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INTEGRATION OF A NEW MCDM APPROACH BASED ON THE DEA, FANP WITH MONLP FOR EFFICIENCY-RISK ASSESSMENT TO OPTIMIZE PROJECT PORTFOLIO BY BRANCH AND BOUND: A REAL CASE-STUDY

Abstract *Project Portfolio Management (PPM) is a modern management model and an instrument for evaluating, prioritizing and reviewing projects. To select a project portfolio that is a combination of these criteria, identifying the opportunities, evaluating the alignment between the project and the purposes and structure of the organization and analyzing the costs, benefits and risks of the project are essential. The present article uses a qualitative and quantitative approach for the optimal selection of project portfolios and applies a set of techniques, including data envelopment analysis (DEA) and fuzzy analytic network process (FANP) for project portfolio management space for the first time. This algorithm can also be used to optimize project portfolios based on a multi-objective non-linear programming (MONLP) model. The MONLP model will be solved by efficient branch and bound algorithm. A more accurate estimation can be accomplished for the selection of a low-risk portfolio by adding these two new criteria for computing risk numbers in terms of their proximity to the event and the ability to control and modify them in the future. This algorithm will ultimately be applied for a real case study in Mobarakeh Steel Co., a leading Iranian company producing steel sheets.*

Keywords: *projects portfolio optimization, data envelopment analysis, FANP, efficiency and risk, MONLP, novel RPN method, Branch and Bound (B&B).*

JEL Classification: O30, O22

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1. Introduction

Today, companies are forced to select and manage project portfolios in compliance with their strategic purposes in order to survive in their trade markets, gain a competitive edge, perform business and develop socially and economically. The most important stage of project portfolio management is optimal selection; this stage comprises a periodic activity for the selection of a suitable portfolio from the list of proposed projects or projects whose implementation satisfies the organizational purposes without using additional resources or ignoring other limitations (Levine, 2005). Organizations should select appropriate projects in order achieve their strategic objectives. The impossibility of simultaneously focusing on efficiency and risk parameters causes the failure of the organizations to develop an optimal project portfolio for their agenda. The issue gains importance when considering that organizational resources are limited and organizational goals are also subject to different risks. Achieving the goals within these limitations and risks is regarded as an important responsibility of a manager. The present paper seeks to respond to the following main questions:

- ✓ How can an optimal project portfolio be selected for an organization with maximum efficiency and minimum risk?
- ✓ Does project risk assessment in view of the two criteria of impact and probability sufficiently address the economic conditions and the complexity of the projects in the majority of research and development projects?
- ✓ What is the drawback of current risk assessment methods for project portfolios?
- ✓ Given the inherent correlation between project risks, how is the risk priority number (RPN) of a project calculated?

Responding to these questions can help organization managers select optimal project portfolios and achieve their strategic organizational objectives. Many studies have been conducted on the selection of project portfolios and most of them follow a qualitative and quantitative approach and use combination classification. One of the applied studies conducted on project selection is the one by (Eliat, 2008), in which projects were selected within the combinational framework of DEA and a balance score card was used to select proper research and development projects and one portfolio was ultimately selected from a list of 50 candidate projects for a research company that selects its research portfolio annually; this study showed that DEA can be used for the initial evaluation of projects. Fuzzy hierarchical analysis is another model used for the selection of project portfolios. (Huang et al., 2008) proposed the selection of project portfolios to be based on a multivariate decision-making problem and developed 27 criteria for evaluating portfolios through a fuzzy model. One of the advantages of Huang’s model is that it uses the fuzzy logic to evaluate the projects.

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(Asousheh et al., 2004) presented a management model for selecting technology projects using the model proposed by (Eliat, 2008)and used a balance score card as an extensive framework for evaluating the criteria of technology projects and information.

(Bhattacharyya et al., 2011) discussed the selection of research project portfolios using a fuzzy approach and used one multi-objective planning to facilitate decision-making and the selection of projects. The purpose of their model was to maximize income and minimize costs and risks and they also regarded the correlation between the projects and solve the problem using a genetic algorithm. (Chang and Lee, 2012) used an integrated model of the fuzzy data envelopment analysis Rucksack problem to select a project portfolio and solved the problem using the Pareto algorithm after formulation. The data were first prepared to be entered into the Rucksack problem using fuzzy variables and the problem was then solved using artificial bee colony algorithm.(Ghapanchi et al., 2012) presented a method for the selection of project portfolios and took account of the interaction between the projects and the uncertainty parameter. (Sheikhrabori et al., 2012) presented a reliable and efficient method for prioritizing project portfolios in an electric company. This method composed of two steps; the ANP model was used in the first step and the results obtained were considered as the input of the second step; in the second step, the best project portfolio was selected using the DEA model. The use of qualitative and quantitative data and taking account of the correlations in the problem of project portfolio selection are some of the advantages of the proposed method and fuzzy logic and fuzzy numbers were thus recommended to be used in future studies.

(Nassif et al., 2012) presented a method for project selection in the field of IT using support decision-making instruments based on the fuzzy logic. They ran a case study of the presented model that involved (1) The identification of the projects; (2) Examining the relationship between the projects and the strategic plans; (3) Project classification; (4) Defining the linguistic variables and the fuzzy functions; (5) Defining the rules; (6) Calculating the rules; and (7) Creating a balance in the project portfolio. In a study, (Abbasianjahromi and Rajaie, 2013) proposed a hybrid model based on fuzzy and goal linear planning and calculated the projects' risk value by weighing the method and finally calculated the optimal point of risk and income balance based on the current status of the company and previous successful experiences. (Martinsuo et al., 2014) proposed a framework for uncertainties and their management in project portfolios and discussed how managers can better take uncertainty into account in their planning. In an article, (Abbassi et al., 2014) developed an integrated framework for research project evaluation through the system theory approach and using the results of a technology roadmap. Their research intended to examine the problem of selecting projects with regard to qualitative and quantitative aspects and using hybrid methods and took advantage of qualitative

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instruments, such as the balance score card, panels and questionnaires, as well as quantitative instruments, such as statistical analyses and optimization.

(Pajares and López, 2014) presented a research method for studying the interactions between research projects and showed that the configuration of the company's project portfolio changes significantly when these interactions are also taken into account. They identified checklist, multi-criteria scoring and mathematical models as the most common evaluation methods. (Tavana et al., 2013) proposed a fuzzy group DEA model for high-technology project selection in a real case study. In their study vagueness was resolved with multi-objective fuzzy linear programming and ambiguity was resolved with fuzzy sets and logic.(Hassanzadeh et al., 2014) developed a multi-objective binary integer programming model for R&D project portfolio selection with competing objectives for when problem coefficients in both objective functions and constraints are uncertain. In another study, they developed and evaluated a business support tool to help a contract research organizations (CRO) decide on clinical R&D project opportunities and revise its portfolio of R&D projects given the existing constraints and the financial and resource capabilities (Hassanzadeh et al., 2014).

(Altuntas and Dereli, 2015) presented a new method based on the DEMATEL and PCA (Patent Citation Analysis) to prioritize project portfolios in investment projects. (Tavana et al., 2015) tried to select an optimal project portfolio through three main stages. In the first stage, purposes, projects and criteria of evaluation were identified; projects were evaluated using the DEA. In the second stage, projects were ranked using the fuzzy TOPSIS method. In the last stage, planning was used to select the project portfolio and the TOPSIS method was used to determine the optimal choice according to the decision makers' opinion. (Fernandez et al., 2015) proposed the Non-Outranked Ant Colony Optimization II method, which incorporates a fuzzy outranking preference model for optimizing portfolio problems with partial-support features. (Tahri, 2015) presented two numerical methods for mathematical optimization problems both for single and multiple objectives (ILP and IGP) using the two values (0 and 1) as the decision variable. (Huang et al., 2016) discussed the joint problem of optimal project selection and scheduling in situations when the projects' initial outlays and net cash inflows are determined by experts estimates due to the lack of historical data. (Roland et al., 2016) performed a project portfolio selection that was evaluated by multiple experts; the problem discussed in their study consisted of selecting a subset of projects that satisfied a set of constraints and represented a compromise among the group of experts.

This study determined the efficiency and ranking of the candidate projects using a hybrid methodology based on risk-efficiency and after assessing the projects in terms of the evaluative criteria and measuring their values using DEA. The projects' risk was evaluated and analyzed using a FANP. The conceptual model of the project portfolio

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selection was ultimately designed with a risk-efficiency approach and the model was optimized for the optimal selection of project portfolios. With this introduction and literature review, the second section here discusses the development of a methodology for decision-making using an integrated method based on efficiency-risk for the selection of project portfolio. In the third section, Mobarakeh Steel Co. is introduced as a case study. The fourth section prepares a solution procedure according to B&B method. The fifth section discuses computational experiments and results and finally, conclusions are presented in section six.

2. Develop a methodology for decision making

In this article, an integrated methodology based on efficiency-risk is used for the selection of project portfolios; this methodology uses the evaluative criteria, concepts, project risks, multi-criteria decision-making (including DEA and FANP) and MONLP to achieve this purpose. Some of the techniques used are described in the following. Figure 1 illustrates flowchart of the proposed decision making methodology and different steps in this research. All steps are described well in the rest of this section.

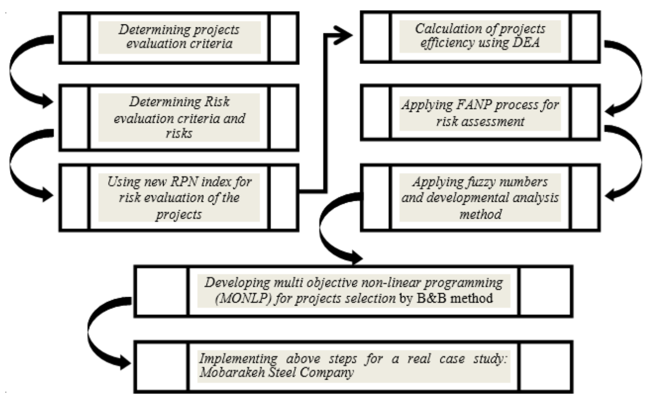

Figure 1. Flowchart of the decision making steps in this research

2.1. Projects evaluation criteria

(Dutra et al., 2014) presented a summary of the criteria used for selecting projects that meet certain evaluative criteria and classified them into an endogenous and an exogenous class. Based on a review of literature, this paper uses the following evaluation criteria for project selection: Improve competitiveness, strategic alignment, social benefits, relation to other projects, staff requirements, market potential, overall profitability, technical significant of the project, invest return, complexity of the project, execution time, ease of implementation, degree of innovation, project scope, overall investment, infrastructure requirements and technological costs.

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2.2. Risk evaluation criteria and risks

There are always risks in the successful implementation of projects. The most important risks include changes in the inflation rate, currency changes, subsidy changes, changes in government policies, international restrictions, risk complexity of designs, shortage of skilled manpower, risks pertaining to the contract, risk of changes in the scope, and execution time of projects and risks pertaining to weather conditions. In most of the reviewed studies, the risk number was calculated based on the two criteria of impact and probability; that is to say, the difficulty or readiness of reaction measures and the occurrence of each risk do not affect the calculation of the risk number. A unique innovation of this study is that it calculates risk based on four criteria rather than two, namely impact, probability, manageability and proximity, and the risk number is obtained by Equation 1:

$$RPN = \text{probability} \times \text{impact} \times \text{manageability} \times \text{proximity} \qquad (1)$$

To measure the probability × severity of each risk based on its probability of risk in either of the classes (Very Low, Low, Medium, High and Very High) and the effect of the risk's occurrence on the project goals (in terms of time, cost and quality), how much is (Very Low, Low, medium, High and Very High). Table 1 presents the points of interest.Depending on risk distance to the current time, the factors to modify the risk number as proximity are extracted from Table 2 and are multiplied by the numbers derived from Table 1.Ultimately, Table 3 presents how hard or easy an action plan for controlling risks is as a manageable number and the multiplication obtained by multiplying the previous step by RPN is achieved.

Table 1.Points probability × severity (*P* × *I*)

		Impacts				
		Very Low	Low	Medium	High	Very High
Probability	Very High	6	12	18	36	72
	High	5	7	14	28	56
	medium	3	5	10	20	40
	Low	2	3	6	12	24
	Very Low	1	1	2	4	8

Table 2.Risk Proximity

	Factor	Proximity
Overdue	1	<=0
Imminent	1	>0
Mid Term	0.9	>60
Distant	0.8	>180

Table 3.The rating of the risk Manageability

Manageability	Factor	Description
Difficult	0.9	Requires many change
Moderate	1	Requires some change
Easy	1.1	Requires minimal change

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2.3. Calculation of projects efficiency using DEA

DEA is a non-parametric model used to estimate efficiency degree and ranking. DEA is an instrument for measuring efficiency or the capacity to have an input and an output and even several inputs and outputs using the outputs' weighed sum to the inputs' weighted sum ratio. Equation 2 presents the basic DEA model named after Charles, Cooper and Rhodes (the CCR model).

$$\begin{aligned}
&Max \frac{\sum_{r=1}^{s} U_r Y_{ro}}{\sum_{i=1}^{m} V_i X_{io}} \\
&St: \\
&\quad \frac{\sum_{r=1}^{s} U_r Y_{rj}}{\sum_{i=1}^{m} V_i X_{ij}} \le 1 \qquad \forall j \\
&\quad U_r \ge 0 \\
&\quad V_i \ge 0
\end{aligned} \tag{2}$$

Parameters and variables in this model are:
n : number of decision making units
m : number of input criteria
s : number of output measures
X_{ij} (i = 1,2,...,m) : the i-th input to the j-th project (j = 1,2,...,n)
Y_{rj} (r = 1,2,...,m) : the r-th output to the j-th project (j = 1,2,...,n)

The objective function of this model tends to maximize the efficiency of each project, i.e., it maximizes the sum of the outputs' weight divided by the sum of the inputs' weight. The model constraint shows that the efficiency value of all of the decision-making units is less than one.

2.4. FANP process

In this section, we aim to assess and analysis risk of the projects using FANP. For this purpose, the exact efficiency number of each project was calculated based on the four criteria of impact, probability, manageability and proximity; the risk number was adjusted with two new criteria, namely manageability and proximity, and was calculated for each project using FANP.FANP was developed in 1971 by Saati with the aim of organizing decision-making processes in a scenario affected by several independent factors. This technique improves AHP as a multivariate decision-making instrument by replacing networks with hierarchies.

Note: *Due to some weaknesses for extended AHP method (Wang et. al., 2008), we aim to apply ANP algorithm for hierarchical processing in this research.*

2.5.Fuzzy numbers and developmental analysis method

After determining the most important criteria, each identified criterion is prioritized. The opinions about the pair-wise comparisons' matrix in should be used for the prioritization. Although experts use their mental faculties to perform comparisons, it should be noted that AHP and ANP cannot thoroughly affect human thoughts. In other words, using fuzzy sets is more consistent with humans' linguistic

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faculties and long-term predictions and decision-making in the real world are better be performed with fuzzy sets.

The numbers used in this method are triangular fuzzy numbers. Different methods are proposed to rank fuzzy numbers and each method has its advantages and disadvantages. The α-cut method is a common one. The central ranking method is sometimes used to rank fuzzy numbers. Extent analysis (EA) is another common method for AHP, and is used in this article

2.6.Multi objective non-linear programming (MONLP):

This model has its limitations and its objective functions are nonlinear or linear and composed of several objective functions. The general form of these models is shown in Equation 3:

$$\begin{aligned} & && F(x): \text{nonlinear equations} \\ \text{Max or Min} \quad & z_1 = f_1(x) && \\ & z_2 = f_2(x) && \\ & \ldots\ldots && \\ & z_k = f_k(x) && \\ & && G(x): \text{nonlinear equations} \\ \text{st}: \quad & && \\ & g_1(x) \leq \geq b_1 && \\ & g_2(x) \leq \geq b_2 && \\ & \ldots. && \\ & g_m(x) \leq \geq b_m && \\ & x \geq 0 && \end{aligned} \qquad (3)$$

The objective functions used in this study are maximizing efficiency and minimizing risk as per the limitations defined in organizations that have several projects.

3. Description of a real case study

Mobarakeh Steel Co. is a leading Iranian company producing steel sheets. This company is built up of seven industrial complexes scattered around the country and has more than 20,000 employees at its different sections. One of the most important decision-making issues in the engineering unit of this company is the selection of optimal project portfolios for investment on a regular basis. The integrated conceptual modeling and portfolio optimization methodology based on risk-efficiency is a suitable option for selecting portfolios for this organization and this company is taken as a real case study in this paper.

Step 1: The contributing factors and their values are determined using expert surveys and literature review on the selection of project portfolios for Mobarakeh Steel Co. Table 4 presents the criteria and values for all the candidate projects for the selection of an optimal project portfolio. These projects are based on the organizational objectives, the annual budget and the production requirements for planning, implementation and deployment.

DOI: 10.24818/18423264/52.1.18.16

Table 4.Mobarakeh steel Co. investment portfolio

row	project title	Total Cost (million Rials)	Number of human resources	Estimated time (months)	Rate of return IRR	In accordance with strategic objectives
1	Development of raw materials storage yard	80.000	20	14	22%	1
2	Construction of new mill of pelletizing area	2.500	25	7	24%	2
3	Construction of dust dry and wet collectors of Iron making area	3.500	10	20	20%	3
4	Designing and installation of new disks of pelletizing area	2.000	8	18	25%	1
5	Supply, installation and commissioning of two 40-ton cranes to air cooling	152.000	8	8	27%	1
6	Increasing the capacity of Direct reduction plants	5.500	7	6	30%	3
7	construction of the 320-ton crane for steel making area	59.755	15	24	21%	3
8	Increasing the mold thickness of continuous casting machines	3.100	4	10	28%	3
9	Installation and commissioning of second station of RH-TOP unit	1.920	6	12	24%	2
10	Implementation of alarm systems and fire suppression in coilers 1 to 3 rolled and hydraulic system H16	7.800	5	16	18%	2
11	Purchase and installation of new descaling devices	48.000	10	6	23%	2
12	Purchase of dechoker of reserved hot rolling area	11.120	12	4	26%	1
13	Machining and installation of new balancing blocks shelf for Hot rolling area	8.000	18	12	22%	1
14	revamping of Preheating furnaces for Hot rolling area	6.900	9	8	25%	2
15	Surface water collecting channel of warehouse equipment	5.100	15	12	28%	1
16	Designing and installation of coating cabin for color coating line	4.400	6	4	23%	2
17	Designing and construction of centralized automated packing line	4.310	10	7	30%	2
18	revamping of galvanizing line of cold rolling area	1.980	8	9	22%	3
19	Purchase and installation of thickness gauge system	1.500	17	10	30%	1
20	Processing of hot slag	1.200	22	8	27%	1
21	Construction new central pump station for fire-fighting	74.370	5	4	23%	2
22	Installation of ladle furnace unit 8	12.000	4	5	25%	2

Step 2: Indicators are obtained from the output of the previous step and are considered an input in order to use DEA and the efficiency of the projects is calculated in Lingo. Table 5 presents the results pertaining to the efficiency numbers of all the candidate projects and the efficient and inefficient projects are thus identified.

Table 5. Results candidate project portfolio efficiency

row	Project Title	Anderson efficiency Peterson
1	Development of raw materials storage yard	0.273579
2	Construction of new mill of pelletizing area	0.9966659
3	Construction of dust dry and wet collectors of Iron making area	0.6698413
4	Designing and installation of new disks of pelletizing area	0.9398855
5	Supply, installation and commissioning of two 40-ton cranes to air cooling	0.6328125
6	Increasing the capacity of Direct reduction plants	1.135739

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7	construction of the 320-ton crane for steel making area	0.3484848
8	Increasing the mold thickness of continuous casting machines	1.754366
9	Installation and commissioning of second station of RH-TOP unit	1.133599
10	Implementation of alarm systems and fire suppression in coilers 1 to 3 rolled and hydraulic system H16	0.5333333
11	Purchase and installation of new descaling devices	0.6666667
12	Purchase of dechoker of reserved hot rolling area	1.130435
13	Machining and installation of new balancing blocks shelf for Hot rolling area	0.4108054
14	revamping of Preheating furnaces for Hot rolling area	0.6475324
15	Surface water collecting channel of warehouse equipment	0.647225
16	Designing and installation of coating cabin for color coating line	1.117029
17	Designing and construction of centralized automated packing line	1.006669
18	revamping of galvanizing line of cold rolling area	1.515152
19	Purchase and installation of thickness gauge system	1.117489
20	Processing of hot slag	1.157353
21	Construction new central pump station for fire-fighting	1.060403
22	Installation of ladle furnace unit 8	1.250226

Step 3: The first project's risks are identified and the weight coefficient of the risks is determined using FANP. The results were calculated and are shown in Table 6.

Table 6.The greatest influence risk factor by FANP

Weight factor	ANP
Changes in inflation rate	0.21854
Change Currency	0.209748
Subsidy	0.114548
Changes in government policies	0.348652
International restrictions	0.083795
Risk complexity of design	0.250951
The risk of lack of skilled manpower	0.325365

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Risks related to contract	0.127656
Risk of changes in the scope and running time	0.288028
Risks related to weather conditions	0.032716

Using tables 1, 2, 3 and 6 and the comments of Mobarakeh Steel Co. project managers, the risk number is calculated using the below equation and the significance coefficients of the risk effect then using the FANP. For this purpose, the RPN of any risk is first calculated. The significance coefficients of the risks are then obtained as shown in Table 6. The weighted average of the RPN is calculated as per Equation 1 and as the risk number of each project. Table 7 presents the results.

Table 7.Number of the candidate project risk

project	1	2	3	4	5	6	7	8	9	10	11
RPN	18.8	27.3	12.9	14.3	20.6	16.4	22.8	21.9	14.5	17.5	19.8
project	12	13	14	15	16	17	18	19	20	21	22
RPN	19.6	18.1	14.4	10.9	17.4	30.4	21.2	33.7	33	31.5	31.4

Step 4: A multi-objective nonlinear planning model seeking to maximize the efficiency number and minimize the risk number of the candidate project portfolios with regard to the organization's constraints on manpower and budget is presented in Equations4 to 8 and the model is implemented in Matlab. After this problem is solved, the optimal portfolio is obtained. Steps 1 to 4 of this article are repeated whenever a new project is added to the list of candidate projects.

$$\text{efficiency objective function Max } z_1 = \sum_{i=0}^{22} \left[(\text{Project effectiveness of i}) \times x_i \right] \quad (4)$$

$$\text{Risk objective function Min } z_2 = \sum_{i=0}^{22} \left[(\text{Project risk number i}) \times x_i \right] \quad (5)$$

$$\text{St}: \quad \sum_{i=0}^{22} \left[(\text{estimated project cost i}) \times x_i \right] \leq 200000 \quad (6)$$

$$\sum_{i=0}^{22} \left[(\text{human project that the number of i}) \times x_i \right] \leq 110 \quad (7)$$

$$x_i = \begin{cases} 1, & \text{if project i is selected} \\ 0, & Otherwise \end{cases} \quad (8)$$

4. Solution procedure

In order to solve the proposed MONLP model, first we should transfer it to a single objective model. For this purpose, bounded objective approach will be applied in which the first objective will be optimized while the second objective will be considered as a constraint by satisfying an upper bound for maximum risk. Therefore, the proposed model will be transferred to a single objective model where it will be solved by branch and bound (B&B) algorithm. In order to use B&B algorithm, the model must be reformed based on the standard version. In a standard version, three constraints must be satisfied. 1) The objective function must be minimization. 2)

DOI: 10.24818/18423264/52.1.18.16

Coefficients of variables must be positive. 3) The constraints must be formulated as ≤ ones. In the proposed model, the first constraint is not satisfied and so we correct it as follows.

$$\text{efficiency objective function Min } z_1' = \sum_{i=0}^{22}\left[\left(\text{- Project effectiveness of i}\right)\times x_i\right] \tag{9}$$

St: (6)- (7)- (8)

$$\sum_{i=0}^{22}\left[\left(\text{Project risk number i}\right)\times x_i\right]\le \beta \tag{10}$$

In above formulation, β is maximum acceptable level of risk for the decision maker of this problem which is equal to 0.75 according to the decision maker in this paper. Now, due to appeared negative coefficients in the new objective function and unsatisfying the second criterion, we introduce a new variable as follows and replace it in the model. The results are as follows.

$x_i = 1 - x_i'$

$$\text{efficiency objective function Min } z_1' = \sum_{i=0}^{22}\left[\left(\text{- Project effectiveness of i}\right)\times (1-x_i)\right] \tag{11}$$

$$\text{St}: \quad \sum_{i=0}^{22}\left[\left(\text{estimated project cost i}\right)\times (1-x_i)\right]\le 200000 \tag{12}$$

$$\sum_{i=0}^{22}\left[\left(\text{human project that the number of i}\right)\times (1-x_i)\right]\le 110 \tag{13}$$

$$\sum_{i=0}^{22}\left[\left(\text{Project risk number i}\right)\times (1-x_i)\right]\le \beta \tag{14}$$

$$x_i' \in \{0,1\} \tag{15}$$

By simplifying above formulation, final binary model in which satisfies all three stated criterions will be modeled as follows:

$$\text{efficiency objective function Min } z_1' = \sum_{i=0}^{22}\left[\left(\text{Project effectiveness of i}\right)\times x_i'\right] \tag{16}$$

$$\text{St}: \quad -\sum_{i=0}^{22}\left[\left(\text{estimated project cost i}\right)\times x_i'\right]\le 200000-\sum_{i=0}^{22}\left[\left(\text{estimated project cost i}\right)\right] \tag{17}$$

$$-\sum_{i=0}^{22}\left[\left(\text{human project that the number of i}\right)\times x_i'\right]\le 110-\sum_{i=0}^{22}\left[\left(\text{human project that the number of i}\right)\right] \tag{18}$$

$$-\sum_{i=0}^{22}\left[\left(\text{Project risk number i}\right)\times x_i'\right]\le \beta-\sum_{i=0}^{22}\left[\left(\text{Project risk number i}\right)\right] \tag{19}$$

$$x_i' \in \{0,1\}$$

In above model, all three right hand sides of the constraints are negative since all constraints are effective and they are not unnecessary. For example, it can be obviously found that 200000 which is maximum budget is less than cost of performing all projects. Now, we solve above model by B&B method according to the following procedure. In the first stage, we add one slack variable to each constraint as follows.

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$$\text{efficiency objective function Min } z_1' = \sum_{i=0}^{22}\left[(\text{Project effectiveness of i}) \times x_i'\right] \quad (16)$$

$$\text{St}: \quad -\sum_{i=0}^{22}\left[(\text{estimated project cost i}) \times x_i'\right] + S_1 = 200000 - \sum_{i=0}^{22}\left[(\text{estimated project cost i})\right] \quad (20)$$

$$-\sum_{i=0}^{22}\left[(\text{human project that the number of i}) \times x_i'\right] + S_2 = 110 - \sum_{i=0}^{22}\left[(\text{human project that the number of i})\right] \quad (21)$$

$$-\sum_{i=0}^{22}\left[(\text{Project risk number i}) \times x_i'\right] + S_3 = \beta - \sum_{i=0}^{22}\left[(\text{Project risk number i})\right] \quad (22)$$

$$x_i' \in \{0,1\}, S_j \geq 0$$

The ideal solution for above model is $X^0 = (0,0,...,0)$ while this solution is not an optimum feasible solution since none of constraints (20), (21), and (22) is not satisfied due to negative values for S_j. So, we must try to set value of some variables x_i' to level one where all S_j are positive and also the objective function is minimized. To do this procedure the following steps are conducted.

Step 0) Node 0 is a node in which all variables are still 0 and therefore all S_j are negative. The upper bound of the solution is $+\infty$.

Step 1)The variable with minimum coefficient in the objective is selected for the row 1. Branching on this variable is conducted where in one branch it is assumed to be zero and in the other branch it is assumed to be one. Now, we have two new free nodes. For each node, if a feasible solution by fixing each value for the selected variable is found (or all S_j are positive), the upper bound is updated by its objective function and the feasible node is closed.

Otherwise, the node is free for further computations. The variable which was selected in this step is removed from the model.

Step 2)**For** i=2 **to***n* (number of 0-1 variables) **Do**

Among remaining variables in the model, a variable with the minimum coefficient in the objective function is selected.

Branching on the free nodes based on the selected variable is conducted. Once new nodes are generated, value for S_j variables are computed for each node according to the constraints (20), (21), and (22) by fixing selected variables. Each new node can be closed by at least one of the following bounding methods.

*Type 1)*A node can be closed once its solution is feasible or values for S_j associated to this node are positive. In this way, if objective function for this node is less than upper bound of the problem, the new value for upper bound is replaced by it and the node is closed.

*Type 2)*If summation of current objective function for a node and coefficient in the objective function for the binary variable in the next iteration is greater than upper

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bound of the problem, the node is closed since branching on this node cannot give a better solution than upper bound.

Type 3) In this method, we close some nodes that we are sure branching on them cannot give even a feasible solution and they are certainly infeasible at the end of the algorithm. In this way, a constraint will be infeasible even if all remaining binary variables get value 1. For this purpose, three formulations are presented and each node is closed if at least one of them is satisfied. In these formulations, $\overline{x_i'}$ denotes value for the binary variables that are fixed previously through the branching process until the current iteration. Also, $\overline{\overline{x_i'}}$ denotes binary variables that are not still inserted in the B&B method and we aim to set them at level 1 by considering worst case conditions in a minimization problem.

$$\begin{aligned} &200000-\sum_{i=0}^{22}\left[(\text{estimated project cost i})\right]+\sum_{i=0}^{N}\left[(\text{estimated project cost i})\times\overline{x_i'}\right] \\ &+\sum_{i=0}^{N'}\left[(\text{estimated project cost i})\times\overline{\overline{(x_i'=1)}}\right]\le 0 \end{aligned} \tag{23}$$

$$\begin{aligned} &110-\sum_{i=0}^{22}\left[(\text{human project that the number of i})\right]+\sum_{i=0}^{N}\left[(\text{human project that the number of i})\times\overline{x_i'}\right] \\ &+\sum_{i=0}^{N'}\left[(\text{human project that the number of i})\times\overline{\overline{(x_i'=1)}}\right]\le 0 \end{aligned} \tag{24}$$

$$\begin{aligned} &\beta-\sum_{i=0}^{22}\left[(\text{Project risk number i})\right]+\sum_{i=0}^{N}\left[(\text{Project risk number i})\times\overline{x_i'}\right] \\ &+\sum_{i=0}^{N'}\left[(\text{Project risk number i})\times\overline{\overline{(x_i'=1)}}\right]\le 0 \end{aligned} \tag{25}$$

N is number of variables that are entered into the process and *N'* in number of variables that are not entered into the B&B. By using above bounding methods, some nodes are closed and some of them will be still free. So, the selected variable in the current step is removed from the model and step 2 will be continued for other iterations and variables until the termination condition is satisfied.

Termination condition: The algorithm will stop once in an iteration and after branching on a variable, all nodes are closed and no free node is available for further variables.

Step 3) After satisfying termination condition in the step 2, we can find value of the decision variables. The optimal solution is the best solution among all nodes that are closed by bounding type 1 and makes the last upper bound. By using optimal node, for variables that are computed by branching process, final value is based on the given value by B&B. For variables that are not computed by B&B method due to satisfying termination condition, their value is zero.

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5. Computational experiments

Above solution procedure is coded and run by Matlab software. The results obtained after solving the model are shown in Table 8. The rows of this table show the candidate projects for the portfolio and the columns show the binary variables for each project. If equaling 1, they are placed in the optimal portfolio; if equaling zero, they are not qualified for placement in the optimal portfolio.

If the decision variables (X_i) show that the optimal solution is zero, the corresponding project cannot be placed in the optimal portfolio project; if the decision variables (X_i) show that the optimal solution is one, the project can be placed in the optimal portfolio with a maximum efficiency and a minimum risk.

Table 8. Result of optimal solution

Row	Subject	Decision variable	Solution Value	Description
1	Offer project 1	X1	0	The project does not have conditions placed on portfolio optimization projects
2	Offer project 2	X2	0	The project does not have conditions placed on portfolio optimization projects
3	Offer project 3	X3	1.0000	The project is selected for optimal portfolio
4	Offer project 4	X4	1.0000	The project is selected for optimal portfolio
5	Offer project 5	X5	0	The project does not have conditions placed on portfolio optimization projects
6	Offer project 6	X6	1.0000	The project is selected for optimal portfolio
7	Offer project 7	X7	0	The project does not have conditions placed on portfolio optimization projects
8	Offer project 8	X8	1.0000	The project is selected for optimal portfolio
9	Offer project 9	X9	1.0000	The project is selected for optimal portfolio
10	Offer project 10	X10	1.0000	The project is selected for optimal portfolio
11	Offer project 11	X11	1.0000	The project is selected for optimal portfolio
12	Offer project 12	X12	1.0000	The project is selected for optimal portfolio
13	Offer project 13	X13	0	The project does not have conditions placed on portfolio optimization projects
14	Offer project 14	X14	1.0000	The project is selected for optimal portfolio
15	Offer project 15	X15	0	The project does not have conditions placed on portfolio optimization projects
16	Offer project 16	X16	1.0000	The project is selected for optimal portfolio
17	Offer project 17	X17	1.0000	The project is selected for optimal portfolio
18	Offer project 18	X18	1.0000	The project is selected for optimal portfolio
19	Offer project 19	X19	0	The project does not have conditions placed on portfolio optimization projects
20	Offer project 20	X20	0	The project does not have conditions placed on portfolio optimization projects
21	Offer project 21	X21	1.0000	The project is selected for optimal portfolio
22	Offer project 22	X22	1.0000	The project is selected for optimal portfolio

The optimal solution model is presented here. Projects 3, 4, 6, 8, 9, 10, 11, 12, 14, 16, 17, 18, 21 and 22 with an integrated efficiency-risk approach are placed in the optimal project portfolio. It should be noted that all the steps of preparing the questionnaire and the optimal portfolio are conducted by experts at Mobarakeh Steel Co. According to the maximum efficiency and minimum cost of the project portfolios with regard to

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synchronization, predecessor and incompatibility projects and the exact solution model, the proposed methodology is valid and reliable.

6. Results& Conclusion

The main project portfolio management stage is the selection of the optimal portfolio and the main difference between portfolio management and project or program management lies in this stage. This article used the concepts of DEA, ANP, risk, fuzzy logic and MONLP modeling to propose an applied methodology for extracting an optimal portfolio of projects. The advantages and outcomes of this methodology include the calculation of the projects' efficiency and the determination of efficient and non-efficient projects, the calculation of the risk of each project and the determination of high-risk projects using FANP to solve uncertainties and the study of the relation between the dependent risks, the calculation of the risk number using the four criteria of impact, probability, manageability and proximity, assessing project risk and using MONLP modeling to combine qualitative and quantitative criteria for the selection of an optimal project portfolio. Some constraints were also defined in this study, such as synchronization, predecessor and incompatibility projects and binary decision variables for conceptual modeling were also used for selecting the optimal project portfolio.

The case study presented on the investment projects of Mobarakeh Steel Co. based on the proposed integrated methodology yielded the following results in brief:
Of the 22 candidate projects, 10 projects are efficient. Of the 10 efficient projects, the risks of investment for Mobarakeh Steel Co., the risk of changes in governmental policies has the highest coefficient. According to the results obtained through calculating the risk number of the projects, projects 19 and 20 have the highest risk number. In the MONLP model of this company, the objective functions maximize efficiency and minimize the risk of the project portfolio and the constraint functions discuss the existing budget and manpower limitations. Once the model was solved, the optimal project portfolio was selected with 14 projects from the total of 22 projects assessed.

The results obtained in the present study can pave the way for future studies on how to include probable nonlinear constraints in the proposed methodology for the selection of optimal project portfolios, clustering of the projects for the optimal portfolio based on a hybrid efficiency-risk approach for better management using data mining techniques, using statistical control charts based on a hybrid efficiency-risk approach to set up and edit schedules and budgeting for the projects and to devise a methodology for the planning and control of the optimal project portfolio based on a efficiency-risk approach.

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