{I}_l(t)$ - fuzzy value of investments in the *l*-th startup in the business incubation center.

Each variable is defined as a linguistic variable with a term set:

$$\widetilde{X} \in \{low, average, high\} \tag{9}$$

Membership functions are specified $\mu(x)$ in the form of a triangular and trapezoidal function.

To select an innovative project for serial production in the FMM FMS, it is necessary to write the efficiency function of the ITS (2) in fuzzy form:

$$\widetilde{U}(t) = \sum_{i=1}^{N} \widetilde{\vartheta}_i \widetilde{R}_i(t) + \sum_{k=1}^{M} \widetilde{\alpha}_k \widetilde{S}_k(t) + \sum_{l=1}^{L} \widetilde{\beta}_l \widetilde{I}_l(t), \tag{10}$$

where $\tilde{\vartheta}_i, \tilde{\alpha}_k, \tilde{\beta}_l$ - weighting coefficients specified as fuzzy numbers.

The constraints for the functions of the research, innovation, incubation and production center of the system are written in the form of fuzzy inequalities:

$$\sum_{i=1}^{N} \widetilde{\vartheta}_i \widetilde{R}_i(t) \le \widetilde{R}_{\max}, \tag{11}$$

$$\sum_{k=1}^{M} \widetilde{\alpha}_k \widetilde{S}_k(t) \le \widetilde{S}_{\max}, \tag{12}$$

$$\sum_{l=1}^{L} \widetilde{\beta}_l \widetilde{I}_l(t) \le \widetilde{I}_{\max}, \tag{13}$$

$$0 \le \widetilde{P}_j(t) \le \widetilde{P}_j^{\max},\ j = \overline{1,K}, \tag{14}$$

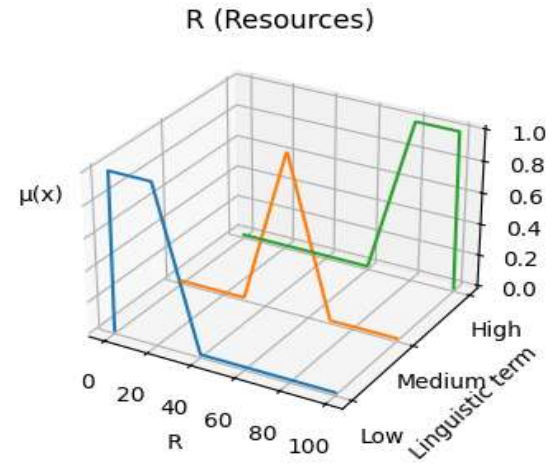
Let us consider three projects undergoing scientific research in a laboratory setting and assembled at the innovation center. Commercialization of these projects at the incubation center then requires the creation of business models and a trial period. Only after these project procedures are their output data analyzed and stored in the ITS.

The next stage of the ITS operation is the development of an expert system to activate the process of selecting the most effective and innovative project (project *A*, project *B*, project *C*) intended for serial production in the FMS production module [26]. Thus, a knowledge base is developed for the ITS, represented by a system of fuzzy production rules of the following form: linguistic scale – numerical interpretation. We adopt the fuzzy number centers as shown in Table 1.

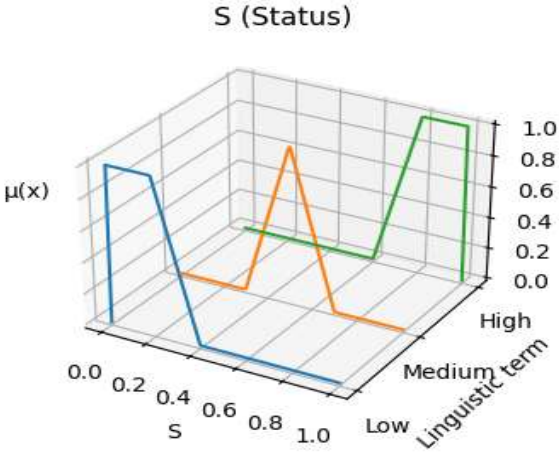
Table 1. Fuzzy estimates of input parameters for project selection assessment

Parameter	Term	Type	Parameters
R (resources)	Low (L)	Trapezoidal	(0, 0, 20, 40)
	Medium (M)	Triangular	(30, 50, 70)
	High (H)	Trapezoidal	(60, 80, 100, 100)
S (status)	Low (L)	Trapezoidal	(0, 0, 0.2, 0.4)
	Medium (M)	Triangular	(0.3, 0.5, 0.7)
	High (H)	Trapezoidal	(0.6, 0.8, 1, 1)
I (investment)	Low (L)	Trapezoidal	(0, 0, 200, 400)
	Medium (M)	Triangular	(300, 500, 700)
	High (H)	Trapezoidal	(600, 800, 1000, 1000)

In accordance with the presented values of *R, S, I* parameters, by comparing them graphically, one can obtain a visual representation of the accepted linguistic terms and their membership functions (Fig. 2).



a)



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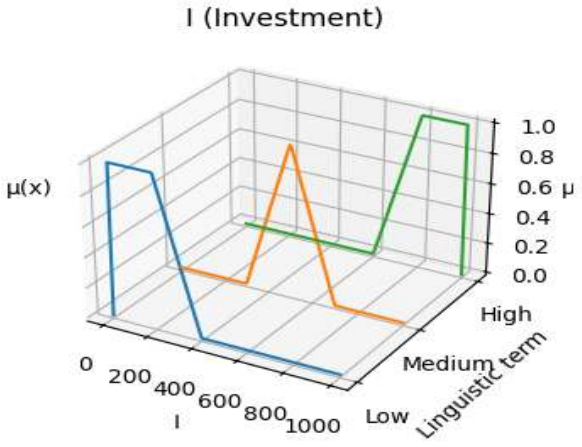

c)

Figure 2. Three-dimensional representation of fuzzy membership functions for the input variables of the Innovation Transfer System (ITS): (a) resources load R, b) project implementation status S, (c) investment level I.

The three-dimensional representation of membership functions provides a more informative visualization of the fuzzy parameter space, where the horizontal axis represents the parameter value, the vertical axis represents the membership degree, and the depth axis corresponds to linguistic terms (*Low, Medium, High*). This allows a better understanding of the overlap and transition between fuzzy sets used in the ITS decision-making process. Each variable is described using linguistic terms *Low*, *Medium* and *High*, defined by trapezoidal and triangular membership functions.

Let us accept the weighting coefficients according to the importance of the input parameter *R, S, I* (table 2):

Table 2. Weighting coefficients of input parameters

Parameter	Weighting coefficient
ϑ (research laboratory resources)	0.35
α (innovative project status)	0.40
β (incubation process investments)	0.25

The values of (R), (S), and (I) are entered directly into the fuzzification stage. The corresponding membership degrees are then calculated using the membership functions defined in Table 1. The same input values are used for all comparative methods to ensure a consistent experimental basis.

Taking into account expression (10), the input data of projects *A, B, C* and the data of the weighting coefficients, we determine the efficiency function of these projects (Fig. 3) Therefore, for project A, $U_A = 0.62$; $U_B = 0.68$; $U_C = 0.395$.

Let us assume that the permissible resource of the ITP system $R_{total} + S_{total} + I_{total} = 1.5$. Then, based on (7), the resource constraints as in Table 3 check.

Table 3. Verification of projects in accordance with the efficiency function and the permissible resource of the ITP system

Project	The efficiency function of the ITP (*U*)	Condition
A	0.62	$0.62 \leq 1.5$
B	0.68	$0.68 \leq 1.5$
C	0.395	$0.395 \leq 1.5$

According to the obtained values of U_A, U_B, U_C it is clear that by comparing these values with the permissible resource of the ITP system, we can finally select the optimal design option for serial production in FMS.

Based on fuzzy modeling and defuzzification of linguistic variables characterizing research laboratory resources, the status of innovative projects, and the investment parameters of the incubation process, an integral function of project efficiency was calculated. It was found that the maximum value of the efficiency function corresponds to project B ($U_B = 0.68$).

The efficiency function surface shown Figure 2 demonstrates the nonlinear relationship between the integral indicator and the input parameters. Maximum values are achieved at high resource, status, and investment levels, confirming the selection of the project *B*.

Taking into account the constraints on the system's overall resources, this project is the most preferable for implementation in serial production under the conditions of a flexible manufacturing system.

IV. DESIGN OF ITS SOFTWARE FOR PROJECT SELECTION AND IMPLEMENTATION IN FMS

This section presents the design and reference implementation of a software innovation transfer subsystem for selecting effective projects and supporting decision making in an agile manufacturing environment. The developed software architecture is designed to support resource assessment, project ranking, and the selection of innovative projects for potential implementation in an agile manufacturing environment. The proposed architecture is based on Mamdani's fuzzy inference and provides a foundation for decision making under uncertainty and resource constraints. At this stage, the implementation is considered a research prototype.

In contrast to existing approaches, an intelligent ITS software architecture is proposed based on fuzzy logic methods, providing adaptive selection of projects under conditions of uncertainty and resource constraints.

The ITS software architecture (Fig. 3) is built on a modular-service principle and includes the following main components: data collection and processing module (laboratories, innovation center, incubator); expert knowledge base (based on fuzzy rules and linguistic variables); fuzzy inference module**;** module for evaluating project effectiveness**;** decision making module**;** interface for interaction with the user and FMS**.**

To evaluate the mathematical model and obtain numerical experimental values, a reference implementation of the proposed algorithm with fuzzy decision making was presented. The implementation steps include five functional components: input data processing, membership function calculation, fuzzy rule evaluation, centroid aggregation and defuzzification, and project ranking.

The implementation process is based on a modular structure, where project data is stored as records containing identifiers and numerical values (R), (S), and (I). The fuzzy model includes the parameters of all input and output membership functions and a complete knowledge base of 27 rules.

Computation sequence:

1. Reading project data;
2. Checking input ranges;
3. Calculating membership degrees for (R), (S), and (I);
4. Calculating the trigger strength of all 27 rules;
5. Applying the principle of implication minimization;
6. Aggregating all rule output values using the maximum operator;
7. Calculating the centroid of the aggregated result;
8. Storing the obtained values (U);
9. Ranking all projects according to (U);
10. Conducting comparative and sensitivity analysis.

The ITS software architecture is oriented towards integration with the university corporate information environment and the FMS production modules, ensuring scalability and expandability of the system.

The expert knowledge base is formed on the basis of expert assessments and is presented in the form of fuzzy production rules:

IF (*R* — resource level)
AND (*S* - project status)
AND (*I* - investment)
THEN (*U* is the level of project efficiency).

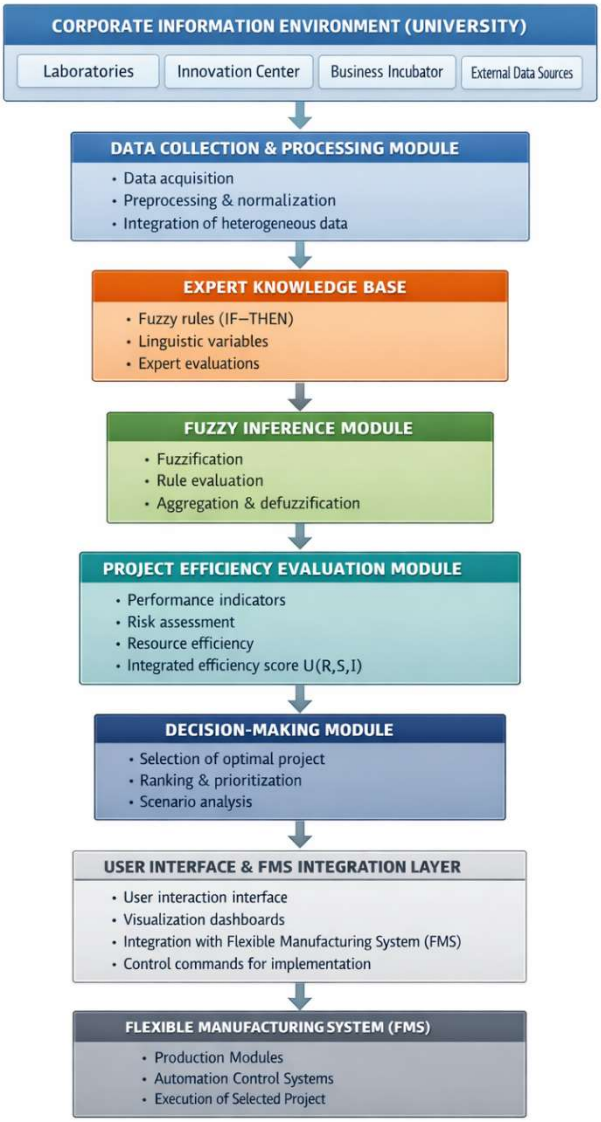

Figure 3. ITS software architecture.

Linguistic variables for research, innovation and incubation centers term sets are defined in the form of the following term sets: *R* (Resources): Low, Medium, High; S (Status): Low, Medium, High; *I* (Investment): Low, Medium, High; *U*

(Efficiency): Very Low, Low, Medium, High, Very High. In accordance with these term sets, we create basic rules for the software implementation of the ITS group subsystem:

Group 1 – Very High and High efficiency

1. IF (R) is High AND (S) is High AND (I) is High THEN (U) is Very High.
2. IF (R) is High AND (S) is High AND (I) is Medium THEN (U) is High.
3. IF (R) is High AND (S) is High AND (I) is Low THEN (U) is High.
4. IF (R) is High AND (S) is Medium AND (I) is High THEN (U) is High.
5. IF (R) is High AND (S) is Medium AND (I) is Medium THEN (U) is High.
6. IF (R) is Medium AND (S) is High AND (I) is High THEN (U) is High.

Group 2 – Medium efficiency

7. IF (R) is High AND (S) is Medium AND (I) is Low THEN (U) is Medium.
8. IF (R) is High AND (S) is Low AND (I) is High THEN (U) is Medium.
9. IF (R) is High AND (S) is Low AND (I) is Medium THEN (U) is Medium.
10. IF (R) is Medium AND (S) is High AND (I) is Medium THEN (U) is Medium.
11. IF (R) is Medium AND (S) is Medium AND (I) is High THEN (U) is Medium.
12. IF (R) is Medium AND (S) is Medium AND (I) is Medium THEN (U) is Medium.
13. IF (R) is Low AND (S) is High AND (I) is High THEN (U) is Medium.

Group 3 – Low efficiency

14. IF (R) is Medium AND (S) is High AND (I) is Low THEN (U) is Low.
15. IF (R) is Medium AND (S) is Low AND (I) is High THEN (U) is Low.
16. IF (R) is Medium AND (S) is Low AND (I) is Medium THEN (U) is Low.
17. IF (R) is Low AND (S) is High AND (I) is Medium THEN (U) is Low.
18. IF (R) is Low AND (S) is Medium AND (I) is High THEN (U) is Low.
19. IF (R) is High AND (S) is Low AND (I) is Low THEN (U) is Low.

Group 4 – Very Low efficiency

20. IF (R) is Low AND (S) is Low AND (I) is Low THEN (U) is Very Low.
21. IF (R) is Low AND (S) is Low AND (I) is Medium THEN (U) is Very Low.
22. IF (R) is Low AND (S) is Medium AND (I) is Low THEN (U) is Very Low.
23. IF (R) is Medium AND (S) is Low AND (I) is Low THEN (U) is Very Low.
24. IF (R) is Low AND (S) is Medium AND (I) is Medium THEN (U) is Low.
25. IF (R) is Medium AND (S) is Medium AND (I) is Low THEN (U) is Low.
26. IF (R) is Low AND (S) is High AND (I) is Low THEN (U) is Low.
27. IF (R) is Low AND (S) is Low AND (I) is High THEN (U) is Low.

The output variable U, representing project effectiveness, is defined as a normalized set using five linguistic terms: Very Low, Low, Medium, High, and Very High. To ensure overlapping transitions between adjacent linguistic states, triangular and trapezoidal membership functions are used (Table 4).

Table 4. Triangular and trapezoidal membership functions with finals output terms and parameters

Output term	Membership function	Parameters
Very Low	Trapezoidal	(0, 0, 0.10, 0.25)
Low	Triangular	(0.15, 0.30, 0.45)
Medium	Triangular	(0.35, 0.50, 0.65)
High	Triangular	(0.55, 0.70, 0.85)
Very High	Trapezoidal	(0.75, 0.90, 1.00, 1.00)

For output variable U ∈ [0,1], the output membership functions are as follows:

$\mu_{Very\ Low}(U)$=trapmf(U; 0, 0, 0.10, 0.25)

$\mu_{Low}(U)$=trimf(U; 0.15, 0.30, 0.45)

$\mu_{Medium}(U)$=trimf(U; 0.35, 0.50, 0.65)

$\mu_{High}(U)$=trimf(U; 0.55, 0.70, 0.85)

$\mu_{VeryHigh}(U)$=trapmf(U; 0.75, 0.90, 1.00, 1.00).

The output membership functions obtained above can be represented graphically, as shown in Figure 4.

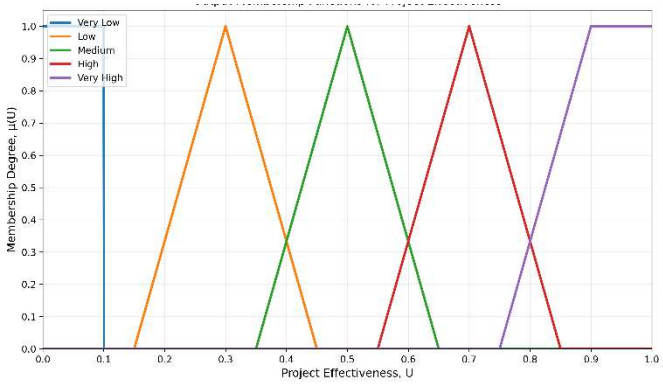

Figure 4. Output membership functions for project effectiveness

Taking into account the values in Table 1 and above, the rules developed for the core of expert knowledge of the ITS software architecture, a final rule for selecting the optimal project is drawn up:

IF U is Maximum AND Resource Constraint is Satisfied *THEN* Select Project for FMS Implementation.

A graphical representation of the input current data of the states of a set of projects, respectively, researched, manufactured and commercialized sequentially in the research, innovation and incubation centers for their effective selection of the best optimal project for the purpose of manufacturing in the production modules of the FMS using the fuzzy logic method is shown in the block diagram (Fig. 5).

The ITP software operational sequence begins with collecting input data from the current *R, S and I* values for each project. Next, the numerical values are converted into membership degrees in the following form:

$$\mu_{low}(x),\ \mu_{medium}(x),\ \mu_{high}(x) \qquad (15)$$

Fuzzy inference is implemented (Mamdani) with the use of knowledge base rules in the form of a logical operation *AND* →*min* and aggregation → *max*. Next, for defuzzification

The center of gravity method is used to transform the fuzzy result into a crisp value. After defuzzification, the U value can be further adjusted using a weighted linear combination of factors:

$$U = \vartheta R + \alpha S + \beta I, \quad (16)$$

where R, S, and I represent the corresponding decision factors, while ϑ, α, and β are expert-defined weighting coefficients satisfying, for example $\vartheta+\alpha+\beta=1$.

The final project performance indicator is determined solely by the defuzzified Mamdani output:

$$U_{final}=Defuzz(\mu^{agg}{}_U) \quad (17)$$

In this case, the weighted coefficients ϑ, α, and β are not used to adjust U. If necessary, membership functions are directly included during the design of the fuzzy knowledge base. This ensures model consistency, prevents double counting, and preserves the interpretability of Mamdani's fuzzy decision-making mechanism.

The selection of a project for serial production in FMS is carried out using the following expression:

$$U_{opt} = max(U_A, U_B, U_C) \quad (18)$$

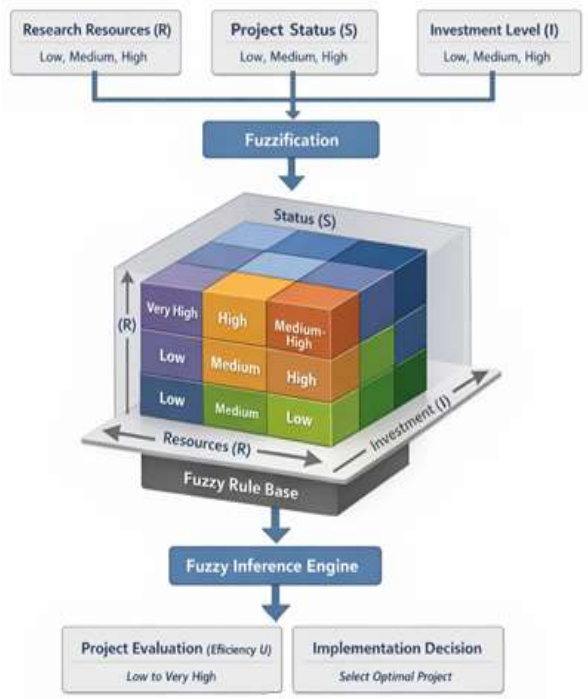

Figure 5. Block diagram of Mamdani's fuzzy algorithm.

The developed software architecture of the ITP based on fuzzy logic allows:

- take into account uncertainty and expert assessments;
- automate the process of selecting an innovative project;
- ensure informed decision-making;
-increase the efficiency of integration of science, innovation and production.

The operation of the ITS software is carried out according to the following algorithm:

1. Entering values of parameters *R, S, I*;
2. Input data fuzzification;
3. Application of fuzzy rule base;
4. Implication (operation *AND* → *min*);
5. *max* operation;
6. Defuzzification (center of gravity method);
7. Calculation of project efficiency;
8. Selecting the optimal project.

Unlike classical multicriteria selection methods (AHP, TOPSIS), the proposed approach takes into account the ambiguity of initial data; handles linguistic variables; and ensures the model's flexibility and adaptability. The developed system can be applied in university technology parks, innovation clusters, and Industry 4.0 digital production systems.

Thus, the proposed approach provides intelligent support for FMS control and allows for the efficient selection of optimal projects for serial production. As a result of the software implementation, the Mamdani fuzzy inference system generated a 3D efficiency surface (Fig. 6), $U=f(R,S,I)$.

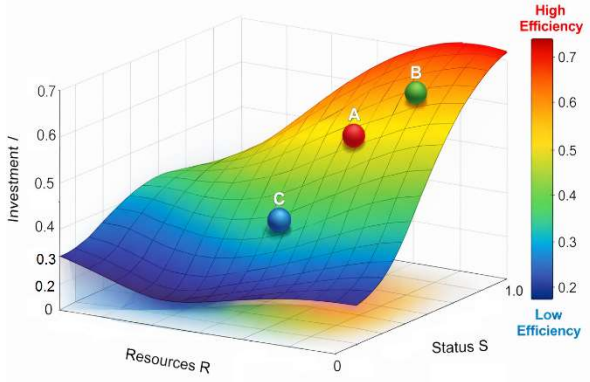

Figure 6. Graph of the efficiency function of projects A, B, C.

The resulting graph with visualization, where all three projects have their positions according to the obtained values of the nonlinear surface of the graph of the efficiency function of projects *A, B, C* and the color of the surface corresponding to the scale, shows the level of efficiency of the selected most optimal project for serial production in the FMS.

V. DISCUSSION

The results obtained in this study provide a computational implementation of the proposed corporate governance system and its core intelligent component—fuzzy decision support for selecting innovative projects. The developed model provides a formalized mechanism for coordinating research, innovation, technology transfer, and flexible manufacturing processes within a single digital framework. Numerical experiments demonstrate that the proposed approach, based on the Mamdani model, can transform resource availability, project implementation status, and investment attractiveness into an integrated project performance indicator and can be used to rank alternative projects.

The obtained results can be interpreted as validation at the simulation and prototype levels. The experimental evaluation is based on a limited number of alternative projects and simulated input data. Therefore, the practical effectiveness of the proposed system in a real-world university-industrial and flexible manufacturing environment requires further empirical verification.

One of the key findings of this research is the successful application of fuzzy logic for modeling decision-making processes in innovation management. Unlike traditional deterministic approaches, the fuzzy inference system enables the incorporation of expert knowledge and linguistic variables,

which are essential in environments characterized by incomplete, uncertain, and qualitative data. The use of the Mamdani algorithm allowed the transformation of complex multidimensional input parameters (resources, project status, and investments) into a single integral efficiency indicator.

A comparison of projects A, B, and C demonstrates the process of the proposed decision-making mechanism. Since a demonstration using three projects alone is insufficient to confirm overall robustness, the robustness process is also assessed separately using sensitivity analysis and comparative experiments. This result highlights the capability of the ITS to support strategic decisions in selecting projects for industrial implementation within FMS.

To ensure the robustness of the project ranking to changing model parameters, a sensitivity analysis was conducted, considering three perturbation scenarios: a ±10% change in criterion weights, a ±10% change in the membership function boundaries, and a 10% change in the fuzzy rules. For each scenario, the project rankings were recalculated and compared to the baseline rankings based on the Spearman rank correlation coefficient and the percentage of cases, with the best project remaining unchanged.

Another important outcome is the demonstration of the adaptability of the proposed system. The integration of research laboratories, innovation centers, business incubators, and production modules into a unified digital platform ensures continuous information flow and synchronization of processes. This significantly reduces the time required for technology transfer from research to production and enhances the responsiveness of the system to dynamic changes in external conditions.

Mamdani's proposed model was compared with three baseline approaches: the weighted sum method, AHP, and TOPSIS. All methods used the same design alternatives and the same input criteria (R), (S), and (I). The applied experimental framework prevents ranking differences caused by different sets of input data (Table 5).

Table 5. Definition of the best project and its ranking agreement and characteristics

Method	Best project	Ranking agreement with Mamdani	Main characteristic
Mamdani FIS	P23	1.000	Handles linguistic uncertainty
Weighted Sum	P23	0.91	Simple deterministic aggregation
AHP	P23	0.89	Pairwise-criteria comparison
TOPSIS	P23	0.94	Distance from ideal solution

The comparison shows that Mamdani's approach provides an explicit representation of linguistic uncertainty and expert knowledge, while showing its suitability for the decision-making task at hand.

At the same time, it should be noted that the effectiveness of the fuzzy model depends on the quality of the expert knowledge base and the correctness of membership function design. Inaccurate parameterization may lead to biased results. Therefore, further research should focus on hybrid approaches combining fuzzy logic with machine learning techniques for automatic tuning of rules and parameters.

The proposed architecture is also aligned with the principles of Industry 4.0, including digital platforms, cyber-physical systems, and intelligent decision support. This confirms the applicability of the model in modern smart manufacturing environments and university-based innovation ecosystems.

Additionally, the study demonstrates that the integration of ITS improves:

- decision-making speed (reduction of selection time);
- reliability of project evaluation under uncertainty;
- scalability of innovation processes.

However, the study has several limitations. The experimental validation is based on a limited number of projects and simulated data. Real-world implementation in industrial environments is required to fully validate the model. Furthermore, the current system does not incorporate real-time data streams or predictive analytics, which could further enhance its performance.

Future research should address these limitations by:

- integrating real industrial datasets;
- applying machine learning for adaptive rule generation;
- extending the model with digital twin technology;
- developing cloud-based platforms for large-scale deployment.

In summary, the discussion confirms that the proposed corporate management system with an innovation transfer subsystem represents a promising direction for improving the efficiency of university innovation ecosystems and accelerating the commercialization of scientific research.

Despite the promising results, the experimental validation is limited to three projects. Therefore, future work should focus on extending the dataset and validating the proposed model using real industrial case studies and larger-scale implementations.

V. CONCLUSIONS

This study presents an integrated corporate governance system for coordinating research, innovation, technology transfer, and flexible manufacturing processes in a university environment. The proposed system integrates research laboratories, innovation centers, a business incubator, and flexible manufacturing modules through an innovation transfer subsystem and a unified digital management architecture.

The main scientific contribution of the study is the formalization of a fuzzy decision-making model for selecting innovative projects under uncertainty and resource constraints. Using Mamdani's inference mechanism, it derives resource availability, project implementation status, and investment attractiveness using linguistic variables and fuzzy membership functions, transforming these criteria into an integrated project performance indicator.

The developed benchmark software implementation demonstrates the computational feasibility of the proposed approach. The constructed Mamdani fuzzy inference model was applied to alternative projects, yielding corresponding performance indicators. The model also provides a systematic procedure for fuzzification, fuzzy rule evaluation, aggregation, defuzzification, and project ranking.

A comparative analysis using the weighted sum method, AHP, and TOPSIS demonstrates the applicability of the proposed fuzzy approach to the project selection problem under consideration. However, the results should be interpreted as a research prototype and formal decision support mechanism, rather than as a fully implemented production management system. Its practical effectiveness requires further verification using real university-industry projects, large datasets,

independently assessed expert knowledge, and data obtained from flexible manufacturing systems.

Future research will focus on experimental implementation in a real university innovation ecosystem, integration with real-time manufacturing and corporate information systems, expansion of the experimental dataset, adaptive tuning of membership functions and fuzzy rules, and integration with digital twin and machine learning technologies.

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