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Fuzzy Assessment of the Effectiveness of Innovative Projects in Industry

Nataliya MUTOVKINA[1]
Tver State Technical University, Tver (170023), Russia

Abstract. The innovative activity of industrial enterprises is the key to their successful operation and maintaining competitiveness in the market. The useful of innovations in product manufacturing technology, as well as in the management and control system, allows not only to maintain competitive positions but also to strengthen them. However, any innovative activity requires financial investments. Assessing the expediency of these investments, ensuring the possibility of comparing the planned results with the costs of innovation, is a problematic area of this work. Despite the certain development and proposals of solutions in this area, the problem of accurate assessment of the effectiveness of innovations remains relevant. This is important to the specifics of industrial enterprises, their industry affiliation, financial and other capabilities. As practice and set publications on this topic show, there is no single method for evaluating the effectiveness of innovations. The decision to invest in innovation is influenced by many factors that are different for each business entity. Most owners and managers, when evaluating innovative projects, solve the problem of choice, relying on traditional methods of calculating performance indicators and considering an innovative project as an investment. Such methods include calculations of net discounted income, internal rate of return, payback period of the project, profitability index, and other indicators. However, when using these methods, the qualitative effects of the introduction and application of innovations are not taken into account. In addition, the quantitative effects expected from the use of innovations are also predictive values evaluated by experts. Accordingly, there is always a possibility that these effects will not be obtained. Decision making on the investment of an innovative project becomes more complicated if we are talking about several projects. Then making a decision that reduces to a binary value (the project is accepted /the project is rejected) turns into a choice task. Such a problem is characterized by a larger dimension, therefore, an increased complexity of the solution. The more alternatives, the higher the difficulty (the harder the choice). The article proposes a method for fuzzy evaluation of the effectiveness of innovative projects in industry, which is based on the formation of a system of linguistic expert rules. This system is being developed based on the results of active work with experts in industrial innovation and represents a fuzzy knowledge base. As a criterion for the effectiveness of such a system, the level of consistency of the solutions proposed by the system with expert assessments of the effectiveness of an innovative project serves. If the system shows results that are practically indistinguishable from the results issued by the expert group, then a decision is made on its operation.

Keywords. Innovative projects; efficiency, financing; decision-making; fuzzy logic; expert assessments.

[1] Correspondence author, Nataliya MUTOVKINA, Tver State Technical University, Tver (170023), Russia; Email: letter-boxNM@yandex.ru

1. Evaluating the Effectiveness of Innovative Projects

The essence of the problem under consideration is as follows. When deciding on an innovation project at an industrial enterprise, several interested groups are usually identified: owners, hired management, employees of the enterprise and owners of the innovation, and members of the public. An individual participant in the decision-making process can be a member of several groups at once. The owners of the innovation can be representatives of the listed groups.

Any innovative project involves serious costs, so the major problem is the cost recovery in an acceptable time. Cost recovery refers to the excess of the beneficial effect over the costs in a time acceptable to the decision-maker. For each of these groups of participants, the perception of an innovative project is different. Some participants see it as a "salvation" from aggravated problems, other individuals consider it as an obstacle in the enterprise, since additional expenses of funds are required for implementation, maintenance, staff training. Therefore, even confirmation of the economic efficiency of the project does not guarantee the success of its implementation at the enterprise.

The goals and interests of the participants in the decision-making process for the development and implementation of innovations differ significantly. The goal of owners and managers is to maximize profits from the use of innovation in the production process and eliminate the possibility of financial losses. The interests of the company's employees usually include of ensuring the stability of their own work without additional efforts and loads in maintaining the usual rhythm of work. The interests of the owners of the innovation are to profit from the sale of the innovation to the owners of the enterprise. The goal of the public representatives is to minimize the harmful effects of innovation and prevent potential damage to the environment.

The lack of experience of successful innovation implementation at the enterprise makes the problem of evaluation even more acute. Therefore, the owners and management of the enterprise are interested in making the fullest use of the experience of experts. It is necessary to exclude possible subjective mistakes made by individual participants in the decision-making process.

Thus, the aim of this study is to develop a model for fuzzy evaluation of the effectiveness of innovative projects for industrial enterprises, allowing all participants in the decision-making process to come to an agreed opinion on the need for innovation.

The novelty of the research lies in determining the important kinds of effectiveness of an innovative project and developing a system of rules for fuzzy inference on the overall effectiveness of the project.

2. Potential Solutions to the Problem of Evaluating the Effectiveness of an Innovative Project

The realization of innovations in modern industrial enterprises is a necessary condition for maintaining the competitiveness of enterprises, the demand for their products in the market, and leadership in the industry. However, not all innovations are useful for the enterprise. Some innovations can not only destabilize the work at the enterprise but also cause significant damage to the additional costs for technical re-equipment, downtime of equipment, employees. Therefore, the evaluation of the usefulness of an

innovative project should not be limited only to the calculation of its economic efficiency.

This section examines existing approaches to evaluating the effectiveness of innovative projects, and highlights the most important types of innovation efficiency, which form a general idea of the need and possibility of introducing innovation at the enterprise.

2.1. Literature Review

Often, the authors base the evaluation of the effectiveness of an innovative project on a comparative analysis of the volume of investments and future cash receipts [1–3]. The disadvantage of this approach is that, here, an innovative project is equated with an investment project, the definition of which is much broader and does not include the specifics of innovation. The profitability of many innovations has a delayed strategic nature. For example, managerial innovations (changes in the organizational structure, acquisitions and mergers, the new methods of personnel management) produce results in an enormous time gap in relation to the period of investment; innovative activities are carried out in conditions of uncertainty and increased risk. The process of developing and implementing innovations is quite long, and the external environment changes intensely. Therefore, it is difficult even for experts to predict and evaluate the result of the innovation at the initial stage.

Many researchers distinguish the effect in innovation: economic, scientific, technical, resource, social, environmental, ethnic and cultural [4,5]. In some publications, you can find large than ten types of the effect of innovation. For example, in [6] there are twelve of them. A detailed analysis of these and other publications made it possible to identify the main kinds of efficiency necessary for evaluating innovations: economic efficiency, technical efficiency and social efficiency.

2.2. Types of Effectiveness of the Innovation Project

Economic efficiency, first, lies in the possibility for the enterprise to profit from the use of innovations. Technical efficiency consists in the renewal and modernization of the major production assets of the enterprise. The installation and updating of new technological lines, the replacement of the most worn-out units ensure an increase in product quality and, ultimately, the strengthening of the company's competitive position in the market. Social efficiency can be considered both internal and external. Internal social efficiency refers to the improvement of the quality of a work of the company's personnel in the innovation, the manifestation of an ergonomic effect. External social efficiency is characterized by the improvement of the life of society, consumers of innovative goods, digital services.

Each of the above kinds of innovation efficiency can be calculated using the following formulas:

- Economic efficiency (EE)

$$EE = \frac{\sum p_t}{\sum c_t} > 1 \tag{1}$$

where p_t is the positive financial effect of the realization of an innovative project at time *t* (income from the project), c_t is the cost of achieving a financial effect at time *t*.

- Technical efficiency (TE)

$$TE = \frac{\{PD\} + \{ZD\}}{n} \to 1 \tag{2}$$

where $\{PD\}$ is the number of target indicators of technical efficiency of an innovation project for which the inequality $\left(x_i^* - x_i\right) > 0$, $\{ZD\}$ is valid is the number of target indicators of technical efficiency of an innovation project for which the equality $\left(x_i^* - x_i\right) = 0$, $i = \overline{1,n}$, n is the total number of target indicators of technical efficiency of an innovation project. Here, x_i^* is the value of the indicator after the realization of innovation, x_i is the value of the same indicator before the realization of innovation.

- Social efficiency (SE)

$$SE = \{SEI\} + \{SEE\} > 2 \tag{3}$$

where $\{SEI\}$ is internal social efficiency, $\{SEE\}$ is external social efficiency, the indices of which are calculated by the formula:

$$\{SEI\} = \frac{\sum \psi_{Ei}^{(+)}}{\sum \psi_{Ei}^{(-)}} > 1, \ \{SEE\} = \frac{\sum \psi_{Ee}^{(+)}}{\sum \psi_{Ee}^{(-)}} > 1 \tag{4}$$

where $\sum \psi_{Ei}^{(+)}$ is the sum of the effects of the innovation project on the employees of the enterprise, perceived by them as positive, $\sum \psi_{Ei}^{(-)}$ is the sum of the effects of the innovation project on the employees of the enterprise, perceived by them as negative. The same meaning of these designations for the external environment of the enterprise.

2.3. Methods of Obtaining Initial Information for Evaluation

You can get information from representatives of the internal and external environment of the enterprise where the implementation of an innovative project is planned, for example, by a questionnaire. It is most expedient to organize an on-line questionnaire via e-mail or social networks. It is recommended to specify no large than ten questions in the questionnaire, the answers to which the respondent gives from a pre-agreed scale. An increase in the number of questions, as well as the complexity of their formulations, may lead to respondents' refusal from the questionnaire. Therefore, the compiler of the questionnaire should take this into account without fail.

Thus, the expert group will have at its disposal the following elements that require an assessment procedure (table 1).

Table 1. Elements of the effectiveness of an innovative project for evaluation.

Participants in the decision-making process	EE	TE	SEI	SEE
Owners and management of the company	$\{EE_m\}$	$\{TE_m\}$	$\{SEI_m\}$	—
Employees of the company	—	$\{TE_{ec}\}$	$\{SEI_{ec}\}$	—
Owners of innovation	$\{EE_{oi}\}$	—	—	$\{SEE_{oi}\}$
Members of the public	—	—	—	$\{SEE_p\}$

The curly brackets in TABLE 1 show the set of values of each estimated indicator. The calculation of the economic efficiency of an innovation is carried out by its owners (developers), owners and management of the enterprise. The calculation of technical efficiency is carried out by an expert commission formed by the managers and employees of the enterprise. Social efficiency is also calculated in each group based on the results of filling out special questionnaires by participants in the decision-making process.

3. Modeling of fuzzy evaluation of innovation efficiency

The MatLab system was chosen as a software environment for modeling, since it contains special fuzzy modeling tools with which you can perform the entire complex of research on the development and application of fuzzy models [7,8].

Fuzzy modeling in the MatLab environment is carried out using the Fuzzy Logic Toolbox extension package.

3.1. Description of Variables Included in the Model

Economic efficiency is considered as the first input variable. The project is effective if condition (1) is met. Thus, the lower bound of this indicator is equal to one. The upper bound is a fuzzy value, since it is impossible to accurately determine this value for different projects when they are evaluated by different participants.

The technical efficiency of the project is used as the second input variable. Acceptable by this criterion is the project for which condition (2) is met. However, here the upper bound is rarely when it's equal to one. This is an ideal option, practically not found in practice. Therefore, the acceptable lower and upper bounds are set by experts.

The third input variable is social efficiency, the index of which cannot fall below two (condition (3)). The upper bound for the criterion is also set by experts.

The overall assessment of the effectiveness of the innovation project is used as an output variable.

figure 1 shows the membership functions of the terms of the input variable “Economic efficiency”.

The membership functions of the other variables also have four terms (as in Figure 1). The boundaries of their values were determined according to formulas (1)-(4) and expert assessments.

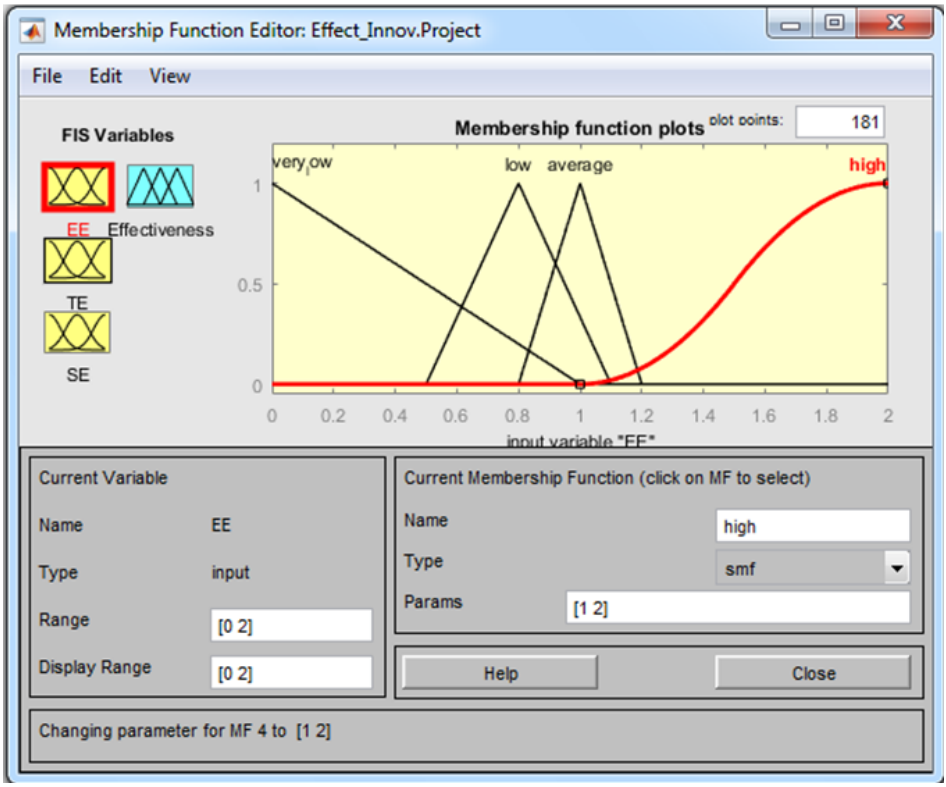

Figure 1. Membership functions of the terms of the input variable "Economic efficiency"

3.2. Formation of the Rule Base of the Fuzzy Inference System

The volume of the rule base was 48 rules based on the conditions: three input variables and four terms.

3.3. Evaluation of the Constructed Fuzzy Inference System

To assess the adequacy of the constructed fuzzy inference system, a quantity of experiments were conducted, some results of which are recorded in table 2.

Table 2. Experimental results.

EE	*TE*	*SE*	*Effectiveness*	*EE*	*TE*	*SE*	*Effectiveness*
1.0	0.5	2.0	0.387	1.1	0.8	3.0	0.630
1.0	1.0	2.0	0.625	0.9	0.8	3.0	0.575
1.0	1.0	3.0	0.630	0.9	0.4	2.2	0.361
1.1	1.0	3.0	0.830	1.0	0.95	1.5	0.500

The values of input variables calculated according to formulas (1)–(3) for some innovative projects planned for implementation at industrial enterprises were used as

initial data. Comparison of the results of fuzzy inference for these values of input variables received by expert analysis and using the developed fuzzy model shows good consistency of the model.

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