An Intuitionistic Fuzzy-Based DEMATEL to Rank Risks of Construction Projects

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Abstract

The modern-day project management has focused on the risks management due mainly to the complexities in nowadays projects. On this factual basis, recognizing and mitigating the most critical project risks assist in achieving more efficiency in the project management. Therefore, an effective project management system will help projects not to fail meeting their due dates, not to fall short on customer expectations, and also not to exceed the budget. In this article, an intuitionistic fuzzy Decision making Trial and Evaluation Laboratory (DEMATEL) is presented in order to prioritize risks of the construction projects. In this study, the Risk Breakdown Structure (RBS) presented by the Project Management Institutes' (PMI) is utilized as a framework. The project expert opinions are collected as a source of knowledge through a number of questionnaires. Intuitionistic fuzzy sets (IFS) theory which benefits from a number of merits compared to classic fuzzy sets theory is applied to tackle the vagueness and imprecision of human subjective judgments. The results have revealed that "External" risks were the most significant risk categories in the construction projects.

Keywords
Intuitionistic Fuzzy Set Theory, DEMATEL, Project Risk Management, Construction Projects

1. Introduction
Project risk represents the occurrence chance of an event with negative influence on project objectives. Risk management should be practiced as a highly significant task in order to arrive at efficient delivery of projects (Vafadarnikjoo et al., 2015(a)). A Risk Breakdown Structure (RBS) illustrates groups and sub-groups of a common project risks (PMI 2008). The structure on the basis of RBS provides risk managers with a superb tool for systematically identifying individual sources of risks at a consistent detail. The adopted RBS was shown in the PMI's Project Management Body of Knowledge (PMBOK) Guide which is also depicted in Figure 1.
The main categories illustrated in Figure 1 include "Technical", "External", "Organizational" and "Project Management" (PMI 2008; Vafadarnikjoo et al., 2015(a)): 1) Technical risks are those which connected to the

technology applied in the project; 2) External risks are not in the authority of project managers such as inflation rate and environmental factors; 3) Organizational risks usually appear when shortage of organizational resources exists; and 4) Project management risks are related to managing tasks including estimating, planning, controlling and communication.

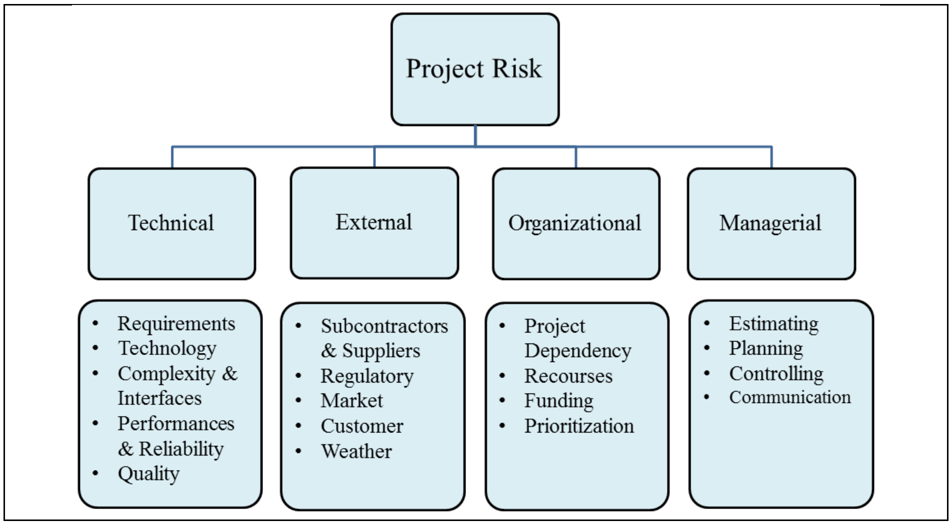

Figure 1. Risk Breakdown Structure (RBS) (PMI 2008)

As far as we investigated the literature, it is concluded that there is no integrated method of DEMATEL and intuitionistic fuzzy set (IFS) theory in the context of project risks ranking. Furthermore, practically risks of project have some sort of dependencies and there would be a degree of interrelationships between them. Therefore, DEMATEL method is utilized to consider the sophisticated relations between risks groups. Intuitionistic fuzzy set theory is also applied in order to handle human's subjective judgments. A detailed description of the advantages of IFSs are presented in (Govindan et al., 2015; Xu and Liao, 2013; Liu and Wang, 2007).

Consequently, intuitionistic fuzzy DEMATEL is proposed in this research to prioritize the various types of project risks on the basis of RBS of the PMBOK Guide for the construction projects to reach more cogent assessment. The result will be a helpful tool for risks managers of projects in the construction industries. The literature review of the study is represented in Section 2. The proposed research methodology is described in Section 3. The proposed methodology is applied to prioritize the risks of the construction projects as a case study in Section 4. The results of applying the proposed model are presented in Section 5. Finally, Section 6 provides the conclusions and guidance for potential future studies.

2. Literature review

In this section, the existing approaches in the project risk management are reviewed. The MCDM methods have been extensively applied in the realm of project risks management are represented in the Appendix. Vafadarnikjoo et al. (2015(a)) proposed an integrated gray-fuzzy DEMATEL to obtain the most significant categories of project risks. Askari, and Shokrizade (2014) recognized the risks of Build-Operate-Transfer (BOT) projects and then ranked these risks on the basis of their severity and effect on project objectives by Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) and Fuzzy Simple Additive Weighting (FSAW). Ebrahimnejad et al. (2014) investigated the significance of risk ranking in mega projects by fuzzy compromise programming methods. They applied three MCDM methods including TOPSIS, VIKOR, and LINMAP in fuzzy environment and compared these approaches performance. They also developed a new fuzzy VIKOR method to assist managers in handling mega project risks. Taylan et al. (2014; 2015) introduced new method to assess construction projects and related risks under uncertain decision making environment. Kuo, and Lu (2013) utilized a fuzzy decision-making approach to analytically evaluate risk for a metropolitan construction project. They used consistent fuzzy preference relations (CFPR) to measure the relative influence on project performance of twenty identified risk factors involved in four risk dimensions. They also utilized fuzzy multiple attributes direct rating (FMADR) approach to analyze the occurrence probability of multiple risk factors. Yazdani-Chamzini et al. (2013) used the ELECTRE technique to rank the risks imposed during tunneling project in a subway project. Khatami Firouzabadi, and Vafadar Nikjoo (2012) investigated ranking the most significant project risks using fuzzy DEMATEL on the basis of the PMBOK standard. Rezakhani (2012) categorized the most important risk factors in a construction project in a hierarchical structure and in order to select an effective risk factor, a modified rational MCDM is developed and fuzzy logic also applied to this model. Taroun, and Yang (2011) illustrated the merits and downsides of Dempster-Shafer Theory (DST) compared to probability theory (PT), fuzzy sets theory, and the AHP for handling risk assessment and decision making in the construction projects. Mousavi et al. (2011) used non-parametric resampling technique, called bootstrap, with interval analysis to evaluate the Large Engineering Projects (LEPs) risks. They expressed that their method outperformed the traditional techniques in terms of the accuracy and efficiency. Tavakkoli-Moghaddam et al. (2011) proposed an applicable fuzzy MCDM to identify and prioritize project risks in the EPC projects. KarimiAzari et al. (2011) applied fuzzy TOPSIS method to evaluate the risk of a construction firm. Zavadskas et al. (2010) proposed risk assessment of construction projects on the basis of MCDM methods including gray TOPSIS and gray COPRAS methods. In Ebrahimnejad et al. (2010), Fuzzy TOPSIS (FTOPSIS) and Fuzzy Linear Programming Technique for Multidimensional Analysis of Preference (FLINMAP) methods were utilized to rank high risks in BOT projects. Bu-Qammaz et al. (2009) proposed analytic network process (ANP) to provide the interrelations among risk related factors in the international construction projects. They utilized the result of ANP method as an input to a decision support tool. Additionally Tavana et al. (2016a) applied an ANP approach for assessing the risk of outsourcing the reverse logistics activities to third party reverse logistics providers (3PRLP) in a manufacturing firm. Ebrahimnejad et al. (2008) identified the important risks in construction industry project and applied fuzzy TOPSIS and fuzzy LINMAP approaches to evaluate the high risks in the projects. Ebrahimnejad et al. (2009) applied fuzzy TOPSIS and fuzzy LINMAP methods to rank the high risks in an onshore gas refinery plants. Their results revealed that fuzzy LINMAP performed more accurate than fuzzy TOPSIS. Mojtahedi et al. (2008) presented a novel methodology to identify and analyze risks by using multi attribute group decision making (MAGDM). They presented a new procedure in order to categorize potential risks breakdown structure (PRBS). Wang et al. (2008) proposed an integrated AHP and DEA method to evaluate bridge risks of a myriad of bridge structures. According to their evaluation, the maintenance priorities of the bridge structures can be determined. Cervone (2006) developed a realization of the setbacks related to the risk management in digital library projects, as well as, methods for mitigating risks in these projects. Baccarini et al. (2004) determined 27 risks in IT projects by means of in-depth interviews with IT experts from leading corporations in Australia. Parker, and Mobey (2004) used research in a major UK firm on the introduction of an electronic document management system to investigate perceptions of and attitudes to risk. Their article determined a number of factors, and established a framework that should support a greater realization of the risk evaluation and project management by the academic community and practitioners. Baccarini, and Archer (2001) described the application of a methodology for the risk prioritizing of projects which is conducted by the Department of Contract and Management Services (CAMS in Western Australia (WA). Tah, and Carr (2000) represented a hierarchical risk breakdown structure to establish a proper method for qualitative risk assessment.

3. Research Methodology

In this study, the intuitionistic fuzzy DEMATEL is proposed to prioritize the various types of project risks on the basis of RBS of the PMBOK Guide for construction projects. The framework of the intuitionistic fuzzy DEMATEL is depicted in Figure 2. In Figure 2, IFN stands for intuitionistic fuzzy numbers

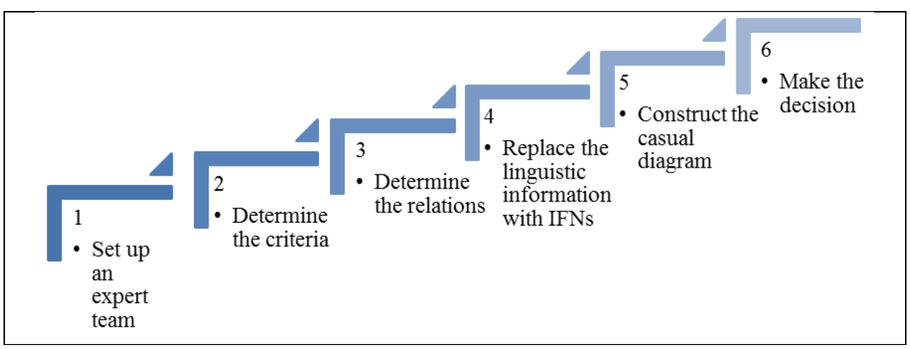

Figure 2. The intuitionistic fuzzy DEMATEL framework

3.1. Intuitionistic fuzzy set theory

In 1965, Zadeh (1965) initiated fuzzy sets theory. Afterwards, a novel theory, named intuitionistic fuzzy set theory, was suggested by Atanassov (1986). Nehi, and Maleki (2005) proposed intuitionistic trapezoidal fuzzy numbers which are the extension of intuitionistic triangular fuzzy numbers. Both intuitionistic triangular and trapezoidal fuzzy numbers are the extensions of the intuitionistic fuzzy set. In other words, it produces a continuous set from a discrete one (Ye, 2011). IFS theory can be characterized by the membership function as well as a non-membership function. Intuitionistic fuzzy sets have shown definite merits of handling vagueness and uncertainty in comparison with fuzzy sets theory that cannot consider hesitancy degree of experts (Govindan et al. 2015; Tavana et al. 2016b). Some basic definitions and concepts of IFS theory are presented as follows (Nikjoo, and Saeedpoor, 2014):

Definition 1. Consider X as a fixed set. Then an IFS A in X can be defined as:

$$A = \{(x, \mu_A(x), v_A(x)) | x \in X\} \tag{1}$$

In Equation (1), $\mu_A(x): X \to [0,1]$ and $v_A(x): X \to [0,1]$ are defined in a way that $0 \le \mu_A(x) + v_A(x) \le 1, x \in X$. The number $\mu_A(x)$ denotes the membership degree and $v_A(x)$ signifies the non-membership degree of the element $x \in X$ to the set A. $\pi_A(x)$ is the hesitance level of $x \in X$ to A and $0 \le \pi_A(x) \le 1, x \in X$ which can be determined according to Definition (1) as follows (Büyüközkan and Güleryüz, 2016; Atanassov, 1986):

$$\pi_A(x) = 1 - \mu_A(x) - v_A(x), \quad x \in X, \tag{2}$$

Definition 2. An intuitionistic trapezoidal fuzzy number A with parameters $b_1 \le a_1 \le b_2 \le a_2 \le a_3 \le b_3 \le a_4 \le b_4$ is expressed as: $A = ((a_1, a_2, a_3, a_4), (b_1, b_2, b_3, b_4))$ in R which is a set of real numbers. In order to obtain membership and non-membership functions of A, Equations (3) and (4) can be utilized (Nehi and Maleki, 2005) (see Figure 3).

$$\mu_A(x) = \begin{cases} 0 & x \prec a_1 \\ \dfrac{x - a_1}{a_2 - a_1} & a_1 \le x \le a_2 \\ 1 & a_2 \le x \le a_3 \\ \dfrac{x - a_4}{a_3 - a_4} & a_3 \le x \le a_4 \\ 0 & a_4 \prec x \end{cases} \tag{3}$$

$$v_A(x) = \begin{cases} 1 & x \prec b_1 \\ \dfrac{x - b_2}{b_1 - b_2} & b_1 \le x \le b_2 \\ 0 & b_2 \le x \le b_3 \\ \dfrac{x - b_3}{b_4 - b_3} & b_3 \le x \le b_4 \\ 1 & b_4 \prec x \end{cases} \tag{4}$$

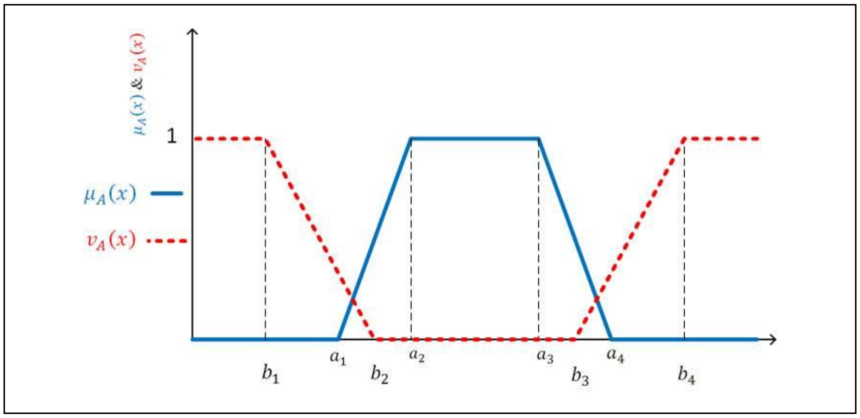

Figure 3. Membership function of an intuitionistic trapezoidal fuzzy number (Vafadarnikjoo et al. 2015(b))

If we consider that $b_2 = b_3$ and $a_2 = a_3$ in an intuitionistic trapezoidal fuzzy number A, then, it changes to an intuitionistic triangular fuzzy number. Considering $A_1 = ((a_1, a_2, a_3, a_4), (b_1, b_2, b_3, b_4))$ and $A_2 = \big((c_1, c_2, c_3, c_4), (d_1, d_2, d_3, d_4)\big)$ as intuitionistic trapezoidal fuzzy numbers and $k \succ 0$, the following properties (Equations (5) and (6)) are meaningful according to Nehi and Maleki (2005):

$$A_1 + A_2 = ((a_1 + c_1, a_2 + c_2, a_3 + c_3, a_4 + c_4), (b_1 + d_1, b_2 + d_2, b_3 + d_3, b_4 + d_4)) \quad (5)$$
$$kA_1 = ((ka_1, ka_1, ka_1, ka_1), (kb_1, kb_2, kb_3, kb_4)) \quad (6)$$

Theorem 1. Suppose $A = ((a_1, a_2, a_3, a_4), (b_1, b_2, b_3, b_4))$ be an intuitionistic trapezoidal fuzzy number in R which is a set of real numbers. On the basis of Equation (7), the expected value can be calculated when $(x - a_1)/\,(a_2 - a_1)$, $(x - a_4)/\,(a_3 - a_4)$, $(x - b_2)/\,(b_1 - b_2)$, $(x - b_3)/\,(b_4 - b_3)$, $b_1 \le a_1 \le b_2 \le a_2 \le a_3 \le b_3 \le a_4 \le b_4 \in R$ (Grzegrorzewski, 2003).

$$EV\ (A) = \frac{1}{8}(a_1 + a_2 + a_3 + a_4 + b_1 + b_2 + b_3 + b_4) \quad (7)$$

3.2. DEMATEL method

The DEMATEL approach was first utilized to solve fragmented and antagonistic issues of world societies. DEMATEL method is based on a foundation of graph theory specifically directed graph called digraph which empowers decision-makers to investigate and explain problems by visualization method. These graphs are more helpful than directionless graphs because they can show the directed relationships of sub-systems (Vafadarnikjoo et al. 2015(a); Gabus, and Fontela 1972; Gabus, and Fontela 1973; Wu, and Lee 2007). In order to deal with complex issues, the DEMATEL method was developed between 1972 and 1976. This method puts all factors into two distinct categories called "cause" and "effect" by applying impact values between factors. This categorization results in a more thorough realization of system's components and correspondingly finding solutions to resolve complex system's problems. In DEMATEL, "factors" or "criteria" are defined the same, both are elements that a decision maker is keen on determining the interrelationships between them by constructing a pair-wise relation matrix. Steps of this method are elaborated as following (Govindan et al. 2016; Vafadarnikjoo et al. 2015(a)):

Step 1. The direct relation matrix should be generated: The matrix $(A_{n\times n})$ can be achieved by pair-wise comparisons between criteria that is carried out by expert team and each element of this matrix (a_{ij}) denotes the influence value of criterion i on criterion j. The influence of criterion (factor) i on a criterion (factor) j means how increase/decrease in i can increase/decrease j.

Step 2. The direct relation matrix should be normalized by using Equations (8) and (9):

$$X = k \times A \quad (8)$$
$$k = \frac{1}{max \sum_{j=1}^{n} a_{ij}} \qquad 1 \le i \le n \quad (9)$$

Step 3. The total relation matrix should be produced by Equation (10) in which I is called the identity matrix.

$$T = X(I - X)^{-1} \tag{10}$$

Step 4. A causal diagram is generated by applying Equations (11)-(13), summation of rows (D) and summation of columns (R) are calculated according to matrix T. D value of a factor is its influential impact on others. R value is an impact the factor receives from others (Lin, 2013).

$$T = [t_{ij}]_{n\times n} i,j = 1,2,\dots,n \tag{11}$$

$$R = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} = [t_{.j}]_{1\times n} \tag{12}$$

$$D = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = [t_{i.}]_{n\times 1} \tag{13}$$

where $(D + R)$ represents the horizontal axis vector which is called prominence and indicates the relative importance of each criterion. $(D - R)$ is named relation. In general, we have the following: if $(D - R) > 0$, then the criterion is a member of cause group; and if $(D - R) < 0$, then the criterion is a member of effect group.
Cause factors have impact on the entire system, their performance can influence on the overall goal. Moreover, the criteria belong to cause group should be paid more attention. Effect factors are tended to be easily impacted by others which causes factors in effect group inappropriate to be a critical success factor (Lin, 2013).
Step 5. The inner dependence matrix is attained. In total relation matrix, the sum of each column would be equal to 1 by the normalization method after which the inner dependence matrix can be resulted.

3.3. Proposed Intuitionistic Fuzzy DEMATEL Methodology

In this section, the proposed methodology for determining priorities of criteria in a typical decision making problem by using intuitionistic fuzzy DEMATEL method is explained.
Step 1. Provide the expert team: In order to do pair-wise comparison of criteria and also ensuring that decision goals are achieved, it is required to establish a team of experts. This team must include members with good experience and knowledge in the related decision-making field.
Step 2. Identify the evaluation criteria: The evaluation of alternatives would be meaningless without considering a set of criteria. An efficient set of criteria will provide a better evaluation. Therefore, in order to achieve this goal, the knowledge and expertise of an expert team must be acquired. In addition, by conducting a literature review, a set of criteria can be formed.
Step 3. Determine the relations: In this step, the experts will determine the relations between and among the criteria by considering one of the five scales in each pair-wise comparison: 0 (no influence), 1 (low influence), 2 (medium influence), 3 (high influence) and 4 (very high influence) which are presented in Table 1. This scale can be various in different studies. Accordingly, the initial direct relation matrix will be achieved that can be utilized in DEMATEL technique.
Step 4. Replace the linguistic information with the intuitionistic fuzzy linguistic scale: The intuitionistic fuzzy numbers will be used to replace the influence scores of linguistic information in direct relation matrix. Afterwards, Equation (7) will be used to get the crisp values to use DEMATEL technique.
Step 5. Obtain the causal diagram: According to Equations (8-13), the causal diagram can be constructed.

Table 1. The intuitionistic fuzzy linguistic scale

Linguistic phrases	Influence score	Intuitionistic trapezoidal fuzzy numbers	Expected crisp values
No influence	0	((0,0,0,0), (0,0,0,0))	0
Low influence	1	((0, 0.1, 0.2, 0.3), (0, 0.1, 0.2, 0.3))	0.15
Medium influence	2	((0.3, 0.4, 0.5, 0.6), (0.2, 0.4, 0.5, 0.7))	0.45
High influence	3	((0.7, 0.8, 0.9, 1), (0.7, 0.8, 0.9, 1))	0.85
Very high influence	4	((1,1,1,1), (1,1,1,1))	1

4. Application of the Proposed Methodology in a Case Study

In Step 1, the expert team is identified. The team consists of seven experts who have appropriate knowledge and experience in project management in different project-based organizations. They are asked to fill out our questionnaire. Their opinions are shown in Table 2.

In the second step, the main project risks are identified. In Figure 1, the RBS on the basis of PMBOK fourth edition Guide is presented. The, in the third step, the experts were asked to fill out the questionnaire in order to evaluate the interrelationship of each risk using a five-point linguistic rating scale, indicating the influence of each risk on the other risk (See Table 2).

Table 2. The opinions of seven experts

	Technical	External	Organizational	Project Management
Technical	0,0,0,0,0,0,0	3,1,0,4,3,2,3	2,3,0,2,3,3,4	4,4,1,4,3,3,3
External	2,3,3,4,3,2,3	0,0,0,0,0,0,0	2,2,3,3,4,2,3	2,3,4,4,2,2,3
Organizational	1,4,1,2,3,3,1	2,1,2,3,4,2,1	0,0,0,0,0,0,0	2,3,4,3,4,3,2
Project Management	1,4,3,4,3,3,1	2,1,2,4,2,2,1	2,4,4,3,4,3,2	0,0,0,0,0,0,0

In Step 4, the linguistic information are converted to intuitionistic fuzzy linguistic scale. It should be mentioned that we used intuitionistic trapezoidal fuzzy numbers (Table 1) for replacing the influence scores of linguistic information in direct relation matrix. Afterwards, Equation (7) is used to get the crisp values to use DEMATEL technique.

Table 3. The overall crisp opinions of seven experts

	Technical	External	Organizational	Project Management
Technical	0.0000	0.5929	0.6357	0.8143
External	0.7475	0.0000	0.7000	0.7214
Organizational	0.5143	0.5000	0.0000	0.7786
Project Management	0.6929	0.4429	0.8000	0.0000

In the last step the causal diagram should be created. The normalized initial direct-relation matrix was produced by using Equations 8 and 9. The total relation matrix was calculated by using Equation 10 as shown in Table 4. The prominence and relation axes for cause and effect groups were computed by using Equations 11 to 13 in MATLAB software are also presented in Table 4. If the $(D-R)$ is negative, the risk is grouped into the effect group. Therefore, the causal diagram can be acquired by mapping the dataset of the $(D+R, D-R)$, which presented in Figure 4. The causal diagram can give us valuable insight into the realization of the whole system and recognizing important risks.

Table 4. Total relation matrix

	Technical	External	Organizational	Project Management	*D*	*R*	*D+R*	*D-R*
Technical	2.3644	2.1727	2.7891	2.9870	10.3132	9.9160	20.2293	0.3972
External	2.7378	2.0565	2.9311	3.0967	10.8221	8.2186	19.0407	2.6035
Organizational	2.3231	1.9514	2.3101	2.7095	9.2941	10.7408	20.0350	1.4467
Project Management	2.4908	2.0380	2.7105	2.5860	9.8254	11.3793	21.2047	1.5540

5. Computational results

Findings from the total relation matrix (Table 4) and the causal diagram (Figure 4) show that "Organizational" and "Project Management" risks belong to effect group because their $(D-R)$ scores are negative and they are tended to be easily impacted by other risks. On the other hand, "Technical" and "External" risks are in cause group because of positive scores of their $(D-R)$ which means they are critical risks that can influence on the overall achievements of the organization. "Project Management" risk has the highest $(D+R)$ score and it means its relative importance is greatest among other risks. In order to prioritize risks, we must consider both prominence and relation axes which are $(D + R)$ and $(D - R)$ respectively. In overall consideration, we have the following ranking in which "External" risk has gained the first rank because it has very high $(D - R)$ score compared to others. The results of this study are in line with those of Vafadarnikjoo et al. 2015(a): External > Technical > Project Management > Organizational.

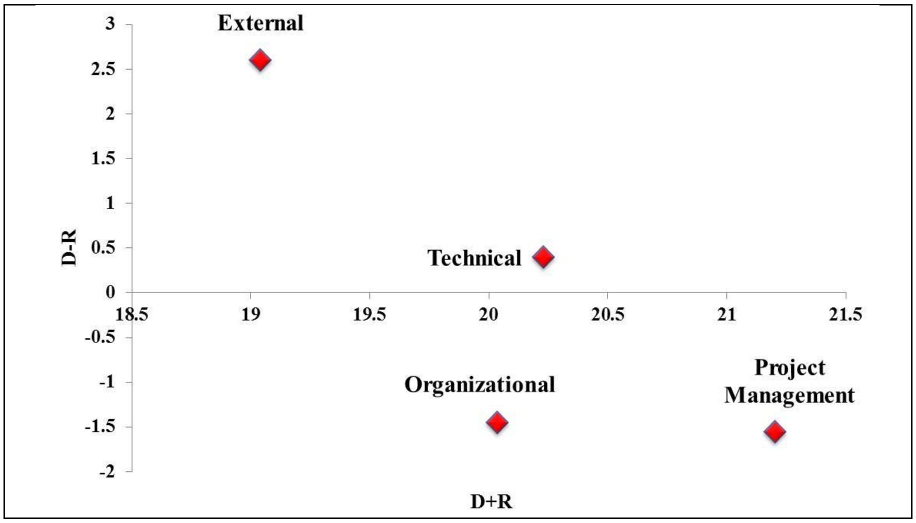

Figure 4. The Causal Diagram

6. Conclusions

The findings of this research would provide the risk managers with a number of valuable implications. It is vivid that cause group risks must be regarded as highly noteworthy risk groups which are "Technical" and "External" risks. It is revealed that "External" risks are the first significant risks groups including factors such as inflation rate and environmental factors. This result indicates that applied technology in construction projects should be regarded as one of the key sources of risks in construction projects and must be treated well in order to mitigate the effects of "Technical" risks. These components are not under control of the project manager's authority but they bring about a broad range of issues and managers should be vigilant to lower their negative effects. As there are a myriad of complexities in present-day projects, an effective project management system would help projects not to fail meeting their due dates, not to fall short on customer expectations and also not to exceed budget. In this study, we introduced intuitionistic fuzzy DEMATEL to incorporate both interrelationships between various project risks categories on the basis of the PMBOK Guide’s RBS and also to handle the linguistic ambiguity and uncertainty of human being's judgment.

The outcome of this research indicates that "External" risk is of high significance and must be paid the most attention by managers after which the most critical risks categories are "Technical", "Project Management" and "Organizational" respectively in project-based construction firms. Future research may be done in the fields of different industry’s sectors to achieve more exclusive results which would be more useful for the specific types of projects.

This study suffers from a few limitations that may be further investigated in future researches. The number of experts can be increased to achieve more reasonable and valid evaluations. To deal with uncertainty of the experts' judgments, different theories like hybrid gray theory, hesitant fuzzy sets and type-2 fuzzy sets theories can be applied and compared. It is also worthwhile to rank sub-categories of main risks according to RBS of the PMBOK Guide.

Appendix: Summary of the MCDM methods applied in the realm of project risks management

Article	Year	Method	Characteristics
Lin et al.	2016	DEMATEL, DANP & VIKOR	Aimed at minimizing cloud CRM project risks
Sarkar & Panchal	2015	Fuzzy Interpretive Structural Modeling (FISM)	Aimed at developing a project risk management model for constructing a port
Vafadarnikjoo et al.	2015(a)	Gray-Fuzzy DEMATEL	Risks are prioritized in the construction projects industry based on the PMBOK's RBS
Askari, & Shokrizade	2014	FTOPSIS & FSAW	Risks of the BOT projects are identified and ranked according to their severity and effect on project objectives by the two methods
Taylan et al.	2014	FAHP & FTOPSIS	Identified and ranked key construction projects risks
Ebrahimnejad et al.	2014	FTOPSIS & FVIKOR & FLINMAP	Risks are ranked in the area of mega projects
Kuo & Lu	2013	consistent fuzzy preference relations (CFPR)	Risks are assessed for a metropolitan construction project
Yazdani-Chamzini et al.	2013	ELECTRE	Risks of tunneling project in a subway project are ranked
Rezakhani	2012	Modified Rational MCDM	Risks of construction projects are ranked
Khatami Firouzabadi & Vafadar Nikjoo	2012	FDEMATEL	Risks are ranked on the basis of RBS of PMBOK
KarimiAzari et al.	2011	FTOPSIS	Risks of an construction firm are assessed
Taroun & Yang	2011	Dempster-Shafer theory (DST), probability theory (PT), fuzzy sets theory and AHP	Risks are assessed in construction industry
Tavakkoli-Moghaddam et al.	2011	Fuzzy entropy & FVIKOR	A fuzzy MCGDM approach for risk identification and ranking in EPC projects is introduced
Ebrahimnejad et al.	2010	FTOPSIS & FLINMAP	Two methods are compared according to the following: separation among alternatives, fuzzy error in criteria's weights, risk response planning, and finally, numerousness of alternatives in proportion to criteria
Zavadskas et al.	2010	GTOPSIS & COPRAS-G	Used the two methods to rank risks of construction projects
Bu-Qammaz et al.	2009	ANP	Risks of international construction projects are ranked
Ebrahimnejad et al.	2009	FTOPSIS & FLINMAP	Risks in Iranian onshore gas refinery plants are ranked
Ebrahimnejad et al.	2008	FTOPSIS & FLINMAP	Risks in construction industry project are identified and evaluated
Mojtahedi et al.	2008	MAGDM	Applied in gas refinery plant construction
Wang et al.	2008	Hybrid AHP-DEA	Bridge risks are evaluated

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