SUSTAINABLE PROJECT SELECTION IN A PORTFOLIO BY A NEW UNCERTAIN MATHEMATICAL PROGRAMMING

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ABSTRACT

Project portfolio selection is one of the most important tasks carried out by organizations in order to keep their competitive advantage in today's changing and highly competitive market. On the other hand, the contemporary social, economic and environmental conditions have made it insufficient to solely consider economic factors in project selection problems. In this paper, the concept of sustainability is integrated into project portfolio selection problem. A new method of project portfolio selection is proposed that simultaneously considers economic, social and environmental factors. Moreover, in order to consider the uncertain environment of projects and the lack of knowledge at the initial phases of them, interval-valued fuzzy sets (IVFSs) are used. This method consists of two main parts: in the first part, a modern decision index is adopted to utilize funneling down the proposed projects. In the second part, a sustainable project portfolio selection model based on the concept of IVFSs is proposed. This mathematical programming model considers the three pillars of sustainability in addition to risk. Finally, in order to illustrate the effectiveness and efficiency of the proposed uncertain mathematical programming, it is used to solve a practical example and the results are presented.

Keywords: Sustainability, project portfolio, mathematical programming, interval-valued fuzzy sets

1 INTRODUCTION

Organizations often have a variety of goals that cannot easily be reached by only a single project. Consequently, they choose groups of projects (i.e., portfolios) that share a limited number of resources over a given period of time to overcome the issue [1]. Choosing a portfolio of projects is a complex process since many factors and considerations are involved. These issues exist from the moment that the problem initiates until the time that the final project portfolio is chosen [2]. Decision makers (DMs)' ability to correctly analyze is weakened by high risk of uncertainty or inadequacy of project information [3]. Wrong decisions in this complicated decision making process not only harms the organizations by wasting resources but also could deprive them of the benefits that could be gained if the aforementioned resources were correctly allocated [4].

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Making the right decision requires selecting the right set of selection criteria. In the recent decades, the economic criteria are no longer the only important criteria for organizations. The importance of reciprocal impacts of economy, society and environment has emerged the concept of sustainable development. In literature of project life cycle, the economic, social and environmental effects are integrated as sustainability .It is agreed, that the concept of sustainability tries to meet social, environmental and economic objectives. These goals are termed as the three pillars of sustainable development [5]. Considering the pillars of sustainability in project selection decisions requires sufficient and reliable information of projects. Since the project selection process is carried out at the initial phases of project, the lack of knowledge, historical data and the high level of uncertainty are making the process harder. Fuzzy sets theory is a tool used by many scholars to address uncertainty in project selection problems. Since this tool is based on the knowledge of experts and does not require historical data, it is an appropriate tool to be employed in project selection problems.

Wei and Chang [6] integrated multi-criteria group decision making and fuzzy linear programming to propose a model of new product development project selection. Damghani [7] developed a fuzzy rule based system for sustainable project portfolio selection. Perez and Gomez [8] used fuzzy constraints in multi-objective project portfolio selection. Kocadağlı and Keskin [9] approached portfolio selection by using fuzzy goal programming. Perez et al. [2] developed a fuzzy multi-objective model with application in public organizations.

As it can be concluded from the above, fuzzy extensions like interval-valued fuzzy sets (IVFSs) are new to this subject and they were not even applied in the most recent studies. This fuzzy extension is useful when a DM due to lack of knowledge is unable to express an exact opinion in a number in interval [0, 1]. 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 [10]. Also, adding the concept sustainability to project portfolio selection is yet a new and interesting subject.

In this paper, a new mathematical programming method of sustainable project portfolio selection is proposed. The proposed method consists of two main sub-parts. In the first part, an interval-valued fuzzy decision index (IVF-DI) is extended to be applied in sustainable project selection. This part decides if a project is good enough to be considered in the portfolio. In the second part, an interval-valued fuzzy (IVF) model of project portfolio selection is proposed. In the proposed method, risk, financial criteria, social criteria and environmental criteria are comprehensively addressed.

The rest of this paper is structured as follows: in section 2, the model is proposed. Section 3 provides the practical example and the corresponding results and finally section 4 concludes the paper.

2 PROPOSED UNCERTAIN MATHEMATICAL PROGRAMMING METHOD

The concept of fuzzy weighted average, the concept of IVFSs and sustainability are integrated to enhance the conventional decision index (DI) introduced in the literature [6]. This DI is an information-based measure that integrates fuzzy rating and fuzzy weight of all factors that will impact the selection of sustainable projects. Eq. (1) displays the proposed IVF-DI.

$$DI_{(F,S,E,R)} = \frac{\sum_{n=1}^{N}\left[\left((r_{1n}^{U}, r_{1n}^{L}), r_{2n}, (r_{3n}^{L}, r_{3n}^{U})\right) \otimes \left((w_{1n}^{U}, w_{1n}^{L}), w_{2n}, (w_{3n}^{L}, w_{3n}^{U})\right)\right]}{\sum_{n=1}^{N}((w_{1n}^{U}, w_{1n}^{L}), w_{2n}, (w_{3n}^{L}, w_{3n}^{U}))} \quad (1)$$

where $F, S, E\ and\ R$ represent financial, social, environmental and risk criteria, $(r_{1n}^U, r_{1n}^L), r_{2n}, (r_{3n}^L, r_{3n}^U)$ and $(w_{1n}^U, w_{1n}^L), w_{2n}, (w_{3n}^L, w_{3n}^U)$ are the IVF-rating and IVF-weight, $n = 1,2, \ldots, N$ is set of criteria.

The obtained DI for each project is an IVFN. Therefore, comparing them with the GO-Kill crisp threshold requires a ranking method that creates crisp values (CDI). The Go-Kill threshold is decided by the DM based on the policies, strategies, regulations and so on. If a project passes this threshold, it is good enough to be considered in the project portfolio selection process. The ranking is based on the approach proposed by Carlsson and Fuller [11]. They proposed the mean value of triangular interval-valued fuzzy number (IVFN) $\tilde{A} = [(a_1^U, a_1^L), a_2, (a_3^L, a_3^U)]$ as follows:

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

To concurrently maximize the sustainable criteria and minimize the risk, multi-objective formulation is consolidated into single objective problem [12-15]. The acceptable limits for each objective are first set and their difference is also computed. Financial, social, environmental and risk related criteria are addressed by a separate function. These four functions in the proposed mathematical programming method are integrated into a single function using variable of λ which is able to concurrently optimize the four aforementioned functions. The four functions are described as follows:

$$\max \sum_{i=1}^{I} \sum_{j=1}^{J} F_{ij} X_{ij} \tag{3}$$

$$\max \sum_{i=1}^{I} \sum_{j=1}^{J} S_{ij} X_{ij} \tag{4}$$

$$\max \sum_{i=1}^{I} \sum_{j=1}^{J} E_{ij} X_{ij} \tag{5}$$

$$\min \sum_{i=1}^{I} \sum_{j=1}^{J} R_{ij} X_{ij} \tag{6}$$

s.t.

$$\sum_{i=1}^{I} \sum_{j=1}^{J} b_{ij} X_{ij} \leq B \tag{7}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} h_{ij} X_{ij} \leq H \tag{8}$$

$$\sum_{j=1}^{J} X_{ij} = 1, i = 1, \ldots, I \tag{9}$$

where, F_{ij}, S_{ij}, E_{ij}, R_{ij}, b_{ij},h_{ij}, B, and H denote finance, society, environment, risk, budget, human resource, total budget and total human resource, respectively.

The integrated single objective linear programming problem is described in the following:

$$\max \lambda \tag{10}$$

$s.t.$

$$-\sum_{i=1}^{I}\sum_{j=1}^{J} F_{ij}X_{ij} + \lambda d_F \leq -L_F \tag{11}$$

$$-\sum_{i=1}^{I}\sum_{j=1}^{J} S_{ij}X_{ij} + \lambda d_S \leq -L_S \tag{12}$$

$$-\sum_{i=1}^{I}\sum_{j=1}^{J} E_{ij}X_{ij} + \lambda d_E \leq -L_E \tag{13}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} R_{ij}X_{ij} + \lambda d_R \leq U_R \tag{14}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} b_{ij}X_{ij} \leq B \tag{15}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} h_{ij}X_{ij} \leq H \tag{16}$$

$$\sum_{j=1}^{J} X_{ij} = 1, i = 1, \dots, I \tag{17}$$

where, U_N and L_n are the acceptable upper and lower bound for objective *N*, decided by the DM and d_N is the difference between upper and lower bounds for objective *N*.

In this study, project portfolio selection is addressed as an IVF-multi-criteria group decision-making problem that considers the impacts of projects on social, environmental and economic criteria and also regards project risk. In this process, experts express their evaluation of each project; then, the process is converted into a multi-objective binary linear programming problem. In order to simplify the process, the algorithm of the model is proposed as follows:

1. Collect relevant information such as organizational strategy, resources, social and environmental situations of project locations. Form the expert group, identify the project proposals, and set of criteria and the linguistic variables along with IVFNs.
2. Calculate IVF-weight (W_n) and IVF-rating (r_{ijn}) for each criteria of the project as presented in Eqs. (18) and (19).

$$W_n = (\left(\frac{\sum_{k=1}^{K} w_{n1}^{U}}{k}, \frac{\sum_{k=1}^{K} w_{n1}^{L}}{k}\right), \frac{\sum_{k=1}^{K} w_{n2}}{k}, \left(\frac{\sum_{k=1}^{K} w_{n3}^{L}}{k}, \frac{\sum_{k=1}^{K} w_{n3}^{U}}{k}\right)) \tag{18}$$

$$r_{ijn} = (\left(\frac{\sum_{k=1}^{K} r_{ijn1}^{U}}{k}, \frac{\sum_{k=1}^{K} r_{ijn1}^{L}}{k}\right), \frac{\sum_{k=1}^{K} r_{ijn2}}{k}, \left(\frac{\sum_{k=1}^{K} r_{ijn3}^{L}}{k}, \frac{\sum_{k=1}^{K} r_{ijn3}^{U}}{k}\right)) \tag{19}$$

where, $k = 1,2 \dots, k$ is set of decision group, $i = 1,2, \dots, I$ is set of project group, $j = 1,2 \dots, J$ is set of projects, and $n = 1,2, \dots, N$ is the set of criteria.

3. Calculate $DI_{(F,S,E,R)}$ and create the $CDI_{(F,S,E,R)}$.
4. Eliminate the projects with poor economic, social and environmental impacts and high risk.
5. Apply the final model (Eqs. (10-17)) to find the optimum sustainable project portfolio.

3 PRACTICAL EXAMPLE

In this paper a practical example is presented to illustrate an application of the proposed model. The example relates to a decision making process in a project-oriented organization. This organization has to choose a portfolio of projects from two sets of proposed projects. The decision maker has to satisfy the following objective: (1) maximize economic benefits; (2) maximize social satisfaction; (3) follow the environmental regulations and (4) minimize the risk of portfolio. Since the proposed projects are in their initial phases they have the highest level of uncertainty. The organization resources are limited to 50 persons 60 monetary units. Since the resources are limited a process is required to find the most efficient portfolio of the projects. A group of experts consisting of three experts is formed to help with the process. The proposed projects with the required budget and human resources are presented in Table 1. The proposed methodology is illustrated through the following example.

1. Based on experiences of previous projects, existing resources, technical issues and strategies, experts define 8 project evaluation criteria consisting of c_1 and c_2 (financial benefits and return on investment) for financial impact, c_3 and c_4 (customer satisfaction and stakeholder satisfaction) for social impacts, c_5 and c_6 (carbon emission reduction and water pollution reduction) for environmental impacts and finally c_7 and c_8 (financial risk and technical risk) for project risk. The linguistic variables are listed in Table 2.
2. Experts' judgment is presented in Tables 3 and 4. IVF-rating and weight for each criteria of sustainable project are calculated.
3. IVIF-DI and CDI are calculated.
4. Based on the policies of the organization, the threshold for sustainable project evaluation is set and the Go-Kill decisions are made. As the result of the model, projects x_{12} and x_{22} are omitted from the process.
5. The single objective model is solved subject to constraints of 50 units of human resources and 60 units of budget. As a result, the best sustainable project portfolio consists of $x_{11}$and x_{23}.

Implementation of the proposed model provides several advantages in addition to showing the applicability of the model. First, the model uses a more practical tool (i.e. IVFSs) to model the highly uncertain situation of projects. Second, the model unlike most of the conventional models is concerned with sustainability. Third, a new decision index is applied for initial project review and fourth, a new mathematical model is applied to form the final portfolio.

Table 1: Resource requirements of proposed projects

Requirements	Project resource						Resource limit
	x_{11}	x_{12}	x_{13}	x_{21}	x_{22}	x_{23}	
Human resource	22	34	25	33	27	25	50
Budget	24.6	34.5	37	35.5	30	32	60

Table 2: Linguistic variables and corresponding IVFNs

Linguistic weights	Linguistic ratings	triangular IVFNs
VL, Very Low	VP, Very Poor	((0,0),0,(0.1,0.15))
L, Low	P, Poor	((0,0.05),0.1,(0.25,0.35))
ML, Medium Low	MP, Medium Poor	((0,0.15),0.3,(0.45,0.55))
M, Medium	M, Medium	((0.25,0.35),0.5,(0.65,0.75))
MH, Medium High	MG, Medium Good	((0.45,0.55),0.7,(0.8,0.95))
H, High	G, Good	((0.55,0.75),0.9,(0.95,1))
VH, Very High	VG, Very Good	((0.85,0.95),1,(1,1))

Table 3: Importance weights of criteria

Experts	Criteria							
	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8
E_1	H	H	H	M	H	MH	M	M
E_2	H	M	MH	MH	MH	H	M	H
E_3	M	MH	MH	M	MH	M	M	MH

Table 4: Importance weights of criteria

Projects	x_{11}			x_{12}			x_{13}			x_{21}			x_{22}			x_{23}		
Criteria	Experts																	
	E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3
c_1	MG	MG	G	M	P	M	G	M	M	M	MG	G	P	M	M	G	M	VG
c_2	MG	MG	MG	M	M	M	G	M	M	M	VG	MG	M	M	M	VG	M	M
c_3	MG	MG	VG	MP	M	M	M	MG	G	M	G	G	M	VP	VP	VG	M	MG
c_4	MG	G	MG	MP	M	M	G	MG	M	G	MG	MG	P	M	P	G	G	G
c_5	G	G	VG	P	P	M	M	P	M	M	P	M	MP	VP	P	VG	G	VG
c_6	G	VG	G	P	M	P	P	M	MP	M	MP	M	MP	M	MP	VG	G	M
c_7	G	VG	G	P	M	M	G	M	MP	P	M	M	P	P	M	G	G	MG
c_8	VG	M	VG	M	P	MP	M	M	MG	G	MG	M	VP	P	VP	VG	M	G

4 CONCLUSION

Today's social, environmental and economic situation has made it almost impossible to make any development program without considering the concept of sustainability. In this paper, a new model of project portfolio selection is proposed that simultaneously considers the three pillars of sustainability and risk. This model consists of two main parts; in order to make the model reliable under uncertain environment of projects, interval-valued fuzzy sets (IVFSs) are applied to model uncertainty. In the first part, a decision index is extended to be applied in Go-Kill decision making under interval-valued fuzzy (IVF)-environment. In the second part, a linear programming model is proposed to select an optimal sustainable portfolio of projects. In this model, economic, social, environmental and risk related aspects of projects are considered. A step by step guide is also presented to simplify the model. In order to illustrate the application of the model, a practical example is provided and solved and the results are also illustrated.

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