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RESEARCH NOTE

Power Plant Project Risk Assessment Using a Fuzzy-ANP and Fuzzy-TOPSIS Method

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ABSTRACT

Economic growth in developing countries has led in increasing demand for infrastructure projects like power plants. In order to respond to these development needs, the government of Iran has engaged several companies to carry out power plant projects. While many papers have been published on the subject of project risk management, little information exists on the actual use of risk management in practice. The primary objective of this paper is to identify and rank the risks in these power plant projects. The proposed model allows risks to be ranked based on management priorities using a combined fuzzy analytic network process (fuzzy-ANP) and fuzzy Technique for Order Preference by Similarity to Ideal Solution (fuzzy-TOPSIS) method. In classical approaches, Probability and Impact are two commonly used criteria in project risk ranking. However, these criteria do not sufficiently address all aspects of project risk. Moreover, there may be relations and dependencies among the various criteria. Therefore, we proposed a hierarchical structure for ranking risk in power-plant projects. The proposed structure can consider dependence among the different criteria. We use fuzzy-ANP for calculating weights. The outputs of fuzzy-ANP calculations are used in a fuzzy-TOPSIS procedure for the evaluation of important risks. A case study of a power plant project is presented to demonstrate the applicability and performance of the proposed model. More than 100 risks were identified and categorized according to their source and to their relative impact on the project. We evaluated important risks using the fuzzy-ANP and fuzzy-TOPSIS method. In addition, we used a sensitivity analysis to discuss and explain the results of the method. The proposed method is a suitable approach when performance ratings and weights are vague and imprecise.

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1. INTRODUCTION

Risk appears in all aspects of our lives. According to the Project Management Body of Knowledge definition, risk is defined as an uncertain event or condition that has a potential effect on at least one project objective [1]. The purpose of risk management is to improve project performance by systematically identifying and assessing risks, developing strategies to reduce or avoid them and maximizing opportunities [2]. There has been some discussion about the relative importance of different phases of the Risk Management Process (RMP). According to Conrow [3], "all RMP steps are equally important. If you do not do one or more steps, or you do them poorly, you will likely have an ineffective RMP." There is a consensus that the RMP must include two main phases [4]. The first phase is Risk Assessment (RA), including risk identification and risk analysis. The second phase is Risk Response (RR). The initial phases of RMP play a fundamental role and the later phases of RMP play a throughout role. Focusing on one phase and ignoring the other disrupts the RMP. Many researchers have emphasized the importance of RA. Miler [4] states that effective RMP begins with effective RA. Additionally, one cannot manage risks if one does not characterize them and identify what they are, how likely they are, and what their impact might be [5]. On the other hand, many researchers have emphasized the importance of RR. Chapman and Ward [6] are of the opinion that deciding how identified risks will be responded to is critical. Hillson [7] states "identification and assessment will be worthless unless responses can be developed and implemented which really make a difference in addressing identified risks."

Although many papers have been published on the subject of risk management, little information exists on the actual use of risk management in practice [8].

The main objective of this paper is to identify and rank risks in power plant projects. Economic

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development in any region of the world is closely related to availability of energy [9]. In industrialized countries, demand for electrical power is rapidly developing [10]. To meet the development needs, the government of Iran has engaged companies to carry out power plant projects. Power plant projects in Iran are usually done by Engineer-Procure-Construct (EPC) contractors who do the design, engineering, procurement and construction of projects as a whole. The complexity of these projects requires high-level interaction and integrity between each phase of RMP. Ballard [11] noted that EPC projects should not be performed sequentially and in separate phases; instead, the interdependencies and tradeoffs between phases should be considered. A non-overlapping sequence between design, procurement and construction will encourage a misconception that leads to low integrity and interaction between phases and therefore reduces productivity. EPC projects face a number of challenges, including interdependence of activities, phase overlap, work fragmentation, complex organizational structure, and uncertainty in the accurate prediction of desired outcomes [12].

The proposed model allows risks to be ranked for management priority using a combined fuzzy-ANP and fuzzy-TOPSIS method. The remainder of this paper is organized as follows:

In Section 2, the risk assessment, and fuzzy-ANP literature is briefly reviewed. The proposed model for project risk assessment is described in Section 3. In Section 4, a case study is presented to show the applicability and performance of the proposed model. Finally, in Section 5, the results of the application are presented and suggestions for future studies are discussed.

2. LITERATURE REVIEW

2.1. Project Risk Assessment The science of risk management was developed in the sixteenth century, during the Renaissance. Since 1990, various studies have proposed processes for project risk management [13, 14]. Some studies used a detailed process for specification planning, while others used a modified process for evaluating the risk ranking of various projects. The general project risk management process consists of two main phases. The first phase is Risk Assessment (RA), which includes risk identification and risk analysis. The second phase is Risk Response (RR). In the risk identification phase, the main methodologies are brainstorming, document review, Delphi technique, checklist analysis, and assumptions analysis [15]. Brainstorming is the most common risk-identification technique used in practice [16].

An integrative part of risk identification is risk classification, which attempts to structure the diverse risks affecting a project. Many approaches have been suggested for classifying risks. Perry & Hayes [17] presented a list of factors extracted from several sources divided in terms of risks retainable by contractors, consultants and clients. Cooper & Chapman [18] classified risks according to their nature and magnitude. They grouped risks into primary and secondary categories. Tah et. al [19] used a risk-breakdown structure to classify risks according to their origin and their relative impact in the project. Merna & Smith [20] categorized risks as "global" or "elemental". Global risks are those that are normally allocated through the project agreement and typically include political, legal, commercial and environmental risks, whereas elemental risks are those associated with the construction, operation, finance and revenue generation components of the project. Carr & Tah [21] classified risks using a hierarchical risk-breakdown structure (HRBS). Chapman [22] grouped risks into four subsets, environmental, industrial, client and project. Chapman & Ward [6] discuss the nine categories of risk that face any infrastructure project. These risks include technical, construction, operating, revenue, financial, force majeure, regulatory/political, environmental, and project default. In general, there are many ways to classify the risks associated with projects, and the rationale for choosing a method must serve the particular purpose of the research [23].

Risk analysis methods can be divided into qualitative and quantitative methods. The former includes subjective analysis of probability and impact using a probability and impact matrix, while the latter includes sensitivity analysis, expected monetary value analysis, decision-tree analysis using utility theory, simulation, cause-and- effect diagrams, influence diagrams, game theory, fuzzy theory, fault-tree and event-tree analyses [15]. Zou et. al [23] analyzed the key risks in construction projects in China. A total of 25 key risks were identified based on a comprehensive assessment of their likelihood of occurrence and magnitude of consequence on project objectives. Zayed &Chang [24] used the concept of utility theory to drive the weighted expected value as a risk index of build-operate-transfer projects. Kang et.alet.al [25] used a dynamic multi-objective programming approach to establish a risk-assessment model and proposed an iterative algorithm for the model solution. Zeng et. al [26] used a modified analytical hierarchy process to structure and prioritize risk in construction projects.

Ebrahimnejad et. al [27] proposed a new model for BOT (build-operate- transfer) project risk ranking via fuzzy TOPSIS and Linear Programming for Multidimensional Analysis of Preference (LINMAP). Mousavi et. al [28] used the non-parametric jackknife resampling technique for risk assessment in highway projects. Furthermore, Mousavi et. al [29] proposed a novel approach based on non-parametric resampling with interval analysis for large engineering project risks.

A real case study in the bridge project for Tehran Municipality is conducted to illustrate the applicability of the proposed approach. Mojtahedi et. al [30] presented a new methodology for identifying and assessing risks simultaneously by applying multi-attribute group decision making technique. They proposed a new procedure for classifying potential risks based on project work breakdown structure. Nominal group technique is utilized for gathering potential risks. The results have been applied in a gas refinery plant project.

Because different methodologies exist in each process of project risk management, Cano & Cruz [31] recommended appropriate methodologies that take into account project scale, complexity, and organization risk maturity level. In many projects, it may be extremely difficult to analyze the risks associated with a project due to the great uncertainty involved.

2.2. Fuzzy Analytic Network Process The analytic hierarchy process (AHP), developed by Saaty, is essentially the formalization of our intuitive understanding of a complex problem using a hierarchical structure. The AHP enables the decision maker (DM) to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner with conflicting multiple criteria [32].

The crux of the AHP is to enable a DM to structure a multiple attribute decision-making (MADM) problem visually in the form of an attribute hierarchy. A hierarchy has at least three levels, which are as follows: focus or overall goal of the problem at the top, multiple criteria that define alternatives in the middle, and competing alternatives at the bottom.

The basic assumption of AHP is the condition of functional independence of the upper part, of the hierarchy, from all its lower parts, and from the criteria or items in each level. Many decision-making problems cannot be structured hierarchically because the involve interaction of various factors, with high-level factors occasionally depending on low-level factors [33]. Saaty suggested the use of AHP to solve the problem of independence among alternatives or criteria, and the use of ANP to solve the problem of dependence among alternatives or criteria [34]. The ANP, also introduced by Saaty, is a generalization of the AHP. Whereas AHP represents a framework with a uni-directional hierarchical AHP relationship, ANP allows for complex inter-relationships among decision levels and attributes. The ANP feedback approach replaces hierarchies with networks in which the relationships between levels are not easily represented as higher or lower, dominant or subordinate, direct or indirect [35]. For instance, not only does the importance of the criteria determine the importance of the alternatives, as in hierarchy, but also the importance of the alternatives may have impact on the importance of the criteria. Therefore, a hierarchical structure with a linear top-to-bottom form is not suitable for a complex system.

A good decision-making model needs to tolerate vagueness and ambiguity because these are common characteristics in many decision-making problems [36].The AHP method has been extended and applied to deal with fuzzy multiple criteria decision-making (MCDM) problems by various authors [37-45].

Fuzzy logic has many practical applications, but it involves complicated operations. The concept of fuzzy numbers originates from the fact that many qualitative phenomena in the real world can not be expressed by precise and certain numbers [46]. In applications, it is often convenient to work with triangular and trapezoidal fuzzy numbers because of their computational simplicity and because they are useful in promoting representation and information processing in a fuzzy environment [42].

The fuzzy prioritization approach, which was originally introduced by Mikhailov, has been used in many studies. This method has advantages over other fuzzy-AHP approaches. The most important of these advantages is the measurement of consistency indexes for the fuzzy pair-wise comparison matrices. In other fuzzy-AHP methods, it is not possible to determine the consistency ratios of fuzzy pair-wise comparison matrices without conducting an additional study [47]. The fuzzy prioritization approach can be summarized as follows [41]:

Suppose that the decision maker (DM) can provide a set $F=\{a_{ij}\}$ of $m \le n(n-1)/2$ fuzzy comparison judgments, $i=1,2,\dots,n-1,\ j=2,3,\dots,n,\ j>i$, represented as triangular fuzzy numbers $\tilde{a}_{ij}=(l_{ij},m_{ij},u_{ij})$.

The problem is to derive a crisp priority vector $w=(w_1,w_2,\dots,w_n)^T$, such that the priority ratios w_i/w_j are approximately within the scopes of the initial fuzzy judgments, or:

$$l_{ij} \tilde{\le} \frac{w_i}{w_j} \tilde{\le} u_{ij} \tag{1}$$

Each crisp priority vector w satisfies the above double-side inequality with some degree, which can be measured by a membership function, linear with respect to the unknown ratio w_i/w_j

$$\mu_{ij}\left(\frac{w_i}{w_j}\right)=\begin{cases}\dfrac{(w_i/w_j)-l_{ij}}{m_{ij}-l_{ij}}, & \dfrac{w_i}{w_j}\le m_{ij}\\[2ex] \dfrac{u_{ij}-(w_i/w_j)}{u_{ij}-m_{ij}}, & \dfrac{w_i}{w_j}\ge m_{ij}\end{cases} \tag{2}$$

In order to avoid dividing by zero, it is assumed that $u_{ij}>m_{ij}>l_{ij}$. The solution to the prioritization problem by the fuzzy preference programming (FPP) method is based on two main assumptions. The first one requires the existence of non-empty fuzzy feasible area

P on the (n-1)-dimensional simplex Q^{n-1}

$$Q^{n-1} = \{(w_1, w_2, ..., w_n), |w_i > 0, \sum_{i=1}^{n} w_i = 1\} \quad (3)$$

defined as an intersection of the membership functions, similar to (2) and the simplex hyperplane (3). The membership function of the fuzzy feasible area *P* is given by

$$\mu_P(w) = \min_{ij}\{\mu_{ij}(w),\ i = 1,2,...,n-1;\ j = 2,3,...,n;\ j > i\} \quad (4)$$

By defining the membership functions (2) as L-fuzzy sets $\{L = [-\infty, 1]\}$, the assumption of non-emptiness of *P* on the simplex could be relaxed. If the fuzzy judgments are very inconsistent, then $\mu_P(w)$ could take negative values for all normalized priority vectors $w \in Q^{n-1}$. The second assumption of the FPP method specifies a selection rule, which determines a priority vector, having the highest degree of membership in the aggregated membership function (4). It can easily be proved that $\mu_P(w)$ is a convex set, so there is always a priority vector $w^* \in Q^{n-1}$ that has a maximum degree of membership

$$\lambda^* = \mu_P(w^*) = \max_{w \in Q^{n-1}} \min_{ij}\{\mu_{ij}(w)\} \quad (5)$$

Taking into consideration the specific form of the membership functions (2), the maximin prioritization problem (5) can be transformed into a bilinear program of the type

$$\begin{aligned} &\max\ \lambda \\ &\textit{subject to}: \\ &(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \le 0, \\ &(u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \le 0, \\ &i = 1,2,...,n-1,\ j = 2,3,...,n,\ j > i, \\ &\sum_{k=1}^{n} w_k = 1, \quad w_k > 0,\ k = 1,2,...,n, \end{aligned} \quad (6)$$

The optimal value $\overset{*}{\lambda}$, if it is positive, indicates that all solution ratios completely satisfy the fuzzy judgments, which means that the initial set of fuzzy judgments is rather consistent.

In this study we prefer the extent fuzzy-AHP, which was originally introduced by Chang [39]. The steps of this approach are relatively easier than other fuzzy-AHP approaches and are similar to the crisp AHP. The steps of Chang's extent analysis can be given as follows:

Let $X = \{x_1, x_2, x_3, ..., x_n\}$ be an object set, and $G = \{g_1, g_2, g_3, ..., g_n\}$ be a goal set. According to the method of Chang's extent analysis, each object is taken and an extent analysis for each goal is performed. Therefore, *m* extent analysis values for each object can be obtained with the following signs [42, 43]:

$$M_{gi}^1, M_{gi}^2, ..., M_{gi}^m,\ i = 1,2,...,n, \quad (7)$$

where $M_{gi}^j\ (j = 1,2,...,m)$ all are triangular fuzzy numbers.

Step 1: The value of fuzzy synthetic extent with respect to the i^{th} object is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]^{-1} \quad (8)$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$, the fuzzy addition operation of *m* extent analysis values for a particular matrix is performed as

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (9)$$

To obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1}$, the fuzzy additional operation of $M_{gi}^j\ (j = 1,2,...,m)$ values is performed as

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad (10)$$

and then the inverse of the vector in the above equation is computed such that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (11)$$

Step2: The degree of possibility of $M2 = (l_2, m_2, u_2) \ge M_1 = (l_1, m_1, u_1)$ is defined as

$$V(M_2 \ge M_1) = \sup_{y \ge x} \left\lfloor \min(\mu_{M_1}(x), \mu_{M_2}(y)) \right\rfloor \quad (12)$$

And can be equivalently expressed as follows:

$$V(M_2 \ge M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1 & \text{if } m_2 \ge m_1 \\ 0 & \text{if } l_1 \ge u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \quad (13)$$

where *d* is the ordinate of the highest intersection point *D* between μ_{M_1} and μ_{M_2} (see Figure1). To compare M_1 and M_2, we need the values of $V(M_1 \ge M_2)$ and $V(M_2 \ge M_1)$.

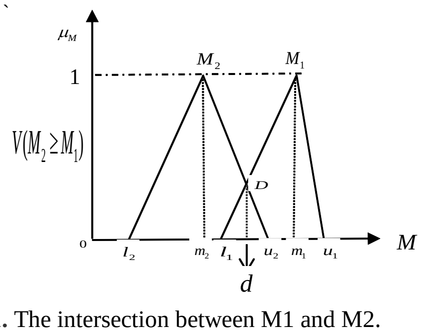

Figure 1. The intersection between M1 and M2.

Step 3: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy M_i (i=1,2,…,k) numbers can be defined by

$$V(M \geq M_1, M_2, ..., M_K) = V[(M \geq M_1) \\ and\ (M \geq M_2) and ... and\ (M \geq M_K)] = \min V(M \geq M_i),\ i = 1,2,3,...,k \quad (14)$$

Assume that $d'(A_i) = \min V(S_i \geq S_k)$ $for\ k = 1,2,,...,n;\ k \neq i.$

Then the weight vector is given by

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T \quad (15)$$

where A_i (i=1,2,…,n) are n elements.

Step 4: The normalized weight vectors are

$$d(A_i) = \frac{d'(A_i)}{\sum_{i=1}^{n} d'(A_i)} \\ W = (d(A_1), d(A_2), ..., d(A_n))^T \quad (16)$$

where W is a non-fuzzy number.

Fuzzy-ANP has been used in solving many complicated decision- making problems because it is a comprehensive multi-purpose decision method. Dagdeviren et. al [34] developed a fuzzy-ANP model to identify faulty behavior risk in work system. Dagdeviren and Yuksel [47] developed a fuzzy-ANP model for measurement of the sectoral competition level. Mikhailov and Singh [48] used fuzzy-ANP to the development of decision support systems. Guneri et. al [49] developed a fuzzy-ANP approach to shipyard location selection. Boran and Goztepe [50] proposed a fuzzy decision support system for commodity acquisition using fuzzy-ANP. Yuksel and Dagdeviren [51] proposed a fuzzy-ANP model for Balanced Scorecard (BSC). In their study, BSC approach was integrated with fuzzy-ANP technique to determine the performance level of a business on the basis of its vision and strategies.

3. PROPOSED FRAMEWORK FOR PROJECT RISK IDENTIFICATION AND ASSESSMENT

Our literature review shows that some researchers have identified risk from only one participative point of view. In this study, the initial objective is to present risks in power plant projects. Therefore, an appropriate hierarchical structure of risks is presented which facilitates identifying and assessing risk in power plant projects.

On the other hand, in previous studies probability and impact are two commonly used criteria in project risk ranking. These two risk measures describe risk events which means that other risk measures are not addressed at all [52]. However, these criteria alone do not sufficiently cover all aspects of project risk [27]. Conrow [3] states that "it is not appropriate to discuss risk in terms of probability of occurrence and consequence of occurrence." On the other hand, MADM gives an opportunity to take advantage of suitable criteria in order to increase the precision of final risk rankings [27]. Therefore, we proposed a hierarchical structure for project risk ranking. The proposed structure can consider dependence among the different criteria.

Under many conditions, crisp data are inadequate for modeling real-life situations. Human judgments, including preferences, are often vague. Thus, one cannot represent preference with an exact numerical value. A more realistic approach may be to use linguistic assessments. In other words, the ratings and weights of the criteria in the problem are assessed by linguistic variables [53]. Cho et. al [54] stated that, for those countries where objective probabilistic data for risk assessment is extremely rare or insufficient, the utilization of subjective judgmental data based on the experience of experts is inevitable. In such situations, fuzzy approaches may be very useful. Felixchan and Niraj [55] stated that "since the evaluation criteria are subjective and qualitative in nature, it is difficult for the experts and decision makers to express the preferences using exact numerical values and to provide exact pair-wise comparison judgments."

Fuzzy-ANP has some additional advantages according to the conventional ANP method. It gives more practical results in pair-wise comparison process. Therefore the method uses a linguistic scale which helps the decision maker or the expert and provides a more flexible approach in reaching a conclusion [50]. Main advantages of the fuzzy ANP against classical ANP are as follows [48]:

- It better models the ambiguity and imprecision associated with the pair-wise comparison process.
- It successfully derives priorities from both consistent and inconsistent judgments.
- It is cognitively less demanding for the decision makers.
- It is an adequate reflection of the decision maker's attitude toward risk and their degree of confidence in the subjective assessments.

Decision making in power plant projects is a complicated process and, in most cases, the value for each criterion is determined carelessly by DM. Furthermore, in many cases, criteria are examined by linguistic variables. These ambiguities necessitate the use of fuzzy MADM in the proposed model. In this study, MADM methods are used together with fuzzy logic for project risks assessment.

The proposed model has three main steps. First, we determine important project risks to be evaluated by MADM techniques. Then, we use ANP as a MADM technique, combined with fuzzy logic, for calculating weights. The weights that are produced by fuzzy-ANP calculations are used in a fuzzy-TOPSIS procedure. Finally, fuzzy-TOPSIS is applied to evaluate risks. This process results in a preference-order list of project risks. Schematic diagram of the proposed model for project risk assessment is provided in Figure 2. In the remainder of this section, we describe each of main steps of the proposed model.

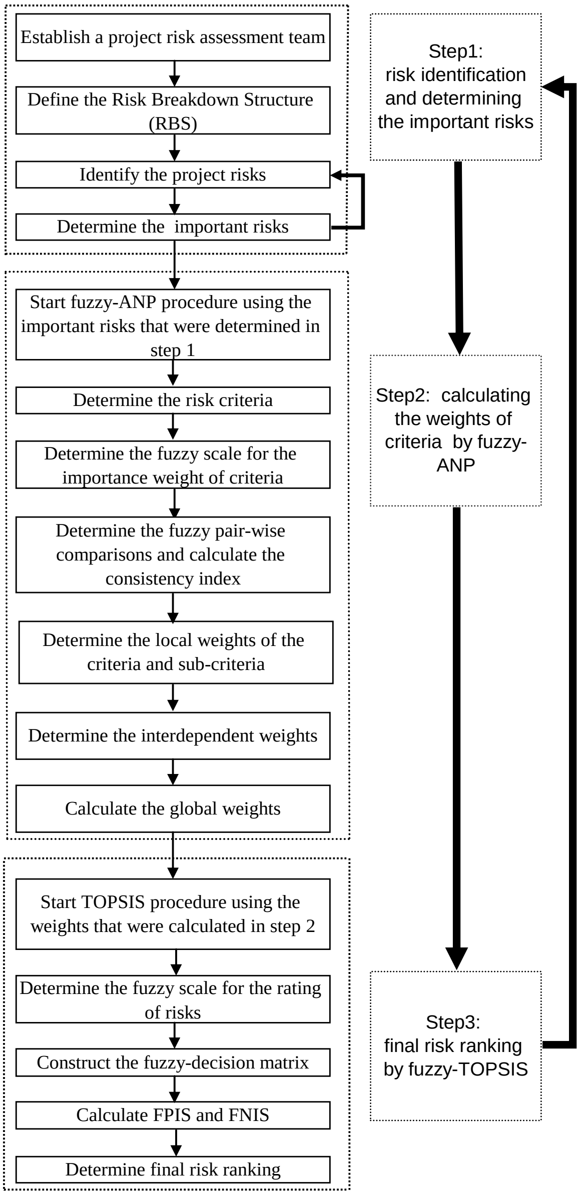

Figure 2. Proposed framework for project risk assessment

3.1. Risk Identification and Determining the Important Risks

In order to identify risks, a decision group composed of different specialists is established. The primary output of this step is a list of important risks. Information is collected through the appropriate mechanism, such as a review of documents, an interview or the Delphi technique. We use a risk-breakdown structure (RBS) to classify risks according to their origin and their relative impact in the project. After identifying project risks, important risks that have crucial impacts on project objectives are selected by taking into account expert judgments. We use the important risks as alternatives in the fuzzy-ANP and fuzzy-TOPSIS procedures. Unimportant risks, which have low relative impacts and probabilities of occurrence, are not considered in MADM procedures.

3.2. Calculating the weights of criteria by fuzzy-ANP

3.2.1. Determining the Risk Criteria As mentioned earlier, we use a hierarchical structure for project risk ranking. These criteria, which are presented in Figure 3, are:

1- Risk probability: the likelihood that each specific risk will occur.

2- Risk impact: the potential effect on a project objective. It is divided to three sub-criteria (time, cost and quality). As Figure 3 shows, these sub-criteria are dependent. The arrows represent the inner-dependence among the sub-criteria.

3- Risk detection: the ease of detecting a given risk.

4- Risk manageability: the degree of influence of control for a given risk.

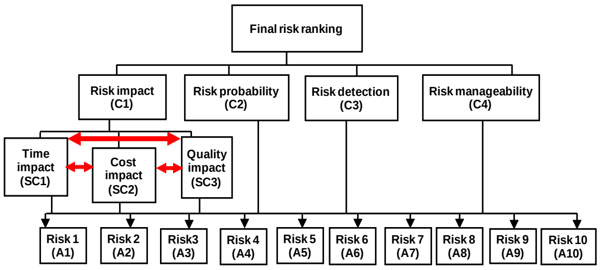

Figure 3. Proposed criteria and sub-criteria for project risk ranking

In the proposed model, additional criteria can be considered as follows:

Risk effect delay: the time latency between the event and the actual impact of the risk [56].

Risk proximity: some risks occur early in the project cycle and others late in the cycle. Risk proximity is the interval during which the risk is expected to occur.

Risk predictability: this measure determines where and when in the project the risk might occur.

Risk coupling: the effect that a risk would have on measures of other risks.

Risk growth: the variation of risk measures in time, if left unattended.

Risk uncertainty: the lack of information about the nature of the probability distribution function of risk measures. This measure captures risk classification including knowns, unknown knowns and unknown unknowns.

Risk uniqueness: Occasionally, when dealing with a special subject, a risk may receive particular attention.

For example, a special marketing situation may guide risk management analyst to give high weight to a given risk.

In this study, we identify the appropriate criteria and sub-criteria, as shown in Figure 3. These criteria and sub-criteria are determined using review of literature, interviews with different experts and viewpoints of managers in power plant projects. Obviously, based on real world condition, the proposed model is capable of considering the different criteria.

3.2.2. Determining the Fuzzy Scale for the Importance Weight of Criteria Members in the decision group are required to state their judgments based on their knowledge and experience related to each criterion and sub-criterion. The expert can state a precise numerical value, a range of numerical values, a linguistic term or a fuzzy number. In many circumstances, experts find that it is hard to give numerical values due to the uncertainties involved or because the evaluation criterion is quantitatively immeasurable [26]. In these cases, a linguistic variable or a fuzzy number can be used in the proposed model, e.g. "risk impact is very important", "risk detection is important" and "the score of risk detection is around 5-8". In order to make a quantitative analysis for the criteria and sub-criteria, we use triangular fuzzy numbers because of their simplicity in modeling and their ease of interpretation. The linguistic comparison terms and their equivalent fuzzy numbers that were considered in this study are shown in Table 1.

Table 1. Triangular fuzzy scale for the importance weight of criteria

Linguistic scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
equal	(1,1,1)	(1,1,1)
Weakly important	(1,2,3)	(1/3,1/2,1)
Strongly more important	(2,3,4)	(1/4,1/3,1/2)
very strongly more important	(3,4,5)	(1/51/4,,1/3)
absolutely more important	(4,5,6)	(1/6,1/5,1/4)

3.2.3. Calculating the Weights of Criteria Based on the pair-wise comparison results, the calculation process of weights was developed. The suggested procedure includes the following steps:

Step1: determine the local weights of the criteria and sub-criteria by using pair-wise comparison matrices. In this stage, assume that there is no dependence among the criteria and sub-criteria. The pair-wise comparisons are made according to the triangular fuzzy conversion scale in Table 1. This fuzzy scale will be used in fuzzy-AHP method. As mentioned above, we use Chang's method [39] because the steps are easier than other fuzzy-AHP approaches and are similar to the crisp AHP. However, DMs may define different comparison matrices. For this reason, we proposed a group decision based on fuzzy-AHP to improve pair-wise comparisons. Assume that a decision group has K DMs and the fuzzy rating of each DM can be represented as a positive triangular fuzzy number. A good aggregation method should consider the range of fuzzy ratings for each DM, meaning that the range of aggregated fuzzy ratings must include the ranges of all DM fuzzy ratings [53]. Let fuzzy pair-wise comparison of the k^{th} DM be $\tilde{x}_{ijk} = (l_{ijk}, m_{ijk}, u_{ijk})$. Hence the aggregated fuzzy pair-wise comparison value can be calculated as $\tilde{x}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ where

$$l_{ij} = \min_k \{l_{ijk}\},\quad m_{ij} = \frac{1}{K}\sum_{k=1}^{K} m_{ijk},\quad u_{ij} = \max_k \{u_{ijk}\} \tag{17}$$

Step2: determinethe inner dependence matrix of each sub-criterion with respect to the other sub-criteria, using fuzzy scale in Table 1. This inner dependence matrix is multiplied with the local weights of the sub-criteria to compute the interdependent weights of the sub-criteria.

Step3: calculate the global weights for the sub-criteria. Global sub-criteria weights are computed by multiplying the interdependent weight of the sub-criteria with the local weight of the criterion to which it belongs.

3.3. Final Risk Ranking by Fuzzy-TOPSIS We use the fuzzy-TOPSIS method for final risk ranking. The TOPSIS was first proposed by Hwang and Yoon. They developed TOPSIS based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution. The TOPSIS method is one of the useful MADM techniques to manage real-world problems [57]. The method has been widely used in the literature [58]. Furthermore, the TOPSIS method has been extended to deal with fuzzy MCDM problems [42-44, 58, 59].

We briefly review the rationale of triangular fuzzy number before the development of fuzzy-TOPSIS as follows:

Definition 1. Let $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ be two triangular fuzzy numbers, then the vertex method is defined to calculate the distance between them, as equation (18):

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]} \tag{18}$$

The basic operations for fuzzy triangular numbers are as follows [60]:

For approximation of multiplication:

$$\tilde{a} \times \tilde{b} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3) \quad (19)$$

For addition:

$$\tilde{a} + \tilde{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \quad (20)$$

Given the above-mentioned fuzzy theory, the main steps of the proposed fuzzy-TOPSIS are presented. Suppose a fuzzy MCDM problem has *m* alternatives and *n* decision criteria (attributes). All the values (ratings) assigned to the alternatives, with respect to each criterion, form a fuzzy decision matrix denoted by $\tilde{X} = (\tilde{x}_{ij})_{m\times n}$. Let $\tilde{W} = (\tilde{w}_1, \tilde{w}_2, ..., \tilde{v}_n)$ be the relative weight vector for the criteria. In this study, we use the linguistic scale for evaluating of the alternatives (risks). The linguistic terms and their equivalent triangular fuzzy numbers are shown in Table 2 [51].

Table 2. Triangular fuzzy scale for the rating of risks

Linguistic scale	Triangular fuzzy scale
Very low (VL)	(0,0,.25)
Low (L)	(0,.25,.5)
Medium (M)	(0.25,.5,.75)
High (H)	(0.5,.75,1)
Very high (VH)	(0.75,1,1)

The normalized fuzzy decision matrix denoted by $\tilde{R} = (\tilde{r}_{ij})_{m\times n}$. The fuzzy linguistic rating $(\tilde{x}_{ij})$ preserve the property that the ranges of normalized triangular fuzzy numbers belong to [0,1]. Thus, there is no need for a normalization procedure. For this instance, the $\tilde{X}$ is equivalent to the $\tilde{R}$ [44, 60]. Then, the fuzzy-TOPSIS procedure is summarized as follows:

Step 1: calculate the weighted normalized fuzzy decision matrix $\tilde{V} = (\tilde{v}_{ij})_{m\times n}$:

$$\tilde{v}_{ij} = \tilde{w}_j . \tilde{r}_{ij} \quad i = 1, 2, ..., m; \; j = 1, 2, ..., n. \quad (21)$$

where $\tilde{w}_j$ is the weight of j^{th} criterion. In this study $\tilde{w}_j$ is a real number that was calculated by fuzzy-ANP and $\sum_{j=1}^{n} w_j = 1$.

Step 2: determine the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS):

$$A^+ = \{\tilde{v}_1^+, \tilde{v}_2^+ ..., \tilde{v}_n^+\} = \{(\max_i \tilde{v}_{ij} \mid j \in \Omega_b), (\min_i \tilde{v}_{ij} \mid j \in \Omega_c)\} \quad (22)$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^- ..., \tilde{v}_n^-\} = \{(\min_i \tilde{v}_{ij} \mid j \in \Omega_b), (\max_i \tilde{v}_{ij} \mid j \in \Omega_c)\} \quad (23)$$

where Ω_b is associated with benefit criteria (the larger the rating, the greater the preference)and Ω_c is associated with cost criteria(the smaller the rating, the greater the preference).

Max and min operations does not give triangular fuzzy member but it is possible to express approximated values of min and max as triangular fuzzy numbers. According to the weighted normalized fuzzy decision matrix, we know that the elements $\tilde{v}_{ij}$ are normalized positive triangular fuzzy numbers and their ranges belong to the closed interval [0, 1]. Thus, we can define the FPIS and FNIS as

$$\tilde{v}_j^+ = (1,1,1) \; j \in \Omega_b, \; \tilde{v}_j^+ = (0,0,0) \; j \in \Omega_c \quad (24)$$

$$\tilde{v}_j^- = (0,0,0) \; j \in \Omega_b, \; \tilde{v}_j^- = (1,1,1) \quad j \in \Omega_c \quad (25)$$

Step 3: calculate separation measures. The distance of each alternative from the FPIS and the FNIS can be determined using equations (26) and (27).

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+) \quad i = 1, 2, ..., m \quad (26)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad i = 1, 2, ..., m \quad (27)$$

Step 4: calculate the relative closeness of each alternative to the ideal solution:

$$RC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad i = 1, ..., m. \quad (28)$$

Step 5: by comparing RC_i values, rank the alternatives (risks).

4. CASE STUDY

In this section, we study risk assessment in an Iranian power plant project. The MAPNA (Iran Power Plants Projects Management Co.) has been engaged by the IPDC (Iranian Power Development Company) to carry out the conversion of the two existing gas turbines at Yazd power station to a combined cycle operation using waste heat recovery technology. The existing plant included two units with a total nominal capacity of 2x123.4 MW. The conversion will comprise generation through one steam turbine for a total additional capacity of 1x160 MW. The waste heat from the gas turbines will be recovered through two HRSG boilers so that the steam turbine is served by two boiler units. The preliminary project schedule provided by MAPNA required that the power plant be completed and commissioned within 38 months.

Other projects can be listed as well, such as Kazeroon, Neka and Abadan. The contract for the project is based on an EPC approach with the MAPNA working as the general contractor responsible for design, procurement, and construction of the combined cycle plant. Project risk assessment is considered based on the model proposed in Section 3.

4.1. Determining Important Risks In order to identify project risks, a decision group composed of different specialists was established. Information was collected in an integrated approach using four mechanisms:

1- Review of similar project risk management studies in the literature.
2- Review of requirements for documents and other program planning materials.
3- Interviews with different power plant project experts.
4- Review of a list of risks prepared by project and program managers.

To improve the risk identification process, we develop a proper RBS for power plant projects. The proposed RBS is presented in Figure 4. Then, by different mechanisms, more than 100 risks were identified and categorized according to their source (client, general contractor, sub-contractor and external) and to when, in the life cycle of the power plant project, the impact from the risk was likely to occur. In the next stage, risks with low impact and probability of occurrence were eliminated from calculations of fuzzy-ANP and fuzzy-TOPSIS procedures. We determined 10 important risks, which we refer to as A1 to A10, as alternatives of MADM methods.

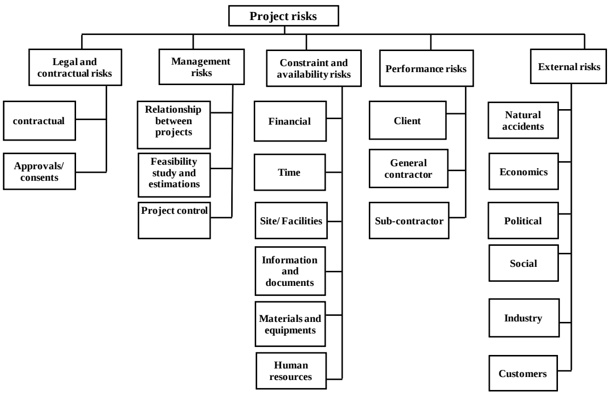

Figure 4. Proposed risk breakdown structure (RBS) for power plant projects

4.2. Calculating the Weights of Criteria Important risks and determined criteria were used as fuzzy-ANP inputs. We selected three DMs to establish a power plant project risk ranking team. Each DM was asked to make pair-wise comparisons for criteria and sub-criteria. The pair-wise comparisons were made according to the triangular fuzzy conversion scale in Table 1. Then, aggregated pair-wise comparison values were obtained according to equation (17). The aggregated pair-wise comparison matrix of the criteria is given in Table 3.

TABLE 3. Aggregated pair-wise matrix of criteria

	C1	C2	C3	C4
C1	(1,1,1)	(1,5/3,3)	(1,8/3,4)	(1,1,1)
C2	(1/3,2/3,1)	(1,1,1)	(1,8/3,4)	(1,1,1)
C3	(1/4,7/18,1)	(1/4,7/18,1)	(1,1,1)	(1/4,4/9,1)
C4	(1,1,1)	(1,1,1)	(1,7/3,4)	(1,1,1)

To obtain the consistency index (λ) of these criteria, a non-linear model of the type (6) with one equality and 12 inequality constraints was established. The consistency index was calculated by solving this model with LINGO software. Because the consistency index for comparison matrix of criteria is equal to zero, the comparison matrix is weakly consistent and the fuzzy comparison judgments are satisfied just at their boundaries.

The local weights of these criteria were calculated with fuzzy-AHP. The values of fuzzy synthetic extents with respect to the criteria were calculated as follows:

$$S_{C1} = (4, 6.334, 9)(.037, .052, .076) = (.148, .329, .688)$$
$$S_{C2} = (3.333, 5.337, 7)(.037, .052, .076) = (.123, .278, .535)$$
$$S_{C3} = (1.75, 2.222, 4)(.037, .052, .076) = (.065, .116, .306)$$
$$S_{C4} = (4, 5.33, 7)(.037, .052, .076) = (.148, .277, .535)$$

The degrees of possibility were calculated as follows:

$$V(S_{C1} \geq S_{C2}) = 1,\ V(S_{C1} \geq S_{C3}) = 1,\ V(S_{C1} \geq S_{C4}) = 1$$
$$V(S_{C2} \geq S_{C1}) = .882,\ V(S_{C2} \geq S_{C3}) = 1,\ V(S_{C2} \geq S_{C4}) = 1$$
$$V(S_{C3} \geq S_{C1}) = .424,\ V(S_{C3} \geq S_{C2}) = .529,\ V(S_{C3} \geq S_{C4}) = .493$$
$$V(S_{C4} \geq S_{C1}) = .881,\ V(S_{C4} \geq S_{C2}) = .999,\ V(S_{C4} \geq S_{C3}) = 1$$

For each pair-wise comparison, the minimum of the degrees of possibility was determined as follows:

$$V(S_{C1} \geq S_{C2}, S_{C3}, S_{C4}) = \min\{1,1,1\} = 1$$
$$V(S_{C2} \geq S_{C1}, S_{C3}, S_{C4}) = \min\{.882, 1, 1\} = .882$$
$$V(S_{C3} \geq S_{C1}, S_{C2}, S_{C4}) = \min\{.424, .529, .493\} = .424$$
$$V(S_{C4} \geq S_{C1}, S_{C2}, S_{C3}) = \min\{.881, .999, 1\} = .881$$

These values yielded the following weights vector:

$$W'_{criteria} = (1, .882, .424, .881)$$

Via normalization, the local weights of the criteria were determined as follows:

$$W_{criteria} = (.314, .277, .133, .276)$$

Using a similar method, the local weights of the sub-criteria of Criterion C1 were calculated. The aggregated pair-wise comparison matrix of the sub-criteria and related local weight vector is presented in Table 4. Since the value of the consistency index for sub-criteria is equal to 0.993, the corresponding comparison matrix is strongly consistent.

TABLE 4. Local weights and aggregated pair-wise comparison matrix of sub-criteria

	SC1	SC2	SC3	Local weights
SC1	(1,1,1)	(1/3,5/6,1)	(1/4,17/18,3)	0.308
SC2	(1,4/3,3)	(1,1,1)	(1/3,7/6,3)	0.339
SC3	(1/3,11/6,4)	(1/3,7/6,3)	(1,1,1)	0.353

In this stage, interdependent weights of the sub-criteria are calculated and the dependencies among the sub-criteria are considered. Dependence among the sub-criteria is determined by analyzing the impact of each sub-criteria on every other sub-criteria using pair-wise comparisons. The pair-wise comparison matrices and resulting relative importance weights are presented in Tables 5-7.

TABLE 5. The inner dependence matrix of the sub-criteria with respect to SC1

SC1	SC2	SC3	Relative importance weights
SC2	(1,1,1)	(1,2,3)	0.692
SC3	(1/3,1/2,1)	(1,1,1)	0.308

TABLE 6. The inner dependence matrix of the sub-criteria with respect to SC2

SC2	SC1	SC3	Relative importance weights
SC1	(1,1,1)	(1,2,3)	0.692
SC3	(1/3,1/2,1)	(1,1,1)	0.308

TABLE 7. The inner dependence matrix of the sub-criteria with respect to SC3

SC3	SC1	SC2	Relative importance weights
SC1	(1,1,1)	(1,1,1)	0.5
SC2	(1,1,1)	(1,1,1)	0.5

Using the computed relative importance weights, the dependence matrix of the sub-criteria is determined. Interdependent weights of the sub-criteria are computed by multiplying the dependence matrix of the sub-criteria with the local weights of sub-criteria provided in Table 4. The interdependent weights of the sub-criteria are calculated as follows:

$$\begin{bmatrix} 1 & .692 & .5 \\ .692 & 1 & .5 \\ .308 & .308 & 1 \end{bmatrix} \times \begin{bmatrix} .308 \\ .339 \\ .353 \end{bmatrix} = \begin{bmatrix} .719 \\ .729 \\ .552 \end{bmatrix}$$

Then, the normalized interdependent weights are determined as follows:

$$W_{sub-criteria} = [.360,\ .364,\ .276]$$

Significant differences are observed in the results obtained for the sub-criteria weights (Table 4) when the interdependent weights are not taken into account. The results change from .308 to .360, .339 to .364, and .353 to .276 for the weight values of sub-criteria SC1, SC2 and SC3 respectively.

4.3. Final Ranking of Risks by Fuzzy-TOPSIS We use the fuzzy-TOPSIS method for final risk ranking. The fuzzy-TOPSIS procedure uses the weights that were calculated by fuzzy-ANP. The alternatives (risks) must be evaluated with respect to criteria C2, C3 and C4. Moreover, the alternatives must be evaluated with respect to each sub-criterion (SC1, SC2 and SC3). We use the linguistic scale in Table 2 for evaluating of the alternative. Then, aggregated rating of risks were obtained according to Equation (17). The aggregated fuzzy decision matrix is given in Table 8.

TABLE 8. Alternatives (Risks) evaluation with respect to criteria and sub-criteria

	SC1	SC2	SC3	C2	C3	C4
A1	(0,.17,.5)	(0,.17.5)	(0,.17,.5)	(.5,.75,1)	(.5,.83,1)	(.25,.75,1)
A2	(.25,.5,.75)	(0,.25,.5)	(0,.08,.5)	(.5,.83,1)	(.25,.67,1)	(0,.42,.75)
A3	(.5,.83,1)	(0,.42,.75)	(0,.25,.75)	(.5,.92,1)	(.25,.5,.75)	(0,.25,.5)
A4	(.25,.58,1)	(0,.42,.75)	(0,.17,.5)	(.25,.58,1)	(.25,.58,1)	(.25,.5,.75)
A5	(.25,.5,.75)	(0,.33,.75)	(0,.17,.5)	(.25,.58,1)	(.5,.83,1)	(.25,.5,.75)
A6	(.5,.75,1)	(.25,.67,1)	(.25,.67,1)	(.5,.75,1)	(.25,.58,1)	(0,.42,.75)
A7	(.25,.67,1)	(.25,.67,1)	(.5,.83,1)	(.5,.83,1)	(0,.33,.75)	(0,.25,.5)
A8	(.25,.5,.75)	(.25,.58,1)	(.25,.67,1)	(.5,.75,1)	(.5,.75,1)	(0,.42,.75)
A9	(.25,.67,1)	(0,.33,.75)	(0,.33,.75)	(.25,.75,1)	(.25,.58,1)	(.25,.58,1)
A10	(.25,.5,.75)	(0,.42,.75)	(0,.17,.5)	(.25,.67,1)	(.25,.67,1)	(0,.17,.5)

Then, the ratings of alternatives with respect to sub-criteria (SC1, SC2 and SC3) were combined and the ratings with respect to criterion C1 was determined. The ratings of the alternatives according to each criterion are shown in Table 9.

TABLE 9. Alternatives (Risks) evaluation with respect to criteria

	C1	C2	C3	C4
A1	(0,.17,.5)	(.5,.75,1)	(.5,.83,1)	(.25,.75,1)
A2	(.09,.29,.59)	(.5,.83,1)	(.25,.67,1)	(0,.42,.75)
A3	(.18,.52,.84)	(.5,.92,1)	(.25,.5,.75)	(0,.25,.5)
A4	(.09,.41,.77)	(.25,.58,1)	(.25,.58,1)	(.25,.5,.75)
A5	(.09,.35,.68)	(.25,.58,1)	(.5,.83,1)	(.25,.5,.75)
A6	(.34,.70,1)	(.5,.75,1)	(.25,.58,1)	(0,.42,.75)
A7	(.32,.71,1)	(.5,.83,1)	(0,.33,.75)	(0,.25,.5)
A8	(.25,.58,.91)	(.5,.75,1)	(.5,.75,1)	(0,.42,.75)
A9	(.09,.45,.84)	(.25,.75,1)	(.25,.58,1)	(.25,.58,1)
A10	(.09,.38,.68)	(.25,.67,1)	(.25,.67,1)	(0,.17,.5)

The ratings of the alternatives in Table 9 were used in the fuzzy-TOPSIS procedure. The weighted normalized fuzzy decision matrix was determined using Equation (21). This matrix is presented in Table 10.

Next, the ranking of the risks was determined using Equations (22) - (28). In this study, Criteria C1 and C2 are considered benefits (the larger the rating, the greater the importance) and Criteria C3 and C4 are considered as costs (the smaller the rating, the greater the importance). Therefore, we can define FPIS and FNIS as:

$$A^{+} = \{(1,1,1),\ (1,1,1),\ (0,0,0),\ (0,0,0)\}$$

$$A^{-} = \{(0,0,0),\ (0,0,0),\ (1,1,1),\ (1,1,1)\}$$

The final ranking is presented in Table 11.

4.4. Discussion of Results The fuzzy-TOPSIS results using fuzzy-ANP weights are presented in Table 11. The evaluation of risks shows that inadequate skill

TABLE 10. Weighted normalized fuzzy decision matrix

	C1	C2	C3	C4
A1	(.000,.053,.157)	(.139,.208,.277)	(.067,.110,.133)	(.069,.207,.276)
A2	(.028,.092,.185)	(.139,.230,.277)	(.033,.089,.133)	(.000,.116,.207)
A3	(.057,.163,.264)	(.139,.255,.277)	(.033,.067,.100)	(.000,.069,.138)
A4	(.028,.128,.242)	(.069,.161,.277)	(.033,.077,.133)	(.069,.138,.207)
A5	(.028,.109,.214)	(.069,.161,.277)	(.067,.110,.133)	(.069,.138,.207)
A6	(.107,.219,.314)	(.139,.208,.277)	(.033,.077,.133)	(.000,.116,.207)
A7	(.100,.224,.314	(.139,.230,.277)	(.000,.044,.100)	(.000,.069,.138)
A8	(.079,.181,.286)	(.139,.208,.277)	(.067,.100,.133)	(.000,.116,.207)
A9	(.028,.142,.264)	(.069,.208,.277)	(.033,.077,.133)	(.069,.160,.276)
A10	(.028,.119,.214)	(.069,.186,.277)	(.033,.089,.133)	(.000,.047,.138)

TABLE 11. Final ranking of the risks

Risks	Description	Distance from FPIS	Distance from FNIS	Relative closeness	Ranking
A1	Delay in delivering of ground	2.026	2.019	0.499	10
A2	Delay in providing utilities on site(such as, water, electricity, telephone, etc.)	1.909	2.145	0.529	6
A3	Difficulties in financing the project	1.774	2.269	0.561	2
A4	Delay in providing design information	1.937	2.121	0.523	7
A5	Delay in procuring equipment	1.968	2.079	0.514	9
A6	Inaccurate estimation of duration and cost	1.804	2.250	0.555	3
A7	Inadequate skill of staff	1.722	2.327	0.575	1
A8	Conflicts between equipment and design documents	1.848	2.202	0.544	4
A9	Improper financial management by contractor	1.950	2.123	0.521	8
A10	Weather conditions	1.879	2.184	0.538	5

TABLE 12. Resulted weights from different methods for criteria and sub-criteria

Method number	Method for calculating weights of criteria and sub-criteria	Method for data gathering of risks evaluation	Risks ranking method	Weights of criteria	Weights of sub-criteria
1	Fuzzy-AHP based on extent analysis	Pair-wise comparison	TOPSIS	(.314,.277,.133,.276)	(.308,.339,.353)
2	Fuzzy-ANP based on extent analysis	Pair-wise comparison	TOPSIS	(.314,.277,.133,.276)	(.360,.364,.276)
3	Fuzzy-AHP based on extent analysis	Direct evaluation	Fuzzy-TOPSIS	(.314,.277,.133,.276)	(.308,.339,.353)
4	Fuzzy-ANP based on extent analysis	Direct evaluation	Fuzzy-TOPSIS	(.314,.277,.133,.276)	(.360,.364,.276)
5	Fuzzy-AHP based on fuzzy prioritization approach	Direct evaluation	Fuzzy-TOPSIS	(.301,.301,.098,.300)	(.307,.371,.322)
6	Fuzzy-ANP based on fuzzy prioritization approach	Direct evaluation	Fuzzy-TOPSIS	(.301,.301,.098,.300)	(.358,.368,.274)

TABLE 13. Final ranking of the risks in different methods

Method number		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
1	RC i	0.087	0.359	0.620	0.373	0.320	0.564	0.640	0.513	0.365	0.542
	Ranking	10	8	2	6	9	3	1	5	7	4
2	RC i	0.084	0.371	0.667	0.378	0.340	0.537	0.627	0.504	0.397	0.542
	Ranking	10	8	1	7	9	4	2	5	6	3
3	RC i	0.499	0.528	0.559	0.521	0.512	0.555	0.575	0.544	0.520	0.536
	Ranking	10	6	2	7	9	3	1	4	8	5
4	RC i	0.499	0.529	0.561	0.523	0.514	0.555	0.575	0.544	0.521	0.538
	Ranking	10	6	2	7	9	3	1	4	8	5
5	RC i	0.505	0.535	0.566	0.526	0.519	0.560	0.579	0.551	0.524	0.543
	Ranking	10	6	2	7	9	3	1	4	8	5
6	RC i	0.505	0.536	0.567	0.527	0.520	0.560	0.579	0.550	0.525	0.544
	Ranking	10	6	2	7	9	3	1	4	8	5
Difference between max and min rankings		0	2	1	1	0	1	1	1	2	2

of staff (A7) is the most important risk. Among the other risks, difficulties in financing of project (A3) are the most important. On the other hand, A1 is the least important.

In order to verify the obtained results and justify the proposed method, we calculated weights of the criteria (and sub-criteria) and ranking of the risks using 6 different methods. In method 1, we use the extent fuzzy-AHP for calculating the weights of criteria (and sub-criteria) and suppose that criteria (and sub-criteria) are independent. Moreover, in order to increasing accuracy of risks evaluation, we use pair-wise comparisons for evaluating risks with respect to criteria and sub-criteria. Information of these methods and the obtained weights are shown in Table 12. According to results of Table 12, the weights of criteria are sensitive regard to selected method. Comparing obtained weights for the criteria using methods 1-4 with methods 5-6 shows these differences. In addition, significant differences are observed in the results obtained for the sub-criteria weights when the dependence among the sub-criteria is considered using ANP. For example, comparing weights of sub-criteria in methods 1 and 2 shows that results change from .308 to .360, .339 to .364, and .353 to .276 for the weight values of sub-criteria SC1, SC2 and SC3 respectively.

Final rankings of the risks in different methods are presented in Table 13. Actually, the results of Table 11 are obtained from method 4. As Table 13 shows, A7 is the most important risk in all methods except in method 2. On the other hand, in all methods, A1 is the least important risk. The last row of Table 13 shows that there are not significant differences between obtained rankings for the risks in different methods. Therefore, the results of proposed model in Table 11 are valid.

The results of risk assessment can be used in the risk response phase. In this phase, risk sources and affected work elements were defined. Then, a list of candidate risk abatement actions was determined and their associate costs and expected effects (time, cost and quality) were estimated. Using this information, we can select suitable actions. Detail of risk response phase is out of scope of this study and we don't present them here. In future study, we will present an integrated optimization model for selecting response actions.

5. CONCLUSIONS

In order to respond to the development needs, the government of Iran has engaged several companies to carry out power plant projects. Usually, these projects are implemented in dynamic and complex environments due to their inherent uncertainties and risks. The primary objective of this study was to identify risks in these projects and to develop a framework for ranking them. Companies have limited resources for managing all project risks. Therefore, they need to prioritize the important risks. In particular, resources would be allocated to managing risks with higher priorities.

In classical approaches, probability and impact are two commonly used criteria in project risk management. However, these criteria alone do not sufficiently cover all aspects of project risk. Moreover, there may be relations and dependencies among the various criteria. Therefore, we proposed a hierarchical structure for risk ranking in power plant projects.

We used fuzzy-ANP to calculate criteria weights. The model is capable of considering dependencies among the different criteria. Also, the model calculates consistency indices for the fuzzy pair-wise comparison matrices. The calculated weights were used in a fuzzy-TOPSIS procedure for the evaluation of important risks. The proposed model was applied to a power plant project. In this case study, more than 100 risks were identified and categorized according to their source (client, general contractor, sub-contractor and external) and according to when, in the life cycle of the power plant project, the impact of the risk was likely to occur. Next, important risks were used as alternatives for the fuzzy-ANP and fuzzy-TOPSIS procedure, and assessment results were developed.

We concluded that inadequate skill of staff is the most important risk in such projects. Among the other risks, difficulties in project financing are very important. In order to verify the obtained results and justify the proposed method, we calculated weights of the criteria (and sub-criteria) and ranked the risks using 6 different methods. We use the extent fuzzy-AHP and fuzzy prioritization approach for calculating the weights of criteria (and sub-criteria). According to obtained results, significant differences are observed in the weights of sub-criteria when the dependences are considered. In addition, there aren't significant differences between rankings of risks for different methods. The results show that the proposed method is a suitable approach when performance ratings and weights are vague and imprecise.

In future research, other multiple-criteria methods could be used to evaluate the risks of power plant projects. Additionally, the proposed method could be applied to evaluating project risks in other sectors. Moreover, a user-friendly interface could be developed to speed up and simplify the calculation of weights and ratings. By increasing the number of criteria and sub-criteria, the calculations of pair-wise comparison matrixes are increased. Therefore, a heuristic (or meta-heuristic) method should be applied with fuzzy-ANP. Besides, proposed model includes the dependencies and relations among the sub-criteria. In future research, the relations among criteria can be analyzed via fuzzy-ANP.

6. ACKNOWLEDGMENT

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RESEARCH NOTE

Power Plant Project Risk Assessment Using a Fuzzy-ANP and Fuzzy-TOPSIS Method

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چکیده

رشد اقتصادی در کشورهای در حال توسعه نیازمند پروژه های زیربنایی از جمله پروژه های نیروگاهی می باشد. در راستای پاسخگویی به این نیاز، پروژه های نیروگاهی زیادی در کشور ایران در حال اجرا می باشد. اکثر این پروژه ها بخاطر مواجهه با ریسکهای مختلف، قادر به تحقق اهداف تعیین شده نمی باشند. هرچند تحقیقات متعددی درباره مدیریت ریسک پروژه منتشر شده است، با اینحال مقالات اندکی درباره کاربرد آن در دنیای واقعی موجود می باشد. هدف اصلی این تحقیق شناسایی و رتبه بندی ریسکها در پروژه های نیروگاهی می باشد. در روشهای کلاسیک برای ارزیابی ریسکها از معیارهای احتمال وقوع و تاثیر استفاده می شود ولی این معیارها به تنهایی بیانگر تمام جنبه های ریسک نمی باشند. از طرف دیگر ممکن است بین معیار های مختلف وابستگی وجود داشته باشد. برای رفع این مشکلات، یک مدل بر اساس فرآیند تحلیل شبکه ای و الگوریتم تاپسیس در محیط فازی ارائه گردیده است. ساختار سلسله مراتبی پیشنهادی وابستگی بین معیارها و زیرمعیارها را در نظر می گیرد. برای محاسبه وزن معیارها و زیر معیارها از فرآیند تحلیل شبکه ای فازی استفاده می شود. سپس رتبه بندی ریسکها از طریق الگوریتم تاپسیس فازی انجام می شود. در مطالعه موردی با استفاده از رویکردهای مختلف، بیش از ۱۰۰ ریسک شناسایی و بر اساس منشا و تاثیر آنها در مراحل مختلف پروژه تقسیم بندی گردیده اند. سپس ریسکهای مهم توسط مدل پیشنهادی ارزیابی و نتایج مربوطه به همراه تحلیل حساسیت ارائه گردیده است. با توجه به مبهم و غیر دقیق بودن داده ها در اغلب پروژه ها، مدل پیشنهادی برای دنیای واقعی مناسب می باشد.

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