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A Fuzzy Comprehensive Approach for Risk Identification and Prioritization Simultaneously in EPC Projects

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1. Introduction

Long lasting complicated processes and organizational features generate abundant risks in Engineering, Procurement and Construction (EPC) projects. Iran witnesses an unprecedented boom in engineering, procurement and construction activities at all levels with the government's goal of diversifying its income away from oil dependence to commercial and industrial activities based on the fourth economical development plan. The number, size and complexity of new EPC projects have created an extra burden on the participants and resulted in lots of risks. It is important to identify and prioritize the important risks in Iran to help local and international companies to consider these important risks. Hence, risk identification and prioritization are influential factors in risk monitoring decisions (Ebrahimnejad et al., 2009).

The risk management process aims to identify and assess project risks in order to enable them to be understood clearly and managed effectively. In fact, project risk management is a systematic way of looking at areas of risk and consciously determining how each area should be treated. It is a management tool that aims at identifying sources of risk and uncertainty, determining their impact, and developing appropriate management responses (Thomas, 2003.). There are many commonly used techniques for risk identification and prioritization separately. These techniques generate a list of risks that often does not directly assist the project manager in knowing where to focus risk management attention. Qualitative assessment can help to prioritize identified risks by estimating their probability and impact, exposing the most significant risks; this approach deals with risks one at a time and does not consider their possible correlations, and so also does not provide an overall understanding of the risk faced by the project as a whole (Hillson, 2002).

Project risk prioritization is usually affected by numerous factors including the human error, data analysis and available information. The great uncertainty in projects often causes difficulty in assessing risk factors. However, many risk assessment techniques currently used in EPC projects are comparatively mature, such as fault tree analysis, event tree analysis, monte carlo analysis, scenario planning, sensitivity analysis, failure mode and effects analysis, program evaluation and review technique (Carr & Tah, 2001).

In this paper, an applicable approach in an uncertain environment that can identify and prioritize project risks simultaneously is introduced. A decision approach is proposed that

consists of three sections. In the first section, data of project potential risks are gathered. In the second section, a group decision-making approach is used in a fuzzy environment in order to prioritize all potential risks. In the third section, identified and non-identified risks are separated by using an appropriate threshold concurrently. Finally, a case study in one EPC project in Iran is conducted to illustrate the applicability of the proposed fuzzy comprehensive approach in mega projects. Meanwhile, special attention is paid to the various subjective analyses in the selection and prioritization process by using triangular fuzzy numbers in an uncertain environment.

The paper is organized as follows: The related literature for mega projects is reviewed in Section 2. In Section 3, the researchers briefly introduce some basic concepts on fuzzy sets, including fuzzy arithmetic numbers. In Section 4, the theoretic descriptions for the fuzzy entropy and compromise ranking (known as VIKOR) techniques are presented respectively. In Section 4, the researchers propose the project risk identification and prioritization approach in mega projects. Section 7 investigates a case study using the proposed model to illustrate their potential applications in one EPC project. The discussion of results is provided in Section 6. Finally, conclusions are offered in Section 8.

2. Literature review

The general consensus in the current literature in the field of risk management incorporates four core steps in the process of risk management (Al-Bahar & Crandell, 1990; Ebrahimnejad et al., 2008b; Raftery, 1999). These are:

1. Risk identification and classification
2. Risk analysis
3. Risk response
4. Risk monitoring

The second step of the project risk management process, risk analysis is to measure the impact of the identified risks on a project. Depending on the available data, risk analysis can be performed qualitatively or quantitatively or semi quantitatively (Alborzi et al., 2008; Chapman, 1998, 2001; Mojtahedi et al., 2009).

The evolution of risk management in EPC projects has resulted in the development of various risk identification and prioritization techniques. These techniques are used in situations experiencing uncertainty in order to ease decision making regarding the project's future. These beneficial and practicable developments have resulted in EPC practitioners becoming progressively aware of the importance of using these techniques at various stages of a project to achieve a greater project success (Thevendran & Mawdesley, 2004).

Risk identification and classification is the first step of the project risk management process, in which potential risks associated with an EPC project are identified. Numerous techniques exist for risk identification, such as brainstorming and workshops, checklists and prompt lists, questionnaires and interviews, Delphi groups or NGT, and various diagramming approaches, such as cause-effect diagrams, systems dynamics, influence diagrams (Chapman, 1998; Ebrahimnejad et al., 2008a). There is no any "best method'' for risk identification, and an appropriate combination of techniques should be used (Ebrahimnejad et al., 2008a). As a result, it may be helpful to employ additional approaches to risk identification, which were introduced specifically as broader techniques in group decision-making field (Ebrahimnejad et al., 2010; Hashemi et al., 2011; Makui et al., 2007, 2010; Mojtahedi et al., 2009,2010; Mousavi et al., 2011; Tavakkoli-Moghaddam et al., 2009).

As an integrative part of risk identification, risk classification attempts to structure the diverse risks affecting an EPC project. Several approaches have been suggested in the literature for classifying risks. Perry & Hayes (1985) presented a list of factors extracted from several sources that were divided in terms of risks retainable by contractors, consultants and clients. Combining the holistic approach of the general system theory with the discipline of a work breakdown structure as a framework, Flanagan & Norman (1993) suggested three ways of classifying risk: by identifying the consequence, type and impact of risk. Chapman (2001) grouped risks into four subsets, namely environment, industry, client and project. Shen et al. (2001) categorized them into six groups in accordance with the nature of the risks, i.e. financial, legal, management, market, policy and political, as well as technical risks. In a word, many ways can be used to classify the risks associated with oil and gas projects.
Mojtahedi et al. (2008) presented a group decision-making approach for identifying and analyzing project risks concurrently. They showed that the project risk identification and analysis can be evaluated at the same time. Moreover, they applied the proposed approach in a mega project and rewarding results were obtained.
Insufficient information, uncertain project environment, and unique EPC projects lead to gain some benefits from the fuzzy set theory in risk assessment. In fact, there have been limited attempts to exploit fuzzy logic within the mega project risk management domain. Kangari (1988) presented an integrated knowledge-based system for construction risk management using fuzzy sets. This system, which is called Expert-Risk, performs the risk analysis in two situations, namely before construction and during construction. Chun & Ahn (1992) proposed the use of the fuzzy set theory to quantify the imprecision and judgmental uncertainties of accident progression event trees. Peak et al. (1993) proposed the use of fuzzy sets for the analysis of bidding prices for mega projects. Tah et al. (1993) tried a linguistic approach to risk management during the tender stage for contingency allocation, using fuzzy logic. Ross & Donald (1995) described a method for assessing risk based on fuzzy logic and similarity measures. This approach uses linguistic variables catering for vagueness and subjectivity to devise rules for assessing the management of hazardous waste sites. Ross & Donald (1996) also used the fuzzy set theory for the mathematical representation of fault trees and event trees as used in risk analysis problems. Wirba et al. (1996) used linguistic variables. This approach considers a method, in which the probability of a risk event occurring, the level of dependence between risks, and the severity of a risk event, is quantified using linguistic variables and fuzzy logic. Carr & Tah (2001) presented a formal model for the construction project risk analysis. This model involved the relationships between risk factors, risks, and their impacts based on cause and effect diagrams. They used fuzzy approximation and composition, the relationships between risk sources and the impacts on project performance measures.
Dikman et al. (2007) also proposed a fuzzy risk analysis for international construction projects. This methodology utilizes the influence diagramming method and estimate a cost overrun risk rating. Zeng et al. (2007) introduced a risk analysis model based on fuzzy reasoning and modified Analytical Hierarchy Process (AHP) to handle the uncertainties arising in the construction process. Makui et al. (2010) developed the concept of safety to risk identification and assessment simultaneously in a fuzzy environment. They focused not only on the time and cost criteria but also on the health, safety and environment critera. Then, the NGT and MAGDM techniques were utilized for identifying and assessing risks in a gas refinery plant construction with emphasizing the potential risk breakdown structure. Ebrahimnejad et al. (2009) introduced effective criteria for evaluating risks, and presented a

fuzzy multiple criteria decision-making (MCDM) model for risk assessment with an application to an onshore gas refinery. In addition, Ebrahimnejad et al. (2010) identified the risks in build–operate–transfer power plant projects and designed a fuzzy multi–attribute decision–making model for analyzing important risks.
Going through the literature indicates that the risk identification and prioritization problem has not been considered concurrently in EPC projects; moreover, few studies had been performed mega projects in Iran (Ebrahimnejad et al., 2008a; Makui et al., 2007; Mojtahedi et al., 2008). The aim of this paper is to introduce a practical fuzzy comprehensive approach for identifying and prioritizing project risks by applying group decision-making approach concurrently. Moreover, fuzzy logic is used through the proposed approach because of existing ambiguous and uncertain data in projects' environment. Finally, one EPC project as a case study in Iran is conducted to illustrate the applicability of the proposed approach. Meanwhile, special attention is paid to the various subjective analyses in the selection and ranking process by using fuzzy numbers.

3. Basic definitions

In the following, a brief review of some basic definitions of fuzzy sets is presented (Zimmermann, 1996; Chen, 2000). These basic definitions and notations are used throughout the paper.

Definition 3.1. A fuzzy set $\tilde{A}$ in the universe of discourse X is convex if and only if

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)) \tag{1}$$

for all x_1, x_2 in X and all $\lambda \in [0, 1]$, where min denotes the minimum operator (Zimmermann, 1996).

Definition 3.2. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal (Zimmermann, 1996).

Definition 3.3. A linguistic variable is a variable whose values are linguistic terms. Linguistic terms ({not important, somewhat important, important, very important, extremely important} have been found to be intuitively easy in expressing the subjectiveness and/or imprecision qualitative of a decision maker (DM)'s assessments (Zimmermann, 1996).

Definition 3.4. A fuzzy set $\tilde{a}$ in a universe of discourse x is characterized by a membership function $\tilde{a}$ which associates with each element x in X, a real number in the interval [0,1]. The function value $\mu_{\tilde{a}}(x)$ is termed the grade of membership of x in $\tilde{a}$ (Zimmermann, 1996). Fig. 1 shows a fuzzy number $\tilde{a}$.

A triangular fuzzy number $\tilde{a}$ can be defined by a triplet (a_1, a_2, a_3) shown in Fig. 2. The membership function $\mu_{\tilde{a}}(x)$ is defined as given in Zimmermann (1996):

$$\mu_{\tilde{a}}(x) = \begin{cases} 0 & ; x \leq a_1 \\ \dfrac{x - a_1}{a_2 - a_1} & ; a_1 \leq x \leq a_2 \\ \dfrac{a_3 - x}{a_3 - a_2} & ; a_2 \leq x \leq a_3 \\ 0 & ; x \geq a_3 \end{cases} \tag{2}$$

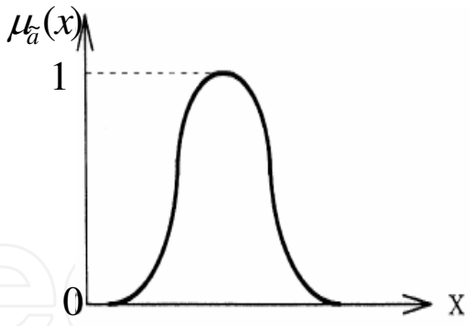

Fig. 1. A fuzzy number $\tilde{a}$.

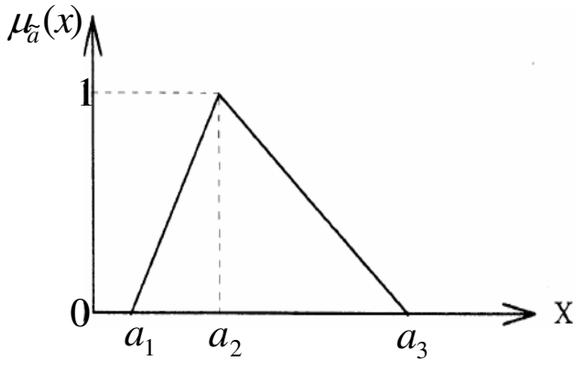

Fig. 2. A triangular fuzzy number $\tilde{a}$.

Definition 3.5. 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 Eq. (3):

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

Property 3.5.1. Assuming that both $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ are real numbers, then the distance measurement $d(\tilde{a}, \tilde{b})$ is identical to the Euclidean distance (Chen, 2000).

Property 3.5.2. Let $\tilde{a}$, $\tilde{b}$, and $\tilde{c}$ be three triangular fuzzy numbers. The fuzzy number $\tilde{b}$ is closer to fuzzy number $\tilde{a}$ than the other fuzzy number $\tilde{c}$ if, and only if, $d(\tilde{a}, \tilde{b}) \le d(\tilde{a}, \tilde{c})$ (Chen, 2000).

The normalization method: To avoid the complicated normalization formula used in fuzzy MCGDM, the linear scale transformation is used here to transform the various criteria scales into a comparable scale. Therefore, we can obtain the normalized fuzzy decision matrix denoted by $\tilde{R}$.

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n}, \tag{4}$$

where B and C are the set of benefit and cost criteria, respectively.

$$\tilde{r}_{ij} = \left(\frac{a_{ij1}}{c_j^*}, \frac{a_{ij2}}{c_j^*}, \frac{a_{ij3}}{c_j^*} \right), \quad j \in B, \ i = 1,2,...,m \ , \ j = 1,2,...,n; \tag{5}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{a_{ij1}}, \frac{a_j^-}{a_{ij2}}, \frac{a_j^-}{a_{ij3}} \right), \quad j \in C, \ i = 1,2,...,m \ , \ j = 1,2,...,n; \tag{6}$$

$$c_j^* = \max \ c_{ij} \quad \text{if } j \in B;$$

$$a_j^- = \min \ a_{ij} \quad \text{if } j \in C.$$

Definition 3.6. Let $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$ be two positive triangular fuzzy numbers. Then basic fuzzy arithmetic operations on these fuzzy numbers are defined as (Dubois & Prade, 1980; Kauffman & Gupta, 1991):

Addition: $\tilde{A} + \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$;

Subtraction: $\tilde{A} - \tilde{B} = (a_1 - b_3, a_2 - b_2, a_3 - b_1)$;

Multiplication: $\tilde{A} \times \tilde{B} \approx (a_1 b_1, a_2 b_2, a_3 b_3)$;

Division: $\tilde{A} \div \tilde{B} = \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1} \right)$.

4. Multiple criteria group decision making in a fuzzy environment

MCGDM often involves DMs' subjective judgments and preferences, such as qualitative /quantitative criteria ratings and the weights of criteria. These problems will usually result in uncertain, imprecise, indefinite and subjective data being present, which makes the decision-making process complex and challenging. In other words, decision making often occurs in a fuzzy environment where the information available is imprecise/uncertain (Zadeh, 1975). In the last few years, numerous studies attempting to handle this uncertainty, imprecision, and subjectiveness have been carried out basically by means of the fuzzy set theory, as fuzzy set theory may provide the flexibility needed to represent the imprecision or vague information resulting from a lack of knowledge or information (Chen & Hwang, 1992). Therefore, the application of the fuzzy set theory to multi-criteria evaluation methods under the framework of the utility theory has proven to be an effective approach (Carlsson, 1982; Zimmermann, 1996). Fuzzy multi-criteria evaluation methods are used widely in fields, such as tool steel material selection (Chen, 1997), evaluating investment values of stocks (Tsao, 2003), bridge conceptual design (Malekly et al., 2010; Mousavi et al., 2008), temporary storage design (Heydar et al., 2008).

4.1 Fuzzy entropy

The concept of entropy in the context of the information theory was first introduced by Shannon, and it can be viewed as an order measure in the signal. Shannon entropy, quantifies the PDF of the signal and it can be computed by:

$$H_{Sh} = -\sum_{i} p_i \log p_i \tag{7}$$

where i goes over all amplitude values of the signal and is the p_i probability that amplitude a_i value occurs anywhere in the signal. This concept can be easily extended in a fuzzy environment.

4.2 Fuzzy VIKOR

The VIKOR method was developed by (Opricovic & Tzeng, 2002). This method is based on the compromise programming of MCDM. We assume that each alternative is evaluated according to a separate criterion function; the compromise ranking can be reached by comparing the measure of closeness to the ideal alternative. The multi-criteria measure for the compromise ranking is developed from the L_P-metric used as an aggregating function for a compromise programming method (Opricovic & Tzeng, 2002; Wu et al., 2010).

Matching MCDM methods with classes of problems will address the correct applications, and for this reason the VIKOR characteristics are matched with a class of problems as follows (Opricovic & Tzeng, 2007):

- Compromising is acceptable for conflict resolution.
- The decision maker (DM) is willing to approve solution that is the closest to the ideal.
- There exist a linear relationship between each criterion function and a decision maker's utility.
- The criteria are conflicting and non-commensurable (different units).
- The alternatives are evaluated according to all established criteria (performance matrix).
- The DM's preference is expressed by weights, given or simulated.
- The VIKOR method can be started without interactive participation of the DM; but, the DM is in charge of approving the final solution and his/her preference must be included.
- The proposed compromise solution (one or more) has an advantage rate.
- A stability analysis determines the weight stability intervals.

The VIKOR method was introduced as one applicable technique to be implemented within MCDM problem and it was developed as a multi attribute decision-making method to solve a discrete decision making problem with non-commensurable (different units) and conflicting criteria (Opricovic & Tzeng, 2002,2007). This method focuses on ranking and selecting from a set of alternatives, and determines compromise solution for a problem with conflicting criteria, which can help the decision makers to reach a final solution. The multi-criteria measure for compromise ranking is developed from the L_P-metric used as an aggregating function in a compromise programming method (Aven & Vinnem, 2005; Aven et al., 2007).

Assuming that each alternative is evaluated according to each criterion function, the compromise ranking can be performed by comparing the measure of closeness to the ideal alternative. The various m alternatives are denoted as $A_1, A_2, \ldots, A_m$. For alternative A_i, the

rating of the *j*th aspect is denoted by f_{ij}, i.e. f_{ij} is the value of *j*th criterion function for the alternative A_i; n is the number of criteria. Development of the VIKOR method is started with the following form of the L_P-metric:

$$L_{pi} = \left\{ \sum_{j=1}^{n} \left[\left(f_j^* - f_{ij} \right) / \left(f_j^* - f_j^- \right) \right]^p \right\}^{1/p} \quad 1 \le p \le \infty; \quad i = 1, 2, \ldots, m. \tag{8}$$

In the VIKOR method, $L_{1.i}$ (as S_i) and $L_{\infty.i}$ (as R_i) are used to formulate the ranking measure. The solution obtained by min S_i is with a maximum group utility (''majority" rule), and the solution obtained by min R_i is with a minimum individual regret of the ''opponent".

5. Proposed fuzzy comprehensive approach

The proposed fuzzy comprehensive approach is designed in three main sections and nineteen sub-steps as illustrated in Fig. 3. Project potential risk data gathering is described in the first section, the fuzzy MCGDM process based on the fuzzy entropy and VIKOR techniques is explained in details in the second section, and separation of identified and non-identified risks is discussed in the section three. The fuzzy theory importance in the proposed fuzzy comprehensive approach is described in following sub-section.

5.1 Fuzzy theory importance in proposed approach

In project risk management, the modelling process of the risks may not be performed sufficiently and exactly, because the available data and information are vague, inexact, imprecise and uncertain by nature. The decision-making process dealing with the modelling of project risks should be based on these uncertain and ill-defined information. To resolve the vagueness, ambiguity and subjectivity of human judgment, fuzzy sets theory can be applied to express the linguistic terms in risk decision making process.

The project risk experts or DMs can provide a precise numerical value, a range of numerical values, a linguistic term or a fuzzy number. Consequently, fuzzy linguistic terms are much easier to be accepted and adopted by the DMs to provide precise numerical judgments about the criteria of each risk event. Therefore, a linguistic term and a fuzzy number can be used in the proposed approach.

Fuzzy membership function: Through the commonly used fuzzy numbers, triangular fuzzy numbers are likely to be the most adoptive ones for their simplicity in modelling and interpreting. We figure out that a triangular fuzzy number can adequately represent the seven level fuzzy linguistic variables and thus it is used for the analysis hereafter. Table 1 illustrates the linguistic terms defined for the criteria of project risk event in this paper. Moreover, the fuzzy membership functions are illustrated in Fig. 4.

5.2 Steps of the proposed fuzzy comprehensive approach

Section 1: Project potential risk data collection

Step 1. In this step, project potential risks are gathered by applying historical information, lessons learned and NGT method in order to establish the potential risk breakdown

structure (PRBS). Many approaches have been suggested in the literature for classifying risks (Chapman & Ward, 2004; Perry & Hayes, 1985; Shen et al., 2001). In this paper, a new practical approach based on Makui et al. (2010) is considered for classifying risks. Potential risks are grouped in adhere to the project work break down structure (WBS) in order to study potential risks in different levels of project and scope of work.

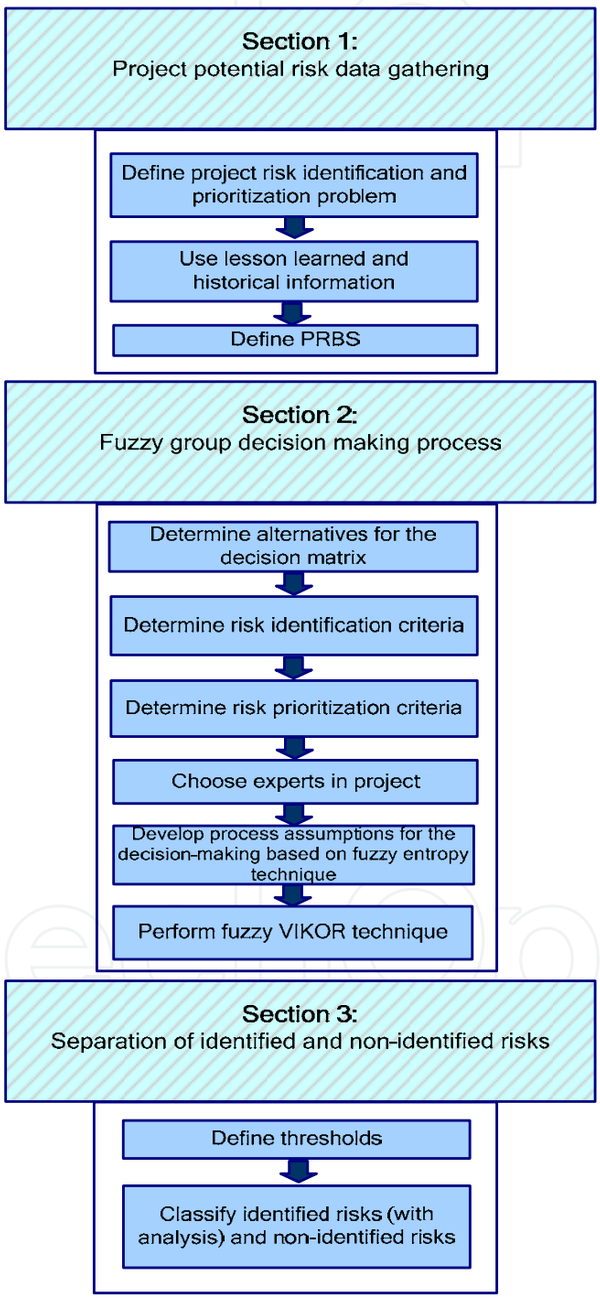

Fig. 3. Proposed fuzzy comprehensive approach for the risk identification and prioritization simultaneously

Description	Scale	Measure
Almost Certain	AC	(0, 0, 0.1)
Highly Likely	HL	(0, 0.1, 0.3)
Likely	L	(0.1, 0.3, 0.5)
Possible	P	(0.3, 0.5, 0.7)
Unlikely	UL	(0.5, 0.7, 0.9)
Rare	R	(0.7, 0.9, 1)
Non-Identified	NI	(0.9, 1, 1)

Table 1. Linguistic variables for the importance weight of each criterion.

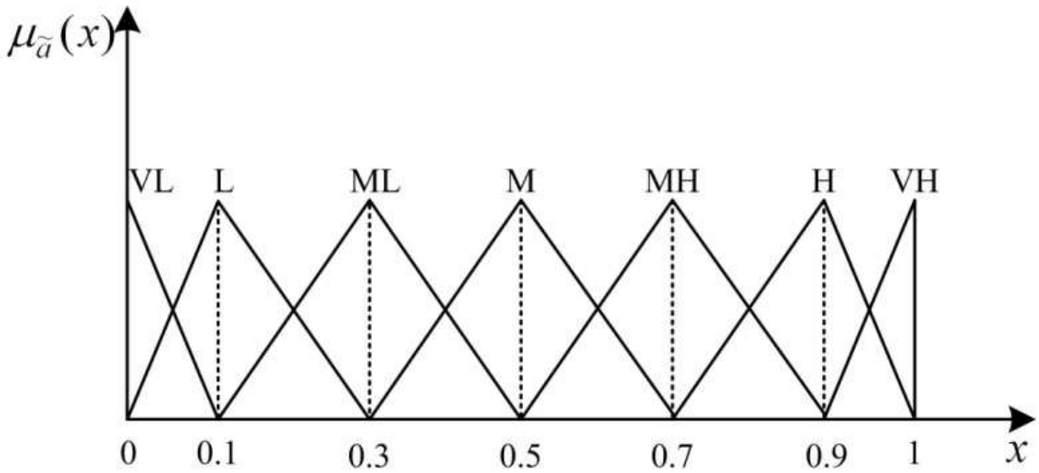

Fig. 4. Fuzzy membership triangular functions.

We propose a solution for structuring the risk management problem in order to adopt the full hierarchical approach used in the WBS, which as many levels as are required to provide the necessary understanding of risk exposure to allow effective management. Such a hierarchical structure of risk source should be known as a PRBS based on WBS. The proposed PRBS is defined here as a source-oriented grouping of project potential risks that organize and defines the total risk exposure of the project based on the WBS. Each descending level represents an increasingly detailed definition of sources of potential risk to the project based on the WBS.

Section 2: Fuzzy group decision-making process

This study aims to identify and prioritize project risks concurrently. Fuzzy entropy and fuzzy VIKOR techniques is used to identify risks from PRBS and prioritize them in the same time in a fuzzy environment.

Step 2. The lowest level of the PRBS constructs the alternatives of the fuzzy decision matrix.

Step 3. Determine risk identification criteria as follows:
C_1 : Existing and observing in other similar projects.
C_2 : Disability to transfer the potential risk to client or employer.
C_3 : Contract's disability to clarify the potential risk.

Step 4. Determine risk analysis criteria as below (Makui et al., 2010):
C_4 : Probability, C_5 : Time impact, C_6 : Cost impact, C_7 : Performance impact

Step 5. The DMs in the project:
The selection of experts for answering potential risk against criteria is very critical and it should be selected from project stakeholders.

Step 6. In order to take precise advantages form the fuzzy VIKOR method, some assumptions can be considered:

a. Criteria are the same for all DMs.
b. Criteria may have different weights but criteria's weights are the same for all DMs.
c. DMs have different weights.

Step 7. Construct fuzzy decision matrix D, $(p=1,2,...,k)$ for each of the experts. The structure of the fuzzy matrix can be depicted by:

$$DM^{(p)} = \begin{array}{c} \\ PR_1 \\ PR_2 \\ . \\ . \\ PR_i \\ . \\ . \\ PR_m \end{array} \begin{array}{c} \begin{array}{ccccccc} c_1 & c_2 & \dots & c_j & \dots & c_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11}^p & \tilde{x}_{12}^p & \dots & \tilde{x}_{1j}^p & \dots & \tilde{x}_{1n}^p \\ \tilde{x}_{21}^p & \tilde{x}_{22}^p & \dots & \tilde{x}_{2j}^p & \dots & \tilde{x}_{2n}^p \\ . & . & & . & \dots & . \\ \tilde{x}_{i1}^p & \tilde{x}_{i2}^p & \dots & \tilde{x}_{ij}^p & \dots & \tilde{x}_{in}^p \\ . & & & & & \\ . & & & . & & . \\ \tilde{x}_{m1}^p & \tilde{x}_{m2}^p & \dots & \tilde{x}_{mj}^p & \dots & \tilde{x}_{mn}^p \end{bmatrix} \end{array} \tag{9}$$

where PR_i denotes the ith potential risk, $\tilde{C}_j$; represents the jth criterion or attribute, $(j=1,2,...,m)$ (which are identified in Steps 3 and 4); with qualitative data. The element of $DM^{(p)}$ is $\tilde{x}_{ij}^p$, which indicates the perform rating of alternative PR_i with respect to criterion $\tilde{C}_j$; by DM $(p=1,2,...,k)$.

Please note that there should be k fuzzy decision matrix for the k members of a group. Observe that the DMs can also set the outcomes of qualitative or intangible criterion for each alternative as discrete values, or other linguistics values will be placed in the above decision matrix.

Step 8. Construct the fuzzy normalized decision matrix $\tilde{R}$, by each DM for n criteria. The normalized value $\tilde{r}_{ij}^p$ in the decision matrix $\tilde{R}^p$ is calculated by Eq. (5); (all criteria are considered as benefit).

Step 9. Construct the group decision matrix $\tilde{G}$ as follows:

$$\tilde{G} = \begin{array}{c} \\ PR_1 \\ PR_2 \\ . \\ \\ PR_i \\ \\ \\ PR_m \end{array} \begin{array}{c} \begin{array}{ccccccc} c_1 & c_2 & \cdots & c_j & \cdots & c_n \end{array} \\ \begin{bmatrix} \tilde{g}_{11} & \tilde{g}_{12} & \cdots & \tilde{g}_{1j} & \cdots & \tilde{g}_{1n} \\ \tilde{g}_{21} & \tilde{g}_{22} & \cdots & \tilde{g}_{2j} & \cdots & \tilde{g}_{2n} \\ . & . & . & \cdots & . & \\ \tilde{g}_{i1} & \tilde{g}_{i2} & \cdots & \tilde{g}_{ij} & \cdots & \tilde{g}_{in} \\ . & & & & & \\ & . & & . & & \\ \tilde{g}_{i1} & \tilde{g}_{i2} & \cdots & \tilde{g}_{ij} & \cdots & \tilde{g}_{in} \end{bmatrix} \end{array} \tag{10}$$

The grouping value for criterion j can be as follows:

$$\tilde{g}_{ij} = \sum_{p=1}^{k} \tilde{W}_D{}^p \times \tilde{r}_{ij}^p \quad ; i = 1,2,...,m \quad , j = 1,2,...,n \tag{11}$$

$\tilde{W}_D{}^p$ is the weight of each DM, where we have:

$$\sum_{p=1}^{k} \tilde{W}_D{}^p = 1 \tag{12}$$

Step 10. Change the evaluation index from different measurement to the same measurement.

$$\tilde{p}_{ij} = \tilde{x}_{ij} \Big/ \sum_{j=1}^{n} \tilde{x}_{ij} \tag{13}$$

Step 11. Calculate entropy of every index weight

$$\tilde{e}_i = -k \sum_{j=1}^{n} \tilde{p}_{ij} \ln \tilde{p}_{ij} \tag{14}$$

where $k > 0, k = 1/\ln n, \tilde{e}_i \geq 0$.

Step 12. Define the difference coefficient $\tilde{g}_i = 1 - \tilde{e}_i$, the bigger the $\tilde{g}_i$, the more important the index is. Identifying the indexes' value and applying entropy weight method.

$$\tilde{w}_i = \tilde{g}_i \Big/ \sum_{i=1}^{m} \tilde{g}_i \qquad (i = 1,2,\ldots,m) \tag{15}$$

Weight vector is $\tilde{w}_1 = (\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_m)$.

There are many methods that can be employed to determine weights (Kuo et al., 2007; Wang et al., 2007). In this paper, the weights provided by the fuzzy entropy technique are used.

Step 13. Determine the best f_j^* and the worst f_j^- values of all criterion functions $j = 1,2,\ldots,n$ .If the jth function represents a benefit, then we have:

$$f_i^* = \max_j f_{ij} \tag{16}$$

and

$$f_i^- = \min_j f_{ij} \tag{17}$$

Step 14. Compute the values S_i and R_i; $i = 1,2,\ldots,m$, by these relations:

$$S_i = L_{1,i} = \sum_{j=1}^{m} w_j \left(f_j^* - f_{ij} \right) \Big/ \left(f_j^* - f_j^- \right) , \tag{18}$$

$$R_i = L_{\infty,i} = \max_j w_j \left(f_j^* - f_{ij} \right) \Big/ \left(f_j^* - f_j^- \right), \tag{19}$$

where w_j are the weights of criteria, expressing their relative importance.

Step 15. Compute the values Q_i; $i = 1,2,\ldots,m$, by the following relation:

$$Q_i = v\left(S_i - S^* \right) \Big/ \left(S^- - S^* \right) + (1-v)\left(R_i - R^* \right) \Big/ \left(R^- - R^* \right) \tag{20}$$

Where

$$S^* = \min_i S_i , \qquad S^- = \max_i S_i \tag{21}$$

$$R^* = \min_i R_i , \qquad R^- = \max_i R_i \tag{22}$$

v is introduced as weight of the strategy of "the majority of criteria" (or "the maximum group utility"), here suppose that v = 0.5.

Step 16. Rank the alternatives, sorting by the values S, R and Q in decreasing order. The results are three ranking lists.

Step 17. Propose as a compromise solution the alternative A', which is ranked the best by the measure Q (Minimum) if the following two conditions are satisfied:

C1. *Acceptable advantage:*

$$Q\left(A'' \right) - Q\left(A' \right) \geq DQ$$

where A'' is the alternative with the second position in the ranking list by Q; $DQ = 1/(m-1)$; m is the number of alternatives.

C2. *Acceptable stability in decision making*:

Alternative A' should be also the best ranked by S or/and R. This compromise solution is stable within a decision-making process, which can be "voting by majority rule" (when $v > 0.5$ is needed), or ''by consensus" $v \approx 0.5$, or ''with veto" ($v < 0.5$). Here, v is the weight of the decision-making strategy "the majority of criteria" (or "the maximum group utility"). If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives A' and A'' if only condition C2 is not satisfied, or
- Alternatives $A', A'', \ldots, A^{(M)}$ if condition C1 is not satisfied; $A^{(M)}$ is determined by the relation $Q\left(A^{(M)}\right) - Q(A') < DQ$ for maximum M (the positions of these alternatives are "in closeness").

The best alternative, ranked by Q, is the one with the minimum value of Q. The main ranking result is the compromise ranking list of alternatives, and the compromise solution with the "advantage rate". VIKOR is an effective tool in MCDM, particularly in a situation where the DM is not able, or does not know to express his/her preference at the beginning of the system design. The obtained compromise solution can be accepted by the DMs because it provides a maximum "group utility" (represented by min S) of the "majority", and a minimum of the "individual regret" (represented by min R) of the "opponent". The compromise solutions can be the basis for negotiations, involving the DM preference by criteria weights.

Section 3: Separation of identified and non-identified risks

Step 18. In this step, one threshold can be determined in order to separate identified risks from potential risks, moreover, some ranges could be developed to assess the identified risks into "Almost certain risks" up to "Rare risks", as shown in Fig. 5.

Step 19. Classify identified risks (with analysis) and non-identified risks.

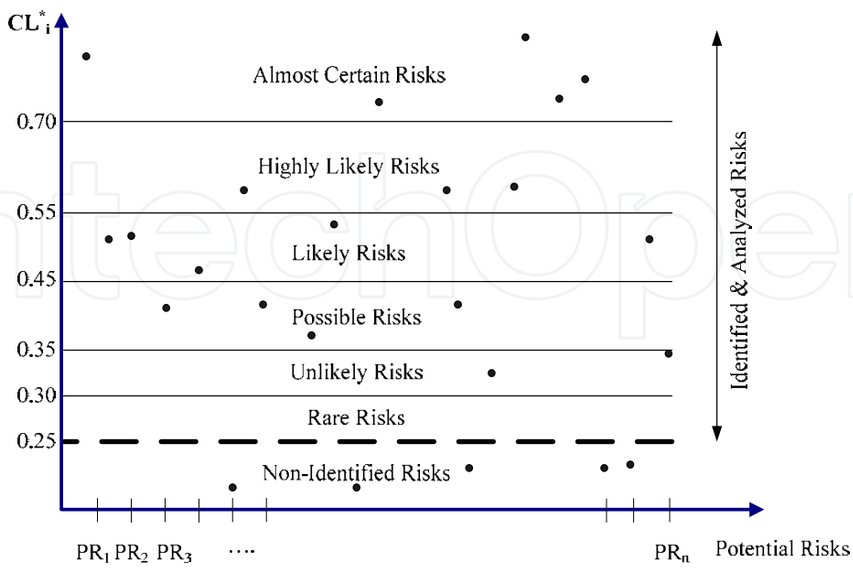

Fig. 5. Identifying and analysing project risks concurrently by defining appropriate thresholds.

6. Application to an EPC project

In this section, the proposed comprehensive approach is applied in the engineering phase of an EPC project. A project, as defined in the field of project management, consists of a temporary endeavor undertaken to create a unique product, service or result (Cooper et al., 2005). Project management tries to gain control over project's variables, such as risk. Thus, a risk analysis is essential for all phases of projects particularly engineering phase because this phase is a commencement phase of project. Project promoters depend upon several project partners (e.g., consultants, architects and contractors) to convert their plans into reality. Among the project partners, EPC contractors play a crucial role in the actual implementation of projects. Depending upon the size of a project, an EPC contractor might execute the same solely or break the project into different categories and delegate it to a number of sub-contractors.

Easy to manage by client, reduction of project time and cost, output guarantees, shortened project life cycle, improving contractors' abilities and financers' interests are the most advantages of EPC contracts. However, increasing contractor risk to perform the job, under-estimating and quality of work are the major disadvantages of EPC contracts. Most engineering contracts can fall into four major scopes of services:

- Basic Engineering (BE)
- Front End Engineering Design (FEED)
- Detailed Engineering (DE)
- Field Engineering (FE)

The main deliverable of a "Conceptual Design", which elaborates project feasibility, is the Master Development Plan (MDP). A basic designer further develops the MDP and creates the necessary integrity in each functional department to aim the proper design for having such industrial complex. The FEED is the extension of BE in order to create Material Requisition (MR) for Long Lead Items (LLI) in the project procurement phase. The BE or FEED will be the input to start the DE. Huge amount of man-hours are spent in comparison to the BE and FEED. The DE produces required documents for the project procurement and construction phases. Although using powerful tools, such as modeling software, helps the designer to minimize construction problems; however, still some problems exist that need and aggressive solutions during construction at project's site. Nowadays companies try to mobilize a technical crew at their site to solve and mitigate such obstacles during construction. These people have both good knowledge of engineering and construction experience. This step mainly is called the FE.
DMs' weights are calculated by using the entropy technique and results as shown in Table 2.

Criteria	Weight	Decision Maker	Weight
C_1	(0.15,0.20,0.30)		
C_2	(0,0.10,0.15)	DM_1	(0.30,0.45, 0.60)
C_3	(0,0.10,0.15)		
C_4	(0.15,0.20,0.30)	DM_2	(0.20,0.35,0.50)
C_5	(0.10,0.15,0.20)		
C_6	(0.10,0.15,0.20)	DM_3	(0.05,0.15,0.30)
C_7	(0,0.10,0.15)		

Table 2. Weights of criteria and decision makers.

Potential risks can be classified into two groups: 1) identified risks and 2) non-identified risks. Moreover identified risks can be classified into several analysis levels. These can be taken by defining appropriate thresholds as determined in Table 3.
The criteria of identified risks are rated on a six-point descriptive scale in terms of their crucial roles in identifying risks. Table 4 shows a suitable scale for identifying risks in EPC projects according to Makui et al. (2010).

Identification & analysis phases concurrently		Q_i
Identified risks	Almost certain risks	> 0.75
	Highly likely risks	0.60-0.75
	Likely risks	0.45-0.60
	Possible risks	0.40-0.45
	Unlikely risks	0.35-0.40
	Rare risks	0.30-0.35
Non-identified risks		< 0.30

Table 3. Thresholds of identification and prioritization phases.

Description	Scale	Existing and observing in other similar or related projects (C_1)	Disability to transfer the potential risk to client or employer (C_2)	Contract disability to clarify the potential risk (C_3)
Almost Certain	AC	> 8 cases out of 10 similar projects	Contract disability is almost certain to transfer the potential risk to client or employer.	Contract disability for clarifying the potential risk is almost certain.
Highly Likely	HL	6-8 cases out of 10 similar projects	Contract disability is highly likely to transfer the potential risk to client or employer.	Contract disability for clarifying the potential risk is highly likely.
Likely	L	4-6 cases out of 10 similar projects	Contract disability is likely to transfer the potential risk to client or employer.	Contract disability for clarifying the potential risk is likely.
Possible	P	2-4 cases out of 10 similar projects	Contract disability is possible to transfer the potential risk to client or employer.	Contract disability for clarifying the potential risk is possible.
Unlikely	UL	1-2 cases out of 10 similar projects	Contract disability is unlikely to transfer the potential risk to client or employer.	Contract disability for clarifying the potential risk is unlikely.
Rare	R	Nothing	Contract disability is rare to transfer the potential risk to client or employer.	Contract disability for clarifying the potential risk is rare.

Table 4. Measure of project risk identification criteria used within the contents of the EPC project.

Table 5 shows an extended probability and impact scales developed for a multi-purpose set of the analysis. They are rated in terms of weekly occurrence and potential impact on the criteria on a six-point descriptive scale for probability and impact criteria, respectively. The scale in Table 5 is used successfully in the risk analysis for EPC projects. However, it can be adapted easily to smaller than less complex projects.
By considering above information (Tables 1 to 5) and fuzzy group decision-making techniques based on the fuzzy entropy and VIKOR (Steps 6 to 17), the computational results are shown in Table 6.

Description	Scale	Probability (C_4)	Time (C_5)	Cost (C_6)	Performance (C_7)
Almost Certain	AC	> 0.9	> 20 weeks	> $50m	Key performance criteria cannot be achieved
Highly Likely	HL	0.7-0.9	15-20 weeks	$30m-$50m	Very Significant reduction in performance
Likely	L	0.5-0.7	10-15 weeks	$10m-$30m	Significant reduction in performance
Possible	P	0.3-0.5	5-10 weeks	$1m-$10m	Some reduction in performance
Unlikely	UL	0.1-0.3	1-5 weeks	$0.1m-$1m	Small reduction in performance
Rare	R	< 0.1	< 1 weeks	< $0.1m	Minimal or unimportant performance impacts

Table 5. Measure of project risk analysis criteria used within the contents of the EPC project.

7. Discussion of results

In this paper, we identify and prioritize risks concurrently by using the fuzzy entropy and VIKOR techniques in the EPC project. The inference of the results is applicably feasible, appealing and interesting in the EPC project. We also classify potential risks in accordance with the work breakdown structure (WBS) in three levels and after applying the proposed fuzzy comprehensive approach, we calculate portion of each WBS levels from identified risks as shown in Fig. 6. For instance, 31.60% of identified and prioritized risks belong to the construction part.
The computational results show that management's risks are in the first priority for responding and further actions. Other ranks are illustrated in Table 7. Furthermore, by considering the defined thresholds in Table 3 and the obtained results from Table 4, the results of the EPC project risk identification and risk prioritization are classified in Table 6. In addition, each portion is illustrated in Fig. 7. As it is evident 10.53% of risks are evaluated as possible risks and 5.26% of risks are evaluated as rare risks. Their ranks are shown in Table 8.

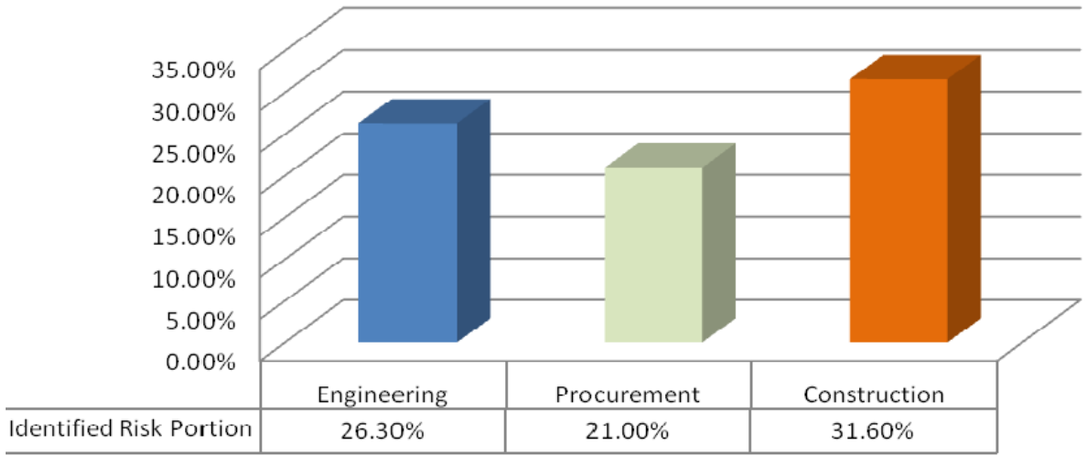

Fig. 6. Each WBS portion from identified risks in the EPC project.

Fuzzy group weighted matrix			
WBS	Potential risk code	Potential risk description	Q_i
Engineering (E)	ENG-01-10	Design failures	0.338
	ENG-02-11	Change in project scope of work	0.432
	ENG-03-12	Data transition from basic to detail design	0.462
	ENG-04-13	Lack of resources	0.392
	ENG-05-14	Inadequate design quality	0.439
Procurement (P)	PRO-01-15	International relations	0.919
	PRO-02-16	Ambiguity in project cash injection	0.540
	PRO-03-17	Inappropriate vendor list	0.362
	PRO-04-18	Delay in purchasing	0.504
	PRO-05-19	Imperfect data transmission to vendors	0.291
	PRO-06-20	Inspection and forwarding problems	0.278
Construction (C)	CON-01-21	Critical weather conditions	0.662
	CON-02-22	HSE matters	0.707
	CON-03-23	Workers riots	0.369
	CON-04-24	Poor team communication	0.099
	CON-05-25	Contagious diseases	0.393
	CON-06-26	Subcontractor interfaces	0.549
	CON-07-27	Inadequate QA/QC inspections and audits	0.233
	CON-08-28	Delay in equipment delivery to site	0.716

Table 6. Fuzzy group decision matrix and ranking outcome for the EPC project risks.

WBS	Portion of Q_i	Rank
Engineering (E)	26.30%	2
Procurement (P)	21.00%	3
Construction (C)	31.60%	1

Table 7. WBS leveling based on the portion of Q_i.

Identified and analysis levels	Portion of Q_i	Rank
Almost certain risks	5.26%	4
Highly likely risks	15.79%	2
Likely risks	21.05%	1
Possible risks	10.53%	3
unlikely risks	21.05%	1
Rare risks	5.26%	4
Non-identified risks	21.05%	1

Table 8. Ranking based on the portion of Q_i.

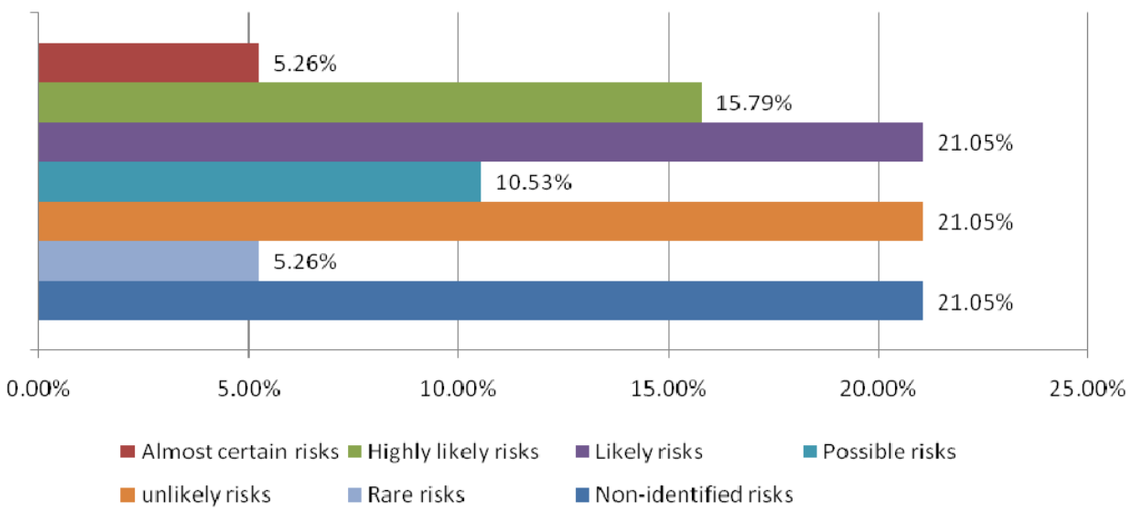

Fig. 7. Portion of each threshold from identified and non-identified project risks.

8. Conclusion

Decisions are made today in increasingly complex environments. In more and more cases, the use of experts or decision makers in various fields is necessary. In many of such decision-making settings, the theory of group decision making can play crucial role. Group decision making in a fuzzy environment can overcome this difficulty as well. This paper has extended a new comprehensive approach for identifying and prioritizing risks of Engineering, Procurement and Construction (EPC) projects by using the Multiple Criteria Group Decision Making (MCGDM) in a fuzzy environment based on the fuzzy entropy and VIKOR techniques. In addition, this study has explored the use of two well-known fuzzy decision-making techniques for solving risk identification and prioritization concurrently. The fuzzy entropy has been utilized to obtain the weights of criteria, and the fuzzy VIKOR has been also used for ranking the potential risks as viable techniques for the problem. The fuzzy VIKOR is suitable for the use of precise performance ratings. When the performance ratings are vague and inaccurate, then the fuzzy MCDGM is the preferred approach. New criteria have been considered for risk management in EPC projects, in which they cover risk identification and risk prioritization concurrently. Then, a new method has been applied for classifying potential risks as PRBS. Furthermore, the techniques and experiences learned from the study can be valuable to future strategic planning for the company. The obtained results from the case study in the EPC project in Iran have shown that the proposed fuzzy comprehensive approach has been viable in solving the proposed risk identification and prioritization problems in EPC projects.

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The term "risk" is very often associated with negative meanings. However, in most cases, many opportunities can present themselves to deal with the events and to develop new solutions which can convert a possible danger to an unforeseen, positive event. This book is a structured collection of papers dealing with the subject and stressing the importance of a relevant issue such as risk management. The aim is to present the problem in various fields of application of risk management theories, highlighting the approaches which can be found in literature.

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