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MULTI-CRITERIA EVALUATION OF INNOVATIVE PROJECTS BY MEANS OF ELECTRE APPLICATION

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Abstract. The purpose of this article is to study the possibilities of using multi-criteria decision-making tools (MCDM), a separate method of multi-criteria analysis (MCA), to evaluate and rank a set of innovative projects that come to innovation development programs, microorganisms. To assess the relative effectiveness of the implementation of innovative projects of the enterprise using the method of the ELECTRE family, namely – ELECTRE-I. The study demonstrated the effectiveness of using ELECTRE-analysis to evaluate innovative projects within the program of innovative development of the enterprise, taking into account performance (benefit factor), time (cost factor) and resources (cost factor). The study concerned a specific machine-building enterprise to prove the possibility of implementing the ELECTRE method and obtain clear results while expanding the input analytical information in the model by including data from other enterprises of the machine-building industry of Ukraine, which will be the subject of our further research. To build a weighted normalized matrix in the framework of ELECTRE-analysis used weights obtained by interviewing managers of innovative projects of the enterprise, which suggests the presence of a certain level of subjectivity in the assessment. The article is designed to close the gaps in the lack of practical experience in using the tools of multi-criteria analysis to establish the relative effectiveness of the implementation of a set of projects in the program of innovative development of Ukrainian enterprises.

Keywords: innovative project, efficiency, ELECTRE analysis, multicriteria decision making.

JEL Classification: G11, M21, O32.

Introduction

Ensuring the innovative development of the enterprise is impossible without the effective implementation of a set of measures aimed at the formation and implementation of tasks defined by the program of innovative development. However, the analysis of the effectiveness of projects included in such a program is in most cases difficult due to the need to develop clear criteria, tools and guidelines for their evaluation. The standard method does not exist both because of the complexity of quantification and the dynamics of factors that affect efficiency, and because of the debatability of its economic content.

We distinguish three possible options for evaluating the effectiveness of the program of innovative development, which follows from the ratio of the effectiveness of the program itself with the effectiveness of innovative projects included in it:

1) the effectiveness of the program of innovative development of the enterprise directly depends on the effectiveness of projects that shape it – based on the premise that the program is considered effective only in the case of a positive result of all innovative projects. Hence, the overall effectiveness of the innovation development program can be defined as the result of the effectiveness of all innovation projects, taking into account their individual contribution to the overall effectiveness of the program. However, the weighting of each project can be quite subjective due to the variety of tasks they are aimed at. Such an additive model provides maximum efficiency only for the program, in which all projects without exception are implemented successfully;

2) there is no direct relationship between the effectiveness of innovative projects included in the program of innovative development and the final effectiveness of the latter. This approach is based on the priority of the organizational function of the innovation development program. In this case, the program is only a shell of the mechanism of the enterprise based on innovation. Therefore, it is advisable to evaluate the program of innovative development on the indicators that characterize it as a system: the unity of structural elements, the integrity

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of intra-system relationships, synergies, protection from unauthorized access, and so on. This approach allows the possibility of a positive evaluation of the program, even if there are projects that have not brought useful results;

3) the effectiveness of innovation projects is only one of many criteria by which to assess the effectiveness of the innovation development program. This option is a combination of the two previous ones and provides a multi-criteria evaluation, in which each parameter is analyzed according to the level of achievement of the optimal result, compared with the resources spent on it (including time). The result is the implementation of the tasks set before the projects, the set of which forms the purpose of the program of innovative development. In the latter, the ranges of deviations for each predicted result, which can be considered acceptable, as well as the values, the receipt of which may indicate the failure of a particular project. In this approach, systemic violations are considered a key reason for obtaining a negative result. Their evaluation is an element of a comprehensive analysis of the causal relationship between innovative projects in the program and the result of its implementation in general. Timely diagnosis and elimination of problems is the key to the successful implementation of the program, but its effectiveness should be determined solely based on achieving pre-established results.

Innovations take place at different levels – national, sectoral, organizational level and individual projects. Information and data related to the implementation of innovations are recorded and stored at these levels. Each level requires an appropriate assessment method. National and sectoral assessments usually address economic growth and GDP, as well as the extent of countries' global competitiveness. What happens at the firm and project level is called micro-assessment. There are also several general approaches to evaluation: quantitative, qualitative and combined. Quantitative is used when it is possible to quantify benefits, while time, costs and income can be used as evaluation criteria. A qualitative approach is used when there are valuable benefits that are difficult to measure. The combined evaluation method is used when there are several aspects of the project that can be measured, while the rest can only be evaluated qualitatively (Maghsoudi et al., 2015).

In recent years, in practice, methods of multi-criteria analysis are increasingly used, which allow expending the possibilities of assessing the totality of innovative projects, including indicators that cannot be quantified.

The advantages of using the multicriteria method are significant when you need to make a choice or make a decision based on criteria that are evaluated qualitatively (fuzzy criteria). Multicriteria analysis not only determines the desired solution but also organizes in a certain way all possible solutions, from those that include the best alternatives to those that contain the least desirable (Chwastyk, 2013).

Given the significant risk and uncertainty of the results of innovative projects under the program of innovative development of the enterprise, the study aims to assess their effectiveness by multi-criteria analysis of decision-making.

1. Literature review

The results of numerous studies on innovation at the organizational level are often contradictory. Research indicates significant deviations that occurred in obtaining the results of the empirical study of the innovation process. Factors recognized as important for innovation in one study are considered much less important, or even unimportant or have a negative impact on innovation, in another (Borocki et al., 2013).

Determining factors that determine the problems of forming a methodology for evaluating the effectiveness of innovative projects are: availability of own financial resources, high cost of innovation, which determines the increased risks for investors, high economic risk, and low innovation potential of the enterprise (Paraniuk, 2018).

The following quantitative indicators are most often used to evaluate innovative projects: 1) Net Present Value – evaluates (before launch) the difference between future cash inflows and outflows, discounting their value to date; 2) Return on Investment – sets (after launch) net income from launched projects, comparing income and investment costs; 3) Percentage of profits from products less than n years old – provides information on how new projects contribute to the turnover and competitiveness of the firm; 4) Total patents filed / pending / awarded – explains how firms can secure patent rights, giving an idea of the future licensing potential, etc.; 5) Time-to-market – describes the speed of development of an innovative project from investment to the first order; 6) Success / failure rate of projects – measures the degree of success / failure of new projects in the portfolio; indicates the ability to choose the "right" projects for implementation (Kristiansen & Ritala, 2018). The advantages and disadvantages of their use to assess the effectiveness of innovative programs were presented in the paper (Boychuk, 2018).

The variety of indicators and methods of their complex generalization is presented in scientific works: the use of the indicator Net Present Value, NPV (Zizlavsky, 2014); Return on Innovation investment methodology, ROI^2 (Kandybin, 2009); Rate of Innovation Project's Effectiveness, Re and Innovation Project's Effectiveness Index, Ie, which allow you to quantify and compare the actual values of project competitiveness with a statistically determined level of variability (Sipos, 2009); a system of global performance indices, which includes indicators for assessing the stage of development and implementation of the innovation project (Sipos & Ciurea, 2007); an integrated indicator that allows to rank innovative projects according to their economic efficiency with regard to further commercialization (Pererva et al., 2019); a comprehensive parameter for the evaluation of an innovative project, which combines scientific, technical, economic, social and environmental consequences, taking into account the factors of time, risk and uncertainty of project implementation (Novikova & Burmaka, 2014); a comprehensive criterion for direct evaluation of an innovation project, which is the sum of the weighted average values of the sub-criteria for evaluating the effectiveness of: marketing innovations; commodity innovations; technological innovations; organizational innovations; market innovation (Ershova et al., 2019).

At the same time, the advantages of multicriteria analysis increasingly provide priority for the use of its tools in modern research: the use of the method of analytical hierarchy Multi-criteria Decision-making, MCDM for ranking in a highly specialized sector of eco-innovative projects (Stosic et al., 2016); Fuzzy Topsis method to optimize software selection projects (Vysochan et al., 2021c); DEA-analysis methodology for assessing the effectiveness of investing in innovation in small and medium-sized manufacturing enterprises in Slovakia, using as input data on research and development costs, as well as training costs for employees (Durana et al., 2020); use of the DEA-analysis method to assess the relative effectiveness of research and development at the macro level (overall efficiency, research efficiency, translation efficiency, economic efficiency) using data from 25 countries (Chen & Hung, 2016), the activities of health care institutions in the field rehabilitation in Hungary (Denes et al., 2017) and the technical efficiency of the Korean government-funded biotechnology research and development projects between 2007 and 2013 (Park & Shin, 2018); Innovation project performance evaluation model, which is based on a study of operational and product characteristics of innovation and involves a survey of respondents – innovation managers and project managers with testing on the example of 219 innovative projects in mechanical engineering, construction, information technology and related industries (Blindenbach-Driessen et al., 2010); assessment of the effectiveness of innovative costs of industrial enterprises according to the criteria of the form of financing; sources of investments and reflection in the accounting system (Hyk et al., 2021) and others. The use of multi-criteria analysis to solve related tasks, such as clustering of non-budget non-profit organizations and regions of Ukraine according to the level of effectiveness of the development of the tourism sphere, was considered by us earlier (Vysochan et al., 2021a; Vysochan et al., 2021b).

2. Methodology

A comparison of three models for evaluating the effectiveness of investment in innovative projects – Cost Benefit Analysis (CBA), Data Envelopment Analysis (DEA), Multi Criteria Analysis (MCA) – allows Kogabayev and Maziliauskas (2016) to choose the best alternative MCA methods.

The basis of multicriteria decision-making techniques is the construction of a preferential relationship in a set of multi-attribute alternatives, based on the preferences expressed for each attribute and "inter-attribute" information, such as weight. Based on this preferential relationship (or, more generally, on the basis of various relationships derived from sustainability analysis), a recommendation is developed (e.g., representing a subset that may contain "best" alternatives) (Bouyssou, 2001).

In fact, in a situation where, having a defined set of decisions (actions, options) and an agreed set of criteria, the decision maker seeks to:

1) establish a subset of solutions (actions, options) that are considered the best for a set of considered criteria (the problem of choice);

2) divide the set of solutions (actions, options) into subsets, in accordance with the established rules (the problem of classification or sorting);

3) to classify a set of solutions (actions, options) from the best to the worst (the problem of positioning or ranking) (Andres & Padilla, 2018).

With this in mind, one of the most valuable tools for selecting and evaluating innovative projects is the ELECTRE-I method. With this in mind, one of the most valuable tools for selecting and evaluating innovative projects is the ELECTRE-I method. Its advantages are ease of interpretation of the results for the decision-maker; lack of need to involve additional computing power, as the criteria calculation algorithm is relatively simple; stability of the method, which is achieved by a small number of external parameters and sufficient quantification of each of them. It was these factors that became decisive when choosing tools to solve the problem posed in the article.

The ELECTRE method (ELimination Et Choix Traduisant la Realité, exclusion and choice of reality transformation) was proposed by Benayoun et al. (1966) in France. This method belongs to the family of Outranking techniques (Multi-criteria Decision Making, MCDM) (Mal & Majumdar, 2019).

The implementation of the ELECTRE method involves the sequential implementation of the following 8 steps (Mal & Majumdar, 2019; Mesran et al., 2017; Napitupulu & Hasibuan, 2017; Yucel & Gorener, 2016):

Stage 1. Construction of a matrix of decisions

The decision-making matrix is formed from alternatives (by rows) and criteria for their selection (by columns) (Equation (1)):

$$x_{ij} = \begin{pmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{pmatrix}, \quad (1)$$

where, n – selection criterion for decision making; m – alternative; x_{ij} – performance evaluation indicator i-alternative for j-criterion; $i = 1, 2, \dots m$; $j = 1, 2, \dots n$.

Stage 2. Normalization of the decision matrix

Normalization is the process of reducing the elements of the decision matrix to comparable comparable values. The new elements make up the normalized matrix (Equation (2)):

$$r_{ij} = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}. \quad (2)$$

The element r_{ij} of the normalized matrix for the parameters oriented to the benefit is defined as follows (Equation (3)):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad (3)$$

where, r_{ij} – normalized efficiency assessment i-alternative for j-criterion.

The element r_{ij} normalized matrix for cost-oriented parameters is defined as (Equation (4)):

$$r_{ij} = \frac{1/x_{ij}}{\sqrt{\sum_{i=1}^{m} (1/x_{ij}^2)}}. \quad (4)$$

Stage 3. Assignment of weights and construction of a weighted normalized matrix

Decision makers assign a percentage (weight) for each criterion. The matrix of weights looks like this (Equation (5)):

$$w_{ij} = \begin{pmatrix} w_1 & 0 & \ldots & 0 \\ & w_2 & \ldots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \ldots & w_n \end{pmatrix}. \quad (5)$$

Weight makes it possible to express the importance of each individual criterion in relation to others (w_j). It is clear that the sum of the weights is 1 (Equation (6)):

$$\sum_{j=1}^{n} w_j = 1. \quad (6)$$

The weighted normalized matrix is formed on the basis of the matrix of weights and the normalized matrix of solutions (Equation (7)):

$$v_{ij} = w_j \times r_{ij}. \quad (7)$$

The weighted normalized index of efficiency assessment of the i-alternative by the j-criterion (v_{ij}) is obtained by multiplying each element of the normalized decision matrix by columns by the weighting factor of the corresponding criterion (Equation (8)):

$$v_{ij} = \begin{pmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{pmatrix}. \quad (8)$$

Stage 4. Setting sets of concordance and discordance indices

Set of concordance indices C_{kl} two alternatives A_k i A_l, where $m \geq k, l \geq 1$, is defined as the set of all criteria for which A_k preferred over A_l, that is, the following (Equation (9)):

$$C_{kl} = \left\{ j \mid v_{kj} \geq v_{lj} \right\}. \quad (9)$$

Accordingly, the set of discordance indices has the following form (Equation (10)):

$$D_{kl} = \left\{ j \mid v_{kj} < v_{lj} \right\}. \quad (10)$$

Stage 5. Construction of concordance and discordance matrices

The calculation of the elements of the concordance matrix (concordance indices, c_{kl}) involves the addition of weights that are included in the concordance set (Equation (11)):

$$c_{kl} = \sum_{j \in C_{kl}} w_j. \quad (11)$$

The concordance indices in the matrix (Equation (12)) express the relative advantage of alternative Ak over alternative Al.

$$c_{kl} = \begin{pmatrix} - & c_{12} & \cdots & c_{1m} \\ c_{21} & - & \cdots & c_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ c_{m1} & c_{m2} & \cdots & - \end{pmatrix}. \quad (12)$$

The value of c_{kl} is in the range from 0 to 1.

The values of the elements of the discordance matrix are calculated by dividing the maximum difference of the values of the criteria that are included in the set of discordance by the largest difference between the values of all existing criteria (Equation (13)):

$$d_{kl} = \frac{\max\left\{\left|v_{kj} - v_{lj}\right|\right\}_{j \in D_{kl}}}{\max\left\{\left|v_{kj} - v_{lj}\right|\right\} \forall_j}. \quad (13)$$

The discordance matrix d_{kl} (Equation (14)) expresses the degree of weakness of the alternative Ak relative to the competing alternative A_l.

$$d_{kl} = \begin{pmatrix} - & d_{12} & \cdots & d_{1m} \\ d_{21} & - & \cdots & d_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ d_{m1} & d_{m2} & \cdots & - \end{pmatrix}. \quad (14)$$

The concordance and discordance matrices have dimensions $m \times m$ and do not contain values at the intersection of the column l and string k (in the case of $k = l$).

Stage 6. Establishment of dominant concordance and discordance matrices

The implementation of this stage is directly related to the determination of the threshold values of the concordance indices – $\underline{c}$ (Equation (15)) and discordance – $\underline{d}$ (Equation (17)).

$$\underline{c} = \frac{\sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl}}{m(m-1)}. \quad (15)$$

The alternative A_k will prevail (dominate) the alternative A_l only if the corresponding concordance index c_{kl} exceeds at least a certain threshold value $\underline{c}$ ($c_{kl} \geq \underline{c}$).

Given the threshold value of $\underline{c}$, the elements of the dominant concordance matrix (f_{kl}) are (Equation (16)):

$$f_{kl} = \begin{cases} 1, & \text{if } c_{kl} \geq \underline{c} \\ 0, & \text{if } c_{kl} < \underline{c} \end{cases}. \quad (16)$$

Similarly, the dominant discordance matrix is constructed taking into account the threshold value of the discordance index (Equation (17)):

$$\underline{d} = \frac{\sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl}}{m(m-1)}. \quad (17)$$

Elements of the dominant discordance matrix (g_{kl}) are as follows (Equation (18)):

$$g_{kl} = \begin{cases} 1, & \text{if } d_{kl} \leq \underline{d} \\ 0, & \text{if } d_{kl} > \underline{d} \end{cases}. \quad (18)$$

Stage 7. Construction of the final dominant matrix

The elements of the final dominant matrix e_{kl} are defined as (Equation (19)):

$$e_{kl} = f_{kl} \times g_{kl}. \quad (19)$$

Thus, the model of final dominance is a matrix, each element of which is determined by multiplying the elements of the matrix f_{kl} by the corresponding elements of the matrix g_{kl} (Equation (20)).

$$e_{kl} = \begin{pmatrix} - & e_{12} & \cdots & e_{1m} \\ e & - & \cdots & e_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ e_{m1} & e_{m2} & \cdots & - \end{pmatrix}. \quad (20)$$

Step 8. Elimination of the least profitable alternative

From the final dominant matrix, you can make a list of alternatives that will be preferred. If $e_{kl} = 1$, the alternative A_k is better than the alternative A_l, in terms of both concordance and discordance criteria. Any column that has at least one element with a value of 1 can be excluded from the matrix. The best alternative is the one that dominates everyone else.

3. Results

3.1. Establishing parameters for evaluating the effectiveness of the innovation development program

When planning innovation processes with a focus on results, the information support of such a process is carried out by three necessary elements:

1) nomenclature tasks for solving certain scientific and technical problems in the form of comprehensive development programs;

2) target indicators (indicators), reflecting the final results of innovative activity of the economic entity – increasing the technical and economic level of production, including the creation and development of new types of production, equipment, technologies, products, and services; reduction of production costs; an increase of labour productivity, etc.;

3) resources needed to implement certain programs.

We believe that the effectiveness of the innovation development program is characterized by three main determinants:

1) optimization of indicators that characterize the effectiveness of the program and based on the goals to which it is aimed;

2) minimization of time spent more than planned for the program;

3) minimization of additional resources spent on bringing the performance indicators of the program to the optimal state.

The combination of these criteria and possible situations that characterize the achievement of the program of innovative development of the planned goals allows for their graphical interpretation (Figure 1).

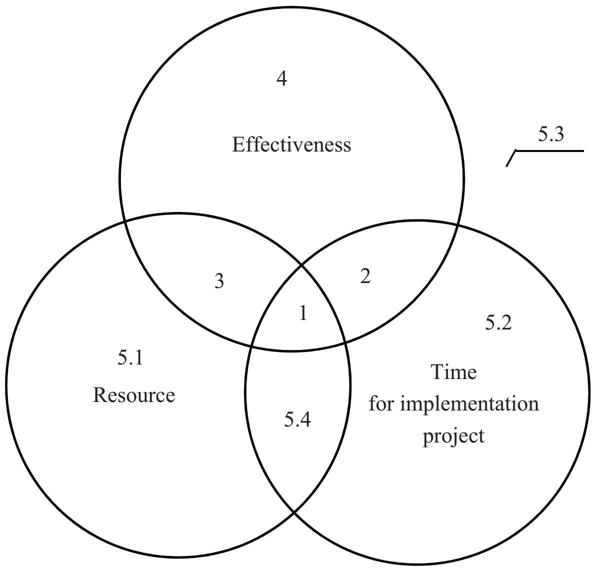


Figure 1. Positioning of possible situations of compliance of values of parameters of an estimation of efficiency of the program of innovative development to the established criteria

To achieve a pre-set goal, the indicator parameter must meet the planned criteria (be in a clearly defined range of values). However, under the influence of internal and external factors, the parameters of the indicator may change, which, as a result, causes deviations from the ultimate goal in one direction or another (the occurrence of a critical event). As a result, this leads to the formation of one of the following situations:

Situation 1. The goal is achieved (within tolerances) without the involvement of additional resources and in a timely manner. The best option is which the actual figures correspond to the planned.

Situation 2. The goal is achieved (within the permissible deviations) in a timely manner with the involvement of additional resources. An acceptable option in which in the process of implementing the program of innovative development there is a need to adjust the parameter to achieve the planned result or minimize losses from non-compliance with pre-set values.

Situation 3. The goal is achieved (within tolerances) without the involvement of additional resources, but with non-compliance with time limits. The option is permissible only in the absence of additional losses from the increase in time for the implementation of the program of innovative development.

Situation 4. The goal is achieved (within tolerances) with the involvement of additional resources and non-compliance with time limits. A problematic situation is the result of a flaw in the development of the program, unqualified operational management or a sharp change in the external situation, which led to a deterioration of the final result.

Situation 5. The goal is not achieved. A critical option that requires a significant revision of the program of innovative development, finding ways to minimize losses from inefficient resources, which can lead to a deterioration of the overall financial condition of the enterprise in the long run.

This situation can have four possible options: 5.1) additional time was spent on correcting the situation, however, without success; 5.2) the goal is not achieved even despite the cost of additional resources; 5.3) neither the cost of additional resources nor additional time did not bring the expected result; 5.4) the goal has not been achieved, but the planned term of the program and the budget for the use of resources have been met.

Of course, in practice, all the above situations are quantified and costly. This is due to the effectively built information support for the management of innovation activities of the enterprise.

Table 1. Evaluation of the effectiveness of measures of the innovation development program implemented by Gorodotsky Mechanical Plant Corp.

Project within the program	Goal	Basic parameter	Parameter value, %	Time for project implementation, months	Project costs, thousand UAH	The end result
Improving the system of labor organization	Improving the efficiency of labor resources	Growth of labor productivity	10	12	200	The goal was not achieved even despite the cost of additional resources (situation 5.2)
Intensification of reproduction and re-equipment of fixed assets	Improving the efficiency of labor	Growth of return on assets	35	6	12 000	The goal was achieved without attracting additional resources and on time (situation 1)
Introduction of advanced manufacturing technologies	Reducing the material consumption of manufactured products	Cost reduction	3	15	450	The cost of additional resources and additional time did not bring the expected result (situation 5.3)
Intellectualization of production	Intensifying the use of the latest information technologies	The growing share of automated production processes	30	6	400	The goals were achieved with the involvement of additional resources and in a timely manner (situation 2)
Reorganization of sales activities	Expanding markets and improving the company's image	Sales growth	40	15	420	The goal was achieved without attracting additional resources and on time (situation 1)
Development and commercialization of innovative products	Activation of innovative activity in the sphere of production	Growth of the share of innovative products in the total volume of its production	10,5	27	2 000	The goal was achieved with the involvement of additional resources and non-compliance with time limits (situation 4)

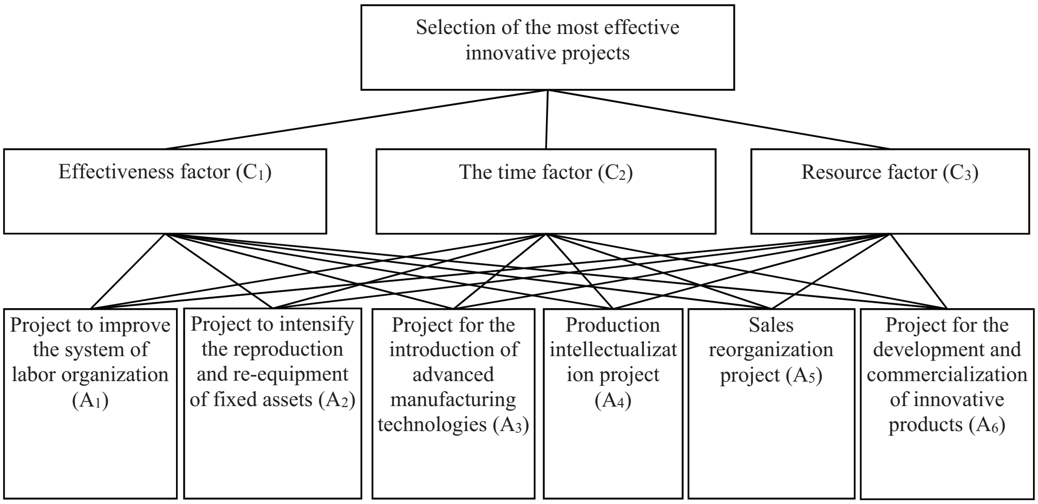


Figure 2. Multicriteria decision-making system for the selection of an innovative project

3.2. Project characteristics and input information for the implementation of the ELECTRE model

Attributes of projects included in the program of innovative development and served as input for the implementation of the model of multicriteria analysis, obtained on the materials of one of the leaders of the engineering industry of Ukraine – Gorodotsky Mechanical Plant Corp. (as a sample), and implemented by him during 2017–2019, are presented in Table 1.

The presented program of innovative development contains six projects:

- project 1 was to redistribute functional responsibilities, create appropriate conditions for personal development of employees, systems of rationing and incentives to increase the efficiency of labor resources. However, despite exceeding the budget, the company failed to achieve the planned increase in productivity;
- project 2 was designed to completely replace obsolete equipment on two production lines with new ones to increase the efficiency of labor. The goal was fully achieved in a timely manner;
- project 3 created organizational and information support for the introduction of advanced technologies for manufacturing products to reduce its cost. However, a small reduction in cost (by 3%) was disproportionate with significant overspending and non-compliance with the set time for implementation. The project was considered a failure;
- project 4 consisted of full automation of processes on all production lines through the introduction of comprehensive management information systems from the receipt of raw materials to the delivery of finished products to the warehouse. The goal was achieved, but with non-compliance with budget indicators;
- project 5 concerned the adjustment of the company's advertising campaign and was to ensure the growth of sales. Despite a slight deviation of the final result, the project is considered successful:
- compliance with the time frame was accompanied by insignificant savings in actual costs incurred;
- project 6 aimed to intensify the innovative activity of the enterprise by offering on the market products with significantly improved technical characteristics in comparison with previous models and analogues. The project did not meet the targets, neither in terms of resources involved nor in terms of time, primarily due to the difficulty and complexity of forecasting such activities. At the same time, the main goal, which was characterized by an increase in the share of innovative products in total production, was achieved.

3.3. Selection of the most effective innovative project according to the ELECTRE method

The hierarchical structure of the problem of decision-making on the selection of the most effective innovative projects as a compromise between alternative developments taking into account the factors of time, efficiency and resources is presented in Figure 2.

The input data for selecting the most effective projects according to the ELECTRE-I method are as follows (Table 2):

Table 2. Matrix for solving the problem of choosing the most effective innovation project

Criteria		C_1	C_2	C_3
Weights		0,35	0,30	0,35
Innovative projects	A_1	10	12	200
	A_2	35	6	12000
	A_3	3	15	450
	A_4	30	6	400
	A_5	40	15	420
	A_6	10,5	27	2000

Matrices that are built to achieve the final result (stage 1, 2, 3, 5, 6 and 7 of the ELECTRE-I method), with the calculation of numerical values using the MS Excel application package and the open resource Decision Radar (https://decision-radar.com/), summarized in Table 3.

Table 3. Matrices used in solving the problem of selecting the most effective innovative projects

Stage	The name of the matrix	Notation of the matrix	Matrix elements
1	Solution matrix	x_{ij}	$\begin{pmatrix} 10; & 12; & 200 \\ 35; & 6; & 12\,000 \\ 3; & 15; & 450 \\ 30; & 6; & 400 \\ 40; & 15; & 420 \\ 10.5; & 27; & 2000 \end{pmatrix}$
2	Normalized decision matrix	r_{ij}	$\begin{pmatrix} 0.1592; & 0.3089; & 0.7705 \\ 0.5573; & 0.6179; & 0.0128 \\ 0.0478; & 0.2472; & 0.3424 \\ 0.4777; & 0.6179; & 0.3852 \\ 0.6369; & 0.2472; & 0.3669 \\ 0.1672; & 0.1373; & 0.0770 \end{pmatrix}$
3	Matrix of weights	w_{ij}	$\begin{pmatrix} 0.35; & 0; & 0 \\ 0; & 0.3; & 0 \\ 0; & 0; & 0.35 \end{pmatrix}$
	Weighted normalized matrix	v_{ij}	$\begin{pmatrix} 0.0557; & 0.0927; & 0.2697 \\ 0.1951; & 0.1854; & 0.0045 \\ 0.0167; & 0.0741; & 0.1199 \\ 0.1672; & 0.1854; & 0.1348 \\ 0.2229; & 0.0741; & 0.1284 \\ 0.0585; & 0.0412; & 0.0270 \end{pmatrix}$
5	Concordance matrix	c_{kl}	$\begin{pmatrix} -; & 0.35; & 1; & 0.35; & 0.65; & 0.65 \\ 0.65; & -; & 0.65; & 0.35; & 0.3; & 0.65 \\ 0; & 0.35; & -; & 0; & 0; & 0.65 \\ 0.65; & 0.35; & 1; & -; & 0.65; & 1 \\ 0.35; & 0.7; & 0.7; & 0.35; & -; & 1 \\ 0.35; & 0.35; & 0.35; & 0; & 0; & - \end{pmatrix}$
	Discordance matrix	d_{kl}	$\begin{pmatrix} -; & 0.53; & 0; & 0.83; & 1; & 0.01 \\ 1; & -; & 0.64; & 1; & 1; & 0.16 \\ 1; & 1; & -; & 1; & 1; & 0.45 \\ 1; & 0.21; & 0; & -; & 0.5; & 0 \\ 0.84; & 0.89; & 0; & 1; & -; & 0 \\ 1; & 1; & 1; & 1; & 1; & - \end{pmatrix}$

End of Table 3

Stage	The name of the matrix	Notation of the matrix	Matrix elements
6	The dominant concordance matrix	f_{kl}	$\begin{pmatrix} 0; & 0; & 1; & 0; & 1; & 1 \\ 1; & 0; & 1; & 0; & 0; & 1 \\ 0; & 0; & 0; & 0; & 0; & 1 \\ 1; & 0; & 1; & 0; & 1; & 1 \\ 0; & 1; & 1; & 0; & 0; & 1 \\ 0; & 0; & 0; & 0; & 0; & 0 \end{pmatrix}$
	Dominant discordance matrix	g_{kl}	$\begin{pmatrix} 1; & 1; & 1; & 0; & 0; & 1 \\ 0; & 1; & 1; & 0; & 0; & 1 \\ 0; & 0; & 1; & 0; & 0; & 1 \\ 0; & 1; & 1; & 1; & 1; & 1 \\ 0; & 0; & 1; & 0; & 1; & 1 \\ 0; & 0; & 0; & 0; & 0; & 1 \end{pmatrix}$
7	The final dominant matrix	e_{kl}	$\begin{pmatrix} 0; & 0; & 1; & 0; & 0; & 1 \\ 0; & 0; & 1; & 0; & 0; & 1 \\ 0; & 0; & 0; & 0; & 0; & 1 \\ 0; & 0; & 1; & 0; & 1; & 1 \\ 0; & 0; & 1; & 0; & 0; & 1 \\ 0; & 0; & 0; & 0; & 0; & 0 \end{pmatrix}$

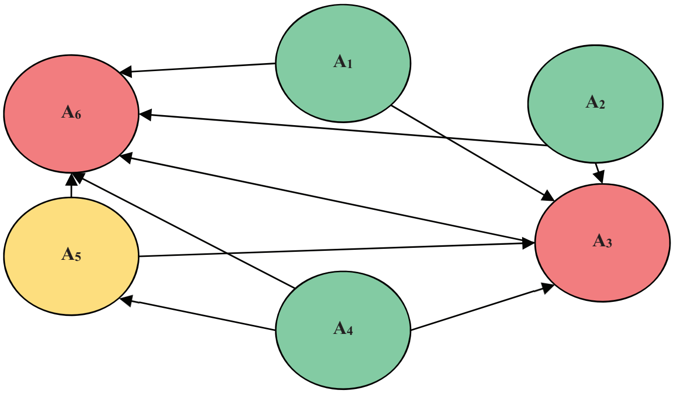
The threshold value of $\underline{c}$ for constructing the dominant concordance matrix is calculated at the level of 0.48. The elements of the dominant concordance matrix are defined as follows:

$$f_{kl} = \begin{cases} 1, & \text{if } c_{kl} \geq 0.48 \\ 0, & \text{if } c_{kl} < 0.48 \end{cases}.$$

The threshold value $\underline{d}$ for constructing the dominant discordance matrix is 0.6686.

$$g_{kl} = \begin{cases} 1, & \text{if } d_{kl} \leq 0.6686 \\ 0, & \text{if } d_{kl} > 0.6686 \end{cases}.$$

Interpretation of research results: the project to improve the system of labor organization (A_1) is better than the project to implement advanced manufacturing technologies (A_3) and the project to develop and commercialize innovative products (A_6); the project on intensification of reproduction and re-equipment of fixed assets (A_2) is better than the project on introduction of advanced technologies of production (A_3) and the project on development and commercialization of innovative products (A_6); the project for the introduction of advanced manufacturing technologies (A_3) is better than the project for the development and commercialization of innovative products (A_6); the project on intellectualization of production (A_4) is better than the project on introduction of advanced technologies of production (A_3), the project on



Note:

A_1; A_2; A_4 – innovative projects, which according to the results of the analysis are defined as "the most successful" (taking into account the factors efficiency, time and resources), the experience of their implementation can be used in the future;

A_3; A_6 – innovative projects that received a negative overall assessment and the basic principles of their implementation should reviewed;

A_5 – an innovative project, the final decision on the effectiveness of which must be made by the management enterprises taking into account additional parameters.

Figure 3. Graph of the problem of multi-criteria decision-making to select the most effective innovation project

reorganization of sales activity (A_5) and the project on development and commercialization of innovative products (A_6); the sales reorganization project (A_5) is better than the project for the introduction of advanced manufacturing technologies (A_3) and the project for the development and commercialization of innovative products (A_6).

The choice of the most effective innovative project is illustrated in Figure 3.

According to the used model, the projects of Gorodotsky Mechanical Plant Corp. can be positioned as follows (Figure 4).

It should be noted that the set of indicators for determining each parameter and their quantitative composition may be different depending on the goals to be achieved by a particular innovation program.

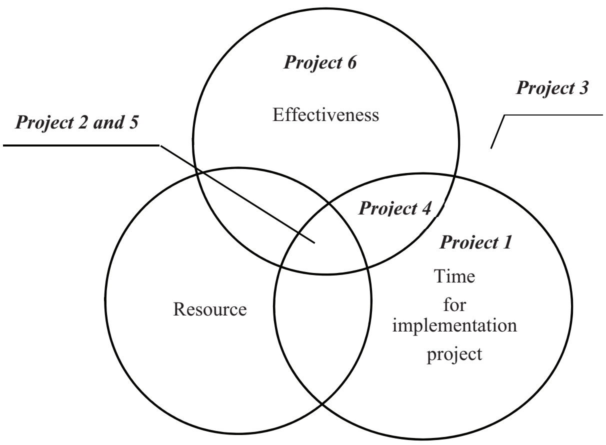


Figure 4. Positioning of projects of the program of innovative development for an estimation of their efficiency through conformity to the established criteria

During the evaluation of the effectiveness of the innovation development program, the range of planned values of indicators of each of the three parameters is compared with the actual ones. In case of deviation of one or several actual indicators from the defined optimal range (occurrence of one of the five previously described situations) – the management of the enterprise makes a management decision on the feasibility of further implementation of this program and innovative projects within it.

Discussion and conclusions

Thus, the results of the ELECTRE-analysis showed that the most effective are the project of intellectualization of production (A_4; goals achieved with a small amount of additional resources and on time), the project to improve the system of a labour organization (A_1; goals achieved in part, the cost of additional resources insignificant, the project was completed on time) and the project to intensify the reproduction and re-equipment of fixed assets (A_2; the goal was achieved without attracting additional resources and in a timely manner), which, however, cannot be compared. The sales reorganization project (A_5), despite the high indicators obtained by all criteria, dominates the A_4 project due to the short deadlines of the latter, which reduces the risks of its implementation. The least effective project was the development and commercialization of innovative products (A_6; the goal was achieved, but with the involvement of a relatively large amount of additional resources and non-compliance with time limits).

The presented model (Figure 4) makes it possible to establish that the biggest problem in the implementation of the program of innovative development was the excess of the planned amount of costs. While two projects (projects 2 and 5) achieved the planned goals, one (project 3) was considered a failure. Next, it is necessary to assess the extent to which the failure of a particular project will affect the final assessment of the effectiveness of the program as a whole.

The initial analysis demonstrated the high efficiency of the program of innovative development of the enterprise, albeit with non-compliance with the budget of individual projects. A detailed graphical study of the "Cost Reduction" parameter made it possible to single out two events that caused the failure of the project related to the introduction of advanced manufacturing technologies. It was found that both problems could have been avoided at the stage of developing the program of innovative development, while the actions of managers aimed at eliminating their negative consequences were considered untimely, which led to non-compliance with the project and the program as a whole.

We emphasize the high efficiency of results-oriented management using the method of multicriteria analysis (in our case – ELECTRE-I), as the most useful in assessing the effectiveness of the program of innovative development of the enterprise using three main determinants: indicators that characterize the effectiveness of the program, to achieve which it is aimed; time spent more than planned to implement the program; additional resources spent on bringing the performance indicators of the program evaluation to the optimal state. To detail the analysis of parameters that characterize the effectiveness of the program of innovative development of the enterprise, we consider the most appropriate to use a graphical approach, which focuses on compliance with the optimum performance indicators, as well as minimizing time and resources for development and implementation. interfere with the implementation of planned actions, as well as the response time of the manager to these events.

A limitation of the presented research is the ambiguity of the selection of the core of alternatives, which depends on the threshold values and conditions. At the same time, the set may include too many alternatives. Also, the problem is the human factor when assigning a specific weight to the criteria. The collective setting of criteria values in such a case can be considered a priority.

The results of the research can be used for the development of an expert decision-making support system both at the level of an individual enterprise and the entire machine-building industry, which will allow finding a relevant analytical justification for decision options made by top management in the field of innovation. We consider the formation of an economic-mathematical basis for evaluating a set of alternative projects in a typical program of innovative development of enterprises in the machine-building industry to choose an effective alternative from possible to be of additional value in the field of research. This will allow decision-makers to obtain the necessary tools to increase the effectiveness of innovative activities of business entities of industrial systems.

In the future, the results of the study can be expanded by taking into account the features of the innovative activity of machine-building enterprises in Ukraine, taking into account the criteria arising in the new economic conditions of the state's development at the macro level (such as the COVID-19 pandemic and military actions).

Author contributions

O. S. V. – supervision; O. S. V., O. O. V. – methodology; O. S. V., V. H., A. B. – formal analysis, review and editing; O. O. V. – data curation; O. S. V., V. H., A. B. – conceptualization, original draft preparation.

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