A New Approach in Considering Vagueness and Lack of Knowledge for Selecting Sustainable Portfolio of Production Projects

V. Mohagheghi[1], S.M. Mousavi[1], A. Siadat[2]
[1]Department of Industrial Engineering, Faculty of Engineering, Shahed University, Tehran, Iran
[2] LCFC, Arts et Métier Paris Tech, Metz, France
(sm.mousavi@shahed.ac.ir)

Abstract - **Today's changing and competitive market forces the organizations to consider uncertain factors in any production related decision making efforts. On the other hand, considering sustainability in choosing a portfolio of production projects to make justice between generations is essential. Achieving satisfactory results in sustainable goals without considering uncertainty is almost out of the question. Therefore, in this paper a new approach in considering uncertainty in sustainable decision making is introduced that is based on Atanassov fuzzy sets. This new model of sustainable project portfolio selection with application in production projects has two main phases: first, a new decision index is extended to evaluate the proposed projects. Second, a mathematical model is proposed to consider sustainability and risk. Moreover, a highly flexible method of ranking is introduced. Eventually, to depict the effectiveness and efficiency of the approach, it is used to solve a practical example and the results are presented.**

Keywords – **Atanassov fuzzy sets, production projects, project portfolio, sustainability, uncertainty**

I. INTRODUCTION

Project portfolio selection as a common problem in practice frequently requires the evaluation of each project by multiple experts. The main objective of the problem is to choose a subset of projects that satisfies a set of constraints in addition to providing a compromise among the group of experts. Budget satisfaction and project dependencies are some of the most common constraints [1,2].Considering sustainability in this problem adds social and environmental aspects, dimensions and factors to the process. Moreover, high risk of uncertainty or inadequacy of project information perils decision makers (DMs)' ability to correctly analyze the information and the situations [3].

Involving the three aspects of sustainability in the process of selecting a portfolio of production projects cannot be effectively achieve dunless sufficient and reliable information and data of projects and products are available. On the other hand, since the process of selecting a portfolio of production projects is carried out at the initial phases of projects, lack of knowledge and historical data, high level of uncertainty, vagueness and hesitations are unavoidable. Fuzzy sets theory is an uncertainty modeling tool used by many scholars in this problems. Fuzzy sets theory is an appropriate tool for project selection problems for two main reasons: first, this tool is based on the knowledge of experts; second, it does not require historical data.

Chiu [4] described project cash flow and proposed a method to determine the preferred fuzzy projects by employing triangular fuzzy numbers. Chiadamrong [5] proposed a multi-criteria decision making process based on fuzzy set theory to select manufacturing strategies. Lin and Hsieh [6] applied the classical concepts of decision support systems and fuzzy sets theory to introduce a method to select a strategic portfolio. Wang and Hwang [7] introduced a fuzzy zero-one integer programming method to select the optimal project portfolio uncertain environment. Wei and Chang [8] integrated multi-criteria group decision making and fuzzy linear programming to propose a model of new product development project selection.

It can be concluded from the above that new fuzzy extensions like Atanassov fuzzy sets or intuitionistic fuzzy sets (IFS)despite their high ability in handling uncertain situations are yet new to this subject. Mohagheghi et al. [9] applied interval-valued fuzzy sets for project portfolio selection. Their method in spite of its novelty in applying fuzzy extensions was only based on financial criteria and lacked any concerns for sustainability.IFSs express membership degree, non-membership degree and hesitancy degree by using three grades of membership function respectively, but triangular fuzzy numbers and trapezoidal fuzzy numbers lack this ability and each only can denote one crisp grade of membership in the unit interval [0,1] [10].IFS unlike all triangular fuzzy numbers, trapezoidal fuzzy numbers and interval-valued fuzzy numbers can reflect the "disagreement" of the DM in addition to the fuzziness of "agreement" [11].

In this paper, a new model of sustainable project portfolio selection with application to production projects is proposed that consists of two main sub-parts. In the first part, an intuitionistic fuzzy decision index (IF-DI) is modified to be used in sustainable project selection. This part determines if a project has the basic requirements to be considered in the final portfolio. In this part, also a new flexible method of IFS ranking is presented. In the second part, an IF model of project portfolio selection is proposed. In this model, risk, financial criteria, social criteria and environmental criteria are comprehensively addressed. Furthermore, the main characteristics of this paper are as follows: (1) sustainability in production project portfolio selection is considered as a selection criteria; (2) a new method of ranking for IFS is introduced; and (3) a new decision index based on IFS is introduced to evaluate projects versus sustainable criteria;

The rest of this paper is structured as follows: in section II, the model is proposed. Section III provides the practical example and the corresponding results and finally section IV includes the concluding remarks.

II. PROPOSED APPROACH

The concept of fuzzy weighted average, IFSs and sustainability are aggregated to improve the conventional decision index introduced in the literature [8]. This IF-DI is an information-based measure that integrates fuzzy rating and fuzzy weight of all factors that will impact the selection of sustainable production projects. Eq. (1) displays the proposed IF-DI.

$$DI_{(F,S,E,R)} = \left[\sum_{n=1}^{N} \left[\left(\langle \begin{matrix}[(r_{n_1}', r_{n_2}, r_{n_3}'); \mu'_r],\\ [(r_{n_1}, r_{n_2}, r_{n_3}); \mu_r]\end{matrix}\rangle\right) \otimes \left(\langle \begin{matrix}[(w_{n_1}', w_{n_2}, w_{n_3}'); \mu'_w],\\ [(w_{n_1}, w_{n_2}, w_{n_3}); \mu_w]\end{matrix}\rangle\right)\right]\right] \div \left[\sum_{n=1}^{N} (\langle \begin{matrix}[(w_{n_1}', w_{n_2}, w_{n_3}'); \mu'_w],\\ [(w_{n_1}, w_{n_2}, w_{n_3}); \mu_w]\end{matrix}\rangle)\right] \tag{1}$$

where F, S, E and R represent financial, social, environmental and risk criteria, $\langle[(r_{n_1}', r_{n_2}, r_{n_3}'); \mu'_r], [(r_{n_1}, r_{n_2}, r_{n_3}); \mu_r]\rangle$ and $\langle[(w_{n_1}', w_{n_2}, w_{n_3}'); \mu'_w], [(w_{n_1}, w_{n_2}, w_{n_3}); \mu_w]\rangle$ are the IF-rating and IF-weight, $n = 1,2, \dots, N$ is set of criteria.

The resulting IF-DI for each project is a triangular intuitionistic fuzzy number (TIFN)and should be compared with GO-Kill crisp threshold to determine project capabilities. This comparing 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.In this paper, a distance-based similarity measure between two TIFNs is proposed, that is based on the concept of the model introduced by Deng [12] for measuring the closeness between two IFNs. The ranking method is introduced as follows:

1. Determine the triangular intuitionistic fuzzy positive ideal solution as $\tilde{x}_{max} = ([\tilde{x}_{max,1}, \tilde{x}_{max,2}, \tilde{x}_{max,3}]; u_{\tilde{x}_{max}}, v_{\tilde{x}_{max}})$ and the negative ideal solution as$\tilde{x}_{min} = ([\tilde{x}_{min,1}, \tilde{x}_{min,2}, \tilde{x}_{min,3}]; u_{\tilde{x}_{min}}, v_{\tilde{x}_{min}})$.

2. Determine the degree of similarity between each triangular intuitionistic fuzzy number $\tilde{A}_i = ([a_{i,1}, a_{i,2}, a_{i,3}]; u_{a_i}, v_{a_i})$ $(i = 1,2, \dots, n)$ and the positive triangular intuitionistic fuzzy ideal solution $(\tilde{x}_{max})$ by using the following relation[13]:

$$\begin{aligned} ds_i^+(\tilde{A}_i, \tilde{x}_{max}) = \frac{1}{6}\Big(&\big|(1 + u_{\tilde{A}_i} - v_{\tilde{A}_i})a_1 - \big((1 + u_{\tilde{x}_{max}} - v_{\tilde{x}_{max}})\tilde{x}_{max,1}\big)\big| \\ &+ \big|(1 + u_{\tilde{A}_i} - v_{\tilde{A}_i})a_2 - \big((1 + u_{\tilde{x}_{max}} - v_{\tilde{x}_{max}})\tilde{x}_{max,2}\big)\big| \\ &+ \big|(1 + u_{\tilde{A}_i} - v_{\tilde{A}_i})a_3 - \big((1 + u_{\tilde{x}_{max}} - v_{\tilde{x}_{max}})\tilde{x}_{max,3}\big)\big|\Big) \end{aligned} \tag{2}$$

3. Determine the degree of similarity between each triangular intuitionistic fuzzy number $\tilde{A}_i = ([a_{i,1}, a_{i,2}, a_{i,3}]; u_{a_i}, v_{a_i})$ $(i = 1,2, \dots, n)$ and the negative triangular intuitionistic fuzzy ideal solution $(\tilde{x}_{min})$ by using the following relation:

$$\begin{aligned} ds_i^-\left(\tilde{\tilde{A}}_i, \tilde{\tilde{X}}_{min}\right) = d_i^-(\tilde{A}_i, \tilde{x}_{min}) = \frac{1}{6}\Big(&\big|(1 + u_{\tilde{A}_i} - v_{\tilde{A}_i})a_1 - \big((1 + u_{\tilde{x}_{min}} - v_{\tilde{x}_{min}})\tilde{x}_{min,1}\big)\big| \\ &+ \big|(1 + u_{\tilde{A}_i} - v_{\tilde{A}_i})a_2 - \big((1 + u_{\tilde{x}_{min}} - v_{\tilde{x}_{min}})\tilde{x}_{min,2}\big)\big| \\ &+ \big|(1 + u_{\tilde{A}_i} - v_{\tilde{A}_i})a_3 - \big((1 + u_{\tilde{x}_{min}} - v_{\tilde{x}_{min}})\tilde{x}_{min,3}\big)\big|\Big) \end{aligned} \tag{3}$$

4. Calculate the overall performance index (OPI_i) of each triangular intuitionistic fuzzy number $\tilde{A}_i$ $(i = 1,2, \dots, n)$ by using the following relation:

$$OPI_i = \frac{ds_i^-}{ds_i^+ + ds_i^-}, i = 1,2, \dots, n \tag{4}$$

Step 5. Rank the triangular intuitionistic fuzzy number $\tilde{\tilde{A}}_i$ $(i = 1,2, \dots, n)$ by descending order of OPI_i.

This method provides the DM with more control over the process. Selecting the triangular intuitionistic fuzzy positive ideal solution as $\tilde{x}_{max}$ and the negative ideal solution as$\tilde{x}_{min}$ is a process that can be done based on the nature of the project. This approach in addition to its simplicity, is highly flexible which makes the process more practical for project environments.

In order to maximize the sustainable criteria and at the same time minimize risk, multi-objective formulation is consolidated into single objective problem [14-16]. The acceptable limits for each objective are initially defined and their difference is calculated. Financial, social, environmental and risk related criteria are addressed by different functions. These four functions in the proposed mathematical formulation are aggregated into a single function using variable of λ that is capable of simultaneously optimizing the four aforementioned functions. The four functions are presented as follows:

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

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

$$\max \sum_{i=1}^{I} \sum_{j=1}^{J} PEI_{ij} X_{ij} \tag{7}$$

$$\min \sum_{i=1}^{I} \sum_{j=1}^{J} RI_{ij} X_{ij} \tag{8}$$

s.t.

$$\sum_{i=1}^{I} \sum_{j=1}^{J} fi_{ij} X_{ij} \leq B \tag{9}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} rhr_{ij} X_{ij} \leq HR \tag{10}$$

$$\sum_{j=1}^{J} X_{ij} = 1, i = 1, \dots, I \tag{11}$$

where, FP_{ij}, PSI_{ij}, PEI_{ij}, RI_{ij}, fi_{ij}, rhr_{ij}, B, and HR denote financial profit, positive social impact, positive environmental impact, risk impact, financial investment, required human resource, total budget and total human resource, respectively.

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

$$\max \beta \tag{12}$$

s.t.

$$-\sum_{i=1}^{I} \sum_{j=1}^{J} FP_{ij} X_{ij} + \beta d_{FP} \leq -L_{FP} \tag{13}$$

$$-\sum_{i=1}^{I} \sum_{j=1}^{J} PSI_{ij} X_{ij} + \beta d_{PSI} \leq -L_{PSI} \tag{14}$$

$$-\sum_{i=1}^{I} \sum_{j=1}^{J} PEI_{ij} X_{ij} + \beta d_{PEI} \leq -L_{PEI} \tag{15}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} RI_{ij} X_{ij} + \beta d_{RI} \leq U_{RI} \tag{16}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} fi_{ij} X_{ij} \leq B \tag{17}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} rhr_{ij} X_{ij} \leq HR \tag{18}$$

$$\sum_{j=1}^{J} X_{ij} = 1, i = 1, \dots, I \tag{19}$$

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 of upper and lower bounds for objective *N*.

In this paper, production project portfolio selection is addressed similar to an IF-multi-criteria group decision-making problem that takes social, environmental and economic criteria into account and also considers project risk. In this approach, 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 step by step algorithm is proposed as follows:

1. Collect all the available information such as organizational strategy, resources, social and environmental conditions of production project proposals. Form an expert group, identify the project proposals, and set of criteria and the linguistic variables along with IFNs.
2. Calculate IF-weight (W_n) and IF-rating (r_{ijn}) for each criteria of the project as presented in Eqs. (20) and (21).

$$W_n = \left\langle \begin{matrix} \left[\left(\frac{\sum_{k=1}^{K} w_{nk_1}{}'}{k}, \frac{\sum_{k=1}^{K} w_{nk_2}}{k}, \frac{\sum_{k=1}^{K} w_{nk_3}{}'}{k}\right); \mu'_w\right], \\ \left[\left(\frac{\sum_{k=1}^{K} w_{nk_1}}{k}, \frac{\sum_{k=1}^{K} w_{nk_2}}{k}, \frac{\sum_{k=1}^{K} w_{nk_3}}{k}\right); \mu_w\right] \end{matrix} \right\rangle \tag{20}$$

$$r_{ijn} = \left\langle \begin{matrix} \left[\left(\frac{\sum_{k=1}^{K} r_{ijnk_1}{}'}{k}, \frac{\sum_{k=1}^{K} r_{ijnk_2}}{k}, \frac{\sum_{k=1}^{K} r_{ijnk_3}{}'}{k}\right); \mu'_r\right], \\ \left[\left(\frac{\sum_{k=1}^{K} r_{ijnk_1}}{k}, \frac{\sum_{k=1}^{K} r_{ijnk_2}}{k}, \frac{\sum_{k=1}^{K} r_{ijnk_3}}{k}\right); \mu_r\right] \end{matrix} \right\rangle \tag{21}$$

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 $IF - DI_{(F,S,E,R)}$ 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. (12-19)) to find the optimum sustainable project portfolio.

III. APPLICATION EXAMPLE

Amanufacturer has to choose a portfolio of production projects from a set of proposed projects. Its objective is to reach the sustainable goals while limiting the risk of selected portfolio. The proposed projects with the required budget and human resources are presented in Table I. The monetary resources are limited to 75 units and human resource is limited to 55 people. The selection process is carried out as presented:

1. Based on past experience, resource limitation, technical issues and organizational 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 II.

TABLE I
PROPOSED PROJECTS

Project	Human resource	Required budget
x_1	20	32
x_2	44	45
x_3	33	48
x_4	43	46
x_5	35	39
x_6	25	42

2. Experts' judgement is presented in Tables III and IV. IF-rating and weight for each criteria of sustainable project are calculated.

TABLE II
LINGUISTIC VARIABLES AND CORRESPONDING TIFNS

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

3. IF-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_2 and x_4 are omitted from the process.
5. The single objective model is solved subject to constraints. As a result, the best sustainable project portfolio consists of x_1 and x_6. The final result of the model is presented in Table V

TABLE III
IMPORTANCE WEIGHTS OF CRITERIA

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

TABLE IV
PROJECTS RATING

Criteria / Projects		c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8
x_1	E_1	G	MG	MG	G	VG	G	M	VG
	E_2	VG	G	VG	MG	G	VG	VG	M
	E_3	MG	MG	VG	G	VG	G	VG	VG
x_2	E_1	M	M	M	M	M	P	M	MP
	E_2	P	M	M	M	P	P	P	M
	E_3	M	M	MP	MP	P	M	M	P
x_3	E_1	M	M	G	P	M	M	MP	MP
	E_2	G	M	MG	M	MP	MG	G	M
	E_3	M	G	M	M	P	M	M	P
x_4	E_1	G	VG	G	MG	P	M	M	MG
	E_2	MG	MG	M	G	M	M	P	M
	E_3	M	M	G	MG	M	MP	M	G
x_5	E_1	M	M	VP	M	P	M	M	P
	E_2	M	M	M	P	VP	MP	P	VP
	E_3	P	M	VP	P	MP	MP	P	VP
x_6	E_1	VG	G	G	VG	VG	G	M	MG
	E_2	G	G	VG	VG	VG	MG	M	G
	E_3	G	VG	VG	G	VG	G	MG	VG

TABLE V
FINAL OUTCOME OF THE MODEL

Projects	Final Results
x_1	Selected in the final portfolio
x_2	Rejected in step 4
x_3	Rejected in step 5
x_4	Rejected in step 4
x_5	Rejected in step 5
x_6	Selected in the final portfolio

IV. CONCLUSIONS

Selecting a portfolio of production projects requires considering impacts of project on social and environmental issues as well as economic factors. In this paper, a new method of sustainable project portfolio selection with application in production projects was proposed that not only considered sustainability issues but also addressed risk as well. To make the model reliable under uncertain project environments, intuitionistic fuzzy sets (IFSs) were used to model uncertainty.This paper also presented a novel method of intuitionistic fuzzy numbers (IFNs) ranking. This approach was made oftwo main parts; in the first part, an IF-decision index was introduced to be applied in Go-Kill decision makings. In the second part, a linear programming model was proposed to select an optimal sustainable portfolio of production projects. A step by step algorithm also was presented to clarify how the model was intended to function. In order to illustrate the application of the model, a practical example was provided and solved and the results were illustrated. The practical example demonstrated how the model handled the problem. Weak projects were identified in the initial parts of the model and the DM could get a comprehensive understanding of the projects in the initial steps. Therefore, projects can be omitted or new projects can be added in these steps. Moreover, after omitting the weak projects and having a set of acceptable projects a mathematical model was solved to find the optimum portfolio.

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