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EVALUATION OF INVESTMENT PROJECTS UNDER UNCERTAINTY: MULTI-CRITERIA APPROACH USING INTERVAL DATA

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Abstract. Multi-criteria decision making (MCDM) methods have evolved for various types of applications. In the past, even small variations to existing methods have led to the creation of new avenues for research. Thus, in this study, we review the MCDM methods in investment management and examine the advantages and disadvantages of these methods in a risk environment. In addition, we study the effectiveness of investment projects using these methods. The analysis of MCDM methods performed in this study provides a guide for the use of these methods, especially the ones based on interval data, in investment project analysis. Furthermore, we propose a combination of multi-criterial selection and interval preferences to evaluate investment projects. Our method improves on the method of calculating economic efficiency based on a one-dimensional criterion and sensitivity analysis, though our proposal involves complicated calculations.

Keywords: multicriterial approach, risk management, Pareto set, investment project, interval data, investment project evaluation

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1. Introduction

Investment analysis is a commonly performed step before the development or introduction of new, more advanced forms or methods of management into broad practice. The quality of the decisions made is determined, essentially, by the selected alternatives based on the analyses. In making economic decisions, the important steps include (i) the creation of an indicator system, including decision criteria, and (ii) analysis and prediction of the occurrence of the problem for the subsequent generation and selection of alternatives

(Lukicheva and Egorychev, 2016). The quality of the decisions made is essentially determined by the alternative selected based on the analyses.

Multi-criteria decision-making (MCDM) methods are types of Operations Research tools that can be used to solve complex problems with high uncertainty, conflicting objectives, different forms of data and information, and multiple interests and perspectives, and can account for complex and evolving biophysical and socio-economic systems (Wang et al., 2009).

Several attempts have been made to develop Multi-Criteria Approach (MCA) methods that retain the strengths of the Analytic Hierarchy Process (AHP) while addressing some of the weaknesses; for example, MCA method can be considered as a complete aggregation method of the additive type. The problem with such an aggregation is that we obtain the same result with a different ordering by different indicators, in which case, we lose some information. Detailed, and often important, information can be lost by such an aggregation. Our efforts have been focused largely on finding different methods of eliciting and then synthesizing pairwise comparisons. However, it is beyond the scope of this manuscript to discuss these developments in detail. The best-known alternative to the AHP is the Rembrandt system (Beinat and Nijkamp, 1998).

The Rembrandt system is a direct rating system, which is based on a logarithmic scale; it transforms the AHP scale of range 1–9 by including the eigenvector-based synthesis approach instead of the geometric approach, and thus, can be used to estimate weights and scores from pairwise comparison matrices (Olson, 1995).

Investment decisions directly depend on the effectiveness of the comparative evaluation of the alternatives considered; therefore, in the case of strategic decisions, it is important to consider the effectiveness of such a comparative evaluation, because investment decisions involve a considerable amount of resources.

Owing to multilateral nature of economic activities, they cannot be expressed by a one-dimensional index; thus, MCDM is important for investment analysis. In particular, an MCDM framework is suitable for multi-dimensional economic activities, because it considers all factors involved in reducing risk while evaluating investment in projects. These abovementioned and other advantages explain the growing interest in multidimensional methods for analysis and evaluation of economic decisions (Brigham and Ehrhardt, 2015).

All enterprises are to some extent engaged in investment activities; furthermore, decision-making related to such investment activities involves various complicated factors, including limited financial resources, type of investment, and possible losses that the enterprise may incur if the project is less profitable later or fails entirely due to unforeseen circumstances (Jelnova, 2013; Minakova and Anikanov, 2013). Thus, risk management allows confirming the viability of solutions for a project and reducing the likelihood of adopting an inefficient or unprofitable project.

In light of the discussion thus far, we consider the following research questions (RQs) in our study:

RQ1: What are the benefits of implementing multi-criterial approaches for the evaluation of investment projects considering uncertainty?

RQ2: What are the limitations of implementing multi-criterial approaches for the evaluation of investment projects?

Thus, considering these research questions, the following points describe the significance of this research:

(i) The use of interval preferences in this research allows experts to express their opinions in a simpler yet more accurate manner; in addition, uncertainty is considered without using any kind of statistical data.

- (ii) The use of a multi-criteria selection procedure set (Pareto approach: Graph Core) allows different criteria to be evaluated on different scales; this reflects the different aspects of the measured phenomena (particularly, effectiveness of the investment project).
- (iii) The set of indicators can involve other real-world factors aside from those part of the projects' environments.

The remainder of this paper is organized as follows. The theoretical framework is discussed in Section 2, which presents a background of approaches that are used to assess performance considering various criteria and risk conditions. In Section 3, our proposed method to select the optimal investment project in a risk environment based on the Pareto model is described. Section 4 presents the results and discussion, wherein model calculations demonstrating the capabilities of our method and the use of other performance indicators with our method are discussed; in addition, possible future directions for research are introduced. Finally, Section 5 presents our conclusion summarizing the advantages and limitations of our proposed methodology.

2. Background

2.1. Modern approaches for evaluation of investment projects

There are several modern approaches for investment evaluation; some of these are introduced in the following lines:

- (i) Cost Benefit Analysis (CBA): CBA is the most widely used evaluation technique for assessing infrastructural investments worldwide. CBA is based on monetization and inter-temporal discount. In this case, money is the measuring unit used to represent all costs and benefits associated with an investment or policy (Zare et al., 2016).
- (ii) Hexagon Model: This model focuses on the integrated vision of sustainability; it is based on four different types of strongly interconnected capital (government, customer, bank, professional organizations) (Mardani et al., 2015).
- (iii) Analytic Hierarchy Process (AHP): This process consists of decomposing a complex decision-making process into a hierarchical structure (Saaty, 1990).
- (iv) Lexicographical Method: In this method, we formulate the general lexicographical principle and then use it for various selection procedures (Tarp, 2014).
- (v) Pareto Approach: This approach is used to solve multi-criteria selection problems or find the optimal solution among a set of alternatives using automated decision support systems; in particular, it selects the Pareto set from the original set of alternatives (Grierson, 2008).
- (vi) Life Cycle Analysis (LCA): This is forecasting tool used by individuals or enterprises in industrial fields. The LCA analysts are interested in forecasting future materials/costs on a regional or global scale as a function of differences in economic growth and regulatory scenarios.

These abovementioned approaches can reflect the nature or consequences of investments in a business organization.

The Pareto approach is used in our study because it includes a large number of economic indicators, which are well known in business, and can be used by managers to compare various investment alternatives (Savchuk, 2007). For example, decision makers should focus more on selecting, sorting, ranking, and describing the investment alternatives in terms of their performance based on various factors, such as the criteria and risk conditions. These factors can be classified into two different groups, namely internal and external; after this, the influence (rank) of each factor can be evaluated. Academic texts most often advice using the following indicators: net present value (NPV), discounted payback period (DPP), and internal rate of return (IRR) (Mazur et al., 2014).

Based on the value of these indicators, a project can be accepted or rejected or the best alternative from several options can be selected. Nevertheless, these indicators describe the effectiveness of the project being analyzed from different perspectives; therefore, it is necessary to construct a multidimensional criterion (Keshavarz Ghorabae et al., 2015).

In particular, to calculate DPP, we focus on both the primary methods available in literature; these are discussed as follows:

- (i) The first approach involves calculating DPP from the capital owner's perspective. Thus, the payback period is calculated as the period for which the owner receives a profit equal to the amount of invested capital; this suggests that the project in consideration at least leads to the conditions of simple reproduction, considering the presence of a time factor.
- (ii) The second approach involves calculating the DPP from the business manager's perspective, for which the amount of NPP is important. Thus, in this case, the payback period is determined as the time in which a net discounted income that compensates the amount invested in the project capital is obtained (Seitz and Ellison, 1999).

However, the comparison of different projects based on these indicators can lead to differences in the order of effective projects, especially considering the dynamics of various factors that affect the effectiveness of projects. The NPV index provides an overview of the effectiveness of the company's management. Considering this, it is advisable to use the DPP indicator calculated based on the amount of received profit for the formation of a multidimensional criterion.

Furthermore, based on the IRR index, it is possible to obtain an ordering of suitable projects different from that obtained using the NPV index (Stoyanova and Krylova, 2006; Syroezhin, 1980). However, the IRR index is specific and reflects the efficiency of capital investments; therefore, this advantage of IRR is also its major limitation, because it uses a single discount rate to evaluate every investment.

In particular, IRR measures the effectiveness of capital investments; thus, this indicator partially allows the comparison between investment projects with different capital investments and terms of implementation. Typical methodological recommendations for calculating the effectiveness of investment projects solve the problem of selecting from alternative projects by using the NPV indicator for risk evaluation. This method is useful for certain cases, such as efficiency comparison within existing external circumstances. This recommendation helps avoid the conflict of interests as regards which indicators to use. We offer to leave them all as they reflect different aspects (e.g., uncertainty, market situation, project capacity, etc.) of the economic system. All of these aspects are important for the criteria's formation in the economic system.

2.2. Multi-criteria approach for evaluation of investment projects

There are four primary reasons that justify the use of MCDM methods; these are listed as follows:

- (i) MCDM methods allow the investigation and integration of interests and objectives of multiple actors because both quantitative and qualitative information from every actor is considered in forming the criteria and weight factors (Tsoutos et al., 2009).
- (ii) These methods address the complexity of multi-actor setting by providing output information (Hayashi, 2000; Gurumurthy and Kodali, 2013).
- (iii) These are well-known and commonly used methods for the assessment of investment alternatives. Moreover, different versions of these methods are developed for specific contexts (Opricovic and Tzeng, 2004).

(iv) MCDM methods allow for objectivity and inclusiveness of different perceptions and interests of actors (Kangas and Kamgas, 2002).

Because CBA depends on the time at which it is being performed, it is more appropriate as an ex-ante instrument; in contrast, the multi-criteria approach can be adopted both for ex-ante and ex-post assessments (Stoyanova and Krylova, 2006), which is an advantage of the MCA. Considering the dimensions of the project or the policy to be evaluated, the characteristics (evaluative standpoint, decision-relevance, comparability, verifiability, accountability, and scientific progression) of CBA and MCA render the dimensions of the project useful. In particular, on a large scale, i.e., when public and private costs are consistent, the CBA approach is necessary, whereas MCA appears useful at the small-scale, where all the stakeholders can be considered individually, and can be consulted or can express informed opinions on their priorities.

Based on the discussion thus far, it is necessary to use methods for the evaluation of the effectiveness of alternative investment projects that are based on multi-criteria selection. However, the known methods for multi-criteria selection are still not considered in commonly used methods that can solve the problem of selecting the optimal investment solution (Roy, 1976). In particular, the selection of an effective investment project involves the best combination of values based on the analyses of disparate indicators characterizing the investment project.

Another important problem that needs to be acknowledged is that investment projects are generally implemented in a risk environment; this indicates significant environmental uncertainty. Environmental changes can cause a decrease or increase in cash flows during the implementation of particular investment projects. Thus, it is possible that the goals set by an investor might not be achieved, instead the investor might incur losses.

The extent of these losses and their probability characterize the risk that is typical for any type of entrepreneurial activity. Without risk, the evaluation of the alternatives under consideration becomes unrealistic (Orlovsky, 1981; Parrino et al., 2014).

There are two mutually complementary types of project risk analyses, namely quantitative and qualitative risk analyses. In particular, qualitative analysis determines the factors, scope, and types of risk; furthermore, before conducting quantitative analysis, it is necessary to quantify the impact of the identified risks and losses from failure on the project objectives.

In the case of qualitative analysis, the variety of risks associated with investment projects considerably complicates the analysis tasks, including risk classification. In the case of investment projects' evaluation analysis, it seems appropriate to classify the risks based on their origin (Khokhlov, 2011). The calculation of economic efficiency in terms of risk involves identification of risk factors in the classified areas, identification of risk situations, and the correlation of the risk situations with the consequences of implementing the investment project (Rodionova et al., 2013). The flow of risk formation is depicted in Fig. 1.

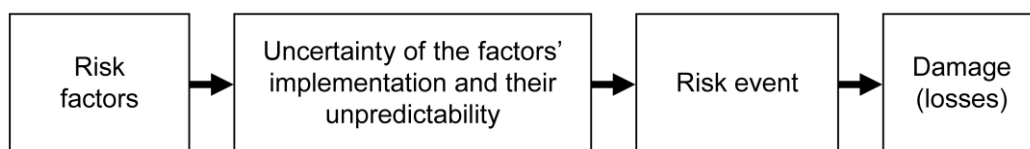


Fig. 1. Formation scheme for risk factors

Source: Rodionova et al., 2013

In general, risk factors are unplanned events that might cause a deviation from the planned progress of the project; the dynamic interaction of various risk factors affects the effectiveness of the project. In particular, the combination of possible risk factors and the ensuing consequences from them determine the risk situation.

Quantitative risk analysis includes the quantification of not only individual risks, but also risks at the project level, i.e., affecting the entire project; through this analysis, the possible damage is also determined. The most common methods of quantitative risk analysis include statistical analysis, scenario building, expert assessments, analytical methods, and the use of decision trees and simulation modeling (Bukhvalov et al., 2011). Each of these methods has certain disadvantages; however, they can be compensated for using an integrated approach.

Most modern methods used for calculating the effectiveness of investment projects assume a one-dimensional criterion; in these cases, risk situation is determined using a sensitivity assessment procedure, which involves analyzing the changes in project results depending on the dynamics of risk factors. However, different authors suggest different approaches (Rodionova et al., 2013; Bukhvalov et al., 2011). Our proposed approach is based on the use of the multi-criteria selection method. The peculiarity of our proposed approach is the use of multi-criteria selection with an interval estimation of project risk.

3. Proposed method

The complex approach for investment decision making involves calculating the NPV, DPP, and IRR of each alternative being analyzed (Rodionova et al., 2013). In addition, this approach is peculiar because it considers the uncertainty of the external environment. To do so, expert estimates of the likelihood of damage from the implementation of a project and the intervals of fluctuation of the three criteria are used to adjudge the effectiveness of the investment project.

In this study, we further develop this approach and include the risk from multidimensional estimation. It is known that uncertainty presupposes the presence of factors under which the results of actions are not deterministic, and the degree of possible influence of these factors on the results is unknown (Vedernikov and Mogilenko, 2011). Thus, we consider more closely the uncertainty factor and possibility of damage occurrence. Therefore, we include the forecast of the market situation in the future as well as the risk assessment in each of the possible situations. This approach allows us to include a generalized risk indicator, which can reflect, as components, various types of risk. This is depicted in Table 1.

Table 1. Proposed method

1	Investment alternatives are selected
2	A selected criterion for each alternative is evaluated as an interval value
3	Membership Function values for each interval and each criterion are calculated indicating magnitude of risk
4	Interval Preferences are introduced
5	Pareto tuple is constructed based on the selected optimal decision (invested project)

Source: Rodionova et al., 2013

We estimate the ranges of values for all indicators considering the risk involved in alternative investment projects. Intervals are determined both in terms of absolute values of the indicators, and in grades (Rodionova et al., 2013).

To estimate the effectiveness of alternative options and select the most preferable one based on the built-in interval preference ratio (IPR), here, we use the notation introduced in Ref. 30.

Consider that $I = \{I_\alpha, \alpha = 1 \dots n\}$ is a set of variants of investment projects,

$K_i(I_\alpha) = [A_i(I_\alpha); B_i(I_\alpha)]$ represent the criteria for assessing the effectiveness of each investment project in the interval form,

$i = 1 \dots r$, r is the total number of evaluation criteria, $A_i(I_\alpha)$ and $B_i(I_\alpha)$ are the lower and upper bounds of the evaluation interval, $K(I_\alpha) = \{K_1(I_\alpha), K_2(I_\alpha), \dots K_r(I_\alpha)\} = \{[A_1(I_\alpha); B_1(I_\alpha)], \text{ and } [A_2(I_\alpha); B_2(I_\alpha)], \dots [A_r(I_\alpha); B_r(I_\alpha)]\}$ is the vector indicator of each investment project's effectiveness.

We introduce the notation II for the set of Pareto-optimal IP ($II \subset I$) with the number of elements $\gamma \leq n$ satisfying the dominance condition $II_{m1} > II_{m2} > \dots II_{m\gamma}$, $m_j = 1 \dots \gamma$. Then, the problem can be formulated as follows to construct the Pareto tuple of considered variants of investment projects, whose elements satisfy one of the conditions

$$K_i(I_{yj}) = \min[K_i(I_\alpha)], I_{yj} \in II \text{ or } K_i(I_{yj}) = \max[K_i(I_\alpha)], I_{yj} \in II.$$

We note that if the exponent is a scalar quantity, it can be represented as a degenerate interval with coincident ends $A_i(I_\alpha) = B_i(I_\alpha)$ (Orlovsky, 1981; Serguieva and Hunter, 2014).

The ambiguity in the selection of the criteria and variety of factors are considered, because of the complexity of the problem of assessing the effectiveness of investment projects. It is necessary to assume that the decision-maker (usually, the project manager) does not have a clear opinion on the preferences for the analyzed alternatives. The representation of indicators using interval values and qualitative difference of the measured quantities, which is expressed as the difference in the units of measurement, make it convenient to compare the variants based on the IPR (Vedernikov and Mogilenko, 2011).

Let m_i be the width of the estimates' interval for the i -th criterion. According to fuzzy methods (Orlovsky, 1981), the interval relation of preference R'' on the set I_α is the set of the Cartesian product $I_k \times I_l$, ($k = 1, \dots, n$, $l = 1, \dots, n$, $k \neq l$). For characteristic of the set of the Cartesian product, we consider the interval membership function $\mu^u K_i(I_k, I_l): I_k \times I_l \rightarrow [-1; 1]$.

$$\mu^u K_i(I_k, I_l) = m_i^{-1} (K_i(I_k) - K_i(I_l)) \quad (1)$$

Each value of the membership function $\mu^u K_i(I_k, I_l)$ estimates the degree of gain and damage in recognizing variant I_k as the dominant variant I_l based on the criterion K_i .

The degree of dominance of the alternative I_k over the alternative I_l based on the interval criterion K_i is represented by the membership function $\mu_D^u K_i(I_k, I_l)$, which determines the ratio of strict interval preference.

$$\mu_D^u K_i(I_k, I_l) = \mu^u K_i(I_k, I_l) - \mu^u K_i(I_l, I_k) \quad (2)$$

For comparison, it is important to establish that the alternative I_k is not undermined compared with the I_l alternative, which is determined using the membership function.

$$\mu_{ND} K_i(I_k, I_l) = 1 - x, x \geq 0; x = \mu_D^u K_i(I_k, I_l) \quad (3)$$

Then, for the i -th interval criterion, the proximity of the alternative I_k to the Pareto-optimal variant is characterized by the value of the membership function for the set of non-dominant alternatives (Orlovsky, 1981; Vedernikov and Mogilenko, 2011).

$$\mu_D^* K_i(I_k) = \min \mu_{ND} K_i(I_k, I_l) \quad (4)$$

The criterion NPV depends on the amount of cash flows at specific times and the discount rate r : (Bukhvalov et al., 2011):

$$NPV = C_1(1+r)^{-t_1} + \dots + C_n(1+r)^{-t_n} \quad (5)$$

As a discount rate, a risk-free interest rate or a rate of interest for projects with the same degree of risk, or the sectoral coefficient of capital investments' efficiency, are typically used. Based on this criterion, a project with a maximum value with the same value of r is selected. Because NPV strongly depends on the discount rate, an ungrounded forecast of the discount rate can lead to incorrect management decisions, e.g., a good project might be rejected or an inefficient one might be accepted. Due to the specification of NPV interval values, it is clarified that the optimal condition for the NPV criterion is the maximum value.

Furthermore, DPP is expressed as a time interval; the optimal condition for this criterion corresponds to its minimum value. In addition, the IRR is expressed in percentages and is given as an interval value; for this criterion, a project corresponding to the maximum value is selected (Rodionova E.A., Shvetsova O.A. et al).

4. Results and discussion

4.1. Data implication and results

Risk assessment is performed based on interval values in grades. Assuming that the interest rate r is a random variable for which the probability of a random event can be found, $NPV(r, t) > 0$, $P(NPV(r, t) > 0) = P(r < IRR) = F(IRR)$. Here $F(x) = P(r < x)$ is the distribution function of r , IRR is the internal rate of return, which is obtained as a solution to the equation $NPV(t, r) = 0$. For different r , it is possible to establish the probabilities that the project will not pay off at time t , and then scores are obtained using the valuation procedure. Here, we conduct the risk evaluation for a project based on the abovementioned methodology for three possible predictable market conditions for which experts estimated the likelihood of implementing each of them. It should be noted that the criterion for assessing the risk of an investment project requires selecting the best option based on the minimum value of the criteria.

Considering the known theoretical representations, the values of m_i are selected as the maximum permissible values for the considered criteria. The initial data required for the investment projects analysis calculations are presented in Table 2.

Table 2. Data implication for different projects

Projects/Indicators	$I1$	$I2$	$I3$	m_i
$K_1(Ia)$ -NPV (USD)	[50;60]	[70;120]	[80;100]	200
$K_2(Ia)$ -DPP (annual)	[3;8]	[4;6]	[5;9]	10
$K_3(Ia)$ -IRR (%)	[16;17]	[10;20]	[14;18]	30
$K_4(Ia)$ -risk evaluation (points)-pessimistic forecast	[6;8]	[3;9]	[5;9]	10
$K_5(Ia)$ -risk evaluation (points)- realistic forecast	[4.5;7]	[5;8.5]	[4;7]	10
$K_6(Ia)$ -risk evaluation (points)-optimistic forecast	[4;5]	[4;6]	[3;5.5]	10

Using Eq. (1), we obtain the values of the membership function $\mu^u K_i(I_k, I_l)$ for each pair of variants for each criterion and compute their estimated matrices. Thus, Eq. (1) can be expanded as:

$$\mu^u K_i(I_k, I_l) = ([\min\{A_i(I_k) - A_i(I_l); B_i(I_k) - B_i(I_l)\}; \max\{A_i(I_k) - A_i(I_l); B_i(I_k) - B_i(I_l)\}]/m_i)$$

and be denoted by

$$C_i^{kl} = \min\{A_i(I_k) - A_i(I_l); B_i(I_k) - B_i(I_l)\}/m_i, \\ D_i^{kl} = \max\{A_i(I_k) - A_i(I_l); B_i(I_k) - B_i(I_l)\}/m_i$$

Then,

$$\mu^u K_i(I_k, I_l) = [C_i^{kl}; D_i^{kl}] \quad (6)$$

Further, the interval membership function for the I_l, I_k takes the following form:

$$\mu^u K_i(I_k, I_l) = [-D_i^{kl}; -C_i^{kl}] \quad (7)$$

Hence, if relation $|C_i^{kl}| = D_i^{kl}$ is true, then the values $\mu^u K_i(I_l, I_k)$ $\mu^u K_i(I_k, I_l)$ coincide as well.

Using Eq. (2), we include the preference intensity for each pair of variants for each criterion through the values of the membership function $\mu_D^u K_i(I_k, I_l)$ and include them in the estimated matrices. Using Eqs. (6) and (7), we simplify the calculations.

Thus, we evidently have

$$\mu_D^u K_i(I_k, I_l) = [C_i^{kl}; D_i^{kl}] - [-D_i^{kl}; -C_i^{kl}] = [C_i^{kl} + D_i^{kl}; C_i^{kl} + D_i^{kl}]$$

Thus,

$$\mu_D^u K_1(I\alpha) =$$

-	-0.4	-0.35
0.4	-	0.05
0.35	-0.05	-

$$\mu_D^u K_2(I\alpha) =$$

-	-0.1	-0.3
-0.1	-	-0.4
0.3	0.4	-

$$\mu_D^u K_3(I\alpha) =$$

-	0.1	0.03
-0.1	-	-0.06
-0.03	-0.06	-

$$\mu_D^u K_4(I\alpha) =$$

-	0.2	0
-0.2	-	-0.2
0	0.2	-

$$\mu_{D_u}^{D_u} K_5(I_\alpha) =$$

-	-0.2	0.05
0.2	-	0.25
-0.05	-0.25	-

$$\mu_{D_u}^{D_u} K_6(I_\alpha) =$$

-	-0.1	0.05
0.1	-	0.25
-0.05	-0.25	-

From Eqs. (3) and (4), we obtain the values of the membership function $\mu_{ND}^u K_i(I_k, I_l)$ for each pair of variants for each criterion and compile the membership function values for the set of non-dominated variants $\mu_D K_i(I_k)$:

$$\begin{aligned}\mu_D^* K_1(I_k) &= \{0.6, 1, 0.95\}, \\ \mu_D^* K_2(I_k) &= \{0.9, 1, 0.6\}, \\ \mu_D^* K_3(I_k) &= \{1, 0.9, 0.93\}, \\ \mu_D^* K_4(I_k) &= \{1, 0.8, 1\}, \\ \mu_D^* K_5(I_k) &= \{0.9, 0.75, 1\}, \\ \mu_D^* K_6(I_k) &= \{0.95, 0.75, 1\}\end{aligned}$$

Based on the analysis of the values $\mu_D^* K_i(I_k)$, it can be concluded that option I_2 is the best one based on the criteria $K_1(I_\alpha)$ and $K_2(I_\alpha)$, option I_1 is the best one based on the criterion $K_3(I_\alpha)$ as well as when considering the risk criterion in case of a pessimistic forecast, and option I_3 is the best one in the case of the risk criterion based on the considered set of variants of investment projects.

To determine the preference relation on the set of variants of investment projects, we define the vector preference in a similar way to some previous studies (Orlovsky, 1981; Vedernikov and Mogilenko, 2011). The membership functions $\mu_D^* K_i(I_k)$ characterize the degree of proximity of the variant I_k to the Pareto-optimal variant of the investment project based on the criterion K_i ; therefore, we use criteria instead of the traditional coefficients indicating the importance of the criteria. Then, we compare the variants I_k and I_l in pairs, analyze the values $\mu_D^* K_i(I_k)$, and introduce the subsets I_{kl}^+ , I_{kl}^- , and $I_{kl}^=$ for the best, worst, and equal values $\mu_D^* K_i(I_k)$ and $\mu_D^* K_i(I_l)$ ($i = 1...4$; $k, l = 1, ... 3$, $k \neq l$) of these variants, respectively. Then, we define the elements of the evaluation matrix $C = \|C_{kl}^\mu\|$ based on these conditions; this is shown in Table 3 (Vedernikov and Mogilenko, 2011).

Table 3. Evaluation matrix

I_{kl}^+	I_{kl}^-	$I_{kl}^=$	C_{kl}^μ	C_{lk}^μ	Notes
$\emptyset$	$\emptyset$	$\{1..3\}$	1	1	-
$\{1..3\}$	$\emptyset$	$\emptyset$	N_2	0	-
$\emptyset$	$\{1..3\}$	$\emptyset$	0	N_2	-
$\neq$	$\emptyset$	$\neq 0$	N_3	0	$1 < N_3 < N_2$
$\emptyset$	$\neq$	$\neq 0$	0	N_3	-
$\neq$	$\neq$	$ S_{ij}^- \geq 0$	Formula (8)	$C_{lk}^\mu = 1/C_{kl}^\mu$	-

Source: Vedernikov and Mogilenko, 2011

$$C_{kl}^{\mu} = \left(\sum_{i=1}^3 \mu_D^* K_i(I_k) \right) \left(\sum_{i=1}^3 \mu_D^* K_i(I_l) \right)^{-1} \quad (8)$$

When creating a matrix of assessments based on the risk criterion, we consider the possibility of the onset of various risk conditions as weighted estimates of matrix elements

$$C_{kl}^{\mu} = \left(\sum_{i=1}^3 a_i \mu_D^* k_i(I_k) \right) \left(\sum_{i=1}^3 a_i \mu_D^* k_i(I_l) \right)^{-1},$$

$a_i = \begin{cases} 1, & i = 1, 2, 3 \\ p_i, & i = 4, 5, 6 \end{cases}$

Then, we get the following matrix of preferences

C =		
-	0.66	5.01
1.51	-	0.94
0.19	1.05	-

Using the proposed technique based on the theoretical scheme, we introduce the indicators: G_l^{μ} and H_l^{μ} , which are the number of elements of the l -th column in **C**, the value of which is less than one, but greater than zero, and greater than one, respectively, and an indicator $C_{kl \max}^{\mu}$ equal to the maximum value element of the l -th column. Then, H_l^{μ} indicates the number of variants of the investment project dominating the l -th column. Furthermore, G_l^{μ} indicated the number of variants of the investment project that dominate the l -th column, and $C_{kl \max}^{\mu}$ reflects the maximum degree of dominance of the k -th version of the investment project over the l -th column.

Let these indicators be included in a matrix, as shown in Table 4.

Table 4. Matrix of indicators

Investment projects, variants	I_1	I_2	I_3
Indicators			
G_l^{μ}	1	1	1
H_l^{μ}	1	1	1
$C_{kl \max}^{\mu}$	1.51	1.05	5.01

Now, based on Table 3, the best alternative to an investment project with a minimum value $C_{kl \max}^{\mu}$ is option I_2 . Therefore, the second version of the investment project is included in the Pareto tuple and excluded from further analysis by deleting the corresponding row and the column in the preference matrix.

The remaining options are analyzed using the new matrix of indicators in a similar manner.

Finally, the tuple of Pareto preferences can be obtained as $\Pi = \{I_2, I_1, I_3\}$. Therefore, the best alternative for the vector inhomogeneous efficiency index $K(I_{\alpha}) = \{K_1(I_{\alpha}), K_2(I_{\alpha}), K_3(I_{\alpha}), K_4(I_{\alpha}), K_5(I_{\alpha}), K_6(I_{\alpha})\}$ should be recognized as the second variant. In the Pareto tuple of the considered variants, preference was expressed for the criteria characterizing the NPV and discounting for the calculation of the DPP in the vector efficiency index.

4.2. Discussion and further research

The selection of alternatives for implementation from the different investment projects in conditions of uncertainty is a difficult task. Therefore, it is necessary to consider a multidimensional efficiency criterion reflecting the different goals of decision makers, because such decisions might be important for many industries in the national economy. In particular, such decisions influence complex projects such as laying gas and oil pipelines. In this case, many risk factors can be identified, most important of which include (i) the volatility of prices for oil and natural gas, (ii) a significant revaluation of reserves in various fields, (iii) natural disasters, industrial accidents, and political uncertainty; these are described in more detail in Table 5. Therefore, it can be seen that it is important to consider both the multidimensionality of the evaluation criterion and the uncertainty factor when evaluating investment projects (Methodical recommendations on the implementation of pre-investment studies in LLC Gazprom, 2008).

Table 5. Risk priority for oil and gas investment projects

Category	Risk	Description
Economic	Product's price	Volatility and lower prices for oil or natural gas lead to a deterioration in operating results and future prospects
Ecological	Natural disaster	A natural disaster leading to an interrupted or lower production or industrial accident
Operational	Industrial Accident	A major accident or oil spill leading to loss of life, environmental damage, regulatory fines, civil liability, loss of operating license, and damage to reputation
Political	Political instability	Supply disruption due to war, civil war, terrorism, or other political instability within/outside the country
Resources	Availability of resources	Significant change in estimates of oil and gas reserves or development potential

Source: Methodical recommendations on the implementation of pre-investment studies in LLC Gazprom, 2008

In the context of modern information technology development, it is important to develop methods for analysing economic systems based on qualitative data estimates and soft calculations to explore opportunities for certain industrial sectors. Thus, problems of investment projects' evaluation can be supported by adequate scientific statement and solution. Furthermore, specific information of investment projects in various industries is considered for interval data presentation.

The application of a multi-criteria approach for the evaluation of investment projects has advantages and disadvantages. The advantages include factors such as usage flexibility, variability, the use of multiple criteria, and the possibility of comparing and evaluating the entire pool of projects in one period.

In contrast, the disadvantages of using a multi-criteria approach can be attributed to the instability of the external environment and the risk factors that affect the attractiveness of an investment project (Brav et al., 2005).

Further, a major weakness of the IRR method compared with the NPV method concerns the rate at which the cash flows generated by a capital project are reinvested. In particular, the NPV method assumes that cash flows from a project are reinvested at the cost of capital, whereas the IRR technique assumes they are reinvested at the IRR.

To eliminate the reinvestment rate assumption of the IRR, some practitioners prefer to calculate the modified IRR (MIRR) (Rodionova et al., 2013; Bukhvalov et al., 2011). In this approach, each operating cash flow is

converted to a future value at the end of the project's life, compounded at the cost of capital. These values are then added to obtain the project's terminal value (TV) (Laufman, 1998).

As future work, we might evaluate investment projects based on MIRR.

Conclusions

Our proposed algorithm for selecting an investment project considers the involved risk. Furthermore, aside from accounting for the diversity of economic interests inherent in the economic system, our proposed method considers the uncertainty of the forecasted states of the system under study; this is achieved by describing the risk situations and introducing a multicomponent representation of the risk component as one of the decision criteria.

This approach enhances the possibility of applying the multi-criteria selection method for conditions of economic activity in practice. These real, practical conditions of economic activity include:

- Selecting the form of investment policy;
- Application of the investment project structure;
- Effects of the local or global environment;
- Scope of risk conditions;
- Ability to cooperate and share risks.

Therefore, the method accounts for specific information for the process of adopting a complex economic or managerial decision in the economic system. Moreover, our algorithm can be used for making long-term strategic decisions in a risk environment.

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References

- Beinat, E.; Nijkamp, P. 1998. *Multi-criteria evaluation in land use management*. Dordrecht: Published by Kluwer Academic Publishers.
- Brav, A.; Graham, J. R.; Harvey, C. R.; Michaely, R. 2005. Payout policy in the 21st century, *Journal of Financial Economics* 77(3): 483–527. <http://doi.org/10.1016/j.jfineco.2004.07.004>
- Brigham, E. F.; Ehrhardt, M. C. 2015. *Financial management: Theory and practice*. Cincinnati: Published by South-Western College Publishing.
- Bukhvalov, A. V.; Bukhvalov, V. V.; Idelson, A. V. 2011. *Financial Calculations for Professionals*. St. Petersburg: Published by BHV-Petersburg.
- Grierson, D. E. 2008. Pareto multi-criteria decision making, *Advanced Engineering Informatics* 22(3): 371–384. <http://doi.org/10.1016/j.aei.2008.03.001>

Gurumurthy, A.; Kodali, R. 2013. Multi-criteria decision-making model for the justification of lean manufacturing systems, *International Journal of Management Science and Engineering Management* 3(2): 100–118. Available on the Internet: <http://www.worldacademicunion.com/journal/MSEM/msemVol03No02paper02>

Hayashi, K. 2000. Multicriteria analysis for agricultural resource management: a critical survey and future perspectives, *European Journal of Operational Research* 122(2): 486–500. [http://doi.org/10.1016/S0377-2217\(99\)00249-0](http://doi.org/10.1016/S0377-2217(99)00249-0)

Jelnova, C. V. 2013. Analysis of the Practice of Decision-Making in the Field of Investment Policy, *Contemporary Economic Issues* 4. <http://doi.org/10.24194/41302>

Kangas, J.; Kamgas, A. 2002. Multiple criteria decision support methods in forest management. An overview and comparative analyses, in Pukkala, T. (Ed.). *Multi-Objective Forest Planning*. Dordrecht: Kluwer Academic Publishers, 37–70. http://doi.org/10.1007/978-94-015-9906-1_3

Keshavarz Ghorabae, M.; Zavadskas, E. K.; Olfat, L.; Turskis, Z. 2015. Multi-criteria inventory classification using a new method of evaluation based on distance from average solution (EDAS), *Informatica* 26(3): 435–451. <http://dx.doi.org/10.15388/informatica.2015.57>

Khokhlov, N. V. 2011. *Risk Management: Practical Allowance for Universities*. Moscow: Published by UNITY-DANA.

Laufman, G. 1998. *To Have and Have Not*. New York: Published by CFO Publishing Corporation.

Lukicheva, L. I.; Egorychev, D. N. 2016. *Decision Making Process in Management*. Moscow: Published by Omega-M.

Mardani, A.; Jusoh, A.; Zavadskas, E. K.; Khalifah, Z.; Nor, K. 2015. Application of multiple-criteria decision-making techniques and approaches to evaluating of service quality: a systematic review of the literature, *Journal of Business Economics and Management* 16(5): 1034–1068. <http://doi.org/10.3846/16111699.2015.109523>

Mazur, I. I.; Shapiro, V. D.; Olderogge, N. G. 2014. *Project Management: Practical Allowance for Universities*. Moscow: Published by Omega-L.

Methodical recommendations on the implementation of pre-investment studies in LLC Gazprom. 2008. Gazprom Publishing 047-2000. Moscow: Published by the Institute for Investment Development, 29–34.

Minakova, L. V.; Anikanov, P. V. 2013. Modelling of area of possible results of the innovative investment project, *Contemporary Economic Issues* 1. <http://doi.org/10.24194/11321>

Olson, D. 1995. *Decision aids for selection problems*. New York: Published by Springer-Verlag. <http://doi.org/10.1057/palgrave.jors.2600636>

Opricovic, S.; Tzeng, G. H. 2004. Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS, *European Journal of Operational Research* 156(2): 445–455. [http://doi.org/10.1016/S0377-2217\(03\)00020-1](http://doi.org/10.1016/S0377-2217(03)00020-1)

Orlovsky, S. A. 1981. *Problems of Decision Making with Fuzzy Source Information*. Moscow: Published by Nauka.

Parrino, R.; Kidwell, D.; Bates, T. 2014. *Essentials of Corporate Finance*. New York: Published by Wiley.

Rodionova, E. A.; Epshtein, M. Z.; Petukhov, L. V. 2013. Multivariate evaluation of investment projects based on interval preferences, *Scientific and Technical Sheets of the Saint-Petersburg Polytechnic University. Information. Telecommunication. Management* 169(2): 141–148.

Rodionova E. A., Shvetsova O. A., Michael Z. E. Multicriterial Approach to Investment Projects: Estimation under Risk Conditions/ *Revista Espacios*, Vol.39 (7) 2018; 28-44

Roy, B. 1976. Problems and methods of solutions in problems with many objective functions, in *Analysis Questions and Decision-making Procedures*. Moscow: MIR, 20–58.

Saaty, T. L. 1990. *Multi-criteria decision making: The analytic hierarchy process*. Pittsburgh: Published by RWS Publications.

Savchuk, V. P. 2007. *Evaluation of the Investment Projects' Effectiveness*. Moscow: Published by Phoenix.

Seitz, N. E.; Ellison, M. 1999. *Capital Budgeting and Long-Term Financing Decisions*. Fort Worth: Published by Harcourt Brace College Publishers.

Serguieva, A.; Hunter, J. 2014. Fuzzy interval methods in the investment risk appraisal, *Fuzzy Sets and Systems* 142(3): 443–466. [http://doi.org/10.1016/s0165-0114\(03\)00166-0](http://doi.org/10.1016/s0165-0114(03)00166-0)

Stoyanova, E. S.; Krylova, T. B. 2006. *Financial Management: Theory and Practice*. Moscow: Published by Perspective.

Syroezhin, I. M. 1980. *Perfection of the System of Efficiency and Quality Indicators*. Moscow: Published by Economy.

Tarp, S. 2014. Theory-based lexicographical methods in a functional perspective. An overview, *Lexicographica* 30(1): 58–76. <http://doi.org/10.1515/lexi-2014-0003>

Tsoutsos, T.; Drandaki, M.; Frantzeskaki, N.; Iosifidis, E.; Kiosses, I. 2009. Sustainable energy planning by using multi-criteria analysis application in the Island of Crete, *Energy Policy* 37(5): 1587–1600. <http://dx.doi.org/10.1016/j.enpol.2008.12.011>

Vedernikov, Y. V.; Mogilenko, V. V. 2011. Scientific and methodical apparatus of vector preference for complex technical systems characterized by quality indicators specified in a limited-indefinite form, *Issues of Modern Science and Practice. System Analysis. Automated Management* 32(1): 81–96.

Wang, J. J.; Jing, Y. Y.; Zhang, C. F.; Zhao, J. H. 2009. Review on Multi-Criteria Decision Analysis Aid in Sustainable Energy Decision-Making, *Renewable and Sustainable Energy Reviews* 13(9): 2263–2278. <http://doi.org/10.1016/j.rser.2009.06.021>

Zare, M.; Pahl, C.; Rahnama, H.; Nilashi, M.; Mardani, A.; Ibrahim, O.; Ahmadi, H. 2016. Multi-criteria decision-making approach in e-learning: a systematic review and classification, *Applied Soft Computing* 45: 108–128. <http://dx.doi.org/10.1016/j.asoc.2016.04.020>

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