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DEVISING A METHOD FOR ASSESSING THE EFFICIENCY OF A PROJECT PORTFOLIO BASED ON A MULTI-CRITERIA APPROACH

Tetiana Prokopenko
Corresponding author
Doctor of Technical Sciences, Professor*
E-mail: t.prokopenko@chdtu.edu.ua
Yevhen Lanskykh
PhD, Associate Professor*
Dmytro Kataiev
PhD*
Vadym Rudenko
PhD Student*
Yaroslav Povolotskyi
PhD Student*
*Department of Information Technology Design
Cherkasy State Technological University
Shevchenko ave., 460, Cherkasy, Ukraine, 18006

Factors of flexibility and dynamic response to changes become important for projects implemented under conditions of economic and political instability, which affects the adoption of strategic decisions. Therefore, processes related to the assessment of the effectiveness of projects and the project portfolio as a whole, which is the object of this study, become important.

The task addressed in this study is to increase the effectiveness of projects by making optimal management decisions that make it possible to achieve the set goals at minimal cost, based on relevant, current information. The result of this study is a method for assessing the effectiveness of a project portfolio. This method was devised based on the application of the Pareto multi-criteria approach, which would provide the opportunity to obtain a comprehensive assessment and make management decisions in dynamics, taking into account current priorities and constraints.

In the process of formalizing the process of assessing the effectiveness of IT projects, it is important to solve the problem that boils down to choosing the optimal alternative among a set of permissible performance indicators. Therefore, the proposed method for assessing the effectiveness of an IT project portfolio is characterized by the features of definition and structuring according to efficiency criteria of various kinds and nature.

Within the framework of the method, a model of multi-criteria Pareto assessment of the effectiveness of an IT project portfolio has been built. This model will provide the possibility of operational assessment of project effectiveness and will facilitate the adoption of strategic decisions based on the received current data.

The result of applying this method is an increase in project effectiveness by avoiding overspending of resources and losses in the project by 7–10%, which contributes to an increase in the overall effectiveness of the project portfolio

Keywords: IT project portfolio, efficiency criteria, multi-criteria assessment, Pareto-optimal solutions

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1. Introduction

To make effective management decisions in the context of dynamic changes, project management in the field of information technology (IT) requires information tools and software that are capable of quickly carrying out a multi-criteria assessment of the state of the technological process. In addition, it is necessary to objectively reflect the current economic situation and create prerequisites for the most effective management of both the project and the project portfolio through timely correction of plans, resources, and priorities. Optimal management decisions based on project effectiveness assessment make it possible to achieve the goals of the project portfolio under the condition of rational use of labor, material, financial, and energy resources, which is especially important given high competition and rapid market changes.

Project and project portfolio management, due to sharp changes in both external and internal factors, requires a prompt assessment of the situation and adaptation to new realities. An important problem to be solved in this case is the ability to make optimal management decisions that make it possible to achieve the goals set at minimal cost, based on relevant, current information, which is a key factor of competitiveness. Devising a method for multi-criteria assessment of the effectiveness of an IT project portfolio according to Pareto makes it possible to see an objective picture of the state of projects in real time, identify Pareto-optimal solutions, and quickly restructure priorities in the portfolio.

Under conditions of economic and political instability, factors of flexibility and dynamic response to changes become important. The environment is characterized by a high degree of uncertainty and does not always contribute to the implementation of projects. In order to survive and evolve in modern conditions, project management must ensure the sustainability of business processes even under difficult conditions. Information technologies that would allow for the consideration of such factors and provide the possibility of a systematic multi-criteria approach to assessing effectiveness do not exist today.

Therefore, an important scientific task arises to devise a method for assessing the effectiveness of an IT project portfolio based on a multi-criteria Pareto approach. This will ensure in practice the adoption of sound management decisions under conditions of rapid market changes, limited resources, increased competition, and high risks, which are characteristic of the modern economy and especially for the information technology sector. Therefore, research into the processes of assessing the effectiveness of projects and project portfolios and the development of appropriate information technologies is relevant.

2. Literature review and problem statement

Under modern conditions, the issue of studying the processes of assessing the effectiveness of projects in various industries, as well as projects included in a portfolio or program of projects, is given considerable attention. Conventional methods for assessing the effectiveness of projects, based on the study of financial and economic indicators of project implementation taking into account discounting, were studied in works [1, 2]. These methods provide the opportunity to obtain conclusions based on indicators of commercial effectiveness of both the project and the portfolio as a whole, based on empirical data of a predictive nature. However, the possibilities of rapid changes in situations under the influence of external and internal factors are not taken into account. The reason for this may be the lack of adequate estimates of effectiveness indicators in accordance with the situation.

The results of a study reported in [3] show that indicators of project cost assessment can be used to assess the mission of the project and achieve its strategic goals. Modeling and analysis of the relationship between operational indicators of project cost assessment demonstrate their impact on the overall effectiveness and success of the project. But the issues related to the development of a tool for assessing the effectiveness of actions and making management decisions under conditions of dynamic change remain unresolved. Work [4] reports a study on the influence of business competence, organizational culture, and leadership qualities on the formation of a project portfolio. The study of cultural aspects, including employee motivation and interpersonal communication, emphasizes the importance of these factors in the approach to organizational change. However, the work does not address the issue of the influence of factors of the technological component of the project, which does not provide an opportunity to fully determine the value and effectiveness of the project. Objective difficulties are associated with the lack of opportunities for structuring information and compliance with the technological and organizational components of the project.

Conventional approaches to solving the problems of assessing the effectiveness of projects in various industries are based on methods for forecasting positive and negative cash flows for the planning period. Similar studies are based on the PERT analysis method [5], which involves analyzing tasks based on data on time and volume of work. However, this does not take into account analysis of the weights of criteria and assessments, which makes it possible to identify which factors have the greatest impact on the overall effectiveness of the portfolio and affect the future strategy. Descriptive statistics methods [6] use empirical data and do not take into account the complexity of the structure of the project portfolio. Correlation and regression analysis methods [7] are used to assess effectiveness in cases where statistical information is fully available. However, they do not take into account the possibility of correctly comparing the properties of projects in a rapidly changing environment. The fundamental impossibility of obtaining up-to-date data under conditions of rapidly changing circumstances and their assessment complicates the use of such methods.

In works [8, 9], the authors investigate the issue of devising a comprehensive method for assessing the effectiveness of projects in the field of information technologies, implemented on the basis of Scrum. The comprehensive method for assessing the effectiveness of projects is developed in the class of organizational and technological systems based on the combined use of formalized, intelligent, and expert methods and ensures the development of effective management decisions. The proposed model of the project effectiveness index takes into account the features of the organizational and technological components of the project and establishes a logical connection between the criteria that characterize, on the one hand, the organizational component of the project, and on the other hand, the project and technological component. The cited study requires expansion to the scale of project portfolio management in the field of information technologies. The reason for this is the implementation of approaches to management within the framework of a project portfolio.

For projects, it is important not only to assess effectiveness but also to devise rational ways to achieve project goals under risky conditions. In [10], the authors studied an approach that considers the effectiveness of project implementation depending on effective risk management practices, since it is with their help that risks for the sustainable development of IT projects can be reduced. The presence of a positive and significant relationship between risk management practices and IT project effectiveness provides opportunities for proactive project risk management since the implementation of IT projects is subject to limitations, challenges, and risks. The dependence of project effectiveness on proactive risk management indicates a comprehensive risk assessment and the preparation of an appropriate management plan. At the same time, there is no research on assessing the effectiveness of approaches to project portfolio management and determining a combination of projects that would provide maximum overall effectiveness, taking into account available resources, limitations, and interrelationships between projects. The reason for this may be the shift in the focus of the study to the assessment of risks, rather than the effectiveness of the project depending on the impact of risks.

In [11], the authors propose a methodology for the project selection process and a set of criteria for evaluating and prioritizing projects. In the work, the project selection process is defined using a comprehensive set of criteria. The authors propose a process consisting of excluding prerequisites, weighing criteria, evaluating projects, and checking them, based on the use of the AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) methods. However, the work does not consider the possibility of simultaneously taking into account several important criteria (for example, financial indicators, risks, strategic perspective, technological component, etc.), which provides a more complete and balanced understanding of the effectiveness of projects. Objective difficulties associated with data structuring do not provide the possibility of formalization based on the selected effectiveness criteria.

In [12], the authors use control theory as a research method and investigate different control modes. They investigate behavioral, performance, clan, and self-control, as well as their role in increasing internal efficiency and psychological outcomes among project participants in the presence of technical uncertainty. The paper recommends prioritizing the performance and clan control modes but does not take into account the presence of various factors that reduce the subjectivity of the selection of projects for implementation within the portfolio. The reason for this may be the focus of the study on the organizational component of projects and the lack of a comprehensive approach.

The authors of [13], using a knowledge-based approach, conduct research that indicates how enterprises use structural IT capabilities to facilitate the development of novelty-oriented business models (NBMD) and the development of efficiency-oriented business models (EBMD). In the study, polynomial regression and response surface analysis show that a high proportion of IT reconfiguration or integration is required to optimize NBMD. The paper explores the theoretical and practical implications of how to develop structural IT capabilities to support BMD. However, the paper does not explore the possibility of changing the set of criteria or weightings in accordance with the current strategic priorities of the enterprise or external changes. The fundamental impossibility of studying a set of criteria of different types and nature depending on changes limits this study.

Paper [14] reports a study of the theory, providing a consolidated view of different but comparable research areas (business value, IT, and system use) in the context of business process analytics (BDA). At the same time, organizations try to use the information potential of BDA to obtain value. In the paper, the authors propose a framework consisting of BDA system capabilities, BDA use, BDA users and tasks, BDA organizational capabilities. It also includes additional organizational resources, BDA training, focused activities, intermediate results, final results, and internal and external environments. The framework also includes 10 propositions that highlight the relationships in the BDA value chain, the BDA learning cycle, and the BDA context. However, the main measures in the study are aimed at determining the impact of BDA on business value and do not make it possible to identify how the impact factors are determined. The reason for this is the need to determine the impact on the overall performance of the portfolio and is useful for further strategic planning.

In [15], the authors propose a concept of integrating project and operational activities in the process of producing complex knowledge-intensive products. A method for coordinating project and operational activities in the process of producing complex knowledge-intensive products has been devised. The following criteria have been proposed: management of operational processes as processes depending on the progress of projects; assessment of project success taking into account the assessment of their provision with operational activity products. However, the impact of the specified criteria on the overall effectiveness of the project is not taken into account. The fundamental impossibility of assessing the impact of the specified criteria does not contribute to a comprehensive assessment of effectiveness taking into account data of various types and nature.

Our review of the literature [1–15] has shown that existing models and methods for assessing the effectiveness of projects and project portfolios in different industries do not provide opportunities for studying the processes of determining the balance between different goals. In addition, no description of the effectiveness of projects and project portfolios as a whole by independent or partially contradictory criteria is provided. There are also no models and methods that would provide the opportunity to provide a comprehensive assessment of IT projects in dynamics from the standpoint of many criteria.

All this gives grounds to argue that it is advisable to conduct research on the development of a method that could ensure the finding of solutions that satisfy several goals simultaneously in a coordinated manner. Therefore, to solve this problem, it is necessary to apply multi-criteria optimization methods and the Pareto solution structure. This will provide an opportunity to support decision-making in managing a portfolio of projects in the information technology industry, taking into account heterogeneous criteria, which is the basis for the development of corresponding information technology.

3. The aim and objectives of the study

The aim of our work is to devise a method for assessing the effectiveness of projects in an IT portfolio based on the Pareto multi-criteria approach. This method will provide the opportunity to obtain a comprehensive assessment and make management decisions in the dynamics, taking into account current priorities and constraints.

To achieve this aim, the following objectives were accomplished:

– to build and study a model of Pareto multi-criteria assessment of the effectiveness of IT projects in the portfolio;

– to substantiate and study the procedure of Pareto multi-criteria assessment of the effectiveness of the IT portfolio, which will contribute to the systematization, monitoring, and control of projects in the portfolio under conditions of complex, rapidly changing crisis circumstances.

4. The study materials and methods

The object of our study is the process of assessing the effectiveness of IT projects within the framework of the implementation of a project portfolio. The formalization of this process is reduced to choosing the optimal alternative among the set of permissible effectiveness criteria that determine the achievement of the set goal. In IT projects implemented under current conditions of dynamic changes, there are usually several such goals. Accordingly, there are also several evaluation criteria, which are often contradictory to each other. Therefore, significant difficulties arise in the process of assessing the effectiveness of an IT project portfolio due to the inability to determine a single criterion, or even to establish a solid hierarchy of performance evaluation indicators.

The main idea is to "compromise" between different goals described by different effectiveness criteria and to find solutions that would to some extent satisfy all the proposed criteria. This approach arose from the understanding that in many cases there is not enough information for linear ranking of the solutions that arise, and only group ranking can be carried out. Accordingly, the mathematical apparatus of optimization has expanded. Along with variational calculus, solving differential equations, linear programming, etc., Pareto optimization methods, construction of indifference planes, etc. were used. This is the main hypothesis of our study.

The practice of assessing the effectiveness of an IT project is based on subjective criteria that can indicate the optimality of one (or several) indicators from a set of indicators. In this case, difficulties can be caused both by the sheer number of possible indicators and by the non-triviality of a specialist's ideas about optimality, which is associated with the need to take into account several performance indicators. Therefore, adequate modeling of the structure of the advantages of performance indicators is the central problem of the process of assessing the effectiveness of an IT project and making decisions that will provide the opportunity to adequately respond to the current situation in the project.

Assessing the effectiveness of an IT project by many criteria means that the management of an IT project is trying to achieve more than one goal, and these goals may have varying degrees of importance. Therefore, it is important to determine the adequate and reliable state of the project in the process of assessing the effectiveness of operating with a set of performance criteria. At the same time, the criteria are characterized by the natural irreducibility of the criteria to one meaningful performance indicator.

It should be noted that a number of difficulties may arise when implementing this approach. The objectivity of assessing the effectiveness of an IT project affects the choice of the appropriate strategic decision, especially among a set of alternative options. Choosing the best option is possible only in cases where a scalar or vector criterion is formed. However, this situation does not always arise, taking into account the portfolio of IT projects. In addition, project management, which implements "manual" decision-making, often does not think about the criteria for assessing effectiveness and, even more so, about the relative importance of criteria at the expense of improving others.

Therefore, it is necessary to take into account the following assumptions adopted in the study:

– evaluation by several heterogeneous performance indicators, which can be both quantitative and qualitative;

– performance criteria are not strictly interdependent, that is, a change in one criterion does not always directly determine another;

– all indicators are collected for the same state of the project environment, without significant time shifts that would distort the result.

To ensure the meaningfulness of the multi-criteria Pareto assessment of the effectiveness of IT portfolio projects, a sufficient number of alternatives is required, among which it is possible to distinguish an effective front. In order to simplify the study and make the model more visible, conditional data are used in the work, which makes it possible to focus on the mechanisms of multi-criteria optimization and the structure of Pareto solutions, which is a simplification of our study.

Under conditions of dynamic change and uncertainty, one of the main problems of project management in the field of information technology is making adequate and relevant management decisions. Operational and strategic decisions will help improve the effectiveness of both individual projects and the project portfolio as a whole. Assessing current effectiveness is a key aspect of project management, which provides information analysis and timely response to changes. In addition, changes in the project implementation process can be so large-scale or abrupt that simple operational measures within the framework of already adopted decisions are not enough. Therefore, it is advisable to study:

– key indicators of the project portfolio (KPI, OKR, financial and quality metrics) in order to notice deviations from the plan in time. This will help adjust strategic goals and make assumptions about the environment in which projects are implemented;

– operational diagnostics of the causes of problems, which will contribute to a fundamental modification of plans, i.e., it is possible to change the project architecture, its key phases, or even abandon part of the planned;

– development and implementation of corrective measures under conditions of time and resource shortage, which is a component of crisis management in order to quickly reorient resources and minimize risks.

Thus, the application of Pareto multi-criteria assessment methods for an IT project portfolio has a number of significant advantages, which will contribute to the generation and analysis of management decision alternatives in real time. A number of important factors are taken into account:

– the heterogeneity of the IT project portfolio, which may include short-term and long-term projects, with high risks or high impact on the strategy, internal infrastructure, and others;

– this approach will provide the opportunity to form effective management decisions taking into account priority advantages, which will ensure a reduction in the risk of subjectivity;

– taking into account the complexity and iterative process in portfolio projects in accordance with performance indicators.

Devising a method for assessing the effectiveness of projects based on the application of multi-criteria Pareto assessment helps provide project management with the information necessary to develop and implement adequate management decisions in real time. Such an information system makes it possible to simultaneously take into account several key indicators (costs, deadlines, risks, strategic significance, ROI (Return on Investment), etc.). Owing to this, management receives a more complete picture of the state of the project portfolio, and not just a one-dimensional assessment. In addition, IT solutions can automatically build Pareto fronts, highlight ineffective solutions, and visualize compromises. This significantly speeds up the preparation of management decisions and minimizes human errors. In addition, it provides opportunities to reorient resources, change the priority of projects, or even terminate ineffective initiatives, which will help increase the efficiency of projects and the portfolio as a whole.

5. Results of investigating the method for assessing the effectiveness of IT portfolio projects

5. 1. Modeling of multi-criteria Pareto evaluation of the effectiveness of the IT project portfolio

According to [16–18], the construction of a model for multi-criteria evaluation of the effectiveness of IT projects that make up the portfolio is considered in terms of heterogeneous performance indicators. This will provide the opportunity to simultaneously assess several important aspects of effectiveness, and not only, for example, finances. The main task will be to construct a model for ranking portfolio projects, which is especially relevant when it is necessary to compare projects of different types, with different goals and risks. This will make it possible to organize portfolio projects by effectiveness not linearly but by groups, which will contribute to more flexible and informed decision-making under complex conditions of uncertainty and multi-criteria. This approach will make it possible not only to select effective projects but also form groups of alternatives with a similar level of effectiveness for further analysis, taking into account resource constraints, risks, and strategic goals of the IT company.

In this case, the priority is set not between individual projects but between equal groups. This approach will not yield results if the ordering is performed according to any one performance indicator or criterion but opens up great opportunities if there are several of these indicators. For example, indicators or criteria that characterize the effectiveness of an IT project are ROI (Return on Investment) – return on investment; NPV (Net Present Value) – net discounted profit of the project. IRR (Internal Rate of Return) – internal rate of return; TCO (costs for implementing and maintaining an IT solution), project implementation duration; assessment of project implementation risks, etc. Given the heterogeneity of the initial data, the group approach to assessing the effectiveness of an IT project will provide the opportunity to combine projects with similar characteristics or level of effectiveness into separate classes (groups), which greatly simplifies the comparison and selection process. Instead of a rigid linear ranking, which may be insensitive to minor differences between projects, grouping makes it possible to take into account both quantitative and qualitative indicators, reducing the risk of erroneous management decisions in cases of uncertainty or incomplete information. In addition, the group approach helps identify typical project profiles, which makes it possible to form more consistent portfolios of IT initiatives, optimize resource allocation and ensure strategic coherence of implemented solutions.

The process of comparing projects according to several performance criteria is at the heart of the model. It is believed that project L_i dominates project L_k if the assessment of project L_i exceeds the assessment of project L_k according to at least one criterion, and all other criteria are no worse than the others.

As practice shows, in the process of implementing IT projects, costs and associated risks acquire significant importance, which can significantly affect the total amount of costs. In particular, risks associated with delays in the performance of work, changes in technical requirements, design errors or underestimation of the complexity of implementation can cause a significant excess of the initially planned budget. Therefore, in the process of assessing the effectiveness of IT projects, it is advisable to take into account not only the basic amount of costs but also potential risks. The main basic costs in an IT project are denoted by V_p, the costs associated with project risks are denoted by V_k, respectively. The profit in an IT project is directly proportional to the income that the project brings and the efficiency of resource use, that is, the ratio of income to expenses. The expression $(V_p, V_k) \to \min$ is appropriate for maximizing profit. Therefore, the efficiency of IT projects is assessed by two main efficiency indicators V_p, V_k.

For example, let project L_1 be characterized by the following indicators: $V_p = 55\%$, $V_k = 25\%$; project L_2: $V_p = 55\%$, $V_k = 23\%$. Accordingly, $L_1 = \{55, 25\}$, $L_2 = \{55, 23\}$. That is, the same basic costs were obtained for project L_2, lower costs associated with risks were obtained, $V_k = 23 < 25\%$. As is known from expression $(V_p, V_k) \to \min$, the more promising project is considered to be the one where indicators V_p, V_k are the smallest. Then project L_2 is more efficient than project L_1 since it is better by the second efficiency indicator, the first indicator is equal in both. If the expression $(V_p, V_k) \to \max$ were true in this example, then project L_1 would be more efficient.

Projects L_i and L_k are considered equivalent if their corresponding efficiency indicators are equal. Projects L_i and L_k are considered to be incomparable if the score of L_i exceeds the score of L_k by one indicator, and the score of L_k exceeds the score of L_i by another. For example, scores $L_1 = \{5.5, 5\}$, $L_2 = \{6.4, 5\}$ are incomparable. Regardless of whether the higher or lower score is considered the "best", it is impossible to compare these scores without additional information; in this case, this information should be the cost of the project team's labor and the cost of energy resources.

The absence of requirements for linear ordering of scores makes it possible to combine some incomparable and equivalent projects in terms of scores into one group and assign this group a number that determines the rank of the group. It is believed that the lower the number, the higher the rank of the group of projects.

Projects are divided into groups according to the following principle. A subset of projects will be selected for each of which there are no other projects that would have scores according to the efficiency criteria that determine their strict superiority (attractiveness) over these projects. In other words, this group will include those projects for which there are no alternatives that are better simultaneously according to all criteria or not worse according to all criteria and better according to at least one.

Thus, the selected subset of projects forms the so-called Pareto front, consisting of alternatives, none of which dominates the other. Such projects are assigned a rank of 1. Similarly, for the remaining group of projects (i.e., for those that were not included in the top priority), we shall select the optimal ones and assign them a rank of 2.

The principle described is explained using the following example. Let those projects with the lowest baseline costs and costs associated with project risks be preferred (Fig. 1).

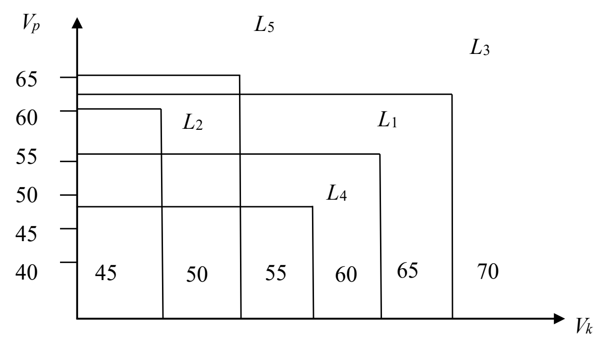


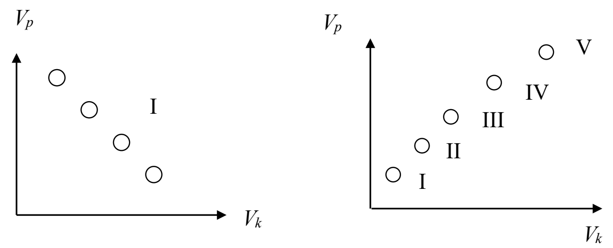
Fig. 1. Indicators of basic costs and costs associated with project risks: V_p – basic costs n, %, V_k – costs associated with project risks, L_1–L_5 – characteristics of five projects

In Fig. 1, V_p – basic costs n, %, V_k – costs associated with project risks, points L_1–L_5 mark the characteristics of five projects in terms of basic costs and technical costs associated with project risks, among which projects L_2 and L_4 occupy an important place. Project L_4 has the best characteristics in terms of basic costs, and project L_2 has the best characteristics in terms of technical costs associated with project risks. At the same time, project L_4 is inferior to some other projects (L_2, L_4) in terms of basic costs, and project L_2 is worse than some others in terms of technical costs associated with project risks (more than in L_4 and L_5). Moreover, each of these projects is better than the others in terms of one of these indicators. In other words, among projects L_1–L_5, only two (L_2 and L_4) have no indicator values that exceed them at the same time, which have lower basic costs and technical costs associated with project risks. Based on this, projects L_2 and $L_4$are assigned rank 1.

Of the remaining projects, for L_1 and L_5 there are no indicator values that strictly exceed them. Thus, these projects are assigned to rank 2, and finally the last project is assigned rank 3.

The number of projects of each rank is determined by the project estimates. The following cases are possible: all projects have the same rank; there are projects with both the same and different ranks.

For example, in Fig. 2, let, as in the previous example, preference be given to projects in which the basic costs and technical costs associated with project risks are the lowest.



a *b*

Fig. 2. Determining the rank of projects: *a* — the same rank; *b* — different ranks

In Fig. 2, *a*, all projects are of the same rank. This is explained by the fact that among all the projects considered, there is no one that is inferior to the others in terms of the totality of indicators. Or among the competing projects, there is no one that is better than any other in terms of the totality of indicators. This means that none of the projects can be preferred according to the criterion of the lowest basic costs and technical risk costs, therefore their work must be considered separately, or using other performance indicators.

Fig. 2, *b* shows another, extreme case, where all projects have different ranks. This means that based on the principle considered, all projects can be strictly linearly ordered. In this case, each project of a higher rank has an advantage over a project of a lower rank in terms of the totality of performance indicators.

Fig. 2 illustrates the most probable and practical case when projects have both the same and different ranks.

The approach considered makes it possible to quickly weed out clearly ineffective projects (which are dominated by others), as well as to reduce the set of options for deeper analysis. The application of Pareto-front methods provides the opportunity to highlight the "best" alternatives that are not dominated by any other. The proposed model makes it possible to systematically, transparently, and flexibly assess the effectiveness of IT projects in the portfolio, combining financial, time, quality, and strategic aspects.

5. 2. Procedure for multi-criteria Pareto evaluation of the efficiency of a portfolio of IT projects

The procedure for multi-criteria Pareto evaluation of the efficiency of a portfolio of IT projects is demonstrated based on the following method for determining the ranks of projects in the portfolio.

Since the rank of a project is determined not by the absolute but by the relative value of the project assessments by indicators, to implement the algorithm it is sufficient to have information on the type of relationship between each pair of projects. Moreover, it is actually important to know only one thing: whether there is a strict superiority relationship between two projects or not. Based on this, a Boolean variable is introduced

$$a_{i,j} = \begin{cases} 1, \text{if project } L_j \text{ has} \\ \text{a strict advantage over project } L_i; \\ 0, \text{otherwise} \end{cases}$$

and a square matrix is constructed, the elements of which are variables a_{ij}. From the definition of a_{ij} it follows that the units in the i-th row determine project L_j, in relation to which the project L_i has a strict advantage. Based on this, if the j-th column contains all zeros, then there is no project that would have a strict advantage over project L_i.

The method considered here for constructing the matrix makes it possible to perform project ranking. Let the project have an advantage if the efficiency indicators are higher. The efficiency of portfolio projects is considered in terms of 3 efficiency indicators: *ROI* (Return on Investment) – return on investment; *TTV* (Time to Value) – time to receive value; *P* – Level of fulfillment of requirements (Requirements Coverage & Quality). Evaluating efficiency according to these indicators will provide the ability to compare projects by payback, determine short TTV, and assess the quality of implementation. That is, the efficiency of portfolio projects is determined, and their rank is defined, based on the condition that project is considered the best for which {ROI, TTV, P} $\rightarrow$ max. It is also assumed that there are conditionally nine projects included in the portfolio, the effectiveness of which is assessed based on the specified performance indicators given in Table 1.

A Boolean matrix with elements a_{ij} is given in Table 2.

Table 1

Portfolio project performance indicators (conditional data)

Project No.	1	2	3	4	5	6	7	8	9
ROI, Return on Investment) %	13.5	13.5	13.5	13.5	13.5	14.0	14.5	15	15.5
Requirements Coverage & Quality, %	75	80	78	75	80	79	75	76	79
TTV, Time to Value, month	15	16	13	18	15	11	14	19	18

Table 2

Boolean matrix

Project No.	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	1	0	1	0	1	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0
5	1	0	1	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	1	0	0	1	0	0	1	0	0
9	1	0	0	0	0	0	0	0	0

To construct this table, values of performance indicators for project L_i were calculated from the values of the corresponding performance indicators for project L_j. The following cases may occur:

a) one or more values of the performance indicators of project L_i are greater than the corresponding values or corresponding values of performance indicators for project L_j, and the remaining indicators are equal. In this case, $a_{ij} = 1$.

For example, the performance of project L_2 is compared with the performance of project L_1. The values of the first indicators in them are equal to (13.5). The value of the second performance indicator of project L_2 is greater than the value of the corresponding indicator for performance indicator of project L_1 (80 and 75). The value of the third indicator for performance indicator of project L_2 is also greater than the value of the third indicator of the performance indicator of project L_1 (16 and 15). The condition is met, thus $a_{ij} = 1$.

Next, the performance of project L_2 is compared with project L_5. The values of the first and second performance indicators of projects L_2 and L_5 are equal to (13.5; 80), and the value of the third performance indicator of project L_2 is greater than the value of the corresponding indicator of project L_5 (16 and 15). That is, $a_{ij} = 1$;

b) one or more performance indicators of project L_i are less than the corresponding value of the performance indicator L_j. Then, regardless of the values of the other indicators, $a_{ij} = 0$.

For example, the value of the second performance indicator for project L7 is less than the value of the corresponding performance indicator for project L_6 (79 and 75), and the remaining indicators are greater, nevertheless $a_{ij} = 0$;

c) the value of all performance indicators for project L_i is equal to the value of the corresponding indicators L_j. In this case, $a_{ij} = 0$.

Table 2 gives a matrix in which values a_{ij} are calculated for the data in Table 1 in accordance with the conditions considered earlier. The numbers in the first column and the first row determine the portfolio project. In order to determine the group of projects of rank 1, it is enough to find the columns in which there are only zeros. Such columns will be 2, 6, 8, and 9. Projects with such numbers receive 1 rank. These projects are the best, and their efficiency is estimated as the best among other projects in the portfolio. These projects do not require changes in efficiency indicators by changing the technology and implementation strategy. Columns 2, 6, 8, 9, and the corresponding lines are deleted from the matrix.

We obtain the following matrix (Table 3).

Table 3

Boolean matrix of elements 1, 3, 4, 5, 7 of portfolio projects

Project No.	1	3	4	5	7
1	0	0	0	0	0
3	0	0	0	0	0
4	1	0	0	0	0
5	1	1	0	0	0
7	0	0	0	0	0

Again, columns containing only zeros are found. These columns will be 4, 5, 7. Projects with these numbers are assigned rank 2. Projects included in rank 2 perform somewhat worse in terms of efficiency than projects of rank 1 and require a review of technologies and implementation strategies.

These columns and their corresponding lines are deleted from the matrix. A matrix (Table 4) consisting of only zeros is obtained.

Table 4

Boolean matrix of elements 1, 3 portfolio projects

Project No.	1	3
1	0	0
3	0	0

We assign a rank of 3 to projects L_1 and L_3. These are the portfolio projects with the worst performance indicators. These projects require a fundamental review of technological solutions.

6. Discussion of results related to investigating the method for assessing the effectiveness of IT portfolio projects based on a multi-criteria approach

The proposed method for assessing the effectiveness of portfolio projects in the IT industry is based on the Pareto approach, which contributes to informed decision-making under conditions of multi-criteria and conflicting goals. The allocation of subsets of projects and the formation of a Pareto front for IT portfolio projects (Fig. 1) provides the opportunity to determine the optimal compromise between efficiency criteria of various kinds and nature. This makes it possible to reject ineffective alternatives and focus on more rational ones from the position of multi-criteria choice. Determining the rank of projects (Fig. 2) contributes to a structured comparison of alternatives, makes it possible to formalize the prioritization process, and provides substantiated support for management decisions in the process of forming and adjusting the IT project portfolio.

The specified approach to devising a procedure for assessing the effectiveness of IT portfolio projects, unlike [4–15], is relevant because it involves multi-criteria analysis. This allows projects to be evaluated not only from the perspective of financial indicators but also taking into account other important aspects of effectiveness, such as technical feasibility, risks, strategic significance, innovation, and resource availability, which is illustrated in Table 1. This approach provides a more comprehensive and balanced view of the real value of projects, which is especially important in a complex decision-making environment, limited resources, and dynamic changes in the IT sector.

The specificity of comparing projects of different types with different goals and risks, which make up the IT project portfolio, is due to structural heterogeneity. The adequacy of the application of a multi-criteria approach makes it possible to take into account the qualitative and quantitative characteristics of projects, to assess the effectiveness of projects taking into account strategic guidelines and interdependences between projects. The increasing complexity of making strategic and coordination decisions in managing an IT project portfolio is due to the high level of interdependence between projects, limited resources, rapid technological changes, and the need to align project goals with the overall strategy of the organization. Under such conditions, there is a need for analysis and comprehensive assessment of interdependent factors based on a formalized description using a multi-criteria approach. Based on determining the ranks of projects in the portfolio (Tables 2–4), adequate and operational data are formed that contribute to comprehensive decision-making. This approach allows for a more substantiated prioritization of projects, the formation of an optimal portfolio composition, increased flexibility and adaptability of the management system, and the achievement of strategic goals under conditions of uncertainty, which distinguishes our study from [4–15].

The main advantage, in contrast to [7–12], of the proposed method for assessing the effectiveness of IT portfolio projects based on a multi-criteria approach is the description and study of research objects from a systematic perspective. This will make it possible to consider objects and processes from the perspective of formal logical and mathematical methods. The multi-criteria approach will provide opportunities for studying IT portfolio projects based on the definition and structuring of efficiency criteria of various kinds and nature. This will contribute to a "through-the-counter" structural and systemic description from a single methodological perspective of the portfolio as a branched hierarchical system of jointly functioning IT projects. For this study, a formalized description of the evaluation process based on a multi-criteria approach is important. At the same time, remaining within the framework of conditional data, the model should be as open to modifications as possible. Adequacy is finally clarified only in the process of real work with the model, which is a disadvantage of this method. However, it should be noted that the process of building the model itself is quite useful for problem analysts even before the start of calculations, since it forces them to structure the problem area.

The proposed method for assessing the effectiveness of IT portfolio projects based on a multi-criteria approach could be used as the basis for relevant information technology and integrated into the overall project portfolio management system. This method is used in the development of an appropriate decision support system that will help select the optimal operational solution to ensure strategic project effectiveness indicators. The result of using this method is to increase the effectiveness of projects by avoiding overspending of resources and losses in the project by 7–10%, which contributes to increasing the overall effectiveness of the project portfolio. This method promotes adaptation to changes in environmental conditions, allowing for quick and effective response under difficult, crisis conditions with minimizing the impact of the human factor.

7. Conclusions

1. A model of multi-criteria Pareto assessment of the effectiveness of the IT project portfolio has been built, which could provide the ability to quickly assess the effectiveness of projects and facilitate strategic decision-making based on the current data received. This model systematically, in detail and dynamically, demonstrates the current state of implementation of projects in the portfolio in the field of information technology, identifies the "weak" points of the portfolio, and contributes to increasing the overall effectiveness of the portfolio.

2. The procedure for assessing the effectiveness of IT portfolio projects based on a multi-criteria approach contributes to making optimal strategic decisions. The result of applying the procedure for assessing the effectiveness of IT portfolio projects is an increase in the overall effectiveness of the portfolio by minimizing the impact of the human factor, reducing project losses and resource overspending.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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