Chapter

Application of Fuzzy Expert Systems in IT Project Management

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Abstract

The available statistics show the growing influence of the IT market on the world economy over the last decade. According to expert information, this situation will continue, despite the IT sector's economic crises, uneven development, and periodic fluctuations. The need to involve fuzzy expert systems (ES) in the IT field is stated, based on the high uncertainty level due to specifics of IT project management. The hypothesis of embedding ES in an IT company's business process management to increase the efficiency of operational and strategic decisions is tested. The structure of ES is offered, built on the basis of fuzzy logic using a combined model of the semantic network and implication rules. The operation of the system is demonstrated in the example of managing an IT company's current business processes to maximize its profits. Comparing the conclusions of the ES with the historical decisions of a real company demonstrates the feasibility of implementing the ES. The operation of the developed ES, using the knowledge base formed on the basis of 30 Ukrainian IT companies, confirmed the effectiveness of its use as a tool to support management decisions and increase the IT sector's financial performance.

Keywords: IT market, IT company, expert system, fuzzy logic, IT business processes, management decisions, project management

1. Introduction

One of the distinguishing features of recent years has been the exponential growth of digital data aggregation. This is accompanied by the expansion of big data analytics, artificial intelligence, cloud computing, and digital platforms. As more devices access the Internet and the number of people using digital services grows, the role of digital data and technology is becoming more widespread, and the digital economy is evolving at a breakneck pace [1]. The information and communication technology (ICT) industry is at the heart of much of this activity, supporting the digital economy and serving as a reliable measure of its effectiveness.

ICT plays a crucial role in the economy not only as a source of potential income but also as a vector of cross-growth, making profound changes in various sectors of the economy. Technologies such as the Internet of Things, robotics, artificial intelligence, cloud computing, big data analysis, 3D printing, and many others are already changing the way businesses design, produce and provide services.

Despite how important IT projects are to all aspects of the modern world, their management is not an ideal process. A recent survey conducted by Standish Group showed that 19% of over 50,000 software projects are failed and never completed [2]. At the same time, over the previous 10 years, the percentage of failures varied from 17–22%, which indicates the regularity of this problem in software engineering [3]. In the context of numerous crisis phenomena of the world economy, against the background of these trends, the importance of the main subjects in the IT industry (product and outsourcing IT firms) and tools to improve the efficiency of their operational business processes is growing. One of the innovative directions is the use of technologies like ES in the management processes to better plan and execute project development. Although the use of expert systems in economics and management is not entirely new, the dynamics of research and application of this artificial intelligence apparatus over the past 20–40 years have undergone significant changes and fluctuations—from discovery and active development to a significant decline, and again to the current trend of scientific recovery and the practical interest of specialists in various fields.

Accordingly, the tasks of the analysis of the history of development and use of expert systems in IT project management are set. The expediency and prospects of using the ES in the management of business processes in IT companies as innovative management methods that take into account the vagueness and uncertainty of the information environment of the facilities are proven. The positive impact of the introduction of intelligent technologies, including fuzzy ones, on the management processes of IT companies is demonstrated, which is reflected in the main financial indicators of their operation.

The article is organized as follows. Section 2 confirms the relevance of embedding expert systems in the overall business process management of IT companies. A retrospective of ES research and examples of applications of specific applications in various fields of economics and management are presented. Section 3 discusses the working hypotheses of the study; the ES architecture developed on the basis of fuzzy logic is offered. Section 4 provides a statement of the simulated situation, which is used for expert consultations using the appropriate knowledge base; an example of forming a knowledge base is described based on information provided by 30 IT companies of Ukraine, as well as using the expertise of agile specialists; the conclusions of the fuzzy expert system obtained as a result of its implementation (expert consultations) and historical decisions made by a functioning IT company are presented. Section 5 provides a comparative analysis of the results of the expert system inference conclusions and the real conclusions of a functioning IT company. Section 6 is devoted to outlining potential ways of further research to determine the useful consequences of the implementation of the proposed mathematical apparatus.

2. Historical analysis and overview

2.1 IT project management research analysis

The characteristic features of a software project are a large amount of research and development work, high uncertainty in the type, timing and cost of work, significant risks, and high costs. On top of that software development is associated with a high degree of complexity in a constantly changing environment. Thus, software projects demand effective management using innovative approaches.

Problems of IT project management are researched in many literature sources. Tam et al. in Ref. [4] conducted a survey of 216 agile professionals and identified the main human factors for the success of agile software development projects. In Ref. [5] Fink and Pinchovski presented an empirical study of the bias of the decision to save time in a software development project by increasing the speed of development and proposed methods to combat this bias. In Ref. [6] Hoffmann et al. presented the principles of designing strategically consistent and effective, but flexible portfolios of IT projects. Einhorn et al. in Ref. [7] consider the importance of taking into account the business case throughout the project life cycle and also provides valuable information on ways to avoid common mistakes and achieve the planned strategic benefits of the project. Lin et al. explore in Ref. [8] how to improve the integration of knowledge by actively addressing the problem of project uncertainty and proposes different management regimes, taking into account the types of uncertainty. In Ref. [9] Bjorvatn and Wald conducted an empirical study of the relationship between project complexity and management efficiency and determined the crucial importance of absorption capacity at the team level. Keil et al. in Ref. [10] research the impact of project management constraints on the possible escalation of software projects. In their work, Tavares et al. [11] analyzed different risk management strategies carried out in Scrum software projects and developed a novel risk management framework.

One of the key issues faced by both software developers and customers is to consider the degree of risk inherent in the various stages of IT project deployment. In [12–17] the classification of risks, their sources—related to incorrect determination of project volumes [13], excess of project costs [14], errors in budget planning [15, 16], deviations from deadlines performance [17].

Several works are devoted to automating some parts of IT project management activities. Alba and Chicano in Ref. [18] applied genetic algorithms to optimally allocate resources for IT projects. Uzzafer in Ref. [19] presented a simulation model for strategic IT project management. The results of the simulation determine the budget and schedule required for a project.

In the process of preparing and implementing a software project, the manager is forced to make decisions in conditions of uncertainty, based on incomplete or inaccurate information about the current state and prospects of the project's development. It is possible to improve the quality of the decisions made by integrating an intelligent component—an expert system—into the decision-making process. However, the use of expert systems in the process of IT project management is almost beyond the attention of researchers.

2.2 Expert system research and usage in IT project management

An expert system is a computer program that, based on the rules laid down in its knowledge base, can give reasonable advice and suggest a solution to a problem. The use of the expert system as a decision support tool is justified for solving problems that cannot be solved based on analytical calculations.

Work on the creation of expert systems began in the early 1950s by Newell et al. [20], who developed a common problem solver for solving problems of elementary logic, proving theorems, and playing chess. This approach underestimated the role of specific knowledge in reasoning. Aware of the possibilities, research has been conducted in more specific areas of knowledge, such as medicine and chemistry. The first expert system was developed in 1965 by Feigenbaum et al. [21] and was intended for the analysis of chemical compounds. Since then, the range of applications of expert systems to industrial and commercial problems has become so widespread that they have become one of the most successful commercial areas of artificial intelligence. Some examples of the ES use in various areas of business are discussed below.

One example of the ES application in management is the software application Business Insight [22]—an expert system to support decision-making and strategic planning. Insight business presents the user with opportunities for strategic analysis, business monitoring; identification of key factors influencing business success; strengths and weaknesses of the business; obtaining the results of forecasts for the implementation of various business strategies. Starting with the user's answer to the questions asked by the system during the introduction, it can conduct a number of analyzes, providing the user with practical understanding and advice on his business and marketing strategies. The system also shows the progress of its logic for each comment or recommendation it makes.

In Ref. [23] Rao et al. present an expert system called PAT (productivity assessment technology), which provides a comprehensive analysis of project effectiveness. PAT uses the same logical process as a specialist in this field would identify the causes of good or bad performance. The proposed system also recommends corrective action and provides the user with explanations or justifications for the results.

When discussing the pros and cons of expert systems, most researchers focus on the list of advantages of expert systems and pay less attention to the disadvantages. In Ref. [24] Zarandi et al. focus on the weaknesses of expert systems, namely:

- Lack of ability and flexibility to adapt to changes in the environment.
- Lack of ability to generate a creative answer when there is no answer.
- Lack of ability to summarize their knowledge using an analogy.
- Impossibility to learn: usually, expert systems do not have the opportunity to learn from experience. Many expert systems cannot automatically change their knowledge base, nor adjust existing rules or add new ones.

One of the methods of combating these shortcomings is a combination of expert systems with methods and techniques of machine learning and artificial intelligence. For example, fuzzy logic can be used to manage uncertainty in expert systems and solve problems that cannot be effectively solved by conventional methods [25]. The main purpose of fuzzy expert systems is to use human knowledge to process uncertain and ambiguous data. Fuzzy expert systems have a history of use in various fields, in particular in economics and IT.

One of the potential areas of ES and fuzzy ES applications is IT projects management and their inherent business processes. Information technology projects are particularly prone to failures due to their specific characteristics, such as the lack of clear constraints, the complexity and abstractness of tasks, and the extremely rapid pace of technological progress. These factors increase the uncertainty, inaccuracy, and subjectivity in information technology projects and require the search for new management methods. Here are some examples of the ES application in the field of information technology.

The work of Dufner et al. [26] discusses the PMA expert system (Project Management Advisor), which can improve control over the IT project by evaluating the proposed project plan, identifying anomalies, and providing guidance for correction.

The PMA was developed as part of the CyberCollaboratory [27], built to facilitate collaborative design work. The PMA was approved by industry experts involved in the knowledge acquisition process and evaluated on 11 realistic project plans. The results showed a clear ability to detect anomalies in the project plan. The PMA also provided explanations and suggested corrective action.

Truică and Barnoschi present in Ref. [28] an expert system for recruiting IT specialists, which helps the human resources department to perform the recruitment of qualified specialists, assessing their skills, and offering advice on appointments. The system is designed to work in the field of information technology. Checking the accuracy of the system showed that the system selected the same three best job candidates as the expert person.

The work of Rodríguez et al. in Ref. [29] proposes a new method of risk assessment for the analysis of projects in the field of IT. The proposed method is based on a combination of a fuzzy process of analytical hierarchy and a system of fuzzy inference, benefiting from their advantages and minimizing their disadvantages. The proposed model takes into account different levels of uncertainty, the relationship between groups of risk factors, and the possibility of adding or suppressing variations without losing consistency with previous estimates. A case study of three actual IT projects showed the suitability and consistency of the proposed method results.

However, despite the fact that the field of information technology is very promising for the use of fuzzy expert systems, a review of the literature shows extremely little use of this apparatus in this area.

3. Fuzzy expert system application design

Historical review of the development and use of expert systems show both the prospects of the direction and the lack of attention to it. Next, we will focus on the architecture, methodological platform, and usage of the developed application—a fuzzy expert system. We will prove the possibilities and efficiency of its use in the business process management of a typical IT company.

Further considerations are based on the following hypotheses:

1. Expert systems, as the apparatus of artificial intelligence, can be used as an innovative method of managing economic processes and systems by taking into account the various informal influences of their uncertain environment.

2. Expert systems should be built into the overall business process management of IT companies, which has a positive effect on the effectiveness of operational and strategic management decisions.

3. The use of the expert system applications, based on fuzzy logic, in the process of managing the IT company business processes, increases the level of the main financial indicators, in particular, net profit.

Classical ES architecture based on inference: Database with initial information necessary to get an output; base of facts for the preservation of intermediate results; knowledge base with information on inference process through the knowledge base and fact base, and the core of inference (see **Figure 1**). The most important components that make sense to explore are the knowledge base and the core inference.

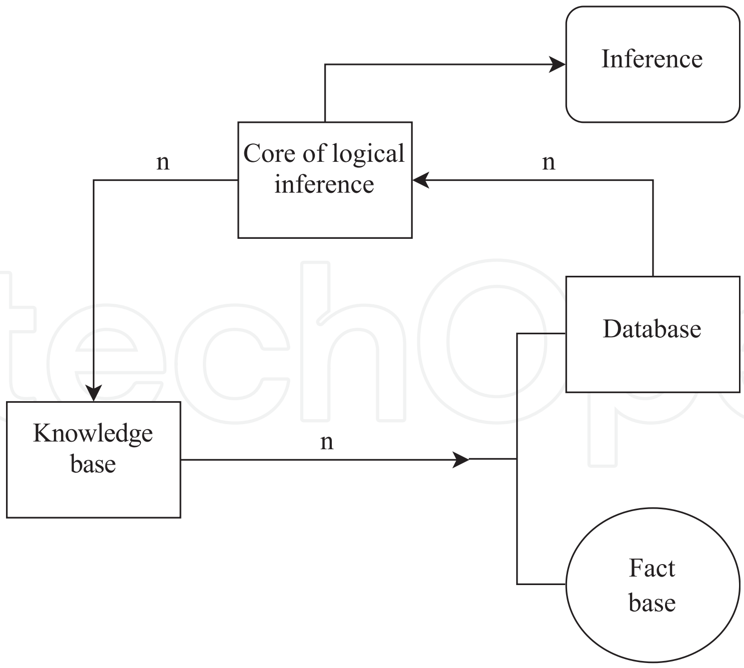

Figure 1.
The classic mechanism of inference.

One of the disadvantages of the classical inference architecture is the constant need to access the database to obtain the necessary information to calculate and maintain the database of facts in the current state. The second disadvantage creates unnecessary questions about the structure and ways to maintain a database of facts, which can be physically part of the knowledge base, which is illogical, or part of the database, which increases the load on the database.

It is possible to get rid of both shortcomings by reviewing how to work with the knowledge base and ways to maintain it. Instead of using crisp inference rules, there is a possibility to use a combination of fuzzy inference rules and simplified linguistic variables, which will be described below. This structure of the knowledge base allows getting rid of the intermediate facts database, which was closely related to the need to store intermediate information in order to have permanent access to the database.

3.1 Knowledge base structure

Before moving on to the use of semantic networks for fuzzy inference core, consider the second important component—the knowledge base. In the terminology of fuzzy expert systems, the knowledge base is a set of inference rules and linguistic variables, on the basis of which the mechanisms of direct and inverse inference work. A production rule can be defined as an IF-THEN structure that links information or facts in an IF part to certain actions or information in a THEN part. Thus, the base of production rules can be composed of an unlimited number of rules of the form:

$$IF\ (X = A)\ THEN\ (Y = C), \quad (1)$$

X, Y are linguistic variables;A, C are fuzzy linguistic equivalents of some crisp value associated with the corresponding linguistic variable.

The second part of the knowledge base is a set of linguistic variables that consists of an unlimited number of variables of the form:

$$X : Initial : [A : Trapezoidal : (A1, A2, A3, A4)|B : Trapezoidal : (B1, B2, B3, B4)], \quad (2)$$

X is a linguistic variable;*Initial/Derivative* indicates that linguistic variable value will be taken, for example, from a database or the value of which will be derived in the process of working with the knowledge base;*A: Trapezoidal:(A1,A2,A3,A4) and B: Trapezoidal:(B1,B2,B3,B4)* are the fuzzy membership functions;*A, B* are sets of values for a linguistic variable *X*;Trapezoidal indicates a trapezoidal type of membership function used to describe the values of a linguistic variable;*(A1,A2,A3,A4), (B1,B2,B3, B4)* are crisp values behind the fuzzy values of *A* and *B*, respectively.

This structure of the knowledge base has several very important features. First, it is possible to expand and reuse. The knowledge base can be expanded with new knowledge in the transition from specialist to specialist. Second, it is a potential opportunity to combine a knowledge base and a database to simplify the creation of a knowledge base based on production rule templates and linguistic variables. In this case, it will be possible to use rule templates instead of the structures of inference rules and linguistic variables described earlier, which will significantly speed up the process of creating a typical content of the knowledge base.

3.2 Inference core: SNePS

Next, we consider the process of fuzzy inference, namely the use of semantic networks for fuzzy inference. Semantic networks have been developed to present knowledge of an intelligent system that uses natural language. For the fuzzy inference problem, it was decided to use the SNePS semantic network processing system from the study of Shapiro and Rapaport [30], which is a denoted directional graph in which nodes represent concepts and arcs represent binary relationships between concepts. A feature of the SNePS semantic network is access to the database once to obtain the initial data. The inference rule can be represented in a graph through the nodes of the rule itself, the formulas of the input and output arguments, as well as the arcs that pass from the nodes of the rule to the nodes of the arguments. We should not forget about the connection between the rules due to the inclusion of linguistic variables from the right or left part of one rule in the right or left part of another rule. If the left part of one rule occurs in the right part of the second, the second rule is called the predecessor. Otherwise—a follower. Consider the following example and semantic network for this set of rules (see **Figure 2**):

R1: IF (A1) THEN (B1)
R2: IF (A2 AND A3) THEN (B2)
R3: IF (B1 AND B2) THEN (C1)

Rule *R1* is an equivalence rule, which means the following—if the predecessor is *TRUE*, then the successor also becomes *TRUE*. Rules *R2* and *R3* are general inference rules, which means that each predecessor must be *TRUE* for the followers to be *TRUE*.

Inference graphs were proposed and developed by Schlegel and Shapiro in Ref. [31] as extensions of propositional graphs. An inference graph is a graph of reasoning that is capable of inverse, direct, and bidirectional inference. It can support parallel processing for reasoning using inference logic. Inference graphs modify propositional graphs by adding channels between nodes along possible inference paths. Channels carry priority messages to transmit new information from one node to another. Message priorities affect the order in which tasks are performed so that messages are executed closer to the inference output and the inappropriate output tasks are canceled. A rule node is capable of performing inference operations using a set of rules known as Rule Usage

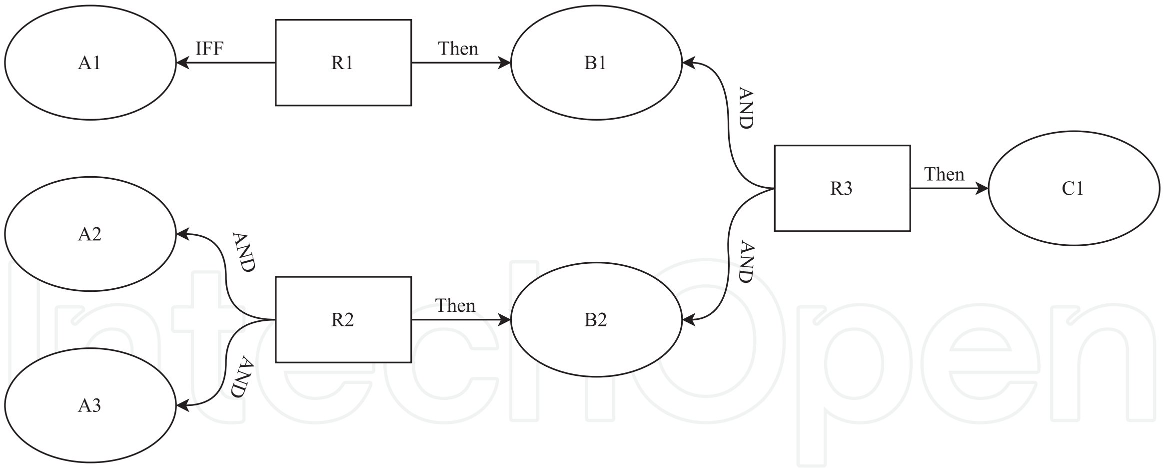

Figure 2.
Semantic network for a set of rules.

Information (RUI) [32]. RUIs contain information about which predecessors are true *TRUE* or *FALSE*, as well as information that explains how these values were derived. When a new RUI is created, it is combined with a set of existing ones. The resulting combination is used to determine whether the inference rule node can be used again.

For fuzzy inference in the developed system, only the direct inference process is used. Therefore, the structure of the inference graphs can be simplified:

1. There is no need for parallel reasoning, so there is no need for priorities for messages.

2. Instead of RUI, it is possible to use the simple status of the rule, which is updated when a new message is received. The status contains the result of counting the statuses of all rule predecessors.

Figure 3 represents a graph from **Figure 2** with the corresponding channels. Channels allow predecessors to report rule nodes when it was calculated and also allow rule nodes to report that they have been calculated. With this use of the semantic network, the dependence on the initial data in the database is reversed so that the core of the inference mechanism, that is, the semantic network, does not need to

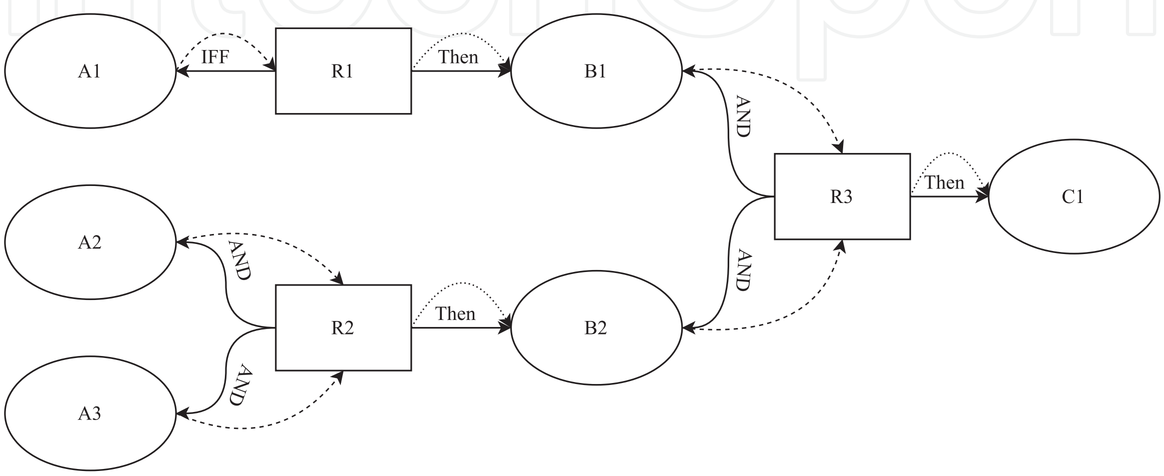

Figure 3.
Semantic network for a set of rules with channels.

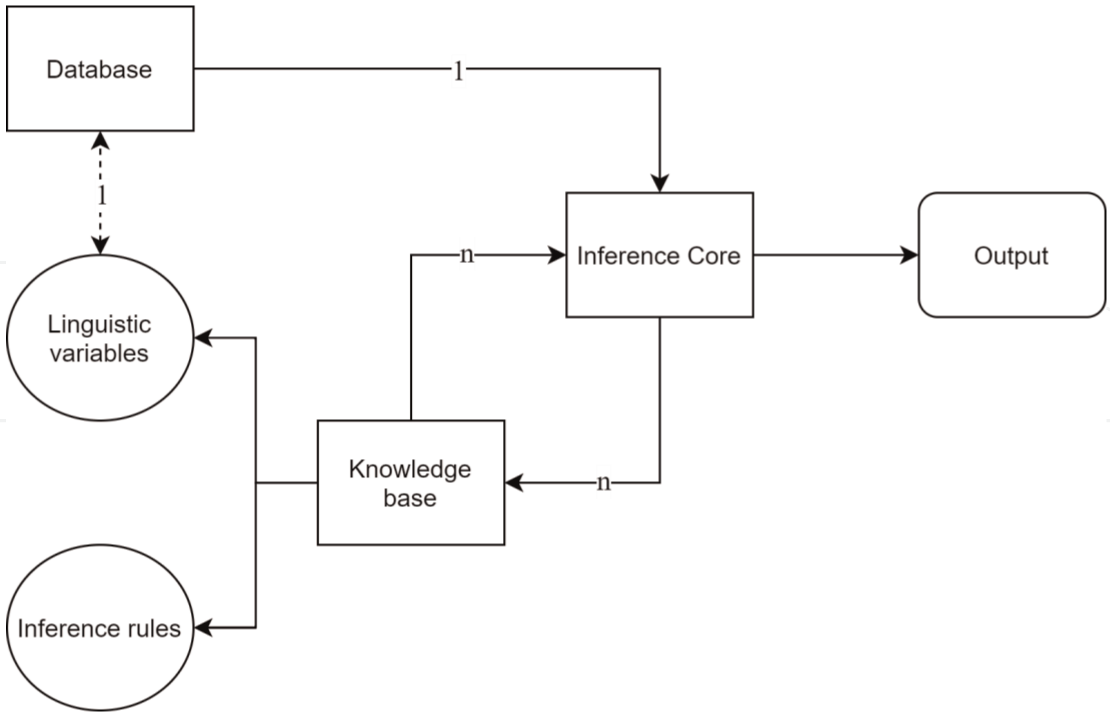

Figure 4.
Modified inference mechanism.

constantly query the data, but only rely on existing initial data and the potential for external expansion during the inference process. Thus, the general architecture of the developed fuzzy ES [1] is shown in **Figure 4**.

More information on the proposed architecture can be found in the authors' work on a detailed review of the methodology for creating a fuzzy expert system application suitable for work in the IT field combined with the Stage-Gate framework [33].

4. Application of fuzzy expert systems in IT project management

On the example of one of the expert consultations, we will demonstrate the work of an expert system based on fuzzy logic using a combined model of the semantic network SNePS (Semantic Network Processing System) and fuzzy inference rules.

Consider the following problem statement for an IT company. The model situation for projects is the availability of five teams (CycleDuo, Templater, Avion, Howl, and Converge) to develop existing and potential projects. A new team (Emerald) was also hired during the year, increasing the total number of available teams to six. The current market situation is to select five projects (Genesis, Crowding, Firantis, Exploration, and Hymera) from two customers (Mazzle, Global State). Also, additional information is provided on costs not directly related to current projects, namely the costs inherent in the maintenance of the office, administrative staff, and the cost of various advertising campaigns. Given the available data, the IT company faces the task of finding the best way to maximize annual profits.

According to the above problem statement, we will demonstrate the results of using a fuzzy expert system based on modeled data and compare those results with

[1] Source code of developed fuzzy expert system could be found at https://github.com/frightempire/FuzzyExpert.

Name	Description
Net revenue	The difference between the company's profit and all costs. From an accounting point of view, net profit is the difference between gross revenue and costs associated with managing the firm.
Total revenue	The total sales of the company and other sources of profit. It is important to note that total revenue differs from net revenue because it does not take into account expenses.
Gross revenue	Income at invoice value received for goods and services over a period of time.
Cost of goods sold (COGS)	Value of goods or services sold during a certain period.
Operating expenses	Amount paid for the maintenance of assets or business expenses, excluding depreciation.

Table 1.
Net revenue calculation indicators.

real historical data. To prove the success of the proposed method, it is necessary to find a way to measure its performance. In this example, it is advisable to consider the criterion of net profit as a measure of the effectiveness of the task of maximizing the company's profits [34]. Next, consider in more detail the process of calculating net revenue.

First, consider the main indicators involved in the calculation of net revenue. **Table 1** provides a general description of these indicators [35].

Let us start with the calculation of gross revenue:

$$\text{Gross revenue} = \text{total revenue} - \text{COGS}, \tag{3}$$

where the value of total revenue can be obtained by summing the planned annual profit from projects in development, and the cost of goods sold in our case is the cost of services, that is, the total cost of compensation for teams working on projects in development.

Given the value of gross revenue, it is possible to calculate the value of net revenue:

$$\text{Net revenue} = \text{gross revenue} - \text{operating expenses}, \tag{4}$$

where operating expenses in our case are the costs of advertising campaigns and assets in the form of office space and administrative staff.

Thus, based on the indicators for which data are available, we can formulate the following method of calculating net revenue:

$$\text{Net revenue} = \text{total revenue} - \text{COGS} - \text{operating expenses}. \tag{5}$$

4.1 Knowledge base creation process

To fill the knowledge base we used a combination of project managers' expertise and leading research results in the field of software project management (described in Section 2). Combining research data with information provided by management specialists from approximately 30 Ukraine IT companies, which describes the general structure of business processes during the management of the project portfolio within the IT company, a knowledge base was formed. Knowledge base corresponds to the IF-THEN structure and is aimed at solving a specific task of maximizing the profits of a typical IT company.

Templates for creating a knowledge base are as follows:

1. *IF (Risk of cooperation with the company X is N1 AND Project Y profit from the company X is N2) THEN ({It makes {no} sense to consider the project Y from the company X)*

2. *IF (Company X is the current customer AND It makes sense to consider the project Y from the company X AND Deviations in company X estimates is N1 AND Project Y profit type from the company X is N2) THEN (Project Y priority is N3)*

3. *IF (It makes no sense to consider the project Y from the company X) THEN (Project Y has no priority)*

4. *IF (Team X will soon complete the project AND Team X compensation is N1 AND Risk of interaction with team X is N2) THEN (Team X priority is N3)*

5. *IF (Team X does not complete the project soon) THEN (Team X has no priority)*

6. *IF (Team X is without match AND Project Y is without match AND Team X priority is N1 AND Project Y priority is N2) THEN (Team X has a match AND Project Y has a match AND Team X corresponds to project Y)*

7. *IF (Team X has no priority OR Project Y has no priority) THEN (Unable to match team X to project Y)*

8. *IF (Team X is without match AND Team X will soon complete the project) THEN (Team X must be disbanded)*

9. *IF (Project X is without match) THEN (Need to look for a new team)*

10. *IF ([Risk of interaction with team X is N]xM OR [...]xM) THEN ({No} risk of remote work)*

11. *IF ({No} risk of remote work AND Office expenses is N1) THEN (It makes {no} sense for remote work transfer)*

12. *IF (Company size is N1 AND The size of the administrative staff is N2) THEN (Need to {reduce, no action, increase} administrative staff)*

13. *IF (Type X advertising campaign expenses is N1 AND The benefits of an type X advertising campaign is N2) THEN (Need to {decrease, no action, increase} a type X advertising campaign)*

4.2 Fuzzy expert system implementation results

As a usage result of a fuzzy expert system, the following recommendations were received from the system:

- To carry out the Genesis project, it is recommended to select the Howl team.
- To carry out the Hymera project, it is recommended to select the Converge team.
- To carry out the Crowding project, it is recommended to hire a new Emerald team.
- To carry out the Firantis project, it is recommended to select the Avion team.
- The Exploration project is not recommended to be taken into development.
- It is recommended to abandon the office space.
- It is recommended to expand the budget for an advertising campaign on social networks.
- It is recommended to leave the budget for the advertising campaign in universities unchanged.
- It is recommended to abandon the advertising campaign through conferences.
- It is recommended to abandon outdoor advertising.

4.3 Modeled historical data

The available historical data were provided by the HYS Enterprise B.V.[2] IT company and is based on an annual breakdown of data close to real data, namely:

- planned annual revenue from potential projects;
- monthly compensation of current teams and administrative staff;
- annual expenses for maintaining an active office;
- monthly expenses to support active advertising campaigns.

Approximate available data on planned annual revenues from projects can be found in **Table 2**. Monthly compensation of teams, annual expenses of supporting assets in the form of office and administrative staff, as well as monthly expenses of active advertising campaigns are provided in **Table 3**.

The value of the annual net revenue was provided already calculated, but for visualization, we will perform this calculation again. This will help to make a similar calculation in the case of expert system usage. Before the calculation, we briefly describe the historically made decisions based on the data described in **Tables 1** and **2**:

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[2] All data are not real, but close to real. Any similarity to real data is a coincidence. HYS Enterprise B.V. is not responsible for the correctness or sharing of the methods proposed in this work, as well as for the quality of the results obtained on their basis. If any questions about described methods, test data, or results occur, it is recommend to contact the authors.

Mazzle	
Genesis	350,000$
Crowding	250,000$
Global state	
Firantis	285,000$
Exploration	90,000$
Hymera	320,000$

Table 2.
Planned annual revenues from potential projects.

Team compensations (monthly)	
CycleDuo	7000$
Templater	4000$
Avion	12,000$
Howl	8000$
Converge	3000$
Emerald	5000$
Asset support expenses (monthly)	
Administrative staff	15,000$
Office space	18,000$
Advertising campaign support expenses (annual)	
Social networks	12,000$
Conferences	90,000$
Universities	50,000$
Outdoor advertising	15,000$

Table 3.
Expenses by different categories.

- To carry out the Genesis project the Howl team was selected.
- To carry out the Hymera project the Converge team was selected.
- To carry out the Crowding project the Avion team was selected.
- To carry out the Firantis project a new Emerald team was hired.
- The Exploration project was not taken into development.
- It was decided not to abandon the office space.
- The size of administrative staff has been reduced.
- The budget for the advertising campaign on social networks was expanded.

- The budget for the advertising campaign at universities was expanded.
- The conference budget was left unchanged.
- It was decided to abandon outdoor advertising.

First, we calculate the planned total revenue based on the planned annual revenues from the projects. Already existing projects are also taken into account in the calculations regardless of their completion date. Another interesting point is the failure of the Crowding project by the Avion team due to the combination of high risk of interaction with the customer Mazzle and the Avion team. Thus, the Crowding project is not taken into account in the calculations:

$$\begin{aligned}\text{Total revenue} &= 12 \times 1000 \times (150 + 90 + 50 + 45 + 35) + 12 \times 1000 \times (350 + 285 + 320) \\ &= 1,640,000\$.\end{aligned} \tag{6}$$

Now we calculate the annual cost of goods sold, which in this example is the sum of the compensation of the teams involved in the development. Teams involved in the development of current projects that have not yet been completed are also taken into account in this calculation:

$$\text{COGS} = 12 \times 1000 \times (7 + 4 + 12 + 8 + 3 + 5) = 468,000\$. \tag{7}$$

It remains to calculate the operating expenses, which consist of advertising campaigns, office support, and administrative staff expenses:

$$\begin{aligned}\text{Operating expenses} &= 12 \times 1000 \times (18 + 15) + 1000 \times (12 + 50 + 90 + 15) \\ &= 563,000\$.\end{aligned} \tag{8}$$

All indicators necessary for calculation of net revenue are prepared:

$$\text{Net revenue} = 1,640,000\$ - 468,000\$ - 563,000\$ = 609,000\$. \tag{9}$$

5. Results

Here we will consider in what aspects the historical solutions coincide and differ with solutions proposed by the expert system and will demonstrate the effects of those differences. Let us briefly summarize the differences in decision making:

- To complete the Crowding project, it is proposed to hire a new Emerald team as opposed to the Avion team.
- To implement the Firantis project, it is proposed to choose the Avion team as opposed to a new Emerald team.
- It is proposed to abandon the office.
- It is proposed to expand the budget for the advertising campaign on social networks, in contrast to the historical data, which left this budget unchanged.

- It is proposed to leave the budget for the advertising campaign in universities unchanged, in contrast to the historical data that increased this budget.
- It is proposed to abandon the advertising campaign in the form of conferences, in contrast to the historical data, which left this budget unchanged.

Other expert system decisions are similar to decisions from historical data. The first major difference is in finding a team for the Crowding project. The expert system analyzed the risk of cooperation with the customer and existing teams and concluded that due to a combination of high risks it is less risky to hire a new team to implement the project than to appoint one of the existing ones. Thus, the probability of successfully completing the project and avoiding the situation demonstrated in the historical data on the failure of the Crowding project due to incompatibility with the Avion team increases. Given this information, the Avion team was tasked with working on the Firantis project.

The next difference is a proposal to abandon the active office. This decision was made after analyzing the risks of working with current teams and obtaining a low overall risk. The usefulness of current advertising campaigns is analyzed. The budget for the social media campaign has been expanded, which on the one hand increases expenses, but due to high utility and small investments creates the most favorable environment for finding new teams and customers. This in the long run leads to a more rapid expansion of the company and increases the likelihood of finding a customer, which will increase the value of total revenue. Due to the average level of utility and costs, it was decided to leave the budget of university advertising campaigns unchanged. After analyzing the low level of utility and high costs of the campaign through conferences, the expert system made an unequivocal decision to abandon this type of campaign.

Next let us make similar calculations of net revenue, taking into account the implementation of the expert system recommendations. But it should be borne in mind that since the data are historical, the implementation of the expert system is modeled. Based on these calculations, we can observe the impact of these decisions on the value of total profit and operating expenses.

We calculate total revenue based on planned annual revenues from existing and potential projects. In contrast to real historical data, the Crowding project corresponds to a team with a lower risk of cooperation, which suggests a higher probability of successful completion of the project. Thus, in this calculation, the Crowding project is taken into account:

$$\begin{aligned}\text{Total revenue} &= 12 \times 1000 \times (150 + 90 + 50 + 45 + 35) + 12 \times 1000 \times (350 + 250 + 285 + 320) \\ &= 1,890,000\$.\end{aligned} \tag{10}$$

The calculation of the compensation amount of the teams involved in the development does not differ from the calculation of historical data. After all, the same teams are involved in the development. The amount of compensation is:

$$\text{COGS} = 468,000\$. \tag{11}$$

Thus, we immediately proceed to the calculation of operating expenses. The difference from historical data is the proposal to abandon the active office, as well as the advertising campaign through conferences. At the same time, do not change the budget for university advertising campaigns. We are reducing the budget for university advertising campaigns compared to historical data from $50,000 to $30,000, which is the size of this budget before expansion. We are expanding the budget for an advertising campaign on social networks in approximately the same proportions from $12,000 to $20,000. Refusing an advertising campaign through conferences and office support, we generally have:

$$\text{Operating expenses} = 12 \times 1000 \times 15 + 1000 \times (20 + 30) = 230,000\$. \quad (12)$$

All indicators necessary for calculation of net revenue are prepared:

$$\text{Net revenue} = 1,890,000\$ - 468,000\$ - 230,000\$ = 1,192,000\$. \quad (13)$$

Comparing historical data and implementation results, we can see that the total profit increased by $250,000. In turn, operating expenses decreased by $333,000. Thus the total increase in annual net revenue is $583,000.

6. Conclusions

The role of the main subjects in the industry—IT companies—and the level of management of their business processes are growing. Effective management will help to achieve the strategic goals of companies and strengthen their financial stability. The analysis of the instrumental base for support of management decision-making in the conditions of uncertainty and risk brings to the fore the use of expert systems. At the same time, fuzzy expert systems built using methods and models of fuzzy logic seem to be the most effective.

Historical review of research and applications of this mathematical apparatus has shown only some examples of its use in the field of IT—a "bottleneck" that must be overcome because the feasibility of implementing intelligent technologies is confirmed by many factors. Among the main ones—the ability to present available information in linguistic form, smoothing insufficient or missing information, the institutional memory of the ES with tools to supplement and modify it, the presence of built-in mechanisms (for various architectures and algorithms) decision-making, metacomponent to explain expert advice, a library of precedents for adjusting the adoption of previous management decisions with the involvement of expert data, etc.

Given the need and feasibility of implementing the apparatus of fuzzy ES in IT project management, a fuzzy ES application was developed. The main difference between the developed application and the existing one is the proposal of the architectural model of the ES with a modified mechanism of fuzzy inference. This significantly speeds up the process of fuzzy inference and reduces the duration of expert consultations. The effectiveness of the proposed fuzzy ES application is demonstrated by the example of a modeled situation of maximizing the revenue of an IT company in specific circumstances—the business process environment associated with the implementation of current projects.

Currently, the experimental operation of the developed expert system application is carried out on the basis of a number of IT companies. Topics of expert advice on IT business process management include a wide range of tasks, such as search and monitoring of projects (selection of customers, teams, and other resources), forming a balanced portfolio of the company, assessing the status of projects, ensuring strategic goals and improving (in particular, financial) indicators of its activity, etc.

The experience gained based on the sector of outsourced IT companies allowed us to propose a methodology for embedding the ES application in the overall management loop within the Stage-Gate framework, which increases the efficiency of the system.

Further improvement of the application is carried out in the following areas:

- Expansion of knowledge and databases through definitions that meet the specifics of the IT industry functioning.
- Improving the accuracy and adequacy of the implemented fuzzy inference due to:
    - Combining fuzzy and crisp calculations;
    - Integration with the metacomponent of historical analysis;
    - Increasing the flexibility of the fuzzy model for knowledge base creation.
- Creation of a more developed metacomponent to explain in detail the expert consultations results.
- Development of a user-friendly interface for end-users, taking into account the wishes of IT professionals.

In essence, expert systems belong to the reusable apparatus. Their effectiveness as a management tool increases with the enrichment of knowledge and databases through the introduction of new experiences. The rapid development of the IT industry, specification, and standardization of software development processes at the global level provides a fundamental basis for the exchange, reproduction, and implementation of intelligent technologies with elements of fuzzy logic.

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