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A robust multi-objective optimization approach for construction project portfolio by considering sustainability

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Abstract

Macroeconomic investments in recent years has grown dramatically. Since the number of sources are usually less than the number of proposing projects to the organization, project selection and decision-making in this regard is considered as an inevitable issue. Wrong selection, will have negative consequences, such as wasting resources and also eliminate resources which can be properly used in a more appropriate project results in benefits for the organization. Therefore, a method for selecting project portfolio using a mathematical model and focusing on sustainability factors is proposed. In this paper, we present a multi-objective mathematical programming model that is a comprehensive and also a practical model for portfolio selection of construction projects because it uses sustainability criteria to evaluate projects as one of the objective functions. Multi-objective models can also be used to contrast the objectives with each other in project portfolio selection. Other innovations of the proposed model in this paper are multi-period modeling that specifies the precise timing of the selection of selected projects over 10 defined periods. A robust model is then proposed in order to considering the uncertainty, in this paper contains the uncertainty is the duration of the project. The results show that the robust model in terms of mean objective function under different realizations performs better than the deterministic model and may be because the robust model unlike the deterministic model considers the uncertainties caused by the disturbances.

Keywords: Project portfolio, sustainability criteria, loss, benefit, project selection

1-Introduction

Project portfolio management is a bridge between organizational strategies and projects which provides a resource allocation tool (Drenovak and Rankovic, 2014). Generally, in the absence of a large and centralized management system, the projects of the organization are in conflict with each other, and project managers struggle with other project managers to attract more resources to the best of their ability. They will ultimately damage to the whole organization and project clients. Therefore, senior managers should strive to improve the overall performance of the organization by balancing project managers' expectations and project requirements.

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Therefore, project portfolio management can be seen as an approach where the organization's projects are aligned to meet the strategic goals of the organization, which minimizing the costs and time spent on the projects. Portfolio management strives to coordinate portfolio components to achieve the strategic goals of the organization through the selection, prioritization and evaluation of the organization's projects.

Portfolio management combines the two perspectives of focusing on selecting projects that are most aligned with the organization's goals and focusing on timely and accurate project execution. It should be noted, however, that portfolio management is not management of components (Cooper et al.,1997). Project Portfolio Selection is a periodic activity to select a suitable portfolio from the organization's proposed projects and ongoing projects that can optimally achieve organizational goals without wasting resources or without limitations. In selecting a project portfolio, the most important question is what projects portfolio to go along with the goals of the organization? When selecting this mix of projects, factors such as opportunities, project alignment with the organization's strategic goals, cost, profit and risk must be taken into account. Project portfolio selection is an approach that should take into account the results of project analysis and review, and combine the projects that provide the most value to the organization. The implementation of new projects over the last few decades has provided organizations the competitive advantages necessary for success in their respective markets. Despite the commonality of new project implementation in organizations, there are still numerous accounts of either project failure or project instability across various industries (Allen et al., 2014). Project selection is widely recognized as an important task due to limited project management resources, the opportunity cost among different projects, and other company investments. Due to the increased use and potential payback of projects, it is critical for companies to select the best projects to support organizational strategy. One way to select the best projects is through the use of Project Portfolio Selection (PPS).

Mousavi and Jalilibal (2021) presented a mathematical multi-period multi-objective planning model for construction project portfolio selection considering sustainability factors. Bozorgi-Amiri et al. (2020) proposed a balancing method for construction projects by considering resilience factors in crisis. Ma et al. (2020) introduced a sustainability driven multi-criteria project portfolio selection under uncertain decision-making environment. Alyamani and Long (2020)

Salehpoor and Molla-Alizadeh-Zavardehi (2019) proposed a novel decision-making model for optimization of portfolio. They presented a constrained portfolio selection model by considering a hybrid meta-heuristic methods and risk-adjusted measures according to Markowitz method (mean-variance). Keshavarz Hadadha et al. (2018) applied Multi Criteria Decision Making (MCDM) Techniques and Knapsack Approach for clustering the projects. Yan and Ji (2018) proposed a portfolio selection model under uncertainty for oil projects. They considered uncertainty in the programming model to maximize the expected returns and minimize the sine cross-entropy of the actual return from prior return and also used a constraint in order to providing from bankruptcy. Li et al. (2018) proposed a multi-period uncertain portfolio selection model by considering bankruptcy limitation which maximize the final wealth and minimize the risk of investment. Perez et al. (2018) presented a portfolio selection model which is solved with fuzzy mathematical programming. They considered the constraints to be fuzzy. Their proposed model contains time order relations among projects, incompatibilities and synergies. Pourahmadi (2015) presented binary mathematical programming method for portfolio selection under uncertainty conditions. The objectives of the problem are to maximize the benefits of selecting projects and minimize deviations from the allocation of resources, respectively. Hassanzadeh et al. (2014) presented binary mathematical modeling and a robust multi-objective linear model for portfolio project selection. Ghahtarani and Najafi (2013) used multi-objective robust ideal modeling to select the optimal portfolio. Ghapanchi et al. (2012) proposed a new approach based on considering variables in the fuzzy environment and project interactions to select portfolio of projects under uncertainty. Carazo et al. (2011) proposed a comprehensive multi-objective model over a time horizon for the problem of project portfolio selection, which selected both efficient project portfolio and optimized project timing due to resource constraints. It identified the strategic needs and the interdependencies and interactions of projects. Zhang et al. (2011) developed an optimization model for project portfolio selection and evaluation. In this model, investment index and net cash flow are considered as fuzzy variables. Solak et al. (2010) proposed a multi-stage probabilistic integer programming model under uncertainty for portfolio selection of research and development projects. The objective function of this problem is assumed to maximize the expected return on capital and the model is discussed based on different scenarios. Doerner et al. (2006) proposed a multi-objective linear integer programming for project portfolio selection and solved the model in two steps to improve the quality of the results. So that in the first stage, they obtained the optimal Pareto portfolio and in the second stage, in the Pareto space, they searched for the most efficient solution possible.

In this paper, a model for project portfolio selection is presented that focuses the selection on sustainability criteria. This model has three objectives: sustainability score, profit and loss. Considering sustainability as a goal function is one of the most prominent model innovations. To the best of our knowledge, very few previous studies have examined the qualitative factors of sustainability that influence project selection, and none of these sustainability studies have been considered functionally in modeling. These are qualitative factors. Waste also means using the maximum amount of resources available and utilizing them in projects that have rarely been addressed in portfolio selection. The proposed model is then solved using TH approach and the model is implemented on an application of construction projects in petroleum refinery. The objective of the paper is to find a set of selected construction projects among all considering sustainability criteria and the question is how to select these projects by a mathematical model.

The following article is organized as follows: The second section deals with the background of the research and also research methodology. In the third section, the proposed model is described in detail and solving methods are introduced briefly. The fourth section analyzes the research data and findings. Section 5 also concludes and discusses the results.

2-Research methodology

Selecting the methodology of a study depends on the purpose and nature of the subject and its executive facilities. So, we can decide on how to study a subject, when the nature and extent of the specific research topics and targets is determined. Selecting an optimum method among various methods of quantitative and qualitative research methods, is an important step because it directly affects the results and their accuracies. This decision depends on the nature and goals of research and also the objectives and scope of the study. This study uses data and information on refinery construction projects that have been forbidden from disclosing the full names of the projects and companies for security reasons. In this section, we present a number of proposed projects and present a model for selecting these proposed projects for the organization in question. To this end, we propose a multi-objective mathematical programming model by considering sustainability factors, as qualitative factors and considering integration of financial factors as quantitative factors. We also consider restrictions on raw materials, human resources and machinery.

2-1-Sustainability factors

Many researchers have shown that construction projects cause many disadvantages for the environment (Griffith et al., 2005). In order to avoid some of these negative effects, sustainability issue becomes a goal. By appearing the Agenda 21 at the 1992 Earth Summit, necessity of applying sustainability arose in a strategic level in urban areas. In the current time, many municipalities all over the world, are involved in the process of Agenda 21. It means that, as the scheme of Agenda 21 shows, the need to construct a set of sustainability criteria that result in urban development as well as other targets determined by organizations, exist all over the world. Moreover, at present time, more than 70 tools and techniques are used to classify and assess construction projects based on a set of sustainability criteria (Fernández-Sánchez and Rodríguez-López, 2010). These criteria have also caused significant problems; for instance: uncertainty and subjectivity during the selection of criteria, criteria and dimensions (Hueting and Reijnders, 2004); the domination of environmental criteria during the assessment of construction projects, shortage of stakeholder's participation during the project life cycle and minimizing the number of criteria which are very high in the existing system of criteria. Many studies have addressed detrimental effects of construction projects on the environment (Shen and Tam, 2002; Tam et al., 2002). These criteria generically comprise of noise pollution, land misuse, waste generation, energy consumption, water discharge, misuse of water resources, dust and gas emission and consumption of non-renewable natural resources (Shen et al., 2005;

Chen et al.,2005). As these social, economic, and environmental challenges get more complex, some actions such as fundamental changes in management, defining activities with higher adaptability and innovative actions should be done (Pope et al., 2004). Numerous studies have addressed project management and sustainability context separately, whereas few studies have focused on the intersection between these two contexts. According to Gimenez et al. (2012) and Kleindorfer et al. (2005), sustainability comprises of economic, social and environmental issues which integrate to create a logical use of resources in present and expose a routine life for future generations. Some recent studies have tried to integrate these two topics which are already underway (Kleindorfer et al., 2005; Martens et al., 2013; Sánchez,2015; Bernhardi et al.,2000, Bodea et al., 2010; Jones, 2006; Mulder and Brent, 2006), while more further researches are needed to extend new tools, techniques and methodologies (Turlea et al., 2010) which could be applied on project management problems in order to evaluate an aspect of sustainability in projects and organizations (Turlea et al., 2010; Thomson et al., 2011). Themes of sustainability and project management are converged in some recent studies which is necessary for current business context, participated with the increasing importance of both issues in the area of business nowadays. This study intends to clarify the context of sustainability in project management in order to introduce a set of criteria as criteria for project portfolio selection. According to Bochini et al. (2014), project management can be used to integrate sustainability criteria in projects. In the context of project management, sustainability attracts the interest of professionals and academics. Sustainability as a concept, divides into economics, social and environmental sub criteria which form Triple Bottom Line. World Bank (1996) used "Triple bottom line" expression which includes economic, environmental, and social in order to define the issue of sustainability. It is obvious that sustainability, especially in large project-based organizations, is a major criterion, although both social and environmental aspects cannot be integrated in projects or programs (Martens et al., 2013). Due to remarkable impacts of construction projects on sustainability development, several management methods and approaches are developed as a guidance for managers in order to attain better sustainability performance throughout their projects. Shen et al. (2005) proposed a novel framework for evaluating sustainability performance of construction projects by creating a performance checklist in order to understand the significant criteria affecting sustainability of construction projects. Fernandez Sánchez and Rodríguez Lopez (2010) have developed a method for identifying sustainability criteria for civil engineering projects which is applied on the case study on infrastructure projects in Spain country.

According to literature review, there are great deal of criteria which could be used in project portfolio selection. These criteria comprise of economic, environmental and social issues. These criteria are effective in selecting construction projects. Literature reviews which has been done in the context of project portfolio and sustainable criteria (Siew, 2016; Wang et al., 2013; Xing et al., 2009), expressly the construction projects, a series of sustainability criteria can be scrutinized, which divided into three groups of the economic, environmental, and social criteria (tables 1,2,3).

Table 1. Economic criteria effective in selecting construction projects

	criteria	**Sub criteria**
Economic	Profit	Revenue of the project
		Operating cash flow
	Expenditure risk or debt	Depreciation or maintenance cost
		Cost surplus
		Disaster risk (Replacement Cost/Revenue)
	Aid from government/ organization	Significant financial assistance received from government (proportion of project cost funded)

Table 2. Environmental criteria effective in selecting construction projects

	Criteria	Sub criteria
Environmental	Consumption of energy	Estimated direct energy consumption per project
		Estimated indirect energy consumption per project
		Renewable energy consumption per project
	Waste production	Estimated total waste produced per project
	Water production	Estimated total water consumption per project
	Water savings	Estimated total amount of water reuse per project
		Estimated amount of water saved per project
	GHG emissions	Estimated total direct greenhouse gas emissions per project
		Estimated total indirect greenhouse gas emissions per project
	Emission of ozone depleting substances/ other emissions	Estimated emissions of ozone-depleting substances by weight per project
		NO, SO and other significant air emissions by weight per project
	Pollution	Noise
		Water
		Fugitive dust pollution
	Environmental incidents	Estimated total environmental incidents based on scale of project
	Environmental design criteria	Quality of design
	Land productivity	Estimated land area affected by human activity
	Usage of recycled materials/products	Estimated life cycle cost
		Weight of recycled materials used
	Compliance & enforcement	Monetary value of significant fines

Table 3. Social criteria effective in selecting construction projects

	Criteria	Sub criteria
Social	Leadership/ Knowledge management	Ratio of accredited professionals
		Proportion of sustainability related clauses in project contracts
	Supply chain	Number of significant suppliers, contractors and other business partners that have undergone human rights screening
	Health and Safety	Estimated total injuries
		Estimated total fatalities
	Training	Total training hours for project members in sustainability
		Quality of improvement by training
	Job creation	The number of jobs created per projects
		Diversity of jobs created per projects

2-2-Fuzzy DEMATEL method

In various studies, DEMATEL technique has been accomplished for problems such as selection. In most studies DEMATEL has been combined with other prioritization methods for selecting or weighting alternatives. Here, DEMATEL method is summarized in steps described below. For using DEMATEL method expert's opinion is required and these comments contain verbal expressions which are ambiguous. In order to integrate and clarify them, it is best to convert these phrases to fuzzy numbers. To solve this problem, Lin and Wu (2008) propose a DEMATEL model in a fuzzy environment. Process of fuzzy

DEMATEL look just like DEMATEL with the difference that in fuzzy DEMATEL include fuzzy verbal scales which proposed by Li (1999) is used.

Step 1: First, compute matrix "A" which is average initial direct-relation matrix. For constructing this matrix, some experts are asked to have a pairwise comparison between criteria which represents the impact of relation between them. The relationship between the vertices is examined and determined and the matrix of pairwise comparisons of factors at $n \times n$ is established, indicating the extent of influence between these factors (in which a_{ij} is the degree of influence of factor i is on factor j).

$$A = \begin{pmatrix} 0 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & 0 \end{pmatrix} \tag{1}$$

To produce the average initial direct-relation matrix, we use five scales in order to measure the relationship between different criteria: N (no influence), VL (very low influence), L (low influence), H (high influence), VH (very high influence), which is shown in table 4.

Table 4. Fuzzy numbers corresponding to linguistic variables linguistic variables (Li, 1999)

Linguistic variables	Fuzzy numbers corresponding to linguistic variables
N	(0,0,0.25)
VL	(0,0.25,0.5)
L	(0.25,0.5,0.75)
H	(0.5,0.75,1)
VH	(0.75,1,1)

Step 2: compute matrix "Z" which is normalization of initial direct-relation matrix. According to the studies, the normalization coefficient with the maximum row sum and maximum mean matrix column sum is obtained by multiplying the direct relation matrix in the normalization coefficient, the normalized direct relation matrix. According to literature, the normalization coefficient is equal to equation (2).

$$\lambda = Max(Max\sum_{j=1}^{p} aij, Max\sum_{i=1}^{p} aij)\,,\ Z = \lambda^{-1}A \tag{2}$$

Step 3: compute matrix T which is criteria total-influence matrix. After the normalized direct relation matrix is obtained, the final matrix formulation is obtained by the following formula in which the matrix I is the same and is computed with the equation (3):

$$T = \lim(Z + Z^2 + Z^3 + ... + Z^k) = Z(1 - Z)^{-1} \tag{3}$$

Step 4: Using t_{ij} values, the sum of each row (D_i) and the sum of each column (R_j) can be calculated, which represent the direct and indirect relation matrix elements which can be computed as equation (4):

$$D_i = \sum_{j=1}^{p} t_{ij} (i = 1,..., p), \; R_j = \sum_{i=1}^{p} t_{ij} (j = 1,..., p) \tag{4}$$

Summation of each rows (D_i) represents the level of penetration and effectiveness level of criteria i and summation of each columns (R_j) demonstrates the level of permeability and the influence level of criteria i. Hence, values of ($D_i + R_j$) and ($D_i - R_j$) are computed which are threshold values and demonstrate the casual relation among criteria.

The sustainability factors that influence the project portfolio selection are shown in tables 1, 2, 3. We considered the overall criteria which results from the abovementioned tables and proposed a set of sustainability criteria in table 4. In this study also, the importance of each factor against it has been determined using expert opinions and fuzzy dimensional methods (decision making methods). The importance of each factor in the DEMATEL method is equal to D + R (Wu, 2012).

Table 5. Sustainability factors

Sustainability factors
profit
cost
Technical requirement
soil
water
Atmosphere
Energy consumption
Biodiversity
Waste production
risk
Health and safety
Public Service
Social integration
responsibility

After implementing fuzzy DEMATEL on the sustainability criteria considered in this paper, the relevance importance of each criterion is obtained from the fuzzy DEMATEL method. So that, we can compute the sustainability score of each project by using a linear combination each criterion with the corresponding importance as the coefficient. Therefore, by asking experts to give us a score between 1-10 per criterion and per project, we can compute the sustainability score easily.

3-Mathematical programming

Indices	
Time Period	t
Number of projects	i

Parameters and Variables	
Estimated sustainability score from project i	$score_i$
The amount of benefit gained by the project i at the time t	b_{it}
Total amount of raw materials	R_{st}
Total amount of human resources	R_{ht}
Total amount of machinery	R_{mt}
The amount of raw materials used by the project i at the time of t	${r^s}_{it}$
The amount of human resources employed by the project i at the time of t	${r^h}_{it}$
The amount of machinery used by the project i at the time of t	${r^m}_{it}$
Total amount of surplus raw materials	sl_s
Total amount of human resources surplus	sl_h
Total amount of machinery surplus	sl_m
Project i duration	d_i
The amount of budget available to the organization	S
The cost of implementing project i at the time t	C_{it}
Total revenue from project i at the time t	H_{it}
Maximum time limit for doing part of project i at time t	β_{it}
Minimum time limit for doing part of project i at time t	σ_{it}
The maximum number of projects that can be completed at time t.	M_t
The minimum number of projects that can be completed at time t.	n_t
Total time horizon	T
Decision Variables	
Whether or not to select project i at time t. If this project is selected at time t, the value of this variable will be equal to one, otherwise its value will be zero	x_{it}
Percentage of project i was done at time t. If a percentage of this project is executed at time t, the value of this variable will be equal to one, otherwise its value will be zero.	Y_{it}

$$\text{Max} \sum_i \sum_t score_i x_{it}, \tag{5}$$

$$\text{Max} \sum_i \sum_t b_{it} x_{it}, \tag{6}$$

$$\text{Min } (sl_s + sl_h + sl_m), \tag{7}$$

$$s.t. \tag{8}$$

$$\sum_{i=1}^{n} \sum_{t=1}^{T} \boldsymbol{r^s}_{\boldsymbol{it}} x_{it} \le R_{st}, \tag{9}$$

$$\sum_{i=1}^{n} \sum_{t=1}^{T} \boldsymbol{r^h}_{\boldsymbol{it}} x_{it} \le R_{ht}, \tag{10}$$

$$\sum_{i=1}^{n} \sum_{t=1}^{T} \boldsymbol{r^m}_{\boldsymbol{it}} x_{it} \le R_{mt}, \tag{11}$$

$$\sum_{i=1}^{n} \sum_{t=1}^{T} C_{it} x_{it} \le S, \tag{12}$$

$$\sum_{t=1}^{T} (t + \widetilde{d_i}) x_{it} \le T + 1, \tag{13}$$

$$\sum_{t=1}^{T} x_{it} \le 1, \tag{14}$$

$$\sigma_{it} Y_{it} \le x_{it} \le \beta_{it} Y_{it}, \tag{15}$$

$$n_t \le \sum_i x_{it} \quad \forall t, \tag{16}$$

$$\sum_i x_{it} \le M_t \ \forall t. \tag{17}$$

This section describes the proposed model. This problem has three objective functions and linear mathematical programming is used. The first objective function shown in equation (5) considers the maximization of the score obtained from the project sustainability factors in the problem. This score is calculated using the weights obtained by interviewing the experts and DEMATEL results derived as the importance of sustainability factors. Sustainability score is calculated as the linear combination of sustainability factors, where the coefficient of each factor is the output of DEMATEL (D + R) as the importance of the factors. The second objective function of this problem, shown in equation (6), is to maximize the profit of the problem. Given the estimated cost and revenue for each project, we calculate the projected profit. The third objective function of this problem, illustrated by equation (7), is to minimize the waste of resources so that the utilization of resources (human resources), human resources and the number of machines available in the organization, other goals. Maximize utility and keep the least amount of resources (raw materials), human resources and number of machines after allocating resources to projects. In other words, minimize the surplus of all resources. Constraints (8), (9) and (10) indicate resource allocation, which includes raw materials, human resources and machinery. Due to the constraints of raw materials, human resources, and machinery during project implementation, we have to allocate a limited number of these to the number of projected priorities and estimated resources for each project. Constraint (11) indicates the allocation of funds to projects according to the estimated costs for each project. Because of limited funding, we are not able to select all the proposed projects and this budget is only responsible for some projects. Constraint (12) states that if a project is selected in period t and its duration isd_i, it must be completed before the end of the project's last period of time, and if not completed within this time limit, the project cannot be selected. This constraint ensures that all projects in the selected portfolio must be completed before the planned horizon in the problem is completed. Constraint (13) states that each project can be selected or not selected at time t and can only be selected once. Selection or non-selection are usually represented by a binary variable. Constraint (14) indicates the minimum and maximum percentage that each project must do in period t. Finally, constraints (15) and (16) indicate the maximum and minimum number of projects in progress in period$t$. These limitations are also due to the limitations in the organization.

4-Solving methods

4-1-Solving multi-objective mathematical model using TH method (Torabi and Hassini, 2008)

Step 1. Determine the ideal positive and negative answer for each of the objective functions.

Step 2. Determine the linear membership function for each objective function.

Step 3. Converting the existing model to a single-objective equivalent model using the TH method

Step 4. Definitely the single-objective model

4-2-Determine the ideal positive and negative objective functions

In this paper, in order to reduce the level of complexity in the computation, the negative ideal solutions have been estimated using positive ideal solutions instead of solving the other integer programming model separately. v_{ξ}^{*} and $G_{\xi}(\mathrm{v}_{\xi}^{*})$, respectively, are the ideal positive answer to i[th] objective function and its value. Therefore, the ideal negative answer is estimated using the following equations (18) and (19):

$$G_i^{NIS} = \min\left\{G_i(\mathrm{v}_1^*), G_i(\mathrm{v}_2^*), G_i(\mathrm{v}_3^*)\right\}; i = 3, \tag{18}$$

$$G_i^{PIS} = \max\left\{G_i(\mathrm{v}_1^*), G_i(\mathrm{v}_2^*), G_i(\mathrm{v}_3^*)\right\}; i = 1, 2\,. \tag{19}$$

4-3-Determine the membership function for each of the target functions

The following relationships represent the membership functions defined for each of the target functions according to their maximization or minimization.

$$\mu_1(v) = \begin{cases} 1 & G_1 \le G_1^{PIS} \\ \dfrac{G_1^{NIS} - G_1}{G_1^{NIS} - G_1^{PIS}} & G_1^{PIS} \le G_1 \le G_1^{NIS} \\ 0 & G_1 \ge G_1^{NIS} \end{cases}$$

$$\mu_2(v) = \begin{cases} 1 & G_2 \le G_2^{PIS} \\ \dfrac{G_2^{NIS} - G_2}{G_2^{NIS} - G_2^{PIS}} & G_2^{PIS} \le G_2 \le G_2^{NIS} \\ 0 & G_2 \ge G_2^{NIS} \end{cases}$$

$$\mu_3(v) = \begin{cases} 1 & G_3 \ge G_3^{PIS} \\ \dfrac{G_3 - G_3^{NIS}}{G_3^{PIS} - G_3^{NIS}} & G_3^{NIS} \le G_3 \le G_3^{PIS} \\ 0 & G_3 \le G_3^{NIS} \end{cases}$$

Using the TH method, we convert the existing multi-objective model into a single-objective equivalent model as shown in the following equation (20):

$$\begin{aligned}
&\max \sigma(\mathrm{v}) = \eta\sigma_0 + (1-\eta).(\theta_1.\mu_1(\mathrm{v}) + \theta_2.\mu_2(\mathrm{v}) + \theta_3.\mu_3(\mathrm{v})) \\
&\sigma_0 \le \mu_1(\mathrm{v}) \\
&\sigma_0 \le \mu_2(\mathrm{v}) \\
&\sigma_0 \le \mu_3(\mathrm{v}) \\
&\mathrm{v} \in \mathrm{F}(\mathrm{v}), \eta, \sigma_0 \in [0,1]
\end{aligned} \tag{20}$$

4-4-Robust counterpart

In this section, the robust model is presented, in which the parameter that contains the uncertainty is the duration of the project. Bertsimas and Sim (2004) optimization model is also used to write the robust model. we assume the parameter of duration of the project is uncertain and changes in the following range:

$$d_{ij} : \left[\tilde{d}_i - \hat{\tilde{d}}_i \xi_i^{\tilde{d}}, \tilde{d}_i + \hat{\tilde{d}}_i \xi_i^{\tilde{d}}\right].$$

After defining the level of protection $\beta^{\tilde{d}}(\Gamma^{\tilde{d}})$ for the rate of change in the parameters $\tilde{d}_i$, constraint (13) is written as model (21):

$$\sum_{t=1}^{T} t + \sum_{t=1}^{T} \tilde{d}_i X_{it} - T - 1 + \beta^{\tilde{d}}(\Gamma^{\tilde{d}}) \le 0. \tag{21}$$

$$\beta^{\tilde{d}}(\Gamma^{\tilde{d}}) = \max_{\{s^{\tilde{d}} \cup \{t^{\tilde{d}}\} \mid s^{\tilde{d}} \subseteq t^{\tilde{d}}, s^{\tilde{d}} \le \lfloor \Gamma^{\tilde{d}} \rfloor, t^{\tilde{d}} \in J^d \setminus s^{\tilde{d}}\}} \sum_{i \in J^{\tilde{d}}} X_{it} \hat{\tilde{d}}_i + (\Gamma^{\tilde{d}} - \lfloor \Gamma^{\tilde{d}} \rfloor) \hat{\tilde{d}}_{tt'} x_{tt'}.$$

$\beta^d(X_{it}^*, \Gamma^{\tilde{d}})$ is the optimal value of the model (22),

$$\beta^d(X_{it}^*, \Gamma^{\tilde{d}}) = \sum_{i \in J^{\tilde{d}}} X_{it} \hat{\tilde{d}}_i \xi_i^{\tilde{d}}, \tag{22}$$

s.t

$$\sum_{i \in J^{\tilde{d}}} \xi_i^{\tilde{d}} \le \Gamma^{\tilde{d}},$$

$$0 \le \xi_i^{\tilde{d}} \le 1 \qquad i \in J^{\tilde{d}}.$$

Since model (22) is a backpack problem, so the dual model is written as equation (23):

$$\begin{aligned}
&\min \sum_{i \in J^{\tilde{d}}} P_i^d + \Gamma^{\tilde{d}} Q^{\tilde{d}}, \\
&Q^{\tilde{d}} + P_i^{\tilde{d}} \ge \hat{\tilde{d}}_i x_{it} \quad \forall i \in J^{\tilde{d}}, \\
&Q^{\tilde{d}} + P_i^{\tilde{d}} \ge 0 \qquad \forall i.
\end{aligned} \tag{23}$$

Finally, we set its value instead of $\beta^d(X_{it}^*, \Gamma^{\tilde{d}})$.

4-5-Summary of the main steps

An overview to the main steps of this paper is summarized in the following steps:

- Selecting the sustainability factors which influenced the project portfolio selection
- Applying DEMATEL on the selected sustainability factors and calculate their relevant importance
- Computing sustainability score
- Proposing a multi-objective mathematical model for project portfolio selection
- Using TH method for solving multi-objective mathematical model
- Considering uncertainty in the model and applying robust counterpart

5-Analysis of research data and findings

5-1-An application

In this paper, the main criteria which is considered as influential ones on selecting the projects are sustainability criteria. According to this problem, often these criteria are used in construction projects for evaluating. Therefore, we consider a set of 45 projects which are related to projects in petroleum refinery and the experts in this fields are asked to be interviewed and give us an overview about the projects in sustainability criteria and implementing our proposed framework.

5-2-DEMATEL results

Each criteria indicates some sub criteria and based on these criteria a 14*14 pairwise comparison matrix was adjusted as a questionnaire with guidance and sub criteria for each of the criteria; these questionnaire was given to experts and gained data were used as the elements of direct relationship matrix and the impact of the relationship between them is clearly observed. In this study, we use a five-degree Likert scale as a guidance of scoring criteria for experts. According to the questionnaire N (no influence), VL (very low influence), L (low influence), H (high influence) and VH (very high influence) are the guidance for scoring the criteria. After gathering data by filling the questionnaire by experts, DEMATEL method is applied in order to find the cause and effect relationship among criteria and presence or absence of the final relationship between the two criteria is determined by MATLAB software and the judgment of majority of experts. After coding and determining linguistic variables, the first step of fuzzy DEMATEL, ' T ' which is tracing initial direct-relation matrix, should be performed. After this step, fuzzy numbers equivalent to linguistic variables are substitute in the table and then they are converted to crisp numbers with a de-fuzzy operation.

Table 6. Output of Fuzzy DEMATEL method

Sustainability factors	profit	cost	Technical requirement	soil	water	Atmosphere	Energy consumption	Biodiversity	Waste production	risk	Health and safety	Public Service	Social integration	responsibility
D	0.4658	0.6039	0.3163	0.4478	0.1883	0.3535	0.3883	0.1888	0.5509	0.4993	0.2176	0.2100	0.3517	0.5655
R	0.2410	0.3910	0.3392	0.3208	0.3116	0.1814	0.2150	0.5777	0.3102	0.2725	0.4013	0.4230	0.5566	0.8065
D+R	0.7069	0.9949	0.6555	0.7685	0.4999	0.5348	0.6033	0.7665	0.8612	0.7718	0.6189	0.6329	0.9083	1.3719
D-R	0.2248	0.2129	-0.0229	0.1270	-0.1233	0.1721	0.1733	-0.3889	0.2407	0.2269	-0.1837	-0.2130	-0.2049	-0.2409

Table 7. Importance of sustainability factors (output of fuzzy DEMATEL method)

Sustainability factors	Importance ($D_i + R_j$)
profit	0.7069
cost	0.9949
Technical requirement	0.6555
soil	0.7685
water	0.4999
Atmosphere	0.5348
Energy consumption	0.6033
Biodiversity	0.7665
Waste production	0.8612
risk	0.7718
Health and safety	0.6189
Public Service	0.6329
Social integration	0.9083
responsibility	1.3719

5-3-Deterministic model results

In this section, the solution of the proposed model of deterministic selection using TH method is investigated. Due to the different parameters in this model, membership functions have different effects. Therefore, changes in parameters should be considered individually or simultaneously. Therefore, in this section, sensitivity analysis is performed on different parameters of the proposed model.

The TH method, also referred to as TH, is an interactive method that assigns different weights as the degree of satisfaction of each objective function according to the decision makers' preferences to the existing objective functions, and obtain different values for as a response to the proposed model in table 7. As can be seen in table 7, by increasing the value of η, the degree of satisfaction of the objective functions yields more balanced values, and also the lower degree of satisfaction becomes more desirable.

Table 8. The final results of the mathematical model

η	$\mu_i(v)$	$(\theta_1, \theta_2, \theta_3)$				
		(0.9,0.05,0.05)	(0.85,0.075,0.075)	(0.75,0.2,0.05)	(0.6,0.3,0.1)	(0.5,0.4,0.1)
0.2	$\mu_1(v)$	1.258	1.249	1.284	1.245	1.173
	$\mu_2(v)$	0.999	1.098	1.067	1.062	1
	$\mu_3(v)$	1.303	1.331	1.403	1.384	1.408
0.4	$\mu_1(v)$	1.7	1.723	1.835	1.904	1.167
	$\mu_2(v)$	1.14	1.172	1.076	1.063	1.09
	$\mu_3(v)$	1.549	1.467	1.471	1.502	1.443
0.6	$\mu_1(v)$	2.625	2.681	2.862	3.199	3.641
	$\mu_2(v)$	1.219	1.201	1.201	1.259	1.288
	$\mu_3(v)$	1.514	1.564	1.531	1.626	1.602
0.8	$\mu_1(v)$	5.359	5.371	5.953	7.13	8.14
	$\mu_2(v)$	1.485	1.465	1.482	1.567	1.605
	$\mu_3(v)$	1.999	1.988	2.062	2.237	2.333

Table 9. Sensitivity analysis on values of objective functions under different relative preferences

	z_i	$(\theta_1, \theta_2, \theta_3)$				
		(0.9,0.05,0.05)	(0.85,0.075,0.075)	(0.75,0.2,0.05)	(0.6,0.3,0.1)	(0.5,0.4,0.1)
0.2	z_1	154.426	154.154	154.437	150.333	146.667
	z_2	1413	1203	1219	1324	1425
	z_3	372081	371919	371956	371946	372019
0.4	z_1	143.749	142.918	142.816	139.248	135.515
	z_2	1157	1137	1197	1290	1196
	z_3	372260	372133	372241	372117	372182
0.6	z_1	127.483	127.899	120.355	112.742	105.961
	z_2	1047	1002	963	852	1025
	z_3	372306	372198	372309	372389	372237
0.8	z_1	77.92	70.091	61.944	41.451	18.894
	z_2	615	595	602	509	211
	z_3	372658	372805	372936	373362	373739

Tables 7 and 8 show the variations in the degree of satisfaction of the objective functions for the change in η, which is the lower limit of significance level of satisfaction of the objective functions and show the degree of balance of each of these objective functions. Given the trend of changes seen in the graphs above with increasing η, since 1-η is considered as the satisfaction change, the satisfaction value of each of the objective functions increases and gets closer to equilibrium. The most favorable case for θ and η is the part that yields maximum satisfaction for the objective function. In this study, according to the obtained results, θ = (0.95, 0.05, 0.05) and η = 0.2 were chosen as the optimal solution and considering the priority of the decision, the final results of the proposed project are examined.

Table 10. Project selection status for each of the time periods considered

	selection	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
P1											
P2											
P3	*									*	*
P4											
P5	*								*	*	
P6	*								*		
P7											
P8	*			*	*	*	*	*	*		
P9											
P10											
P11											
P12	*	*									
P13	*		*	*	*	*	*	*	*	*	*
P14	*		*	*	*	*	*	*	*	*	
P15											
P16	*									*	*
P17	*	*	*								
P18											
P19											
P20	*						*	*	*	*	*
P21											
P22	*		*	*	*	*	*	*			
P23	*			*	*						
P24	*			*	*	*	*				
P25	*		*	*	*	*	*	*	*		
P26	*		*	*							
P27											
P28											
P29	*								*	*	
P30	*								*	*	*
P31	*			*	*	*					
P32											
P33											
P34											
P35											
P36	*						*	*	*	*	*
P37	*	*	*								
P38											
P39											
P40											
P41											
P42											
P43											
P44											
P45											

Table 9 shows the status of proposed projects using the proposed model in this paper. As can be seen, projects 3, 5, 6, 8, 12, 13, 14, 16, 17, 20, 22, 23,24, 25, 26, 29, 30, 31, 36 and 37 as Selected projects are introduced by this model. Also considering that this model is a 10-period model, the start time of each project as well as the periods during which each project is completed are observed.

5-4-Robust model results

Considering the results of the TH approach that examined project portfolio selection under certain conditions, $\theta = (0.9, 0.05, 0.05)$ and $\eta = 0.2$ is considered as the optimal solution and the uncertainty model is considered using the Bertsimas and Sim approach. Tables 10 and 11 analyze the sensitivity analysis of the data deviations from the nominal value and Γ, which determines the level of decision maker conservatism, on the triple values of the objective functions of the robust counterpart model of project portfolio selection and the degree of decision makers' preferences over the target functions.

Table 11. Sensitivity analysis on degree of satisfaction of objective functions under different conservative levels in uncertain conditions

α	$\mu_i(v)$	Γ				
		0.1	0.3	0.5	0.7	0.9
0.2	$\mu_1(v)$	1.559	1.564	1.716	1.738	1.773
	$\mu_2(v)$	0.906	0.953	0.96	0.963	0.639
	$\mu_3(v)$	1.034	1.046	1.016	1.06	0.774
0.4	$\mu_1(v)$	1.559	1.559	1.707	1.723	1.735
	$\mu_2(v)$	0.992	0.992	1.083	1.066	0.948
	$\mu_3(v)$	1.034	1.034	0.989	1.046	0.984
0.6	$\mu_1(v)$	1.559	1.726	1.729	1.73	1.73
	$\mu_2(v)$	0.906	1.03	0.998	0.992	0.874
	$\mu_3(v)$	1.034	1.037	1.055	1.01	0.985
0.8	$\mu_1(v)$	1.559	1.641	1.712	1.724	1.731
	$\mu_2(v)$	0.906	0.957	1.021	1.014	1.085
	$\mu_3(v)$	1.034	0.982	1.055	1.068	1.057

Table 12. Sensitivity analysis on objective function values under different conservative levels in uncertain conditions

α	z_i	Γ				
		0.1	0.3	0.5	0.7	0.9
0.2	z_1	146.803	146.701	143.586	143.43	142.773
	z_2	1302	1223	1212	1187	1152
	z_3	372195	372219	372244	372260	372291
0.4	z_1	146.803	146.801	144.012	143.715	143.481
	z_2	1302	1232	1157	1033	1005
	z_3	372195	372219	372277	372291	372334
0.6	z_1	146.803	143.652	143.596	143.578	142.773
	z_2	1302	1157	1147	1120	1094
	z_3	372195	372201	372238	372297	372333
0.8	z_1	146.803	145.248	143.807	143.69	143.557
	z_2	1302	1223	1120	1080	1001
	z_3	372195	372263	372269	372278	372291

Tables 10 and 11, respectively, show the changes of each of the three objective functions in the proposed model under different conservative levels. The figures examine the extent of the objective functions at the four levels of η. As can be seen, as the level of conservatism increases, the number of objective functions deteriorates depending on the type of maximization or minimization. For example, in figure 4 it can be seen that the value of the objective function of the maximization type in the level of conservatism 0.1 and η = 0.2 is equal to 148.803 and then with the change in the level of conservatism it eventually reaches the level of conservatism. 0.9 and η = 0.2 decreased to 142.773.

Table 13. Final status of selected projects under uncertain conditions

	selection	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
P1											
P2	*					*	*				
P3											
P4	*		*	*							
P5	*				*						
P6											
P7	*					*	*	*	*	*	*
P8	*				*						
P9											

Table 13. Continued

	selection	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
P10											
P11	*				*						
P12											
P13											
P14	*		*	*	*						
P15											
P16	*		*	*							
P17											
P18	*									*	*
P19											
P20											
P21											
P22	*				*	*					
P23											
P24											
P25	*			*	*						
P26	*		*								
P27											
P28	*		*	*							
P29	*								*	*	*
P30											
P31											
P32											
P33											
P34											
P35											
P36	*					*	*				
P37	*		*	*							

Table 13. Continued

	selection	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
P38											
P39											
P40	*									*	
P41	*								*	*	*
P42											
P43											
P44											
P45											

According to table 12, the selected projects are identified in the robust counterpart of Bertsimas and Sim approach. This output is assumed to have a conservatism of 0.5 and a percentage of deviation from nominal data of equal to 0.6. The period in which the project started is also specified, and the estimated duration of each project should be considered during these 10 time periods. As indicated by * in the table, projects 3, 5, 6, 8, 9, 12, 15, 17, 19, 23, 26, 27, 29, 30, 37, 38, 41 and 42 among the proposed projects to the organization are selected. Out of the 45 projects proposed to the organization, only 18 have been selected. As can be seen, the number of projects selected has been reduced by increasing the percentage of conservatism.

5-5-Compare performance of deterministic and robust model

Tables 13 and 14 show the results of the performance of the two deterministic and robust models under the realizations. In these two tables, the mean values of the objective functions, under the realizations, are used as performance measures to evaluate the proposed models. As can be seen, the robust model in terms of mean objective function under different realizations performs better than the deterministic model and may be because the robust model unlike the deterministic model considers the uncertainties caused by the disturbances. It takes and plans for it before the disruption occurs, why it is called robust programming as a kind of proactive programming. As shown in the table, the cost between the averaged realizations on the deterministic and robust models of each of the objective functions is about 17.0881, 917.8, and 459.2, respectively. These numbers actually mean that the model has an average performance of about 17.0881, 917.8 and 459.2 on average compared to the definitive model for each of the objective functions.

Table 14. Performance of the deterministic model using different exponentials

Realization No.	deterministic		
	z_1	z_2	z_3
1	161.775	1580	372518
2	160.362	1568	372614
3	158.449	1498	372688
4	162.314	1613	372503
5	161.775	1580	372518
6	157.95	1462	372635
7	163.612	1648	372489
8	159.607	1509	372693
9	161.775	1580	372518
10	160.362	1568	372614
mean	160.798	1560.6	372579

Table 15. Performance of the robust model using different exponentials

Realization No.	robust		
	z_1	z_2	z_3
1	145.345	652	372072
2	143.186	640	372095
3	141.254	630	372109
4	145.981	638	372099
5	145.345	652	372072
6	140.105	619	372165
7	146.83	681	372285
8	140.523	624	372134
9	145.345	652	372072
10	143.186	640	372095

Tables 13 and 14 show the performance of the deterministic and robust models under different realizations. It is also clear in this figure that the robust model, under various realizations, has generally obtained better values than the deterministic model. Based on the explanations already mentioned, a robust optimization approach for project portfolio selection is justified in terms of disruption.

6-Managerial insight

Project portfolio management can be a good tool to help increase the efficiency and effectiveness of an organizations. Project evaluation is important in the organization, especially when we are aware that most organizations are involved in this so that even a significant portion of their revenue comes from their projects. On the other hand, by superficially examining the projects of these organizations, it can be understood that a large number of projects have been stopped due to lack of access to facilities and resources or in the final stages and lack of compliance and coordination with the organization's goals. The main tools for implementing the strategies of project-based organizations, which include the selection and proper implementation of projects, play an important role in the success of organizations. In other words, project selection is in line with the organization's strategies and ensures that the allocated resources are used effectively and plays a key role in achieving the organization's strategic goals. Considering uncertainty brings the situation closer to reality and provides a more accurate answer than the certain case. In other words, it greatly reduces the probability of fault in decision making, which is one of the main goals of project-oriented organizations, and helps project managers to choose the best portfolio of projects. This decision is made in a situation that puts the sustainability of the system at its highest level. Among the criteria of system sustainability, we can mention the environmental conditions, which are not taken into account and have irreversible effects on the environment, unfortunately.

7-Conclusion and future research suggestion

One of the most important concerns of project-oriented organizations is the correct and intelligent selection of proposed projects that should be considered in the light of current organizational conditions. This can lead to competitiveness and survival. Project selection is a periodic activity to select an appropriate portfolio of proposed organization projects and ongoing projects that can meet organizational goals optimally and without wasting resources. As a result, the best combination of proposed projects can be selected using a mathematical programming model and allocating resources among the selected projects. In this paper, we present a multi-objective mathematical programming model that is a comprehensive and also a practical model for portfolio selection of construction projects because it uses sustainability criteria to evaluate projects as one of the objective functions. Multi-objective models can also be used to contrast the objectives with each other in project portfolio selection. Other innovations of the proposed model in this paper are multi-period modeling that specifies the precise timing of the selection of selected projects over 10 defined periods. A robust model is then proposed in order to considering the uncertainty, in this paper contains the uncertainty is the duration of the project. As can be seen in section 4, the robust model in terms of mean objective function under different realizations performs better than the deterministic model and may be because the robust model unlike the deterministic model considers the uncertainties caused by the disturbances. It takes and plans for it before the disruption occurs, why it is called robust programming as a kind of proactive programming. Finally, it can be said that using this model and considering the limited resources available in the organization, the most desirable combination of the proposed projects will be selected and appropriately allocated to the budget and other resources. Further research must be on proposing on an integrated selection and balancing model for project portfolio which consider sustainability and resilience criteria for selecting and balancing the projects, respectively. Another potential for future study is to use other uncertainty method such as fuzzy logic or stochastic programming and develop a new model for project portfolio selection. Moreover, some novel MCDM method such as SWARA and ARAS can be exploit to evaluate and prioritize sustainability criteria in project portfolio selection.

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