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INFORMATION TECHNOLOGY SUPPORT FOR MANAGEMENT DECISIONS ON THE PORTFOLIO OF DUAL EDUCATION DEVELOPMENT PROJECTS

The article's subject *is information technology for decision-making support in the processes of sustainable development of educational institutions, as well as a model for forming a rational portfolio of dual education development projects.* ***The work aims*** *to improve the efficiency and quality of management decisions when planning dual education learning processes in conditions of uncertainty by creating information technology for decision support using a portfolio model of action areas. This study has several* ***objectives****: 1) To develop a model for forming a portfolio, taking into account the hierarchical structure of the projects value criterion and the positions of stakeholders; 2) To formalize the division of project options into groups to which different development strategies should be applied; 3) Create an interactive visualization and dashboard for advanced analysis of candidate projects for the portfolio.* ***Results.*** *Technology is proposed to classify and divide project options into groups to which different strategies should be applied, and a combined portfolio of different directions (vectors) of action should be managed. A heuristic search optimisation methodology synthesizes a new algorithm for identifying and comparing situation characteristics for selecting non-dominated portfolios. Combining multi-criteria decision analysis (MCDA) and visual methodology simplifies evaluating and comparing candidate projects for the strategic portfolio. This makes this approach valuable for a group of developers in practical scenarios. Customised cross-filtering of visual report data using Power BI made it possible to compare projects by stakeholder groups, candidate projects, and those being successfully implemented. This ensured the management of a combined portfolio of different areas (vectors) of action. The proposed technology is demonstrated by selecting strategies for developing dual education projects by employer partners. Data from previous partnerships with regional companies helps the decision-making group adjust project strategies. Recommendations for action can be created even without information about the probability of a scenario.* ***The conclusions*** *of this study can be used in practice in complex decision-making scenarios that consider the interests of various stakeholders in the dual education system, the uncertainty of situations, and the subjectivity of decision-makers.*

Keywords: *information technology; decision-making; multi-criteria; project portfolio management; mathematical models; heuristic algorithm; dual education.*

1. Introduction

Modern higher education in Ukraine is based on a competency-based approach to developing practical skills and applying knowledge in professional activities. Educational programs are focused on learning outcomes that meet the needs of the labour market. This approach is most effectively implemented through dual education, which combines university studies with practical internships at enterprises. This allows applicants to develop their qualifications through real-life experience and employers to influence staff training content. The Regulations on Dual Education (Order of the Ministry of Education and Science No. 426 of 13 April 2023) provides the regulatory framework, where qualifications are defined as a set of acquired competencies. Dual education is necessary for economic recovery, training specialists with in-demand skills, and integration into the European educational space. Its development requires systematic management through project portfolios that increase the competitiveness of academic institutions in the context of transformation.

1.1. Motivation

The experimental phase of the pilot project for training specialists using a dual education model in vocational and higher education institutions, initiated by the Ministry of Education and Science of Ukraine, has been completed. Reports on the project's implementation results have been prepared, describing the experiences of enterprises and educational institutions; however, many questions remain. Methodological recommendations for the implementation of dual education were developed within the framework of the project "Dual Education for Ukraine", which is implemented in partnership with the Ukrainian Marketing Association and the USAID project "Economic Support to Ukraine" [1]. This guide may be helpful for all interested parties, as it describes the legal mechanisms available to educational institutions. However, the question of which management tools and methods to develop dual education in specific situations remains open.

1.2. State of the art

Dual education is gaining popularity in Europe, with Germany as the recognized leader. In most countries, its adaptation is carried out through top-down government projects, and none of them has been able to fully replicate the German approach, which evolved from the bottom up. According to German experts [2], the success of implementation depends on taking into account the national context. A study [3] compares the German system with the results of a survey of 27 Ukrainian higher education institutions, confirming the need to adapt the model to local conditions. This is due to the peculiarities of the economy, the level of responsibility of employers, their willingness to cooperate, as well as the low readiness of stakeholders to change agreements [3, 4].

Organizations and countries usually integrate projects into portfolios if they plan to develop in several areas, giving preference to the most promising initiatives. This approach ensures project management, process coordination, and optimisation of their implementation [5]. In order to stimulate innovation, a strategic portfolio is created, as well as a set of programs, projects, sub-portfolios, and other measures focused on innovative activities. Each educational institution trains applicants in many educational programs. Dual education projects are targeted at specific groups or individual applicants, and each project has its unique value for stakeholders. Everything confirms the opinion that applying a portfolio management methodology based on stakeholders' values is advisable for managing the dual education development [6].

Effective management of dual education development projects requires a holistic view of the project, programs, or portfolio and careful coordination of all elements. A systematic approach to the development of dual education, which considers development through a portfolio of projects, defines the final product or educational service as accurately as possible [7].

Educational projects have a social orientation. Here, investment is the investment of funds and resources to obtain socio-economic benefits in the future. The main methodological difficulty lies in assessing the value of the project portfolio, which allows the most attractive components to be selected, given limited resources and established criteria. Requiring determinism of input data for decision-making during project analysis is a simplification, as each dual education development project has numerous factors of uncertainty that determine project risks. Portfolios of such projects must address a multi-criteria decision-making problem, managing numerous alternatives, diverse criteria, and varying scales for evaluating those criteria [6].

For project-oriented companies, project portfolio management (PPM) is a constant challenge, as it requires balancing long-term strategies with short-term requirements and constraints. In the PPM process, new projects are evaluated, prioritized and selected, while existing ones may be accelerated, suspended or downgraded in priority. Resources are also reallocated between existing projects [8].

Strategic planning in organizations is increasingly being supplemented or replaced by scenario planning, which, unlike focusing on the most likely future, considers several plausible scenarios for the future [9]. In particular, scenarios draw the attention of decision-makers (DMs) to uncertainty and help them create a reliable strategy that works well in different conditions. It is often helpful to consider strategy not in a holistic sense but as a combination or portfolio of different courses of action. The portfolio approach enables the creation of multiple alternative strategies with minimal effort and streamlines their implementation. The choice of a specific portfolio of actions (or strategy) can be supported by Portfolio Decision Analysis (PDA) methods [10, 11]. Scenario planning for the conditions of a manufacturing enterprise was implemented using an algorithm for identifying and comparing the characteristics of situations in an intelligent decision support system [12].

In complex decision-making scenarios involving many stakeholders, the uncertainty and confidence of decision-makers (DMs) significantly influence the results. This is the so-called problem of "fuzzy large-scale multi-criteria group decision-making (FLSDM)". Article [13] proposes an approach to improving decision-making processes in large groups of DMs under conditions of intuitive fuzzy self-confidence. It presents a hybrid clustering algorithm for identifying common opinion patterns among DMs. However, practical collaboration tools and mechanisms are lacking for complex decision-making scenarios that involve multiple stakeholders and uncertainty—conditions typical in managing the development of a dual education system.

In multi-criteria research, multi-criteria decision analysis (MCDA) is rapidly developing due to its ability to improve the quality of decision-making [11, 14]. This is only possible by constructing an analytical decision-making procedure that is much more efficient, precise, and rational than standard decision-making procedures [15]. MCDA and PDA methods apply analytical

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decision-making models to identify preferences and uncertainties regarding the impact of actions, while mathematical optimization determines the most desirable portfolio within resource and other constraints. In search of a scenario-based portfolio model for building reliable and active scenarios [9], researchers concluded that there are no direct solution algorithms for a set of non-dominated portfolios, but rather, various detailed algorithms are used to form the most desirable portfolio. Recommendations for decision-making are based on pairwise dominance relationships between portfolios of actions. These studies of project portfolio management define it as the optimal Pareto solution for an n-objective 0-1 linear programming problem, i.e., inclusion/non-inclusion, and do not propose methods for dividing project options into groups to which different development strategies should be applied.

Formulating a university development strategy as a portfolio of different courses of action requires dividing project options into groups. Research into project classification methods has shown that, for example, in the context of selecting a portfolio of research projects, an iterative trichotomous approach [16] is used, which involves the sequential and repeated division of project options into three groups:

- promising/acceptable – those that have high priority and are likely to be included in the portfolio;
- questionable – those that require additional information or re-evaluation;
- rejected – those that do not meet the criteria and are excluded from further consideration.

Recent studies demonstrate significant progress in applying portfolio management, particularly in strategic planning for innovation-driven organizations. Portfolio Decision Analysis (PDA) supports the identification of optimal portfolios by evaluating benefits and uncertainties, although final decisions remain context-dependent.

Numerous studies emphasize the importance of managing integrated portfolios based on stakeholder values, which involves multiple alternatives, diverse criteria, and varying evaluation scales. However, far fewer publications propose methods for classifying and grouping projects to enable differentiated strategies—despite the critical role of prioritization in effective portfolio management.

1.3. Objectives and Approach

This article aims to develop information technology to support decision-making and improve the efficiency and quality of management decisions regarding the portfolio of dual education development projects in complex scenarios that consider stakeholders' interests and uncertainty.

Managing a portfolio of dual education development projects in an educational institution is an activity that balances the formation and use of the institution's potential. The specificity of such management lies in focusing on achieving "values" and ensuring the potential for future dual education development projects, which is the basis for portfolio balance.

A balanced portfolio of dual education development projects for an educational institution comprises initiatives whose implementation maximizes the value of the dual education system while maintaining equilibrium between building and utilizing the institution's potential.

When forming a portfolio of projects using a value-oriented approach and fuzzy set theory, two main tasks arise:

– obtaining project indicator assessments in the form of fuzzy numbers;

– creating an optimal portfolio based on these fuzzy assessments.

The first task of forming a portfolio of projects using a value-oriented approach and fuzzy set theory has already been solved [17]. As for the second task, it is proposed that it be solved in the following three stages.

As for the second task, it is proposed to address it through the following three stages.

1. Develop a multi-criteria mathematical model for forming a rational portfolio of dual education development projects, considering the hierarchical structure of the project value criterion and the stakeholders' positions.

2. Develop a method for dividing project options into groups to which different dual education development project strategies should be applied, using an algorithm for identifying and comparing situation characteristics.

3. Develop an interactive visualization and a dashboard for advanced analysis of candidate projects for the action portfolio using Power BI, with recommendations for decision-making.

The article has the following structure. Section 2 presents a model for forming a project portfolio based on two integrated criteria, value and risk, and proposes a heuristic algorithm for dividing project options into groups to which different strategies should be applied.

Section 3 demonstrates the application of the technology using the example of selecting strategies for developing dual education projects with employer partners.

Section 4 examines the implications of the results, including their alignment with current research in portfolio decision analysis and their potential applications in complex, real-world decision-making scenarios.

Section 5 summarizes the main findings and outlines directions for future research.

2. Technology for forming a portfolio of dual education development projects

The aggregation of fuzzy estimates of project value indicators was performed in Microsoft Excel due to its high level of compatibility, functionality in modelling and programming, and easy integration with most editors and databases. We leverage Microsoft Power BI Desktop, a powerful analytical tool, to create interactive visualizations and perform advanced data analysis. We solve the task of multi-objective optimisation using the Python programming language.

2.1. Multi-criteria mathematical model for portfolio formation

Taking into account the specifics of dual education and system modelling, the assessment of the feasibility of projects for inclusion in the portfolio considers four main stakeholders in dual education, namely the state, regional employers, educational institutions and students, with a system of indicators for each party: v – project value, c - resources for project implementation, t - implementation time, and r – risks (Fig. 1).

This study is a logical continuation of the value-oriented approach to managing the dual education development projects portfolio. The project value indicators v_{gov}, v_{bus}, v_{univ}, v_{stud} and v_{stud} are integral assessments of the value of the dual education project for the state, business structures and employers in the region, educational institutions, and applicants, respectively [17].

This integrated value assessments have a hierarchical structure. They are formed taking into account the following specific components:

- the employment rate of graduates in their speciality;
- the degree of compliance with the development of priority sectors in the region and country;
- the number of employers involved in the dual education of students;
- the degree to which the future needs of employers for the competencies they require in employees are met;
- the degree to which the project corresponds to the development strategy of the educational institution;
- quality of project product competencies;
- the employment rate in the company where the education was obtained under the dual education system;
- the level of achievement of the desired quality of the project product.

Thus, dual education projects are valued as integrated assessments that consider the specifics of the competence-based approach and the development strategies of all stakeholders.

When modelling a portfolio of m project proposals $X = \{x^1, \dots, x^m\}$, they are evaluated according to n indicators. Let us denote the value (score) of project x^j according to indicators $i = \overline{1, n}$ by v_i^j. The vector of project value assessments $v^j = [v_1^j, \dots v_n^j]$ reflects the scores of projects x^j according to indicators $i = \overline{1, n}$. These vectors form the rows of the score matrix $v \in \mathbb{R}^{m \times n}$ such that $[v]_{ij} = v_i^j$.

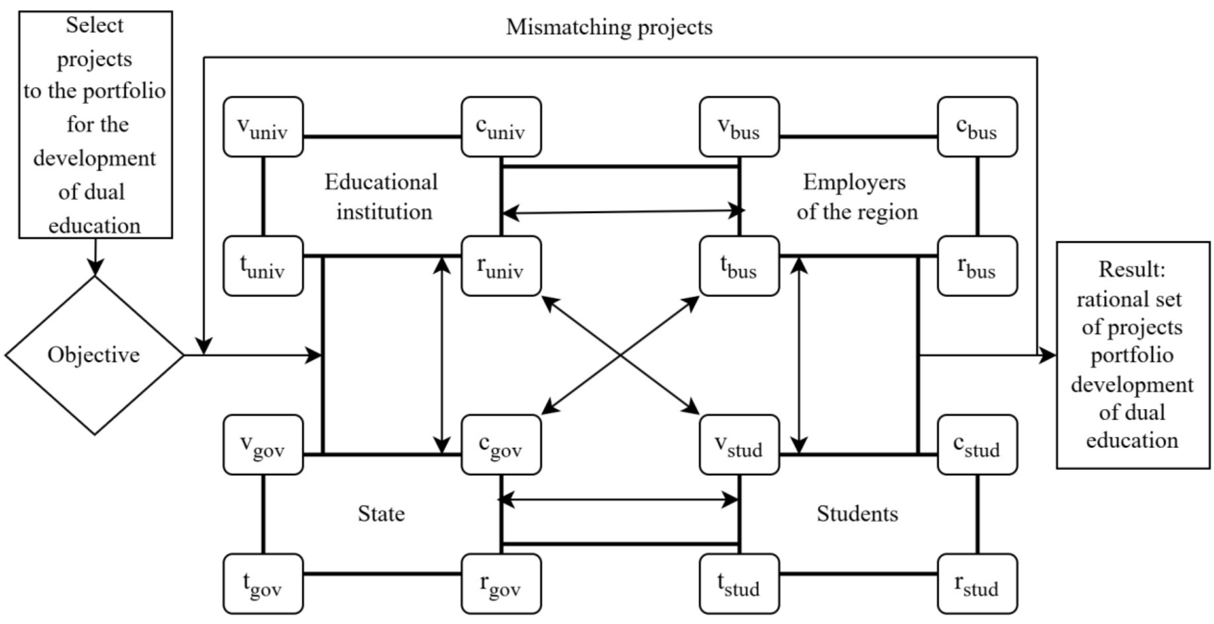

Fig. 1. Systematic model of project evaluation for inclusion in the dual education development portfolio

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The total value of project x^j is calculated using the additive value function and for the systematic project evaluation model (Fig. 1):

$$V_{project}(x^j) = \sum_{i=1}^{4} w_i \cdot v_i^j \ , \quad (1)$$

where w_i is the weight of the relative importance of the $i-th$ attribute, and the weights are $w = [w_1, \dots, w_n]^T, i = \overline{1,n}$. In this case $v_1^j = v_{gov}^j$, $v_2^j = v_{bus}^j, v_3^j = v_{univ}^j$ and $v_4^j = v_{stud}^j$.

As a result of forming a comprehensive assessment of the value of a dual education project [17], the preliminary value of each project $V_{project}(x^j)$ is represented by a trapezoidal fuzzy number. Its clear assessment can be found by performing defuzzification, for example, using the methods of Chiu-Park, Chang, and Kaufman-Gupta [18]. However, to analyze the impact of actions when making management portfolio decisions, namely, to compare projects with each other according to specific criteria, we compiled (1).

A portfolio of projects $z \subseteq X$ is a subset of m project proposals, and the set of all possible portfolios is a powerful set $Z = 2^X$. The value of a portfolio is defined as the total value of all projects in it:

$$V_{portfolio}(z) = \sum_{j=1}^{m} z_j \cdot V_{project}(x^j),$$
$$z_j = \begin{cases} 1, \text{if } x^j \in z\ ; \\ 0, \text{if } x^j \notin z, \end{cases} \quad (2)$$

where $z_j(\cdot)$ is a bijection $z_j: Z \to \{0, 1\}^m$ such that $z_j = 1$ if $x^j \in z$ and $z_j = 0$ if $x^j \notin z$.

The needs of each of the dual education projects for university and business resources c_{univ}^j, c_{bus}^j, $j = \overline{1,m}$. We assume that possible portfolios are those that satisfy $q_1 + q_2$ linear inequalities, defined by the coefficient matrices $C_{univ} \in \mathbb{R}^{q_1 \times m}$, $(c_{univ}^j = [C_{univ}]_{q_1}^j)$ and $C_{bus} \in \mathbb{R}^{q_2 \times m}$, $(c_{bus}^j = [C_{bus}]_{q_2}^j)$, and the vectors $B_{univ} = [b_1, \dots, b_{q_1}]^T \in \mathbb{R}^{q_1}$ and $B_{bus} = [b_1, \dots, b_{q_2}]^T \in \mathbb{R}^{q_2}$, i.e:

$$Z_F = \\ = \{z \in Z \,|\, C_{univ}\, z_j \le B_{univ},\ C_{bus}\, z_j \le B_{bus}\}, \quad (3)$$

where q_1, q_2 are the number of resource constraints of the university and employers involved in the dual education projects in the portfolios.

The best possible portfolio is the one that maximises the total value of the portfolio of dual education development projects (2) in specific conditions and satisfies the resource constraints:

$$\max_{z \in Z_F} V_{portfolio}(z) = \\ = \max_{z} \left\{ \sum_{j=1}^{m} z_j \cdot V_{project}(x^j) \middle| \begin{array}{c} C_{univ}\, z_j \le B_{univ}\,, \\ C_{bus}\, z_j \le B_{bus}\,, \\ z \in \{0,1\}^m \end{array} \right\}. \quad (4)$$

Project portfolio management includes evaluating, prioritising and monitoring projects to maximise benefits and reduce risks.

The value of a dual education project can be assessed by considering the stakeholders' values related to their expectations regarding project outcomes. This can be done by comparing linguistic variables depending on the membership function. The degree of proximity of the $V_{project}$ level to the reference distribution function is determined by the Hamming norm:

$$0 \le \theta = 1 - \max\{|a_1 - b_1|, |a_2 - b_2|, \\ |a_3 - b_3|, |a_4 - b_4|\} \le 1, \quad (5)$$

where (a_1, a_2, a_3, a_4) and (b_1, b_2, b_3, b_4) are the vertices of trapezoidal numbers on a 01-carrie.

Then, there is a risk of not achieving the value of the project: $r_{project}^{value} = 1 - \theta$.

Threats in the socio-economic system are caused by a complex set of interrelated factors and a sequence of events. They can be identified by conducting a systematic analysis of the structure, taking into account exogenous and endogenous influences [17, 19]:

- $r_{pm}^1, r_{bus}^1, r_{univ}^1$ - financial risks of implementing a system for managing the integration of dual education project processes;
- $r_{bus}^2, r_{univ}^2, r_{stud}^2$ - social factors caused by insufficient executive discipline among project stakeholders;
- r^3 - force major situations.

Financial risks associated with non-fulfilment of financial obligations belong to category r^1. Social risks caused by the inadequate executive discipline of stakeholders belong to category r^2.

To analyze risks r^k, $k = \overline{1,3}$, and optimize strategies for managing them, a five-point scale of 0.1 to 0.5 points is used to assess the consequences, where 0.5 corresponds to the most severe potential consequences.

To assess the risks of dual education projects, an in-depth analysis of partner organizations, their strategies and operations is required to determine the probability of risk occurrence p^k, $k = \overline{1,3}$. Based on the data obtained, a comprehensive risk assessment is carried out for both individual projects $R_{project}(x^j)$ and the project portfolio $R_{portfolio}(z)$ as a whole:

$$R_{project}(x^j) = r_{project}^{value} + \sum_{k=1}^{3} r^k \cdot p^k, \ \ \forall j = \overline{1, m}, \quad (6)$$

$$R_{portfolio}(z) = \sum_{x^j \in z} z_j \cdot R_{project}(x^j), \quad (7)$$

$$z_j = \begin{cases} 1, \text{if } x^j \in z; \\ 0, \text{if } x^j \notin z. \end{cases}$$

So, the second objective function of the multicriteria optimisation problem is:

$$\min_{z \in Z_F} R_{portfolio}(z) = = \min_{z} \left\{ \sum_{j=1}^{m} z_j \cdot R_{project}(x^j) \middle| \begin{array}{c} C_{univ}\, z_j \leq B_{univ}, \\ C_{bus}\, z_j \leq B_{bus}, \\ z \in \{0,1\}^m \end{array} \right\}. \quad (8)$$

Therefore, the task of forming a value-oriented portfolio of dual education development projects should be attributed to the sphere of portfolio decision analysis (PDA), i.e., the application of decision analysis to the task of selecting a subset or portfolio from a large set of alternatives, together with a version that contains the multi-criteria nature of the problem.

The developed mathematical model (1 - 4), (6 - 8) of the multi-objective optimisation problem (4), (8) requires detailed algorithms that generate a set of Pareto optimal solutions for the portfolio formation problem. The main feature of decision analysis techniques is the combination of formal methods and informal (expert) knowledge. The latter helps to find new ways to solve the problem that may not be present in the formal model.

2.2. Method of dividing project options into groups to which different dual education development project strategies should be applied

To succeed in an unpredictable environment, an educational institution must develop a robust strategy that will be effective in a variety of possible future scenarios. In such cases, a university can be more successful if it implements a proactive strategy to create an operating environment aligned with its desired direction.

Traditional strategic planning approaches typically rely on forecasts derived from trend extrapolation. However, such methods are inadequate regarding high uncertainty, intensity, and complexity [9]. Therefore, strategic planning in organizations is increasingly being replaced by scenario planning. Unlike traditional planning, scenario planning does not focus solely on the most likely future. Instead, it considers a range of plausible future events, referred to as scenarios. In particular, scenarios draw the attention of decision-makers (DMs) to uncertainty and help them create a robust strategy that works well in different conditions [9]. This is a promising approach to managing risks and opportunities.

It is often helpful to consider strategy not in a holistic sense but as a combination or portfolio of different action vectors. Let the decision maker choose a portfolio of a subset m of the proposed actions-project proposals. The impact of these actions is assessed according to mutually exclusive and collectively exhaustive scenarios, the probabilities of which are determined by the vector $p = [p_1, \dots, p_s]$.. Here, p_s is the probability of the scenario. The actual result of the j-th action in the s-th scenario, denoted by $x_i^j \in \mathbb{R}$,, represents the value of the action project with its i-th indicators in the s-th scenario obtained using a comprehensive assessment [17].

The formation of the final portfolio of decisions is based on valuable data based on previous experience, available in the database of dual education projects, which provides additional information for management decision-making. Thus, it is necessary to compare dual education projects for a specific employer but for different educational programs, especially when there have been successes or failures with this partner in retrospect.

A portfolio of actions is a subset of m available actions represented by a binary vector string $z = [z_1, \dots, z_m] \in \{0,1\}^m$, where $z_j = 1$ if and only if action j is included in the portfolio. This raises the problem of choosing the best portfolio under conditions of uncertainty. Since the probability of each scenario is unknown, a method for comparing different portfolios needs to be developed, taking into account the possible probabilities of scenarios to help decision-makers make the best choice. It is often helpful to acknowledge incomplete information about the probabilities of scenarios and to check which decision-making recommendations are compatible with this information [20].

Research on scenario-based portfolio construction [9] has revealed the absence of algorithms for directly solving the problem of obtaining a set of non-dominated portfolios. Instead, expanded algorithms are used. Thus, the article [9] outlines the key stages of solving the problem: 1) forming portfolios of actions and evaluating the utility function of each; 2) dividing portfolios into sets and checking pairwise dominance within each set reveals non-dominated portfolios in these groups; 3) a set of non-dominated portfolios is formed by combining the identified non-dominated portfolios of all groups.

There are portfolio-oriented approaches to solving

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the problem of obtaining a set of non-dominated portfolios [20, 21].

We implement a project-oriented approach to selecting non-dominated portfolios and develop an analytical model for managing a portfolio of decisions as a decision support system in conditions of incomplete and dependent information about the probabilities of different scenarios.

We divide the set m of project proposals $X = \{x^1, \dots, x^m\}$ into K disjoint subsets $X^1, \dots, X^K$ ($\bigcup_{k=1}^{K} X^k = X$), so that each subset will have its own lower and upper limits of estimates according to the criteria of value V and risk R of projects:

$$X_V^k = \left\{ V \in \mathbb{R}_+^{n\times m} \middle| \begin{matrix} \underline{V}_{project}(x^j) \le V_{project}(x^j) \\ V_{project}(x^j) \le \overline{V}_{project}(x^j) \end{matrix} \right\}, \quad (9)$$

$$X_R^k = \left\{ R \in \mathbb{R}_+^{n\times m} \middle| \begin{matrix} \underline{R}_{project}(x^j) \le R_{project}(x^j) \\ R_{project}(x^j) \le \overline{R}_{project}(x^j) \end{matrix} \right\}, \quad (10)$$

where: $V_{project}(x^j)$ – a comprehensive assessment of the value of the dual education project;

$\underline{V}_{project}(x^j)$, $\overline{V}_{project}(x^j)$ – lower and upper limits of evaluations according to the value criterion;

$R_{project}(x^j)$ – project risks;

$\underline{R}_{project}(x^j)$, $\overline{R}_{project}(x^j)$ – lower and upper limits of assessments according to the risks criterion.

Information set:

$X^k \equiv X_V^k \times X_R^k; ((V_{project}(x^j), R_{project}(x^j)) \in X^k$

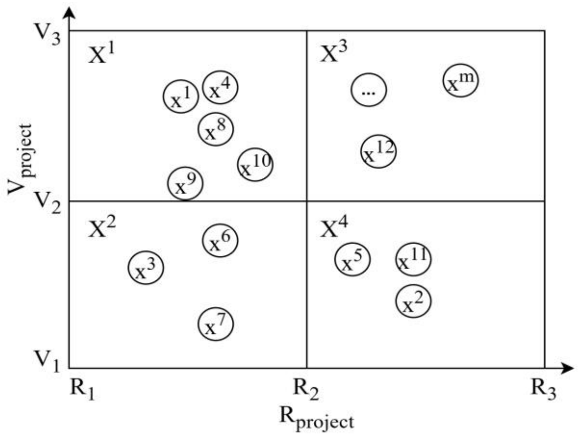

Fig. 2. The matrix for positioning alternative project options based on cost and risk criteria

The study [16] solved the task by sequentially dividing the project options into three groups: promising, doubtful, and rejected. To find similar groups, dividing the set m of project proposals $X = \{x^1, \dots, x^m\}$ into 3-4 non-intersecting subsets is advisable. Figure 2 illustrates the division into four subsets. Four distinct subsets are formed based on the conditions listed in Table 1.

Assuming that the non-intersecting subsets K of $X^1, \dots, X^4$ coincide with the non-intersecting subsets of portfolios $Z^1, \dots, Z^4$, i.e. $X^1 \subseteq Z^1, \dots, X^4 \subseteq Z^4$, then the best possible portfolio z_N^k is the one that maximises the total value (4) and minimizes the risks (8).

Research into modern project portfolio management concepts, including approaches such as Portfolio Decision Analysis (PDA), has shown that such a portfolio can be defined by searching for Pareto optimal solutions for an n-objective zero-one linear programming problem, known as Multi-Objective Zero-One LP (MOZOLP), for which there are several solution algorithms [9, 11, 22].

In [16], it is noted that adapting various constraints for the final portfolio entails corresponding constraints in the mathematical programming (MP) model. We propose identifying the best possible portfolio Z_N^k, which maximizes total value (4) and minimizes risks (8), as a solution to a linear programming problem with zero-one variables. In doing so, we apply the primary criterion method [23]. This criterion selects the value of the portfolio (4), and (11) – (14) are used as additional constraints. Thus, we obtain solutions to four separate linear programming problems. We select the best portfolio:

$$\max_{z \in Z_F} V_{portfolio}(z) = \max_{z} [Z^1, Z^2, Z^3, Z^4]\,. \quad (15)$$

However, the total value of the portfolio (2) depends on the number of projects m in the portfolio. A situation may arise where, according to this additive-linear function, the dominated portfolio will receive a higher rating than the non-dominated one.

Given that in the case of two criteria, when effective ratings can be visualized graphically, the optimal solution is often chosen directly from the graph [23], and a scatter plot with a Pareto set is an effective visualization tool [10]. Let us refer to the positioning matrix of project alternatives according to the 'value-risk' criteria, broken

Table 1

Conditions for forming four distinct subsets of projects

Subsets	Formalization
X^1	$X^1 = \{x^j \in X \mid V_2 \le V_{project}(x^j) \le V_3 \ \wedge R_1 \le R_{project}(x^j) < R_2\};$ (11)
X^2	$X^2 = \{x^j \in X \mid V_1 \le V_{project}(x^j) < V_2 \ \wedge R_1 \le R_{project}(x^j) < R_2\};$ (12)
X^3	$X^3 = \{x^j \in X \mid V_2 \le V_{project}(x^j) \le V_3 \ \wedge R_2 \le R_{project}(x^j) \le R_3\};$ (13)
X^4	$X^4 = \{x^j \in X \mid V_1 \le V_{project}(x^j) < V_2 \ \wedge R_2 \le R_{project}(x^j) \le R_3\}.$ (14)

down into subsets (Fig. 2). Pareto optimality (for two criteria) means that improving one criterion is impossible without worsening the other. Such diagrams allow us to assess the trade-off between losses and benefits when choosing a solution.

Managing the portfolio of dual education development projects involves the systematic selection, analysis and monitoring of projects, which is carried out each semester. New projects are evaluated and prioritized, while existing ones may be accelerated, suspended, or have their priority reduced. Project selection is based on a set of new and existing projects. A relational database with information on successfully implemented projects is required to support decision-making. All this divides the set of project proposals into K disjoint subsets $X^1, \dots, X^K$ according to interval estimates (11 – 14). Figure 3 illustrates the algorithm for identifying and comparing situation characteristics according to interval estimates.

The classification of dual education development projects using an algorithm for identifying and comparing situation characteristics divides candidate projects into four portfolios:

- Portfolio Z^4 includes projects that do not meet criteria (4) and (8) and are recommended to be suspended or downgraded in priority;

- Portfolio Z^1 contains projects that have high priority and form the best possible portfolio Z_N^k, i.e., non-dominated;

- Portfolio Z^2 and Portfolio Z^3 consist of projects for which additional information is needed when forming the final portfolio of decisions.

The formation of the final portfolio of decisions is based on valuable data from previous experience available in the dual education project database. This provides additional information to support management decisions regarding Portfolio Z^2 and Portfolio Z^3 projects.

3. Interactive visualization and dashboard for advanced analysis of candidate projects for the portfolio

The effectiveness of management decisions is determined by the degree to which goals are achieved, economic feasibility, and implementation results. The quality of decisions depends on their validity, timeliness, level of risk, flexibility, and the availability of expert support. For a comprehensive assessment of dual education projects, an integrated index of management decision effectiveness is used, which is a value that combines normalized partial indicators with weighting coefficients (16), as well as an integrated assessment of the risks of dual education projects in the portfolio. These indicators

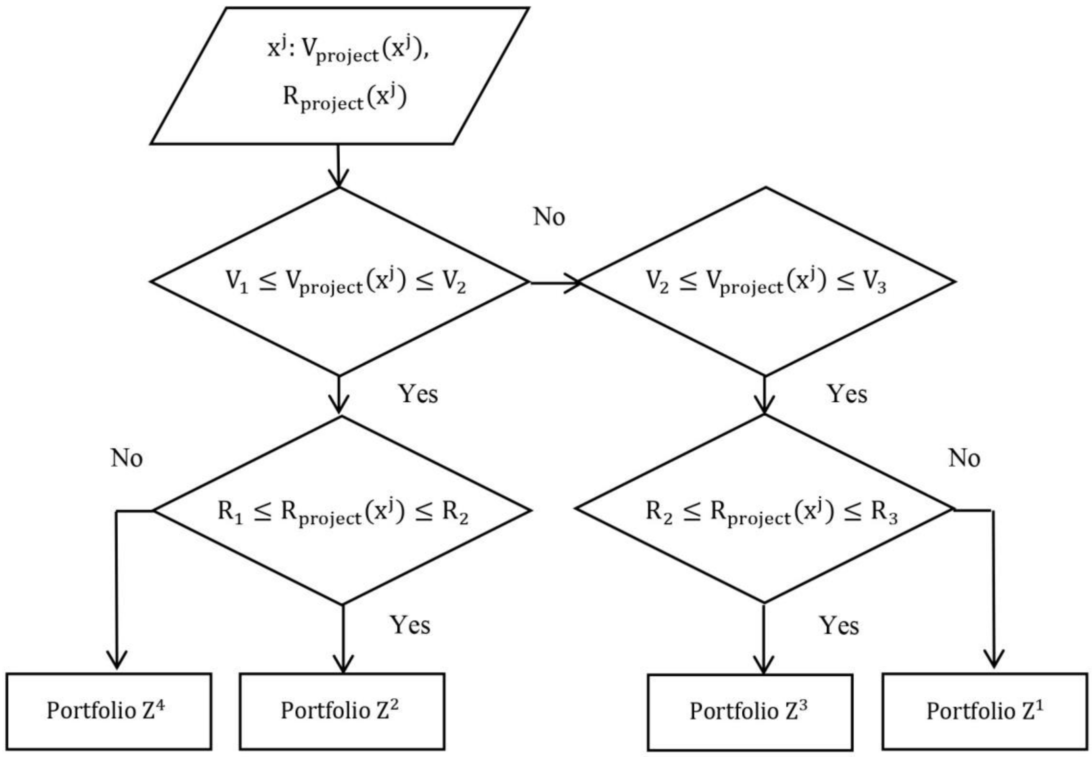

Fig. 3. The heuristic algorithm for identifying and comparing situation characteristics for project-oriented se-lection regarding a set of non-dominated portfolios

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provide objective control over management effectiveness and contribute to improving the organization's efficiency.

As a result of forming a comprehensive assessment of a dual education project [17], value levels were determined as membership functions of integral assessments of project values $\mu_{V_{project}}(x)$. The value criterion $V_{project}$ has a hierarchical structure and considers the positions of interested parties. A comprehensive assessment of the value level of the project was obtained by convolving fuzzy estimates of indicators:

$$\mu_{V_{project}}(x) = \sum_{i=1}^{4} \mu_i(x) \times \omega_{1i}, \qquad (16)$$

where: $\mu_i(x)$ - values of membership functions of value indicators, determined using a standard 0-1 scale classifier; ω_{1i} – weight coefficients of the i-th value indicator at the top level of the hierarchy.

Since the membership functions of value indicators have a trapezoidal shape, the linear superposition (16) is also a trapezoidal fuzzy number. Therefore, it can reduce operations with membership functions to operations with their vertices.

Solving the problem of creating an optimal portfolio based on fuzzy estimates of the value levels of project alternatives requires methods for comparing fuzzy numbers. We perform defuzzification of trapezoidal fuzzy numbers using a modified Chu-Park method [18]:

$$\overline{V}_{project}^{Chu\ Park} = \frac{a_1 + a_2 + a_3 + a_4}{4} + w\frac{a_2 + a_3}{2}. \qquad (17)$$

By selecting a weight coefficient w, for example, w=1, the average values of the projects were found.

When further ranking projects, we accept the integral indicator of project value $V_{project}(x^j) = \overline{V}_{project}^{Chu\ Park}$. Thus, the problem of numerical representation of project proposal ratings by value levels has been solved. As a result of the defuzzification of trapezoidal fuzzy numbers (17), the differentiation of value levels within the range from 0 to 2 increased slightly.

Table 2 shows how r^3 force majeure situations were identified in the project risk assessment (6) due to threats in the socio-economic system caused by the military situation in Ukraine. Depending on the employer-partner's affiliation with a particular industry, expert risk assessment was performed on a five-point scale of impact assessment with a range of scores from 0.1 to 0.5 points, where 0.5 corresponds to the most serious potential consequences. The details of the assessment system are as follows: 0.5 – catastrophic consequences; 0.4 – significant loss of benefits, which may significantly complicate the implementation of strategic goals; 0.3 – noticeable loss of benefits; 0.2 – loss of benefits that does not significantly affect the achievement of strategic goals; 0.1 – insignificant loss of benefits.

The aggregation of fuzzy estimates of project value indicators was performed in Microsoft Excel due to its high level of compatibility, functionality in modelling and programming, and easy integration with most editors and databases. After defuzzification (17) of fuzzy estimates of project value levels (16), their precise estimates $V_{project}(x^j)$ were obtained, and according to (6), risk estimates $R_{project}(x^j)$ were obtained for 41 project proposals at one technical university in Ukraine.

Table 2

Detailing the risk assessment system for dual education projects due to the war

Employer's industry	**Assessment of force majeure situations r^3**
Energy and metallurgy	0.4 – 0.5
Construction	0.3 – 0.4
Engineering	0.2 – 0.3
Other manufacturing	0.1 – 0.2
Information technology	0 – 0.1

The aggregation of fuzzy estimates of project value indicators was performed in Microsoft Excel due to its high level of compatibility, functionality in modelling and programming, and easy integration with most editors and databases. After defuzzification (17) of fuzzy estimates of project value levels (16), their precise estimates $V_{project}(x^j)$ were obtained, and according to (6), risk estimates $R_{project}(x^j)$ were obtained for 41 project proposals at one technical university in Ukraine.

To create interactive visualizations and advanced data analysis based on value-risk criteria (see Fig. 4), we use the powerful analytical tool Microsoft Power BI Desktop. Using Power Query for Power BI, we connect to Excel Workbook, based on which relational database tables are created, and a database model relationship diagram is built. The management decision support system database for the dual education development project portfolio consists of main tables that reflect entities related to dual education projects, university departments, regional employers, and laboratories involved in implementing the dual form of education. A calendar table must be added to synchronize the time of all tables in Power BI Desktop. Next, visual elements are developed.

Figure 4 presents an interactive portfolio report that includes all candidate projects, featuring visual toggles, menus, and synchronized filters. The Value–Risk field displays the current number of dual education project proposals. The cards summarize two criteria: "Portfolio

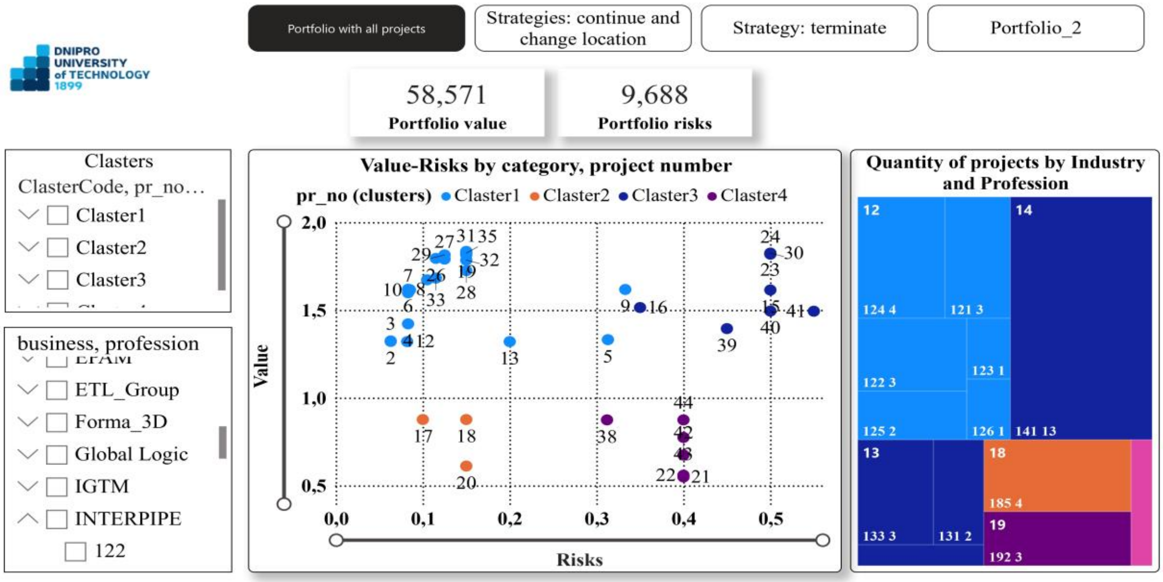

Fig. 4. Interactive portfolio report with all candidate projects in the MS Power BI Desktop environment

value" (2) and "Portfolio risks" (7). If all project proposals are included in the portfolio, their value and risks will correspond to the indicators on the cards. The tree diagram presents the portfolio structure by industry and profession.

Based on the results of cluster analysis, rules are formed for recognizing strategies for selecting new projects and determining the advantages of one of four possible alternatives for the further development of current projects in the dual education portfolio: include, continue, pause, search for partners and change location.

The ‘change location’ strategy is applied when, due to the high risks associated with the military situation, it becomes necessary to change the employer within the holding company or the place of practical training to a specialised laboratory created with the employer at an educational institution.

Power BI Desktop enables cross-filtering by managing relationships established during data modelling. This means that filters between all visual elements of an interactive report are synchronized: focusing on one element filters data on all others, allowing us to obtain crucial analytical information for making informed decisions (Fig. 5, Fig. 6).

The analysis of candidate portfolios based on scenarios is done through interactive interaction with the dashboard. In Fig. 4, candidate portfolios are represented by project clusters: Claster1 $\in$ Portfolio Z^1, Claster2 $\in$ Portfolio Z^2, Claster3 $\in$ Portfolio Z^3, Claster4 $\in$ Portfolio Z^4. These clusters can be considered as separate candidates or combined into larger portfolios. Figure 5 illustrates Claster1 with those projects that have high priority and form the best possible portfolio, i.e., one that is not dominated. Thanks to the cross-filtering configured using Power BI, this portfolio's value (2) and risks (7) have been calculated and visualised with indicators on the cards: “Portfolio value = 38.912” and “Portfolio risks = 3.126”.

Figure 6 illustrates important analytical information regarding the selection of rational strategies for the further development of projects with specific employer partners in dual education. It shows the mechanism of comparative analysis of project value and risk indicators when selecting rational development strategies. Reliable data from prior partnerships with INTERPIPE LLC provides the decision-making team with valuable insights for adjusting project strategies. Thus, Figure 6 illustrates that dual education projects of various educational programs fell into Claster1 and Claster3. Since a specialised laboratory has been created at the academic institution with the support of INTERPIPE LLC, an alternative for the further development of all these projects could be a strategy to “Change location” for projects with a high degree of risk due to the conditions of martial law in the country.

After a certain number of rounds of analysis, a final portfolio is formed, demonstrating selected projects to maximise value while adhering to constraints. Table 3 shows the strategies for selecting projects for the portfolio recommended by Power BI. For comparative analysis of project clustering in Power BI, a Python algorithm was developed based on a multi-criteria mathematical model and a heuristic method of project grouping (Fig. 3). To solve the multi-objective optimisation problems (4) and (8), i.e. Multi-Objective Zero-One LP (MOZOLP), we apply the primary criterion method. The portfolio value

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ISSN 1814-4225 (print)
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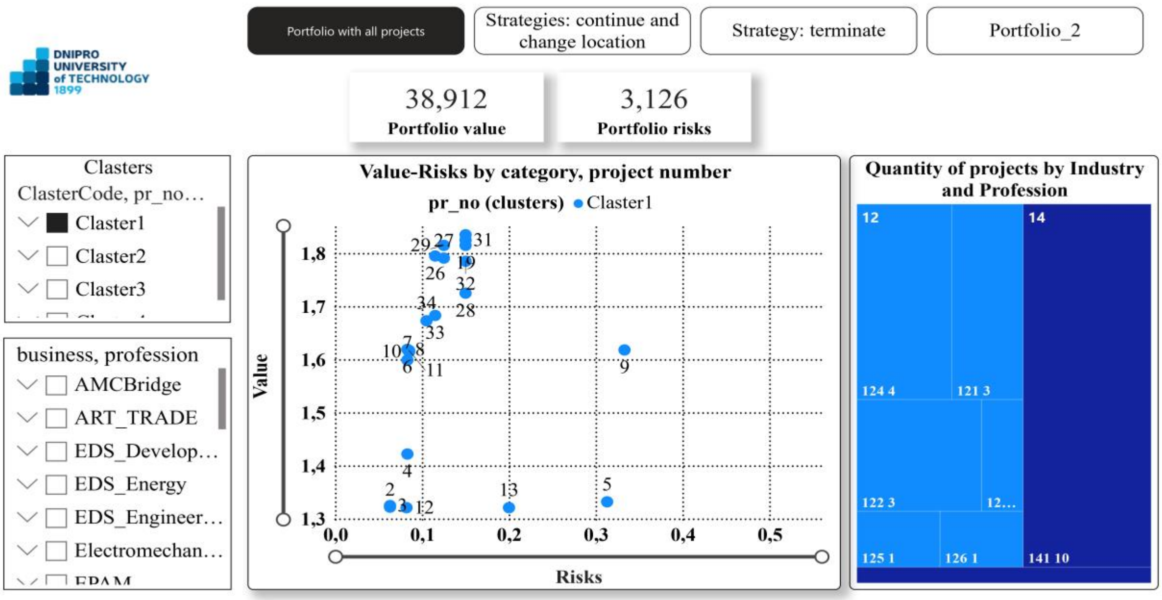

Fig. 5. Identification of an undominated Portfolio Z^1

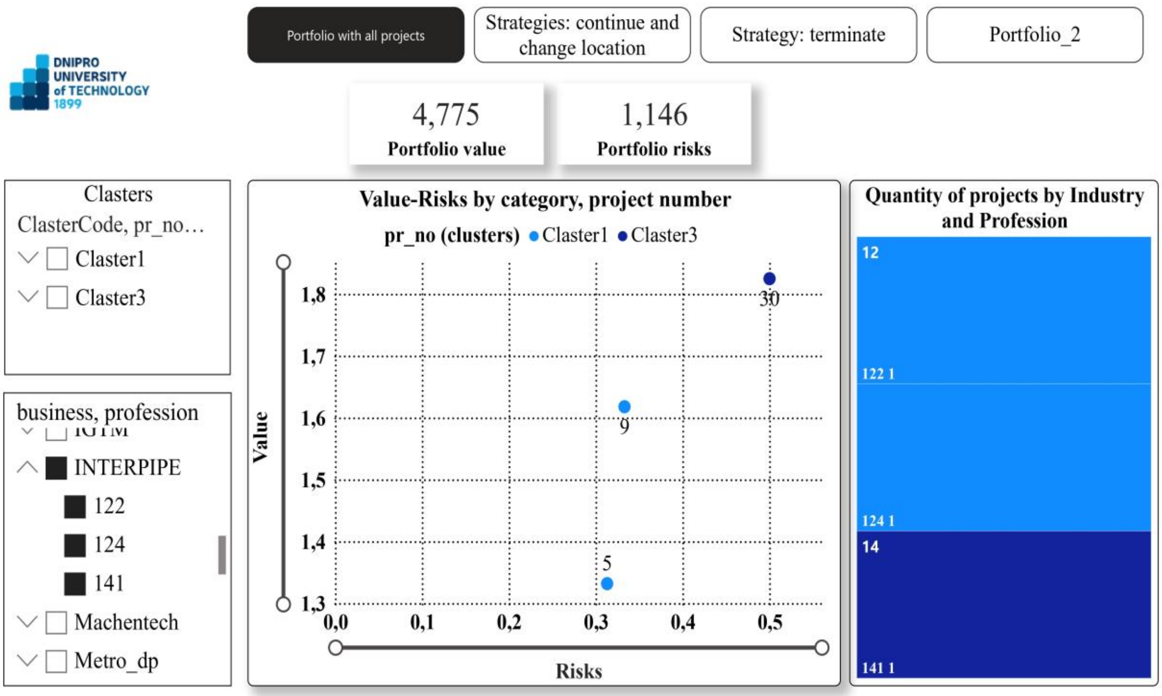

Fig. 6. Mechanism for comparative analysis of project value and risk indicators when selecting rational development strategies

(4) is selected as this criterion, and (11) – (14) are used as additional constraints. We connect to the same Excel Workbook with 41 project proposals with their $V_{project}(x^j)$ and $R_{project}(x^j)$ ratings and conduct a numerical experiment. We have the result of the distribution of projects across portfolios $Z^1, \dots, Z^4$. Figure 7 illustrates a fragment of a numerical experiment with those two portfolios Z^1 and Z^3 in which projects numbered 5 and 9 differ from the Power BI clustering.

Portfolios Z^2 and Z^4 completely coincided with Power BI clusters, so the results of solving the integer linear programming problem using Python for these portfolios are shown only in Table 3.

Table 3

A combined portfolio of different courses of action

Pr_ No.	Pro-fession	Business	Value	Risks	Comparison of project selection strategies for the portfolio	
					Power BI	**MOZOLP: $Z^1, \ldots, Z^4$**
2	124	Soft_Serve	1.322	0.063	Include	Z^1
3	124	SIGMA Software	1.325	0.063	Continue	Z^1
4	124	Privatbank	1,422	0.083	Include	Z^1
5	124	INTERPIPE	1.332	0.313	Continue	$\mathbf{Z^3}$
6	121	Soft_Serve	1.619	0.083	Include	Z^1
7	121	EPAM	1.599	0.083	Continue	Z^1
8	121	RubyGarage	1.619	0.083	Continue	Z^1
9	122	INTERPIPE	1.618	0.333	Continue	$\mathbf{Z^3}$
10	122	Yalantis	1.615	0.085	Continue	Z^1
11	122	AMCBridge	1.617	0.085	Continue	Z^1
12	123	Soft_Serve	1.321	0.082	Include	Z^1
13	126	Noosphere	1.321	0.2	Continue	Z^1
14	125	Global Logic	1.615	0.085	Continue	Z^1
15	125	Pivdenne	1.615	0.5	Change location	Z^3
16	172	DTEK	1.515	0.35	Change location	Z^3
17	131	VariUs	0.877	0.1	Search for partners	Z^2
18	131	SIEMENS	0.877	0.15	Search for partners	Z^2
19	132	Prosthesis_factory	1.815	0.15	Continue	Z^1
20	133	Forma_3D	0.612	0.15	Search for partners	Z^2
21	133	IGTM	0.55	0.4	Pause	Z^4
22	133	Dniprovazhmash	0.56	0.4	Pause	Z^4
23	141	DTEK	1.825	0.5	Change location	Z^3
24	141	TZEK	1.819	0.5	Change location	Z^3
26	141	EDS_Engineering	1.795	0.115	Continue	Z^1
27	141	EDS_Energy	1.791	0.125	Continue	Z^1
28	141	EDS_Development	1.725	0.15	Continue	Z^1
29	141	Volta (Dnipro)	1.815	0.125	Continue	Z^1
30	141	INTERPIPE	1.825	0.5	Change location	Z^3
31	141	Machentech	1.825	0.15	Continue	Z^1
32	141	ART_TRADE	1.785	0.15	Continue	Z^1
33	141	Electromechanical_diagnostics	1.683	0.115	Continue	Z^1
34	141	RETAL_Dnipro	1.673	0.105	Continue	Z^1
35	141	ETL_Group	1.825	0.15	Continue	Z^1
36	141	Metro_dp	1.835	0.15	Continue	Z^1
38	185	Dniprogaz	0.875	0.312	Pause	Z^4
39	185	Dnipropetrovskgaz	1.395	0.45	Change location	Z^3
40	185	Control-Service_	1.495	0.5	Change location	Z^3
41	185	Technical_delivery	1.494	0.55	Change location	Z^3
42	192	Sozidatel	0.675	0.4	Pause	Z^4
43	192	Aska-Development	0.775	0.4	Pause	Z^4
44	192	Modific	0.875	0.4	Pause	Z^4

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```
Optimize_portfolio Z1
(22 projects)
+-------+-------+-------+
| Pr_No | Value | Risks |
+-------+-------+-------+
|   2   | 1.322 | 0.063 |
|   3   | 1.325 | 0.063 |
|   4   | 1.422 | 0.083 |
|   6   | 1.619 | 0.083 |
|   7   | 1.599 | 0.083 |
|   8   | 1.619 | 0.083 |
|  10   | 1.615 | 0.085 |
|  11   | 1.617 | 0.085 |
|  12   | 1.321 | 0.082 |
|  13   | 1.321 |  0.2  |
|  14   | 1.615 | 0.085 |
|  19   | 1.815 |  0.15 |
|  26   | 1.795 | 0.115 |
|  27   | 1.791 | 0.125 |
|  28   | 1.725 |  0.15 |
|  29   | 1.815 | 0.125 |
|  31   | 1.825 |  0.15 |
|  32   | 1.785 |  0.15 |
|  33   | 1.683 | 0.115 |
|  34   | 1.673 | 0.105 |
|  35   | 1.825 |  0.15 |
|  36   | 1.835 |  0.15 |
+-------+-------+-------+
Selected 22 projects
Portfolio value: 35.96
Portfolio risks: 2.48

Optimize_portfolio Z3
(10 projects)
+-------+-------+-------+
| Pr_No | Value | Risks |
+-------+-------+-------+
|   5   | 1.332 | 0.313 |
|   9   | 1.618 | 0.333 |
|  15   | 1.615 |  0.5  |
|  16   | 1.515 |  0.35 |
|  23   | 1.825 |  0.5  |
|  24   | 1.819 |  0.5  |
|  30   | 1.825 |  0.5  |
|  39   | 1.395 |  0.45 |
|  40   | 1.495 |  0.5  |
|  41   | 1.494 |  0.55 |
+-------+-------+-------+
Selected 10 projects
Portfolio value: 15.93
Portfolio risks: 4.50
```

Fig. 7. Fragment of the results of a numerical experiment using a Python algorithm

Let's summarise the results in Table 3 and compare them with the strategies for selecting projects for the portfolio recommended by Power BI and solve MOZOLP. There is a difference between two projects, Pr_No 5 and Pr_No 9.

Clustering using Power BI is probably implemented by one of the traditional clustering strategies, including K-means, fuzzy C-means, and probabilistic K-means, depending on random initial clustering centres. However, Fig. 6 illustrates the mechanism of comparative analysis of project value and risk indicators, which supports the selection of rational development strategies by a group of individuals making management portfolio decisions.

4. Discussion

The proposed approach to forming a portfolio of dual education projects has several advantages over existing methods. In particular:

- Unlike [16], where the portfolio is formed solely based on value criteria, our model also integrates risk assessment, which allows us to avoid including projects with a high probability of failure in the portfolio.

- Unlike [9], where recommendations for decision-making in the search for the most desirable portfolio are based on pairwise dominance relations between portfolios of actions and the set of all possible portfolios is a powerful set $\mathrm{Z} = 2^{\mathrm{X}}$, where X is the set of project proposals, we apply heuristic classification, which divides the set of project initiatives into four subsets and determines the non-dominated portfolio among them. This reduces computational complexity, allowing us to work effectively with a large number of projects.

- Unlike [13], where group decision-making is implemented through opinion clustering, we offer interactive interaction through a dashboard, which provides transparency and flexibility in decision-making.

These features allow improving portfolio management efficiency, in particular:

- reduce project implementation risk by 14% (according to expert estimates),

- improve the portfolio's alignment with employer needs,

- and ensure adaptability to changes in resources and priorities.

The scientific novelty of the research lies in the following:

1. A mathematical model for two-stage project portfolio selection has been developed. Unlike existing models, it ensures the formation of a rational portfolio based on two integrated criteria: value and risk. The integral assessment of project value utilizes a hierarchical structure, accounting for the specifics of the competency-based approach and the strategic priorities of all stakeholders. This approach facilitates more informed decision-making in project portfolio management, particularly under multi-criteria conditions and uncertainty.

2. A method for determining a priority portfolio under multi-objective optimization is proposed. Unlike existing approaches, it enables the identification of non-dominated solutions through a heuristic classification technique. Integrating this method into decision-support systems facilitates adaptation to diverse constraints and enhances the quality of final portfolio selection."

3. An algorithm for identifying and comparing situational characteristics has been developed. It ensures effective project selection and classifies candidate projects, enabling the application of differentiated management strategies for a combined portfolio across various domains.

4. An approach to solving the problem of fuzzy multi-criteria group decision-making is proposed, utilizing an interactive dashboard as a collaborative tool. This approach ensures effective communication within the expert group of the university's coordination center. It facilitates informed decision-making regarding the formation of a dual education development project portfolio.

5. Conclusions

1. In order to improve the efficiency and quality of management decisions when planning dual education processes in conditions of uncertainty, a mathematical model for forming a rational portfolio of dual education development projects has been developed, which takes into account the hierarchical structure of project value criteria from the perspective of stakeholders. The proposed model employs risk assessment to form a rational portfolio based on two integrated criteria: value and risk. This approach accounts for the limited resources of universities and employers in dual education projects.

2. To enhance the efficiency and quality of management decisions in planning dual education processes under uncertainty, we developed a mathematical model for constructing a rational portfolio of dual education development projects. The model incorporates the hierarchical structure of project value criteria from a stakeholder perspective and integrates risk assessment, enabling portfolio formation based on two combined criteria - value and risk - while accounting for the resource limitations of universities and employers involved in dual education initiatives.

3. The application of the proposed method is demonstrated by the example of selecting rational strategies for the further development of dual education projects with specific employer partners in dual education. Valid data based on previous experience of partnerships with companies in the region provide the decision-making group with additional information for adjusting the strategies of higher education institution projects. Importantly, recommendations for specific actions and target portfolios of actions can be created even without information about the probability of a scenario.

4. After the final portfolio of projects in various fields of activity has been formed, the task of managing processes in dual education development projects between educational institutions and employer partners arises.

5. Managing the implementation of dual education projects requires further research into individualizing educational trajectories. After the final portfolio of projects in various fields of activity has been compiled, the task of effectively managing processes in dual education development projects between educational institutions and employers becomes relevant. Further research will focus on developing a model for creating an individualized educational trajectory for applicants within a specific dual education project. Special attention will be paid to aligning the educational process with the specific competencies of the employer's needs. In the model, these needs will be considered constraints determining the required competency development level.

Contributions of authors: conceptualization, methodology – **Valentyna Molokanova;** formulation of tasks, analysis **– Valentyna Molokanova, Svitlana Kozyr;** development of model, software, verification **– Svitlana Kozyr;** analysis of results, visualization **– Svitlana Kozyr;** writing – original draft preparation **– Svitlana Kozyr**, writing – review and editing **– Valentyna Molokanova**.

Conflict of Interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, author ship or otherwise, that could affect the research and its results presented in this paper.

Financing

This study was conducted without financial support.

Data Availability

The data will be provided upon reasonable request.

Use of Artificial Intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, as described in the research methodology section.

All the authors have read and agreed to the published version of this manuscript.

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ІНФОРМАЦІЙНА ТЕХНОЛОГІЯ ПІДТРИМКИ УПРАВЛІНСЬКИХ РІШЕНЬ ЩОДО ПОРТФЕЛЯ ПРОЄКТІВ РОЗВИТКУ ДУАЛЬНОЇ ОСВІТИ

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Предметом дослідження статті є інформаційна технологія підтримки прийняття рішень в процесах сталого розвитку освітніх закладів, а також модель формування раціонального портфеля проєктів розвитку дуальної освіти. **Метою роботи** є підвищення ефективності та якості управлінських рішень при плануванні навчальних процесів дуальної освіти в умовах невизначеності шляхом створення інформаційної технології підтримки рішень з використанням моделі портфелю напрямків дій. Це дослідження ставить перед собою **кілька цілей** : 1) Розробити модель формування портфеля, враховуючи ієрархічну структуру критерію цінності проєкту та позиції зацікавлених сторін; 2) формалізувати розбиття варіантів проєктів на групи до яких варто застосувати різні стратегії розвитку;3) Створити інтерактивну візуалізацію та дашборд розширеного аналізу проєктів-кандидатів до портфеля. **Результати.** Запропоновано технологію із застосуванням методу класифікації та розбиття варіантів проєктів на групи до яких варто застосувати різні стратегії та управляти комбінованим портфелем різних напрямків (векторів) дій. Використано евристичну методологію пошукової оптимізації для синтезу нового алгоритму виділення і порівняння ознак ситуацій для відбору недомінованих портфелів. Поєднання багатокритеріального аналізу рішень (MCDA) та візуальної методології спрощує оцінку та порівняння проєктів-кандидатів до стратегічного портфеля, що робить цей підхід цінним для групи розробників у практичних сценаріях. Налаштована крос-фільтрація даних візуального звіту засобами Power BI дозволила порівнювати між собою проєкти за групами стейкхолдерів, проєкти-кандидати та ті що успішно реалізовуються. Це забезпечило управління комбінованим портфелем різних напрямків (векторів) дій. Запропоновану технологію продемонстровано на прикладі вибору стратегій розвитку проєктів дуальної освіти з роботодавцями-партнерами. Дані попереднього партнерства з підприємствами регіону допомагають групі прийняття рішень коригувати стратегії проєктів. Рекомендації щодо дій можуть бути створені навіть без інформації про ймовірність сценарію. **Висновки** цього дослідження можуть бути використані на практиці у складних сценаріях прийняття рішень, що враховують інтереси різних зацікавлених сторін системи дуальної освіти, невизначеність ситуацій та суб'єктивність осіб, що приймають рішення.

Ключові слова: інформаційна технологія; прийняття рішень; багатокритеріальність; управління портфелем проєктів; математичні моделі; евристичний алгоритм; дуальна освіта.

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