A NEW MULTI-OBJECTIVE OPTIMIZATION APPROACH FOR SUSTAINABLE PROJECT PORTFOLIO SELECTION: A REAL-WORLD APPLICATION UNDER INTERVAL-VALUED FUZZY ENVIRONMENT

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Abstract. Organizations need to evaluate project proposals and select the ones that are the most effective in reaching the strategic goals by considering sustainability issue. In order to enhance the effectiveness and the efficiency of project oriented organizations, in this paper a new multi-objective decision making (MODM) approach of sustainable project portfolio selection is proposed which applies interval-valued fuzzy sets (IVFSs) to consider uncertainty. In the proposed approach, in addition to sustainability criteria, other practical criteria including non-financial benefits, strategic alignment, organizational readiness and project risk are incorporated. The presented approach consists of three main parts: In the first part, a novel composite risk return index based on the IVFSs is introduced and used to form the first model to evaluate the financial return and risk of the proposed projects. In the second part, a new risk reduction compromise ratio model is introduced to evaluate projects versus non-financial criteria. Finally, an MODM model is presented to form the overall objective function of the approach. In order to make the approach more suitable for real-world situations, a group of applicable constraints is included in the proposed approach. The constraints are based on limitations and issues existing in practical project portfolio management. Due to importance of uncertainty and risk in project portfolio selection, they are addressed separately in three parts of the approach. In the first part, a novel downside risk measure is introduced and applied to assess financial risk of projects. In the second part of the approach, not only project risk is accounted for as a criterion, but also a new method is introduced to control and limit the risk of uncertainty and to use the advantages of IVFSs. Finally, the proposed IVF-MODM approach is applied to select the optimal sustainable project portfolio in real case study of a holding company in a developing country. The results show that the approach can successfully address highly uncertain environments. Moreover, risk has been fully explored from different perspectives. Eventually, the approach provided the decision makers with more flexibility in focusing on financial and non-financial criteria in the selection process.

1. Introduction

Corporate managers have to choose portfolios of projects to fund, so that the corporate goals would be met. The main reason for project portfolio selection is that the accumulated funding required by all the candidate projects highly exceeds

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the available investment budget. The main idea is to choose an optimal portfolio of projects that not only achieves the company's goals but also considers the budgetary limitations. Moreover, controlling the risk of the selected project portfolio and keeping the performance objectives, for instance cash flow, in the preferred zone are some of the other goals that should be considered in project portfolio selection process [2, 14].

Project portfolio selection has been attracting researchers for a long time. Project portfolio selection is an important and challenging part of R&D and development departments works. In spite of the numerous studies carried out in this application of project portfolio selection, broad nature of the topic still provides opportunities for further works. Furthermore, project portfolio selection can be applied in other similar fields, and it influences a far-reaching range of practices [24].

Project portfolio studies have developed through the years. The main focus of the early studies was aimed at financial criteria of projects. Later, scholars proposed total frameworks to address the strategic financial criteria. In the recent decades, there has been scattered focus on other criteria such as sustainable development, strategic alliance, risk of investment and organizational readiness [27]. In other words, project portfolio selection has been applied as a tool by many organizations to reach their organizational strategies.

A large number of local and international organizations have adopted their strategies with the concept of sustainability [42]. The concept of sustainability is based on the interrelationship among society, the environmental and financial development. Sustainable development depends on recognition of connections and interactions of these three pillars of sustainability. In other words, sustainable development cannot be reached without adequate understanding of financial decisions impact on the society and the environment [22]. Sustainable project portfolio selection is a step towards organizational sustainable development. Khalili-Damghani and Sadi-Nezhad [26] proposed a decision-making method based on goal programming and TOPSIS to select sustainable projects. They used classical fuzzy sets theory to address uncertainty in the project environment. Khalili-Damghani et al. [27] developed a fuzzy rule based system for sustainable project portfolio selection. Like the other research, uncertainty in that paper was also addressed by classical fuzzy sets theory.

In fact in any real-world project selection process, there are two concepts that increase its complexity. One is the constraints and limitations imposed on the process and the other one is the uncertainty that exists in the project evaluation [34]. In investment decisions, experts often have to deal with insufficient information and lack of expertise [20]. In order to address the uncertainty, many scholars have applied fuzzy sets theory. Chiu [9] described project cash flow and proposed a method to determine the preferred fuzzy projects by employing triangular fuzzy numbers. Chiadamrong [8] proposed a multi-criteria decision-making process based on fuzzy sets theory to select manufacturing strategies. Kuchta [28] introduced a fuzzy single project evaluation approach based on the existing single project evaluation process. Lin and Hsieh [30] applied the classic concepts of decision support systems and fuzzy sets theory to introduce a method of strategic portfolio selection.

Rebiasz [41] addressed project risk evaluation by proposing a method that used fuzzy or random parameters. Wang and Hwang [47] introduced a fuzzy zero-one integer programming method to select the optimal project portfolio in an uncertain environment. Carlsson et al. [5] based on trapezoidal fuzzy numbers proposed a fuzzy mixed integer programming model and also considered a method to foresee future cash flows. Yuen [52] proposed a linguistic possibility-probability aggregation model to analyze decision making with imprecise data. The proposed model was applied in R&D project selection. Chen and Cheng [6] presented a multiple-criteria decision-making method for project selection that applied the fuzzy measures and the fuzzy integral. Liao and Ho [29] focused on a fuzzy net present value (NPV) evaluation method for projects. Zhang et al. [53] introduced a method based on credibilistic expected value and credibilistic lower semi-variance to select the optimal portfolio of projects under a fuzzy environment. Carlsson et al. [4], unlike the aforementioned scholars, used extensions of classical fuzzy sets theory to address uncertainty in project evaluation and selection problems. In their method, they used interval-valued fuzzy (IVF)-numbers to predict net present value. Mezei and Wikstrm [35] also concentrated on interval-valued fuzzy sets (IVFSs) in the project selection. Firstly, they introduced aggregation operators based on IVFSs, and then they applied the introduced operators in the project selection. Ebrahimnejad et al. [13] developed a fuzzy bi-objective model of portfolio selection. Their approach was able to model limits of resource and budget. They also used Pareto plot to help the decision maker (DM) find the most desirable solution while considering accepted level of risk. Yuen [51] used fuzzy cognitive network process (F-CNP) in new product development strategy and through comparison with fuzzy analytic hierarchy process (F-AHP) showed the advantages of the proposed model. In addition, Yuen [50] developed a model that was based on F-CNP and aggregative grading clustering to evaluate criteria in quality function deployment.

To conclude from above, despite a small number of recent studies, new fuzzy extensions are yet new to this subject and their advantages have not been yet fully applied in the project selection problem. In fact, as using fuzzy sets theory to address uncertainty in real-world situations increased, its shortcomings became more obvious and the necessity for improving fuzzy sets theory arose. One of its shortcomings is when a DM has to express an exact opinion in a number in interval [0, 1] [39, 44, 45, 46]. Obviously expressing this degree of certainty in an interval instead of a number is more practical. One of the capabilities of IVFSs is to support this approach [18]. A DM by using IVFSs is able to express unknown and vague membership degrees by intervals in [0, 1] instead of traditional [0, 1] -valued membership degrees. If in a project tangible facts or proofs did not exist and expressing lack of information and vagueness based on feelings rather than facts was inevitable, employing IVFSs could be the right approach. Additionally, in comparison with type-2 fuzzy sets, IVFSs are easier to apply in practice [11].

Based on the review of the related literature, sustainable project portfolio selection is the latest development in project portfolio selection studies. In fact, this new approach, despite its application and necessity, is still a new and challenging topic. In the previous related studies, risk and uncertainty were not fully addressed.

Factors such as project risk and financial risk were not individually discussed and the involved risks in decision-making process were not flexible and controllable. In addition, to the best of our knowledge, other strategic criteria could be added in the process to make the existing methods more applicable in real-world situations. Moreover, as mentioned earlier, uncertainty was addressed by classical fuzzy sets theory and the advantages of new extensions of fuzzy sets theory were not applied in the proposed approaches.

In this paper, a new multi-objective decision-making (MODM) model of project portfolio selection is introduced under uncertainty that is based on the IVFSs. In the proposed model, first a novel composite risk/return index based on IVFSs is introduced to consider return and risk of investment, and then it is extended to a new mathematical model for project portfolio selection. This model investigates the financial strategic dimensions of the process. In the next step, a novel risk reduction compromise ratio method based on footprint of uncertainty (FOU) and IVFSs is proposed to rank the non-financial strategic criteria that include social effect, environmental effect, strategic alignment, organizational readiness, non-financial benefits and project risks. The final results of this step are used to form the second mathematical model. Finally, the two objective functions that were obtained on previous steps are aggregated to form the final objective function of the presented MODM approach. The proposed IVF-based MODM model is eventually applied to a real case of a holding company in a developing country to illustrate the efficiency and the effectiveness of the presented model.

In summary, the main characteristics of the proposed IVF-MODM method leading to its novelty are as follows:

- Addressing financial risk in the first model under IVF-environment by using semi-variance, which is a highly reliable downside risk measure.
- Introducing a novel risk reduction compromise ratio method for controlling and limiting the risk of uncertainty.
- Presenting the risk of project as a separate criterion in the novel risk reduction compromise ratio method.
- Proposing the interrelationship of projects, geographical distribution of the selected projects, balance of the portfolio and similar conditions in the constraints of the proposed approach to consider real-world applications of the model.
- Considering IVFSs to increase flexibility in expressing and calculating the uncertainty of project environments.
- Giving weight to each objective function in the final MODM model, in order to enable the DM to express preference on set of financial or non-financial strategic criteria in the decision-making process.

The rest of the paper is organized as follows. In section 2, preliminary knowledge of IVFSs is described. In section 3, first the selection criteria and the conceptual framework of the model are introduced. In sub-section 3.1, for financial criteria, a composite risk return index is introduced based on IVFSs, and it is extended to a project portfolio selection model. Some of the constraints, related to financial issues are also introduced. In sub-section 3.2, a risk reduction compromise ratio model is introduced to address the non-financial strategic criteria. The results of the model are used to form the second objective function. Some of the constraints related to the second group of criteria are presented in this part. In sub-section 3.3, the final MODM model is presented. In section 4, first the model is used to solve the problems taken from the existing literature. Then, the model is applied in real case study of a holding company. In section 5, the managerial implications of the model are presented. Finally, section 6 concludes the paper.

2. **Preliminaries**

Since the proposed model is based on the concepts of IVFSs, some basic definitions and operations of IVFSs are expressed below to facilitate future discussions.

In a triangular interval-valued fuzzy number, as shown in figure 1, $\tilde{A}^L$ and $\tilde{A}^U$ denote the lower and the upper triangular interval-valued fuzzy numbers. Also, $\hat{W}^L_{\tilde{A}}$ and $\hat{W}^U_{\tilde{A}}$ denote the degrees in which an event x may be a member of the lower and upper numbers respectively [49]. This interval-valued fuzzy number (IVFN) is displayed as:

$$\tilde{A} = [\tilde{A}^L_x, \tilde{A}^U_x] = [(a^L_1, a^L_2, a^L_3; w^L_{\tilde{A}}), (a^U_1, a^U_2, a^U_3; w^U_{\tilde{A}})] \tag{1}$$

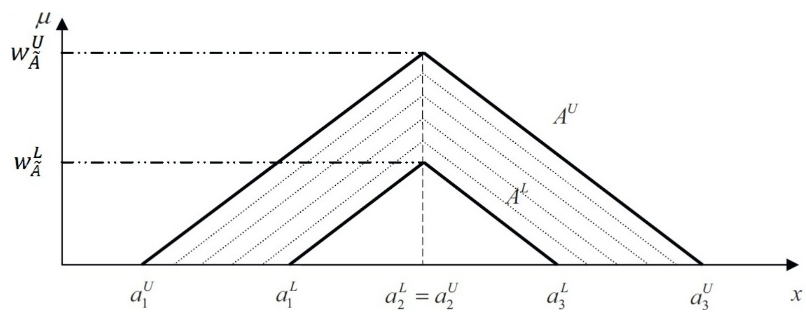

FIGURE 1. An Interval-valued Triangular Fuzzy Number $\tilde{A}(\hat{W}^L_{\tilde{A}} \neq \hat{W}^U_{\tilde{A}})$

It should be noted that in figure 1, the area displayed with hatch lines is called footprint of uncertainty (FOU). It could be concluded from figure 1 that if $\tilde{A}^L_x = \tilde{A}^U_x$ then the generalized triangular-IVFN is a generalized triangular fuzzy number. Additionally, if $a^L_1 = a^U_1 = a^L_2 = a^U_2 = a^L_3 = a^U_3$ and $w^L_{\tilde{A}} = w^U_{\tilde{A}}$ then the IVFN has a crisp value.

Arithmetic operations between two triangular IVFNs $\tilde{A}$ and $\tilde{B}$ displayed as $\tilde{A} = [(a^U_1, a^L_1), a_2, (a^L_3, a^U_3)]$ and $\tilde{B} = [(b^U_1, b^L_1), b_2, (b^L_3, b^U_3)]$, respectively, are presented in the following:

Addition of interval-valued fuzzy numbers $\oplus$ [19]:

$$\begin{aligned}\tilde{A} \oplus \tilde{B} &= [(a^U_1, a^L_1), a_2, (a^L_3, a^U_3)] \oplus [(b^U_1, b^L_1), b_2, (b^L_3, b^U_3)] \\ &= [(a^U_1 + b^U_1, a^L_1 + b^L_1), a_2 + b_2, (a^L_3 + b^L_3, a^U_3 + b^U_3)]\end{aligned} \tag{2}$$

Subtraction of interval-valued fuzzy numbers $\ominus$ [19]:

$$\begin{aligned}\tilde{A} \ominus \tilde{B} &= [(a_1^U, a_1^L), a_2, (a_3^L, a_3^U)] \ominus [(b_1^U, b_1^L), b_2, (b_3^L, b_3^U)] \\ &= [(a_1^U - b_3^U, a_1^L - b_3^L), a_2 - b_2, (a_3^L - b_1^L, a_3^U - b_1^U)] \end{aligned} \tag{3}$$

Multiplication of interval-valued fuzzy numbers $\otimes$ [19]:

$$\begin{aligned}\tilde{A} \otimes \tilde{B} &= [(a_1^U, a_1^L), a_2, (a_3^L, a_3^U)] \otimes [(b_1^U, b_1^L), b_2, (b_3^L, b_3^U)] \\ &= [(a_1^U \times b_1^U, a_1^L \times b_1^L), a_2 \times b_2, (a_3^L \times b_3^L, a_3^U \times b_3^U)] \end{aligned} \tag{4}$$

Generalized division of interval-valued fuzzy numbers $\oslash$ [19]:

$$\begin{aligned}\tilde{A} \oslash \tilde{B} &= [(a_1^U, a_1^L), a_2, (a_3^L, a_3^U)] \oslash [(b_1^U, b_1^L), b_2, (b_3^L, b_3^U)] \\ &= [(a_1^U \div b_3^U, a_1^L \div b_3^L), a_2 \div b_2, (a_3^L \div b_1^L, a_3^U \div b_1^U)] \end{aligned} \tag{5}$$

If k is a crisp number then $k\tilde{A}$ equals the following [19]:

$$\text{If } k > 0 \text{ then, } k\tilde{A} = [(ka_1^U, ka_1^L), ka_2, (ka_3^L, ka_3^U)] \tag{6}$$

$$\text{If } k < 0 \text{ then, } k\tilde{A} = [(ka_3^U, ka_3^L), ka_2, (ka_1^L, ka_1^U)] \tag{7}$$

$$\text{If } k = 0 \text{ then, } k\tilde{A} = [(0,0), 0, (0,0)] \tag{8}$$

Possibilistic mean value of IVFNs is obtained as follows [4]:

$$\begin{aligned} E(A) &= \int_0^1 \frac{\gamma(A_1(\gamma) + A_2(\gamma) + a_1(\gamma) + a_2(\gamma))}{2} d_\gamma \\ &= \frac{(E(A)^U + E(A)_L)}{2} \end{aligned} \tag{9}$$

Where possibilistic mean value of A^U and A_L are denoted by $E(A)^U$ and $E(A)_L$ respectively. Carlsson and Fuller [4] defined possibilistic mean of an IVFS as arithmetic mean of the mean values of its upper and lower fuzzy numbers. Based on that they defined possibilistic mean value and γ-cut of triangular-IVFN $\tilde{A} = [(a_1^U, a_1^L), a_2, (a_3^U, a_3^L)]$ as follows:

$$[\tilde{A}_x^L]^\gamma = [a_2^L - (1-\gamma)a_1^L, a_2^L + (1-\gamma)a_3^L] \tag{10}$$

$$[\tilde{A}_x^U]^\gamma = [a_2^U - (1-\gamma)a_1^U, a_2^U + (1-\gamma)a_3^U] \tag{11}$$

$$E(A) = \frac{(E(A^U) + E(A_L))}{2} = \frac{(a_2^L + a_2^U)}{2} + \frac{(a_3^L - a_1^L)}{12} + \frac{(a_3^U - a_1^U)}{12} \tag{12}$$

Also, the following for two IVFNs A, B and crisp number $c \in R$ is defined.

$$E(cA) = cE(A) \tag{13}$$

$$E(A+B) = E(A) + E(B) \tag{14}$$

Using IVFs gives the model these advantages: (1) it increases the ability of experts and DMs to express more uncertain elements. In other words, it makes the model practical under conditions that uncertainty is so high that classical fuzzy sets have less effectiveness. (2) it increases the flexibility of experts and DMs in expressing the membership degree of uncertain elements, since it is expressed in an interval instead of a crisp value. (3) it gives the model more flexibility and accuracy in calculations.

Eventually, it is worth noting that appling IVFSs instead of classical fuzzy sets has been widely considered in practical decision problems. For instance, Chen et al. [7] applied IVFSs in the construction minerals industry for sustainable development. Cai et al. [3] used IVFSs in robust programming for municipal waste management planning. Mohagheghi et al. [36] applied IVFSs in project evaluation and in porfolio selection. Rashid et al. [40] used these sets in robot selection problem. Lu et al. [31] applied the sets in water resources management.

3. Proposed Approach for Sustainable Project Portfolio Selection

The Brundtland Commissions report described sustainable development as the development that satisfies the needs of the present without endangering the ability of future generations to satisfy their own needs [43]. Almost ten years later the Triple Bottom Line was developed which suggested that the societies and environments in which business operations were taking place were inseparable from achieving the business goals [15]. Adopting the concept of sustainability to the business level could result in defining sustainability as satisfying the needs of an organizations direct and indirect stakeholders without endangering its capability to satisfy the needs of future stakeholders [12]. Therefore, the objective of the business is to develop value and synergies among the economic, social and ecological aspects of corporate performance where the business emphasizes not only on the customers but also on all of the interested parties [32]. Moreover, fundamental strategic changes have undeniable impacts on the project selection and organizational structure. Successful project portfolio management and effective strategy implementation highly depend on firms' structural alignment with the necessities of the project portfolio management [25].

In order to have a comprehensive and effective selection method of the project portfolio not only three pillars of sustainability should be considered but also additional criteria, such as non-financial benefits, organizational readiness and strategic alignment, should also be properly addressed. Another area that requires sophisticated considerations is risk. Risk should be taken into account in every financial decision-making process (e.g. [37, 38]). In the proposed model, risk is addressed from three different perspectives. Risk of return is measured by semi-variance which is a downside risk measure. Project risk, including risks such as project failure, technical failure, and losing customers, is also considered in the proposed model by a separate criterion. Finally, risk of uncertainty is considered and also controlled by proposing a novel flexible risk reduction decision-making model. In Table 1, a brief description of the considered criteria in the proposed model is presented. The criteria are obtained based on careful review of the literature (e.g. [17, 33, 48]).

Criteria	Illustrations
Return on investment	Expected financial return
Risk of return	Risk associated with financial benefits
Social effect	Direct positive social impact
Environmental effect	Direct positive environmental impact
Strategic alignment	Alignment of goals with organizational strategies
Organizational readiness	Knowledge and expertise in project implementation
Non-financial benefits	Benefits achieved by project implementation
Project risk	Risks that directly threatens goals of a project

Table 1. Considered Criteria in Proposed Model of Sustainable Project Portfolio Selection

For further illustration, a conceptual framework of the proposed method is displayed in figure 2. As it can be seen in the aforementioned framework, the selection criteria are divided into two main sub-groups. Return on investment and risk of return are labeled as strategic financial criteria because they have direct financial impacts on project portfolio. The remaining criteria are assigned to non-financial strategic group because of their strategic impacts and the fact that they might not have the direct and immediate financial impacts of the first group. In order to find an optimal project portfolio, the candidate projects should be evaluated against all of these criteria. Therefore, the proposed MODM model is divided in two main models. As presented in the framework, in the first model, a financial analysis of the proposed projects under an IVF-environment is carried out, and the first objective function is yielded. In order to do this financial analysis, first, financial data of the projects, like cash flow in different periods, should be gathered. Then, IVF-NPV is computed. The results are used to find the return index. To address financial risk, semi-variance under an IVF-environment is calculated. This step is displayed in the framework as calculating the risk index. Consequently, the IVF-risk/return composite index is yielded. This index is employed to form the first project portfolio selection model. In this model, financial constraints and limitations should be properly regarded. Some of these constraints and limitations mentioned in the introduced model include the minimum and the maximum amount of total investment, geographical distribution of investment and time perspective of the investment.

The second group of the criteria, as depicted in the framework, are addressed by a different approach. A novel risk reduction compromise ratio model is presented to evaluate each candidate project against the second group of criteria. First, the judgments of the experts are gathered and the decision matrix is formed. Then, the matrix is normalized. As it is presented in the framework, the matrix is weighted and the resulting matrix is used to solve the risk reduction model. The model is solved for each alternative. Then, the quantitative utility of each function is computed. The results are given to each candidate project. Finally, these scores are used to form the second objective function of the model. In the second model, the interrelationship of projects is considered in the constraints. Eventually, the proposed models should be aggregated to select an optimal sustainable portfolio of projects. The concept of utility function is used to aggregate these two models. As presented in the framework, the final objective function is formed. The limitations and constraints are added to the model and eventually, the model is solved. In the final MODM model, in order to increase the control of the DM over the criteria and increase the flexibility of the model, a weight is given to each group of criteria by the DM.

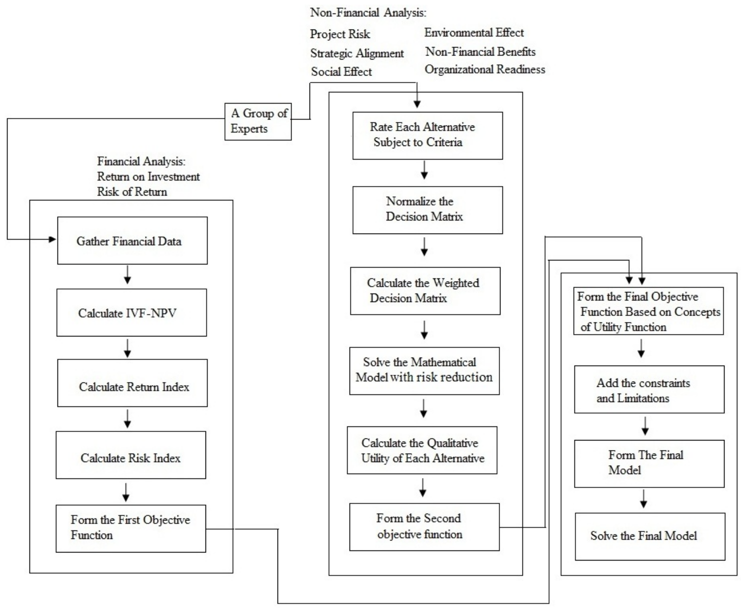

FIGURE 2. Conceptual Framework of the Proposed MODM Approach

3.1. **Financial Analysis.** In order to address the first two criteria of Table 1, a novel risk-return composite index based on the classic model presented by Zhang et al. [53] is introduced. This novel index considers risk and return simultaneously and also calculates the risk of unit return of project. The aforementioned index is used to evaluate and rank the proposed projects. Investment, net cash flow and net present value of projects are described by IVFNs to provide the DM with more flexibility in describing and calculating uncertainty.

In order to present the proposed return index, expected valued of net present value (NPV) under IVF-environment should be calculated. To calculate IVF-NPV, net cash flow at the end of the year (NCF_t) and investment capital (I) of each project under an IVF-environment are needed. IVF-NPV is calculated as follows:

$$NCF_t = [(ncf_{t1}^U, ncf_{t1}^L), ncf_2, (ncf_{t3}^L, ncf_{t3}^U)] \tag{15}$$

$$I = [(i_1^U, i_1^L), i_2, (i_3^L, i_3^U)] \tag{16}$$

$$\begin{aligned} NPV = & \sum_{t=1}^{T} \frac{NCF_t}{(1+\bar{r})^t} - [(i_1^U, i_1^L), i_2, (i_3^L, i_3^U)]) \\ = & \Big[\Big(\Big(\sum_{t=1}^{T} \frac{NCF_{t1}^U}{(1+\bar{r})^t} - i_3^U\Big), \Big(\sum_{t=1}^{T} \frac{NCF_{t1}^L}{(1+\bar{r})^t} - i_3^L\Big)\Big), \Big(\sum_{t=1}^{T} \frac{NCF_2}{(1+\bar{r})^t} - i_2\Big), \\ & \Big(\Big(\sum_{t=1}^{T} \frac{NCF_{t3}^L}{(1+\bar{r})^t} - i_1^L\Big), \Big(\sum_{t=1}^{T} \frac{NCF_{t3}^U}{(1+\bar{r})^t} - i_1^U\Big)\Big)\Big] \end{aligned} \tag{17}$$

It should be noted that in the above equations, $\bar{r}$ represents interest rate. Based on the calculations of the IVF concepts presented in section 2, expected value of NPV is obtained as follows:

$$E(NPV) = \Bigg(\Bigg(\sum_{t=1}^{T} \frac{NCF_2}{(1+\bar{r})^t} - i_2 \Bigg) + \frac{\Big(\sum_{t=1}^{T} \frac{NCF_{t3}^L}{(1+\bar{r})^t} - i_1^L \Big) - \Big(\sum_{t=1}^{T} \frac{NCF_{t1}^L}{(1+\bar{r})^t} - i_3^L \Big)}{12} + \frac{\Big(\sum_{t=1}^{T} \frac{NCF_{t3}^U}{(1+\bar{r})^t} - i_1^U \Big) - \Big(\sum_{t=1}^{T} \frac{NCF_{t1}^U}{(1+\bar{r})^t} - i_3^U \Big)}{12} \Bigg) \tag{18}$$

$E(NPV)$ represents a measure of projects future profit; therefore, if it results in negative values, it indicates that the project is not expected to be profitable and consequently the project would be rejected. This approach results in giving the projects with higher $E(NPV)$ a higher priority.

The return index (RI) of an investment project under an IVF-environment based on the aforementioned equations is presented in the following. It should be noted that h denotes the capital recovery factor.

$$h = (\frac{P}{A}, \bar{r}, T) = \frac{\bar{r}}{(1-(1+\bar{r})^{-T})} \tag{19}$$

$$I = E(NPV) \times h \\ \Bigg(\Bigg(\sum_{t=1}^{T} \frac{NCF_2}{(1+\bar{r})^t} - i_2 \Bigg) + \frac{\Big(\sum_{t=1}^{T} \frac{NCF_{t3}^L}{(1+\bar{r})^t} - i_1^L \Big) - \Big(\sum_{t=1}^{T} \frac{NCF_{t1}^L}{(1+\bar{r})^t} - i_3^L \Big)}{12} + \frac{\Big(\sum_{t=1}^{T} \frac{NCF_{t3}^U}{(1+\bar{r})^t} - i_1^U \Big) - \Big(\sum_{t=1}^{T} \frac{NCF_{t1}^U}{(1+\bar{r})^t} - i_3^U \Big)}{12} \Bigg) \times \frac{\bar{r}}{(1-(1+\bar{r})^{-T})} \tag{20}$$

RI examines the viability of projects and its results are not different from the NPV method. Moreover, it could be employed among projects with equal investment capitals to rank them according to the highest return rate. It is clear that as the projects return increases, RI follows the same pattern [53].

Individual application of the return index results in ignoring risk. Therefore, introducing a risk index is inevitable. In this model, a risk index based on semi-variance is introduced. Semi-variance is known as one of the most efficient downside risk measures which is a direct, clear and straightforward risk measure [21]. Semi-variance unlike variance only considers negative deviations from the expected value. In other words, variance treats negative and positive variations equally which in case of analyzing risk of return on investment results in treating incomes lower and higher than the average income with the same policy which is limiting them. On the other hand, lower semi-variance approach only considers the negative variations from the expected value. In this paper, the concept of lower semi-variance is extended to measure project risk under an IVF uncertainty. Lower semi variance is calculated as follows:

$$LSV(FNPV) = E[(NPV - E(NPV))^{-}]^2 \tag{21}$$

where

$$[(NPV - E(NPV))^{-}]^2 = \begin{cases} (NPV - E(NPV))^2, & NPV \le E(NPV), \\ 0, & NPV \ge E(NPV) \end{cases} \tag{22}$$

The novel risk index under an IVF-environment is obtained as follows. It should also be noted that in the following equations $LSV(NPV)$ denotes lower semi-variance of expected IVF-NPV of project and h denotes the capital recovery factor.

$$LSVI = LSV(NPV)h^2 \tag{23}$$

$$LSVI = E[(NPV - E(NPV))^{-}]^2 \times \bar{r}/(1-(1+\bar{r})^{-T})^2 \tag{24}$$

$LSVI$ can determine the risk of projects, and it could be applied to find the project with lowest risk among projects with equal investment capitals. Lower values of LSVI indicate lower risk. In order to introduce a composite risk-return project evaluation index that is not influenced by life time and investment capitals of projects, the new modern $LSVI/RI$ index is proposed:

$$\begin{aligned} &LSVI/RI \\ &= E[(NPV - E(NPV))^{-}]^2 \times \bar{r}/(1-(1+\bar{r})^{-T})^2/ \\ &\left(\left(\sum_{t=1}^{T} \frac{NCF_2}{(1+\bar{r})^t} - i_2\right) + \frac{\left(\sum_{t=1}^{T} / \frac{NCF_{t3}^L}{(1+\bar{r})^t} - i_1^L\right) - \left(\sum_{t=1}^{T} \frac{NCF_{t1}^L}{(1+\bar{r})^t} - i_3^L\right)}{12}\right. \\ &\left. + \frac{\left(\sum_{t=1}^{T} \frac{NCF_{t3}^U}{(1+\bar{r})^t} - i_1^U\right) - \left(\sum_{t=1}^{T} \frac{NCF_{t1}^U}{(1+\bar{r})^t} - i_3^U\right)}{12}\right) \\ &\times \frac{\bar{r}}{(1-(1+\bar{r})^{-T})} \end{aligned} \tag{25}$$

It is obvious that projects with minimum rate of $LSVI/RI$ are more favorable. Therefore, the following project portfolio selection model based on the composite risk-return index is proposed:

$$\begin{aligned} z_1 = \min \sum_{i=1}^{m} x_i \times &\left(E[(NPV - E(NPV))^{-}]^2 \times ((\bar{r})/((1-(1+\bar{r})^{-T}))^2\right)_i \\ \times &\left(\left(\left(\sum_{t=1}^{T} \frac{NCF_2}{(1+\bar{r})^t} - i_2\right) + \frac{\left(\sum_{t=1}^{T} / \frac{NCF_{t3}^L}{(1+\bar{r})^t} - i_1^L\right) - \left(\sum_{t=1}^{T} \frac{NCF_{t1}^L}{(1+\bar{r})^t} - i_3^L\right)}{12} \right.\right. \\ &\left.\left. + \frac{\left(\sum_{t=1}^{T} \frac{NCF_{t3}^U}{(1+\bar{r})^t} - i_1^U\right) - \left(\sum_{t=1}^{T} \frac{NCF_{t1}^U}{(1+\bar{r})^t} - i_3^U\right)}{12}\right) \times \frac{\bar{r}}{(1-(1+\bar{r})^{-T})} \right)_i^{-1} \end{aligned} \tag{26}$$

Subject to:

$$Q_1 \leq \sum_{i=1}^{N} x_i.[(i_{i1}^U, i_{i1}^L), i_i2, (i_{i3}^L, i_{i3}^U)] \leq Q_2 \tag{27}$$

$$\sum_{i \in short-term} x_i[(i_{i1}^U, i_{i1}^L), i_i2, (i_{i3}^L, i_{i3}^U)] \leq \varphi_1 \sum_{i=1}^{N} x_i.[(i_{i1}^U, i_{i1}^L), i_i2, (i_{i3}^L, i_{i3}^U)] \tag{28}$$

$$\sum_{i \in mid-term} x_i[(i_{i1}^U, i_{i1}^L), i_i2, (i_{i3}^L, i_{i3}^U)] \leq \varphi_2 \sum_{i=1}^{N} x_i.[(i_{i1}^U, i_{i1}^L), i_i2, (i_{i3}^L, i_{i3}^U)] \tag{29}$$

$$\sum_{i \in mid-term} x_i[(i_{i1}^U, i_{i1}^L), i_i2, (i_{i3}^L, i_{i3}^U)] \leq \varphi_3 \sum_{i=1}^{N} x_i.[(i_{i1}^U, i_{i1}^L), i_i2, (i_{i3}^L, i_{i3}^U)] \tag{30}$$

$$\varphi_1 + \varphi_2 + \varphi_3 = 1 \tag{31}$$

where Q_1 and Q_2 are the minimum and the maximum acceptable amount of investment, respectively. In this model, the objective is to minimize the values of lower semi-variance (risk measure) over each unit of expected return (profit measure). Therefore, the objective function finds a portfolio of projects that minimizes the risk and maximizes the expected return. Equations (28), (29), (30) and (31) could be used to balance the investment in different time horizons. φ_i denotes the percentage of each group. Equation (28) limits the amount of short term investments to the stated value of φ_1. Similarly, equations (29) and (30) limit the investment values to stated values of φ_2 and φ_2 for mid-term and long-term investments, respectively. In fact, the strategic goals could also be considered in the proposed model. The following constraints could be added to address the desired geographical distribution of the selected projects.

$$\sum_{i \in \text{Location}A} x_i[(i_{i1}^U, i_{i1}^L), i_i2, (i_{i3}^L, i_{i3}^U)] \leq \varphi_3 \sum_{i=1}^{N} x_i[(i_{i1}^U, i_{i1}^L), i_i2, (i_{i3}^L, i_{i3}^U)] \tag{32}$$

$$\sum_{i \in \text{Location}B} x_i \geq \varphi \sum_{i=1}^{N} x_i \tag{33}$$

Equation (32) dictates that at most φ percent of the allocated budget should get to location A and equation (33) dictates that at least φ percent of the selected projects should be located in location B. These two equations are placed so that the DMs can model their preferred geographical distribution of investments.

3.2. **Proposed IVF-risk Reduction Compromise Ratio Model.** In this section, a new risk reduction compromise ratio model based on IVFs and FOU is proposed to address the impacts of the remaining criteria in sustainable project portfolio selection process. These criteria consist of social effect, environmental effect, strategic alignment, organizational readiness, non-financial benefits and project risk. In the proposed model, the DM is able to set a maximum degree of uncertainty in the decision-making process to control the risk of uncertainty. Moreover, linguistic variables are converted into triangular-IVFNs to address criteria values and criteria weights. These converted values are presented in Table 2 and Table 3.

Linguistic variables	Interval valued fuzzy numbers
Very Poor (VP)	[(0.00, 0.00, 1.00), (0.00, 0.00, 1.50)]
Poor (P)	[(0.50, 1.00, 2.50), (0.00, 1.00, 3.50)]
Moderately Poor (MP)	[(1.50, 3.00, 4.50), (0.00, 3.00, 5.50)]
Fair (F)	[(3.50, 5.00, 6.50), (2.50, 5.00, 7.50)]
Moderately Good (MG)	[(5.50, 7.00, 8.00), (4.50, 7.00, 9.50)]
Good (G)	[(7.50, 9.00, 9.50), (5.50, 9.00, 10.00)]
Very Good (VG)	[(9.50, 10.00, 10.00), (8.50, 10.00, 10.00)]

Table 2. Linguistic Variables Applied to Determine Importance of Criteria

Linguistic variables	Interval valued fuzzy numbers
Very low (VL)	[(0.00, 0.00, 0.10), (0.00, 0.00, 0.15)]
Low (L)	[(0.05, 0.10, 0.25), (0.00, 0.10, 0.35)]
Medium low (ML)	[(0.15, 0.30, 0.45), (0.00, 0.30, 0.55)]
Medium (M)	[(0.35, 0.50, 0.65), (0.25, 0.50, 0.75)]
Medium high (MH)	[(0.55, 0.70, 0.80), (0.45, 0.70, 0.95)]
High (H)	[(0.75, 0.90, 0.95), (0.55, 0.90, 1.00)]
Very high (VH)	[(0.95, 1.00, 1.00), (0.85, 1.00, 1.00)]

Table 3. Linguistic Variables Applied in the Ratings

Using IVFN gives the DM more flexibility in expressing lack of knowledge and vagueness. Unlike the conventional fuzzy methods, DM is not forced to express membership degrees by an exact number in interval [0, 1]. This novel method is introduced by the following algorithm:

I. Develop the initial IVF-decision matrix and the initial IVF-weight matrix as:

$$\tilde{D} = \begin{bmatrix} \tilde{D}_{11} & \dots & \tilde{D}_{1m} \\ \vdots & \ddots & \vdots \\ \tilde{D}_{n1} & \dots & \tilde{D}_{nm} \end{bmatrix} \tag{34}$$

$$\tilde{w} = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_j, \dots, \tilde{w}_m) \tag{35}$$

where $\tilde{D}_{ij}$ is the performance value of ith alternative on jth criterion, m is the number of criteria and n is the number of alternatives compared. $\tilde{w}_j$ is the weight vector of the criteria. It should also be noted that since $\tilde{d}_{ij}$ and $\tilde{w}_j$ are IVFNs they are denoted as follows:

$$\tilde{D}_{ij} = \left[\left((\tilde{d}_{ij})_1^U, (\tilde{d}_{ij})_1^L\right), (\tilde{d}_{ij})_2, \left((\tilde{d}_{ij})_3^L, (\tilde{d}_{ij})_3^U\right)\right] \tag{36}$$

$$\tilde{w}_j = \left[\left((\tilde{w}_j)_1^U, (\tilde{w}_j)_1^L\right), (\tilde{w}_j)_2, \left((\tilde{w}_j)_3^L, (\tilde{w}_j)_3^U\right)\right] \tag{37}$$

II. Develop the normalized IVF-decision matrix ($\tilde{F}$) using equations (39) and (40). In order to make different criteria comparable, normalization process is implemented. In other words, normalization makes dimensionless values of different criteria.

$$\tilde{F} = \begin{bmatrix} \tilde{F}_{11} & \dots & \tilde{F}_{1m} \\ \vdots & \ddots & \vdots \\ \tilde{F}_{n1} & \dots & \tilde{F}_{nm} \end{bmatrix} \tag{38}$$

$$\tilde{F}_{ij} = \left[\left(\left(\frac{{d_{ij}}_1^U}{d*}\right), \left(\frac{{d_{ij}}_1^U}{d*}\right)\right), \left(\frac{{d_{ij}}_2}{d*}\right), \left(\left(\frac{{d_{ij}}_3^L}{d*}\right), \left(\frac{{d_{ij}}_3^U}{d*}\right)\right)\right] \tag{39}$$

$$i = 1, 2, \dots, n, \quad j \in \varrho_B$$

$$\tilde{F}_{ij} = \left[\left(\left(\frac{d^-}{{d_{ij}}_3^U}\right), \left(\frac{d^-}{{d_{ij}}_3^L}\right)\right), \left(\frac{d^-}{{d_{ij}}_2}\right), \left(\left(\frac{d^-}{{d_{ij}}_1^L}\right), \left(\frac{d^-}{{d_{ij}}_3^U}\right)\right)\right] \tag{40}$$

$$i = 1, 2, \dots, n, \quad j \in \varrho_C$$

where ϱ_B denotes the set of benefit criteria and ϱ_C represents the set of cost criteria. d^* and d^- are also obtained as follows:

$$d^* = \max_i \, (d_{ij})_3^U \tag{41}$$

$$d^- = \min_i \, (d_{ij})_1^U \tag{42}$$

III. Develop the normalized weighted IVF-decision matrix by employing equation (44).

$$\tilde{G} = \begin{bmatrix} \tilde{G}_{11} & \dots & \tilde{G}_{1m} \\ \vdots & \ddots & \vdots \\ \tilde{G}_{n1} & \dots & \tilde{G}_{nm} \end{bmatrix} \tag{43}$$

$$\begin{aligned} \tilde{G}_{ij} =& \tilde{F}_{ij} \times \tilde{w}_j \\ =& \Big[((\tilde{d}_{ij})_1^U \times (\tilde{w}_j)_1^U, (\tilde{d}_{ij})_1^L \times (\tilde{w}_j)_1^L), (\tilde{d}_{ij})_2 \\ & \times (w_j)_{2'}, ((\tilde{d}_{ij})_3^L (\tilde{w}_j)_3^L \times, (\tilde{d}_{ij})_3^U \times (\tilde{w}_j)_3^U)\Big] \end{aligned} \tag{44}$$

IV. Solve the following mathematical model for each alternative.

$$\tilde{H}_i = \max\left(\tilde{S}_{\varrho B^i} + \frac{\min \tilde{S}_{\varrho C^i} \times \sum_{i=1}^n \tilde{S}_{\varrho C^i}}{\tilde{S}_{\varrho C^i} \times \sum_{i=1}^n \min \tilde{S}_{\varrho C^i} / \tilde{S}_{\varrho C^i}}\right) \tag{45}$$

Subject to:

$$\tilde{S}_{\varrho B^i} = \sum_{j \in \varrho_C} \sqrt{\frac{1}{3}((g_{ij})_1^2 + (g_{ij})_2^2 + (g_{ij})_3^2)} \tag{46}$$

$$\tilde{S}_{\varrho B^i} = \sum_{j \in \varrho_C} \sqrt{\frac{1}{3}((g_{ij})_1^2 + (g_{ij})_2^2 + (g_{ij})_3^2)} \tag{47}$$

$$\tilde{G}_{ij} = ((g_{ij})_1 + (g_{ij})_2 + (g_{ij})_3) \tag{48}$$

$$(g_{ij})_1^U \leq (g_{ij})_1 \leq (g_{ij})_1^L, \quad j = 1, \dots, m, \quad i = 1, \dots, n. \tag{49}$$

$$(g_{ij})_2^L = (g_{ij})_1^L = (g_{ij})_2^U), \quad j = 1, \dots, m, \quad i = 1, \dots, n. \tag{50}$$

$$(g_{ij})_3^L \leq (g_{ij})_3 \leq (g_{ij})_3^U), \quad j = 1, \dots, m, \quad i = 1, \dots, n. \tag{51}$$

$$\left[\frac{(g_{ij})_3 + (g_{ij})_1^L) - ((g_{ij})_1 + (g_{ij})_3^L)}{(g_{ij})_3^U + (g_{ij})_1^L) - ((g_{ij})_1^U + (g_{ij})_3^L)} \right] \leq \varepsilon \tag{52}$$

$$(v_{ij})_k \geq 0, \quad j = 1, \dots, m, \quad K = 1, 2, 3 \tag{53}$$

Equation (45), as the objective function of this model, is aimed at maximizing the priority of each alternative. Equations (46) and (47) are denoted to compute the distance of each judgment and also the max and min operators are based on the distance method used in them. In this step, based on the concept of FOU, the IVFNs are converted to conventional fuzzy numbers. These new fuzzy numbers are made in the limits of the initial IVFNs by equations (49), (50) and (51). equation (49) sets the first value of type-1 fuzzy number in the limits of the first lower and upper values of the initial IVFN. Equation (50) puts the second value of type-1 fuzzy number in the limits of the second lower and upper values of the initial IVFN, and eventually, eqution (51) sets the third value of type-1 fuzzy number in the limits of the third lower and upper values of the initial IVFN. ε denotes the maximum amount of acceptable uncertainty. This amount is imposed on the mathematical problem by equation (52).

V. Calculate the quantitative utility (U) for each alternative. The degree of each alternatives utility is directly related to its obtained H value. The degree of an alternatives utility, leading to a complete ranking of the candidate alternatives, is determined by comparing the priorities of all the alternatives with the most efficient one and can be denoted as below:

$$U_i = [\frac{H_i}{H_{\max}}] \times 100\% \tag{54}$$

At the end of this algorithm, each alternative is given a score which is presented by U_i. This score shows the desirability of each alternative considering its benefit and cost criteria. These scores are used in the second model. This model aims at creating a portfolio of projects that suits all the remaining criteria in the best way possible. The second model is presented as follows:

$$Z_2 = \max \sum_{i=1}^{m} x_i U_i \tag{55}$$

Subject to:

$$x_i = \begin{cases} 0 & \text{if project i is rejected} \\ 1 & \text{if project i is selected} \end{cases} \tag{56}$$

$$x_i = x_i^{'} \qquad \text{for } i = 1, 2, \dots, n; \quad (i, i^{'}) \in J \tag{57}$$

$$x_i \neq x_i^{''} \qquad \text{for } i = 1, 2, \dots, n; \quad (i, i^{'}) \in K \tag{58}$$

$$x_i = 1 \quad \text{for } i = 1, 2, \ldots, n; \quad \forall i \in L \tag{59}$$

where equation (55) is aimed at finding a portfolio of projects that maximizes the objectives related to the second group of criteria. Equation (56) shows the binary nature of decision variable; Thus, if a project is selected, it will be equal to 1 and otherwise 0. Equations (57), (58) and (59) can be added to the model to provide it with more real-world application capability. Equation (57) expresses the interdependency relationship between project pairs; in other words, it indicates that the projects should be included or excluded together. An example of this sort of constraint is in projects with proceeding constraints. Equation (58) indicates the mutual exclusiveness relationship of projects. Therefore, it allows only one of the projects to be in the final portfolio. An example of this sort of constraint in reality is when the organization is not willing to work on more than one research and development (R&D) project simultaneously. Equation (59) makes inclusion of a certain project in the portfolio compulsory. An example of this constraint is in maintenance projects where there is not a high rate of return on investment and the project is likely to be rejected; but, rejection could result in potential negative impacts on the cash flow of portfolio. Thus, based on the policy of the organization, the project must be selected. J, K and L denote the different groups that each project would belong to.

3.3. **Employing Global Criterion Method to Develop the Final MODM Model.** In a MODM problem, method of global criterion uses the objective function in equation (60) to solve the problem [23]. It should be noted that the first objective is of the type minimization and the second is of the type maximization. Equation (60) is applied to obtain the final objective function of the model. The resulting objective function is presented in equation (61).

$$\min \mathit{Utility}_P = ((Z_1 - Z_1^*)/Z_1^*)^P + ((Z_2^* - Z_2)/Z_2^*)^P \tag{60}$$

$$\begin{aligned} \min Z_{utility} = & w_1 \left(\frac{((\sum_{i=1}^{m} LSVI_i/RI_i)x_i - z_1^*)}{z_1^*} \right) \\ & + w_2 \left(\frac{(z_2^* - \sum_{i=1}^{m} x_i U_i)}{z_2^*} \right) \end{aligned} \tag{61}$$

Subject to:

$$w_1 + w_2 = 1 \tag{62}$$

In the proposed model in order to provide the DM with more flexibility and control over the selection criteria, an special form of utility function that uses the weights (w_r) to address the importance of each objective is employed. This is expressed by equation (62) in the model.

Before solving the MODM, an utility function based on the DMs preferences is needed. The main advantage of the applied method, in addition to its simplicity, is ensuring the most satisfactory solution if the function has been correctly evaluated and applied. The general form considers DMs utility function additively separable while considering the objectives [16].

4. **Model Application**

In this section, to show the validation and applicability of the proposed approach, first each part of the proposed approach is used to solve an existing similar problem in the literature and the results are displayed. Secondly, the approach is used in a real case study of a holding company and the results are presented and discussed.

4.1. **Comparing the Approach with Existing Methods.** Since each part of the approach requires specific input data and the approach, to the best of our knowledge, is different from the existing methods, for each part of the model, after careful review of the existing literature, an existing problem is selected. The model is used to solve them, and the results are displayed and compared with the methods existing in the literature.

To compare the first step of the approach with the existing literature, after careful review, an application example from the proposed method of Zhang et al. [53] is taken and solved in this part. Table 4 displays the condition of projects. Tables 5 and 6 displays the results of the existing method and the proposed approach. As it can be observed, the results are similar. The proposed approach in comparison with the existing method, not only improves the value of objective function, but also gives more flexibility in expressing and computing uncertainty. The proposed approach has significant advantages over existing methods under conditions with high uncertainty.

Projects Years	A	B	C	D	E
1	(43,47)	(30,33)	(30,34)	(30,35)	(40,43)
2	(43,47)	(40,44)	(40,44)	(30,35)	(40,44)
3	(50,55)	(40,44)	(50,55)	(30,35)	(50,54)
4	(60,66)	(30,33)	(50,55)	(50,56)	(50,54)
5	(60,66)	(30,33)	–	(50,56)	(60,66)
6	(70,78)	(30,33)	–	(40,45)	(60,66)
7	(50,55)	–	–	(40,45)	(50,55)
8	(40,44)	–	–	–	–
Capital investment	(200,235)	(100,120)	(80,100)	(120,150)	(150,180)
Lifetime	8	6	4	7	7

Table 4. Uncertain Investment Capital and Cash Flow of Projects (m$) [53]

To compare the second part of the proposed approach with the existing literature, the existing application example provided for the decision method of Ashtiani et al. [1] is used. Table 7 displays the results of the existing method and the introduced approach. Since the proposed approach offers the DM a tool to express the highest level of acceptable uncertainty, this model has more flexibility and reliability in real-world problems.

Objective function	Investment capital (m$)	A	B	C	D	E
0.79	200-300	0	1	0	0	1
0.82	300-400	0	1	1	0	1
0.93	400-500	0	1	1	1	1

Table 5. Results of the Existing Method by Zhang et al. [53]

Objective function	Investment capital (m$)	A	B	C	D	E
0.09	200-300	0	1	0	0	1
0.12	300-400	0	1	1	0	1
0.17	400-500	0	1	1	1	1

Table 6. Results of the Proposed Method

Alternatives	Existing method by Ashtiani et al.[1]		Proposed method	
	Score	Rank	Score	Rank
1	0.673	2	86	2
2	0.664	3	70	3
3	0.683	1	100	1
4	0.583	4	69	4

Table 7. The Results of the Existing Method by Ashtiani et al. [1] and the Proposed Method

4.2. **Case Study in Developing Countries.** Based on surveys, companies that employ formal project selection methods in comparison with companies that do not apply formal project selection techniques achieve better project launch success. Significantly, better profit objectives are also achieved through structured selection methods [10]. Therefore, the proposed MODM approach has been applied for sustainable project portfolio selection of an Iranian holding company. The primary priority of this company is to create value for its shareholders through sustainable development. Therefore, they invest in major strategic sectors with huge growth potential. These sectors include petrochemicals, oil refinery, non-metal minerals, construction and civil, cement production, transportation and food. Another objective of this company is to improve its level of efficiency and efficacy through R&D projects. The company aims to expand its presence in local, regional and international markets through developing a competitive edge over others. Therefore, the company has reserved the information of candidate projects as confidential. Due to confidentiality of the information, limited details of the projects are illustrated in this section.

The company is presented with five independent project proposals with different investment capitals, lifetimes and future cash flows. These projects are geographically distributed in different provinces of Iran. Table 4 presents some characteristics of the aforementioned projects. In order to apply a more flexible tool to address uncertainty, annual net cash flow and investment capitals of projects are expressed by the IVFNs. In figure 3 map of Iran is presented for the purpose of illustration, and the locations of the provinces mentioned are highlighted in Table 8. Moreover, the knowledge and experiences of experts are used to distinguish the relative importance of the proposed criteria of sustainable project portfolio selection. Questionnaires were used to gather data from professional experts of the aforementioned company. These 4 experts had at least 15 years of experience in financial project management. In real problem cases, data gathering in this mixed approach provides more flexibility in analyzing the required information.

Projects	Sector	Type	Province	Investment Capitals (million $)
A	Petrochemical	R&D	Bushehr	[250,20,18;250,29,28]
B	Civil	Construction	Tehran	[10,2,3;10,4,5]
C	Food	Investment	Ardebil	[60,5,8;60,10,11]
D	Cement	NPD	Markazi	[25,3,4;25,7,7]
E	Marine Transportation	Maintenance	Hormozgan	[30,4,4;30,6,8]

Table 8. Projects Characteristics in the Studied Case

Figure 3. Map of Iran Provinces

4.3. **Financial Analysis.** As presented in the previous section, in the first part of the proposed approach a financial analysis is carried out to evaluate net present value of each project while addressing the involved risk. Net cash flow of each project at the end of each year is presented in Tables 9 and 10. These values are based on the values presented in the project proposals and are adapted to IVFNs. The interest rate is assumed as 5%.

Years	1	2
A	[50,5,6;50,9,10]	[65,2,2;65,5,5]
B	[3,0.5,0.5,1,1]	[5,0.5,0.5;5,1,1]
C	[15,3,3;15,5,6]	[25,5,5;25,7,8]
D	[7,2,2;7,4,4]	[10,2,2;10,5,5]
E	[8,1,1;8,3,3]	[8,1,1;8,3,3]

Table 9. Net Cash Flows of Projects (Million $)

Years	3	4	5
A	[70,4,6;70,8,9]]	[75,5,5;75,8,9]	[85,6,7;85,10,11]
B	[6,1,1;6,1.5,1.5]	-	-
C	[35,4,6;35,7,8]	-	-
D	[12,3,3;12,5,6]	-	-
E	[8,2,2;8,4,4]	[8,3,3;8,5,5]	-

Table 10. Net Cash Flows of Projects (Million $)

Net present value, return index and risk index of each project is calculated and presented in Table 11. For the purpose of illustration, calculations of E(NPV), RI, LSVI and LSVIRI for project B, are presented as follows:

$$\begin{aligned} NCF =& \left[\frac{2}{(1+0.05)^1}, \frac{2.5}{(1+0.05)^1}, \frac{3}{(1+0.05)^1}, \frac{3.5}{(1+0.05)^1}, \frac{4}{(1+0.05)^1}\right] \\ &+ \left[\frac{4}{(1+0.05)^2}, \frac{4.5}{(1+0.05)^1 2}, \frac{5}{(1+0.05)^2}, \frac{5.5}{(1+0.05)^2}, \frac{6}{(1+0.05)^2}\right] \\ &+ \left[\frac{4.5}{(1+0.05)^3}, \frac{5}{(1+0.05)^3}, \frac{6}{(1+0.05)^3}, \frac{7}{(1+0.05)^3}, \frac{7.5}{(1+0.05)^3}\right] \\ =&[9.4, 10.8, 12.5, 14.4, 15.7] \end{aligned} \tag{63}$$

$$\begin{aligned} NPV &= [9.4, 10.8, 12.5, 14.4, 15.7] - [6, 8, 10, 13, 15] \\ &= [-5.5, -2.2, 2.5, 6.3, 9.7] \end{aligned} \tag{64}$$

$$E(NPV) = [2.5 + \frac{6.3-(-2.2)}{12} + \frac{9.7-(-5.5)}{12}] = 4.5 \tag{65}$$

$$E(NPV) = (4.5) \times \left(\frac{0.05}{(1-(1+0.05)^{-3})}\right) = 1.67 \tag{66}$$

$$\begin{aligned} PV - E(NPV) &= [-5.5, -2.2, 2.5, 6.3, 9.7] - [4.5, 4.5, 4.5, 4.5, 4.5] \\ &= [-10.1, -6.78, -1.9, 1.8, 5.1] \end{aligned} \tag{67}$$

$$LSVI = [-1.9 + \frac{(0-(-6.78))}{12} + \frac{(0-(-10.1))}{12}]^2 \times \frac{0.05}{(1-(1+0.05)^{-3}))^2} = 0.045 \quad (68)$$

$$\frac{LSV}{RI} = \frac{0.045}{1.67} = 0.027 \quad (69)$$

Years	E(NPV)	RI	LSVI	LSVIRI
A	62.7	14.5	2.05	0.14
B	4.6	1.7	0.04	0.02
C	15	5.5	0.94	0.17
D	6	2.2	0.37	0.16
E	3.4	0.9	0.2	0.21

Table 11. Net Cash Flows of Projects (Million \$)

4.4. **Non-financial Evaluation.** In the second part of the approach, non-financial criteria of the projects are evaluated and at the end of this part each project receives a score that reflects its level of alignment with the non-financial goals of the organization. In order to solve this part of the problem, the four-member team of experts was asked to evaluate each project versus the social effect (C_1), environmental effect (C_2), strategic alignment (C_3), organizational readiness (C_4), non-financial benefits (C_5) and project risk (C_6). It should be noted that the ratings of each alternative considering the criteria C_1, C_2, C_4, C_5 and C_6 are evaluated by IVF-linguistic variables introduced in Table 2. Moreover, the criteria C_1, C_2, C_3, C_4 and C_5 are considered as benefit criteria while the criterion C_6 is considered as cost criterion. In order to avoid interactions in experts evaluations, each one of them assessed the weights of criteria and the values of alternatives with respect to the criteria separately and was not aware of the opinions of the other members. It is important to realize that in this section of the decision-making process, the maximum amount of uncertainty is regarded as 0.5. In addition, the relative importance weights of six criteria are defined using IVF-linguistic variables introduced in Table 3.

Tables 12, 13 and 14 display the original information gathered from the DMs. Fuzzy numbers are aggregated by averaging the IVF-opinions of these four experts. Eqution (70) displays the averaging of the IVF-relative importance weights ($\tilde{W}_j$ when there are k experts and eqution (71) displays the averaging of the IVF-values $\tilde{A}_{ij}$ gathered from the experts. Projects A, B, C, D and E are denoted by A_1, A_2, A_3, A_4 and A_5, respectively.

$$\tilde{W}_j = \Big[\Big(\frac{\sum_{i=1}^{k} w_1^u}{k}, \frac{\sum_{i=1}^{k} w_1^k}{k}\Big), \frac{\sum_{i=1}^{k} w_2}{k}, \Big(\frac{\sum_{i=1}^{k} w_3^l}{k}, \frac{\sum_{i=1}^{k} w_1^u}{k}\Big)\Big] \quad (70)$$

$$\tilde{A}_{ij} = \Big[\Big(\frac{\sum_{i=1}^{k} a_{ij1}^u}{k}, \frac{\sum_{i=1}^{k} a_{ij1}^k}{k}\Big), \frac{\sum_{i=1}^{k} a_{ij2}}{k}, \Big(\frac{\sum_{i=1}^{k} a_{ij3}^l}{k}, \frac{\sum_{i=1}^{k} a_{ij1}^u}{k}\Big)\Big] \quad (71)$$

Normalized IVFNs displayed in Tables 13 and Table 14 are multiplied in $\tilde{W}_j$. The results are used to solve the proposed mathematical model for each alternative. H_i and U_i are finally calculated and the alternatives are ranked. Moreover, each one of them receives a score that can be used to form the second model. In Table 15, the final results of the method are displayed.

Criteria	DM1	DM2	DM3	DM4	Aggregated IVFNs
C1	MH	M	H	MH	[(0.43,0.55),0.7,(0.8,0.91)]
C2	M	ML	MH	H	[(0.31,0.45),0.6,(0.71,0.81)]
C3	VH	H	VH	H	[(0.7,0.85),0.95,(0.98,1)]
C4	H	VH	MH	VH	[(0.68,0.8),0.9,(0.94,0.99)]
C5	ML	MH	M	H	[(0.31,0.45),0.6,(0.71,0.81)]
C6	H	VH	MH	VH	[(0.68,0.8),0.9,(0.94,0.99]

Table 12. The Relative Importance Weights of Criteria

Criteria	Alternatives	DMs			
		DM1	DM2	DM3	DM4
	A_1	F	MG	MP	P
	A_2	MG	G	F	MP
C_1	A_3	VG	G	VG	
	A_4	MG	G	F	MP
	A_5	VP	P	P	MP
	A_1	F	P	MP	VP
	A_2	F	MP	F	MP
C_2	A_3	MG	F	F	G
	A_4	MP	VP	P	F
	A_1	VG	G	VG	MG
	A_2	G	VG	MG	G
C_3	A_3	MG	F	MG	G
	A_4	MG	G	G	F
	A_5	F	MG	F	MP
	A_1	F	MG	MG	G
	A_2	G	MG	VG	G
C_4	A_3	VP	P	P	MP
	A_4	F	G	MG	F
	A_5	MP	MG	F	F
	A_1	P	F	F	MP
	A_2	VP	P	MP	P
C_5	A_3	VG	G	G	
	A_4	MP	MP	P	F
	A_1	G	MG	G	MG
	A_2	VP	P	P	F
C_6	A_3	F	MP	MP	
	A_4	F	P	F	MG
	A_5	F	P	VP	MP

Table 13. The Values of Five Alternatives with Respect to the Six Criteria, and Normalized IVF Ratings

Criteria	Alternatives	Aggregated IVFNs	Normalized IVFNs
	A_1	[(1.75,2.75),4,(5.4,6.5)]	[(0.18,0.28),0.4,(0.54,0.65)]
	A_2	[(3.1,4.5),6,(7.1,8.1)]	[(0.31,0.45),0.6,(0.71,0.81)]
C_1	A_3	[(7,8.5),9.5,(9.75,10)]	[(0.7,0.85),0.95,(0.98,1)]
	A_4	[(3.1,4.5),6,(7.1,8.1)]	[(0.31,0.45),0.6,(0.71,0.81)]
	A_5	[(0,0.6),1.4,(2.3,3.6)]	[(0,0.6),0.12,(0.26,0.35)]
	A_1	[(0.62,1.4),2.25,(3.6,4.5)]	[(0.07,0.15),0.24,(0.4,0.5)]
	A_2	[(1.25,2.5),4,(5.5,6.5)]	[(0.13,0.27),0.43,(0.6,0.7)]
C_2	A_3	[(3.8,5),6.5,(7.6,8.6)]	[(0.4,0.54),0.7,(0.82,0.93)]
	A_4	[(0.62,1.4),2.5, (3.6,4.5)]	[(0.07,0.15),0.24,(0.4,0.5)]
	A_5	[(4.5,6),7.5,(8.4,9.3)]	[(0.5,0.65),0.81,(0.9,1)]
	A_1	[(6.8,8),9,(9.4,9.9)]	[(0.68,0.81),0.91,(0.95,1)]
	A_2	[(6,7.5),8.8,(9.2,9.9)]	[(0.6,0.76),0.89,(0.94,1)]
C_3	A_3	[(4.3,5.5),7,(8,9.1)]	[(0,0.6),0.12,(0.26,0.35)]
	A_4	[(4.5,6),7.5,(8.4,9.2)]	[(0.38,0.5),0.66,(0.77,0.87)]
	A_5	[(2.4,3.5),5,(6.4,7.5)]	[(0.24,0.35),0.5,(0.64,0.76)]
	A_1	[(1.25,2.25),3.5,(5,6)]	[(0.12,0.22),0.35,(0.5,0.6)]
	A_2	[(6,7.5),8.75,(9.25,9.9)]	[(0.6,0.75),0.88,(0.93,1)]
C_4	A_3	[(0,0.63),1.25,(2.62,3.5)]	[(0,0.6),0.12,(0.26,0.35)]
	A_4	[(3.75,5),6.5,(7.62,8.6)]	[(0.38,0.5),0.66,(0.77,0.87)]
	A_5	[(2.4,3.5),5,(6.38,7.5)]	[(0.24,0.35),0.5,(0.64,0.76)]
	A_1	[(5,6.5),8,(8.8,9.8)]	[(0.5,0.65),0.8,(0.88,0.98)]
	A_2	[(0,0.63),1.25,(2.6,3.5)]	[(0,0.06),0.12,(0.26,0.35)]
C_5	A_3	[(7,8.5),9.5,(9.75,10)]	[(0.7,0.85),0.95,(0.98,1)]
	A_4	[(0.63,1.8),3,(4.5,5.5)]	[(0.06,0.18),0.3,(0.45,0.55)]
	A_5	[(6,7.5),8.75,(9.25,9.9)]	[(0.6,0.75),0.88,(0.92,0.99)]
	A_1	[(5,6.5),8,(8.75,9.75)]	[(0.06,0.07),0.08,(0.09,0.12)]
	A_2	[(0.63,1),1.5,(2.75,3.5)]	[(0.18,0.22),0.41,(0.62,1)]
C_6	A_3	[(1.25,2.5),4,(5.5,6.5)]	[(0.1,0.11),0.15,(0.25,0.5)]
	A_4	[(2.38,3.25),4.5,(5.9,7)]	[(0.09,0.1),0.13,(0.2,0.27)]
	A_5	[(0.62,1.38),2.25,(3.6,4.5)]	[(0.14,0.17),0.28,(0.45,1)]

Table 14. The Values of Five Alternatives with Respect to the Six Criteria, and Normalized IVF Ratings

Projects	H_i	U_i	Rank
A	0.34	100	1
B	0.21	62.3	4
C	0.25	74.9	2
D	0.25	74.6	3
E	0.21	62.1	5

TABLE 15. Results of the Proposed MODM Approach

Based on the results displayed in Table 9, the second objective function can be obtained. Eqution (72) shows the objective function:

$$\max(100x_1 + 62.3x_2 + 74.9x_3 + 74.6x_4 + 62.1x_5) \tag{72}$$

4.5. **Final Proposed MODM Model.** Based on the results of sub-sections 4.3 and 4.4, the final objective model is obtained. Other constraints and limitations imposed by the DMs are as follows: The amount of investment should be between 150 million dollars and 300 million dollars. At least one of the selected projects should be located in Ardebil or Markazi. Due to international regulations, the maintenance project in marine transportation must be selected. The organization prefers projects with better financial situation; therefore, the DMs declared values of w_1 and w_2 as 0.7 and 0.3, respectively. The final proposed MODM model is solved using an optimizing solver software and then projects A, B, D and E were selected. Project C had a good score in non-financial criteria; but, the weight imposed on financial criteria by strategic plans of the organization caused the project to be omitted.

4.6. **Sensitivity Analysis.** To display the impacts of giving weight to each group of criteria, different values were given to w_1 and w_2, and the model was solved with them. Making each group of criteria weighted gives the DM the power and ability to evaluate the selected portfolio under different conditions. It can be shown the difference in final results; in case the priority of the firm is on financial or non-financial criteria. Therefore, this analysis gives the DM a comprehensive insight and understanding on the final decision. In this part, only the investment capital limitation was considered in the model. Table 16 displays the results of this analysis.

Situations		A	B	C	D	E	Objective function
1	$w_1 = 0.8$	1	0	0	0	0	0.016
	$w_2 = 0.2$						
2	$w_1 = 0.6$	1	1	0	0	0	0.126
	$w_2 = 0.4$						
3	$w_1 = 0.4$	1	1	0	0	0	0.189
	$w_2 = 0.6$						
4	$w_1 = 0.2$	1	1	0	1	0	0.200
	$w_2 = 0.8$						

TABLE 16. Results of the Proposed MODM Approach

5. Managerial Implication

Implementation of the proposed decision-making approach in real case study of a holding company provides several managerial implications. First, it proposes a new framework that separately addresses financial and non-financial criteria; this approach provides the DM with more flexibility in prioritizing strategic goals. In the studied case, the organization preferred the financial criteria to the non-financial criteria, and this preference is easily expressed in the weight given to criteria in the aggregated model. Second, the proposed approach, in addition to the employed sustainable criteria, applies some other practical criteria in reality, such as organizational readiness, non-financial benefits, strategic alignment and project risk. These criteria are highly practical in the project selection and implementation in developing countries. Past experiences of the organization and the data existing from similar implemented projects provide the sufficient data needed for these criteria. Consequently, the criteria help the organization apply the lesson learned to improve its complex decision-making process. Third, using the IVFSs provide the DMs with more flexibility in expressing uncertainty for computations. In reality, many of the project factors like net cash flow due to an uncertain environment of projects cannot be expressed in crisp values. On the other hand, in complex situations, like today's changing business environment, even using classical fuzzy sets and expressing the degree of membership in a crisp value cannot fully express the existing uncertainty. In the applied case study, experts and the DMs easily expressed the vagueness and uncertainty of the problem, and the results illustrated the advantage of this approach. Fourth, the introduced constraints provide the MODM approach with unique abilities to be applied in real-life problem modeling. Imposed constraints in geographical distribution of the selected projects and the impact of regulations on the decision-making process were easily expressed in the model. Fifth, risk consideration in the proposed approach is comprehensive enough to provide the DM with more flexibility and control over different aspects of risks and its impact on the results. The financial, project and uncertainty risks were considered in the decision-making process for the first time in the literature. The uncertain data of net cash flow was used to calculate lower semi-variance of the proposed project. Experts knowledge and experience were used to assess risk of each project and the risk reduction compromise ratio model was used to control the risk of uncertainty in experts opinions.

6. Concluding Remarks

In this paper, a novel approach based on multi-objective decision making (MODM) has been proposed to select the optimum sustainable project portfolio. In the proposed approach, unlike the previous related studies, interval-valued fuzzy sets (IVFSs) have been used to model uncertainty. This approach has provided the decision maker with more flexibility to define and calculate the uncertainty involved in the complex problem. Risks have been addressed in three parts of the proposed MODM approach. Firstly, a downside risk measure has been used to identify financial risk of the projects. Secondly, project risk has been regarded as a separate criterion among the decision-making criteria. Thirdly, in the second part of the proposed approach, a new decision-making model has been introduced that controls the level of uncertainty. In the proposed approach, the decision-making criteria have been divided in two groups. Investment return and the risk of return have been grouped as financial criteria. This group has consisted of criteria with direct impact on the financial situation of project portfolio. Other criteria, including social effect, environmental effect, project risk, non-financial benefits, strategic alliance and organizational readiness have been referred to as non-financial strategic criteria. It has meant that, they have direct impact on reaching the strategic goals of the organization. The first group of criteria has been considered by proposing a new composite risk-return index, which simultaneously addressed return and financial risk of the project. This index has been used to form the first objective function. For the second group of the criteria, a novel risk reduction compromise ratio method based on the IVFSs has been proposed to form the second objective function of the proposed approach. Finally, the concept of utility function has been applied to aggregate the two models. A weight has been also given to each model to assist the decision makers in expressing their preferences on each set of criteria. At the end of each model, a group of related constraints has been introduced to boost real-world applicability of the proposed MODM approach. Additionally, a new framework has been also introduced to help the decision makers in applying the presented method in project portfolio selection process. The proposed approach has been used in real case study of an Iranian holding company. The results have showed high capabilities of the proposed approach in sustainable problems, in real-world situation and in group decision-making with multi-dimensional perspectives. Eventually, the managerial implications of the approach have illustrated the advantages of the proposed approach over the previous related studies, in addition to its capabilities and abilities in real-world situations modeling. For future research, the authors believe that using a multi-actor approach in the decision making process and also enhancing the role of stakeholders in the process could be a challenging and yet practical subject. However, applying the model in some derivations of intelligent decision support systems could also be an interesting topic.

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