

Construction Risk Management Framework using Fuzzy sets and Failure Mode and Effect Analysis

Mehdi Tavakolan, Assistant Professor and Amir Mohammadi, Ph.D student
University of Tehran
Tehran

Risk management is an important part of project management. So far, several techniques have been proposed for project risk management. Failure Mode and Effect Analysis (FMEA) is one of the most useful techniques in construction risk management domain. The main goal of this technique is to identify failure modes in a system, determine their impact, and dispose corrective actions. In traditional FMEA, the risk priorities of failure modes are specified by using Risk Priority Numbers (RPN), that is the result of multiplication the Occurrence (O), Severity (S), and Detection (D) scores for each risk. This paper presents Risk Management Framework (RMF) by combination of FMEA and Fuzzy sets to overcome the limitations of traditional FMEA. Linguistic variables are used to estimate the scores of risk factors O, S, and D which are expressed in trapezoidal and triangular fuzzy numbers. A fuzzy Expert System (FES) is applied to calculate the importance weight factor for each expert. For verification and receiving feedback, the RMF is applied to analyze risks in a large scale project in oil and gas industry.

Keywords*:* Risk Management, Construction Management, Failure Modes, Fuzzy Sets

Introduction

The nature of different activities of construction projects is determined by many risks and uncertainty inherent in each phase of the project lifecycle (Abdelgawad & Fayek, 2012). The increasing complexity and dynamism of construction projects have imposed substantial uncertainties and subjectivities in the risk analysis process. Over the past decade, many construction projects have experienced uncertainties in the risk management process (Nieto-Morote, A. & Ruz-Vila, F., 2011). It is imperative that construction project managers consider all possible risks and their potential consequences to establish corrective actions in the right time in order to improve the chance of success and minimize the risks of project failure (Kuo & Lu, 2012; Mohammadi & Tavakolan, 2013). Effective risk management of construction projects requires developing more reliable means of risk assessment and risk treatment plan (Ezeldin & Orabi, 2006; Kuo & Lu, 2012). So far, several techniques have been proposed for project risk management such as: Checklists, Cause and Effect Diagrams, Failure Mode and Effect Analysis (FMEA), Hazard and Operability Study, Fault Trees Analysis (FTA) and Event Tree Analysis (ETA) (Ahmed et al., 2007). A lot of methods have been used to solve these complex risk management problems, though the selected risk management technique must be aligned to project objectives (Forbes et al., 2008). FMEA is a risk assessment method recommended by reliable sources such as United States Department of Defense. However, the traditional FMEA has some limitations (Liu et al., 2013). There have been a number of attempts to exploit combination of Fuzzy sets and FMEA within the construction risk management domain (Hu et al., 2009; Chang & Cheng, 2011; Liu et al., 2012; Mohammadi & Tavakolan, 2013).

Our primary contribution is presenting a practical and useful model which can assist project managers to cope with difficulties and uncertainties in the project. In this paper, a risk management framework (RMF) is presented to identify risks in a project, determine their impact, and dispose corrective actions. The RMF combines FMEA and Fuzzy sets to overcome the limitations of traditional FMEA. Furthermore, the Fuzzy Expert System (FES) is developed to calculate experts' importance weights. An actual case study is selected from construction projects to validate the results of the proposed framework.

Risk Management Framework (RMF)

RMF is including two sections shown in Figure 1. It is worth mentioning that the case study is one of the mega projects in Iran which is under construction by Kayson Company (www.kayson-ir.com). So, four experts of Kayson Company are invited to help accomplish the proposed framework. The experts are 27, 36, 42 and 44 years old and they have 2, 14, 17 and 18 years of experience, respectively. The university education of experts is MS in Civil Engineering, BS and MS in Industrial Engineering and MBA. The roles of experts in the company are PMO expert, Project Technical Assistant, Head of Project Planning and Controlling, and PMO manager of Kayson Company. The following steps describe the approach taken to develop the fuzzy FMEA Risk Analyzer and FES.

Fuzzy FMEA Risk Analyzer Establishment

A comprehensive database including risk identification techniques, construction project risks and risk assessment approaches are created by collecting data from previous studies. Two group interviews are conducted with experts to define linguistic terms. The aim of the first meeting was to introduce the proposed framework. At the second meeting experts were asked to answer open-ended questions using the database. The experts decided to employee seven linguistic terms to define Likelihood (L), Detection (D) and Impact (I). Their definition is described in Table 1 and Table 2. Next, a group interview is arranged to define membership functions. Trapezoidal and triangular membership functions shapes are chosen to present the RPNs linguistic terms. These membership functions are not R-functions or L-functions within the trapezoidal. To elicit the membership functions ranges, this study used the direct method with the experts. Figure 2 shows membership functions of L, I, D, and RPN. After determining membership functions, the intersection points of membership functions are clarified. These points divide the 1 to 1000 range into nine sections. Corrective action categories are suggested according to these nine sections. Table 3 shows the corrective action categories and recommended action for specified RPN ranges. If the RPN falls within the range that the risk need mitigation, transfer or avoidance for risk response, then the risk is critical. Using the table 3, if any risk RPN goes more than 287.5, then RMF recommends a corrective action as shown in Figure 1.

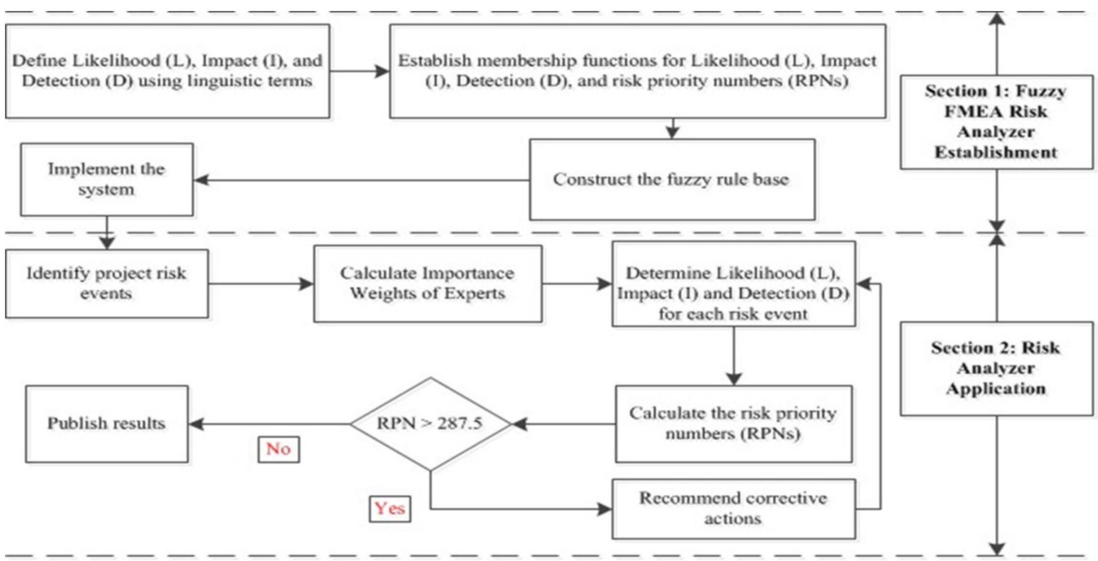

Figure 1: Risk Management Framework (RMF)

Table 1. Linguistic Definition of Impact (I)

Description	Impact categories		
	Cost	**Schedule**	**Quality / Technical**
Very high	Cost increase ≥ 20 %	Time increase ≥ 20 %	The project is unusable.
High	20 %≥ Cost increase ≥ 15 %	20 %≥ Time increase ≥ 15 %	The project is likely unusable.
Medium-High	15 %≥ Cost increase ≥ 11 %	15 %≥ Time increase ≥ 11 %	The project may be unusable.
Medium	5 %≥ Cost increase ≥ 11 %	5 %≥ Time increase ≥ 11 %	The project requires client approval.
Medium-Low	5 %≥ Cost increase ≥ 2 %	5 %≥ Time increase ≥ 2 %	The effect on project is minor, but requires client approval.
Low	Cost increase ≤ 2 %	Time increase ≤ 2 %	The project requires reworks.
Very low	Cost increase is negligible.	Time increase is negligible.	The effect on project is negligible.

In this paper, fuzzy rule base connects Likelihood, Impact and Detection inputs to the RPN. Fuzzy rule base entail "If-Then" rules. There are three inputs and each input has seven linguistic terms. In total, 343 rules should be created to consider all of the input combinations. The rules are elicited from group interviews with multiple choice questions. The minimum operator is used for aggregation; the product operator is used for implication; the maximum operation is used for rule aggregation; and, the center of area is used for defuzzification. MATLAB R.2010 program is applied to implement Fuzzy FMEA Risk Analyzer using Graphical User Interface (GUI) and Fuzzy set toolbox platform of MATLAB R.2010. The user can insert risk data at Fuzzy FMEA Risk Analyzer manually and automatically. Risk ranking based on the RPN values will be presented on risk output table. All the processes are shown in Figure 3.

Table 2. Linguistic Definition of Likelihood (L) and Detection (D)

Description	Likelihood	Detection
Very high	Risk will definitely occur.	The risk will definitely be detected and controlled.
High	Risk will very likely to occur.	There is a very likely chance to detect and control risk.
Medium-High	Risk will probably occur.	There is a likely chance to detect and control risk.
Medium	Risk may occur.	There is a medium chance to detect and control risk.
Medium-Low	Risk will not probably occur.	There is a little chance to detect and control risk.
Low	Risk is unlikely to occur.	There is an unlikely chance to detect and control risk.
Very low	Risk is very unlikely to occur.	The risk will not be detected and controlled.

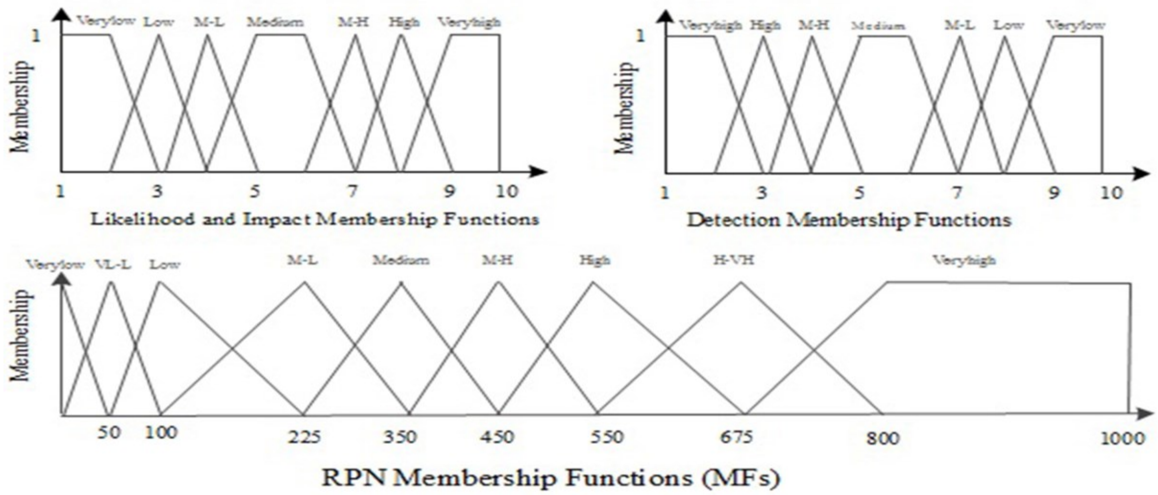

Figure 2: Likelihood, Impact, Detection and RPN MFs

Table 3. Corrective action categories and recommended actions

Corrective Action Categories	Recommended Action	RPN value
Unnecessary to take any corrective actions	Accept	RPN < 25.5
Minor priority to take any corrective actions	Accept	25.5≤ RPN < 75
Very low priority to take any corrective action	Accept	75 ≤ RPN < 162.5
Low priority to take corrective actions	Mitigation	162.5 ≤ RPN < 287.5
Moderate priority to take any corrective action	Mitigation/ transfer	287.5 ≤ RPN < 400
High priority to take any corrective action	Mitigation/ transfer	400 ≤ RPN < 500
Very high priority to take any corrective action	Avoidance/ transfer	500 ≤ RPN < 612.5
Necessary to take any corrective action	Avoidance / transfer	612.5 ≤ RPN < 737.5
Absolute necessary to take any corrective action	Avoidance	737.5 ≤ RPN

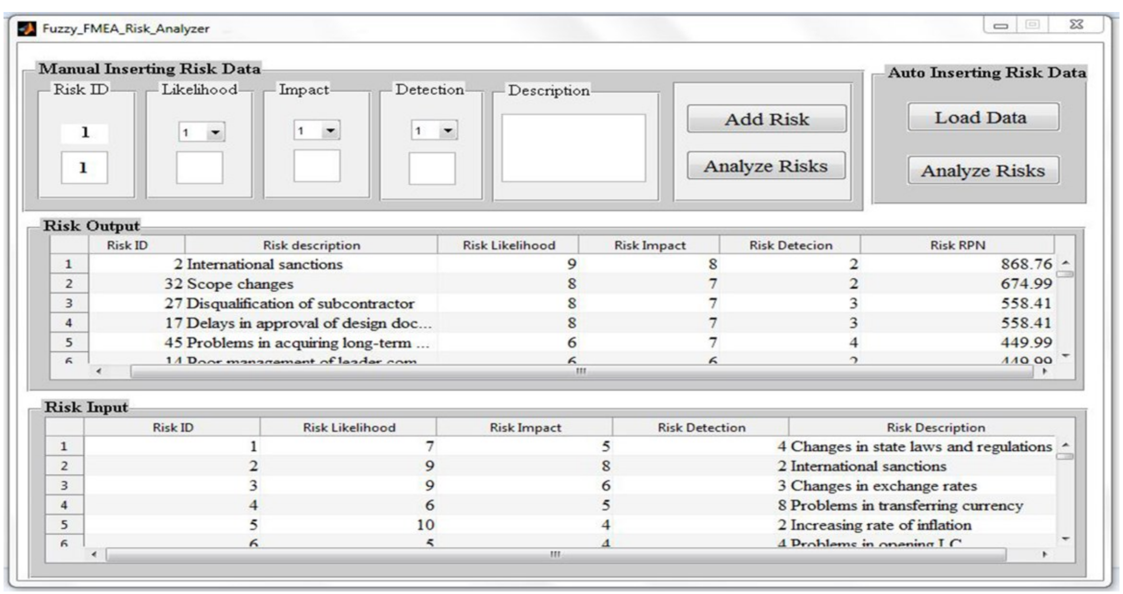

Figure 3: Fuzzy FMEA Risk Analyzer

Calculation Importance Weights of Experts

Fuzzy Expert System is designed to calculate the importance weight of experts. Importance weight factor shows the quality of expert opinion and is based on five attributes: Number of years of experience, Experience diversity, Role in company, Academic Record; and Enthusiasm to participate. The FES is built in MATLAB and four experts participated in two group interviews to fulfill the FES. At the first session, linguistic terms and their definitions for input variables are determined using open-ended questions. Years of experience indicates construction industry experience and ranges from less than one year to more than 20 years. Diversity of experience represents expert's experience in working with various owner's and contractors' organizations. Role in company determines management skill of an expert. Academic Record indicates the expert education. Enthusiasm represents experts' potential and willingness to evaluate risks. Input variables are defined by three membership functions (low, medium and high).Creating membership functions for input and output variables is the next step. Importance weight factor for each expert is output variable of the FES which is defined by five membership functions (very low, low, medium, high, and very high). It ranges on a continuous scale from 0 to 1. There are five inputs and each input has three linguistic terms. At the second session, 243 rules are generated using multiple choice questions using interviews. FES applies minimum operator to complete FES. The product operator is used for implication; the maximum operation is used for rule aggregation; and, the center of area is used for defuzzification. Finally, the output of FES should be normalized to acquire relative importance weight factor (W_i).Risk factors are determined in this step by Equation 1. Where R presents Likelihood (L), Impact (I), and Detection (D); n is the number of experts and r_i is opinion of experts for each risk factor.

$$R = \sum_{i=1}^{n} W_i * r_i \tag{1}$$

The Application of Risk Management Framework

Kayson Company is a privately held engineering and construction company providing world-class design, management, procurement and construction services in Iran and overseas. Kayson has been chosen as Iran's exemplary exporter of technical and engineering services for six years (2000, 2001, 2007, 2008, 2009 and 2010). One of the world's largest gas fields located in the territorial waters of Iran and Qatar called the South Pars gas field. Phase 12 gas field is the largest phase of South Pars gas field. The purpose of this project is to extract and transfer 3 billion cubic feet of gas per day from 45 wells. Phase 12 gas field development project delegated to Petropars by a buyback contract and main processess of onshore refinery started in February 2010. EPC2 project is the main part of phase 12 gas field. Contract terms include design, procurement, construction, facilities installation, testing and commissioning in EPC2 section of phase 12 South Pars gas field. National Iranian Oil Company (www.nioc.ir) is the owner and Petropars LTD. is the client of project, Also, Daelim Company (www.eng.daelim.co.kr), Sazeh Company (www.sazeh.co.ir), Kayson Company and IIND Company (www.iind-co.com) has established a Joint Venture (JV) company to achieve the project objectives. Daelim Company is the leader company of this Joint Venture.

In order to evaluate project risks using RMF, two sections are applied sequentially. In section 2, each step of the RMF is implemented meticulously. First, an extensive list of oil and gas industry risks is collected to identify the project risk events. The list was prepared to save time in the interviews. Several interviews with multiple choice questions are conducted with experts from Kayson Company to identify and determine risk factors for each risk event. The interviews were held in Tehran. The [min, max, average] age of the interviewees is [26, 58, 39] years old. The [min, max, average] years of experience are [2, 37, 14]. The university education of those participants is varied (BS, MS and PhD in civil engineering, BS and MS in industrial engineering, MBA, MS in architectural engineering and BS in geology engineering). The positions of the interviewees are also diverse. Project Manager, Project

Technical Assistant, PMO Experts, Planning Experts, Project HSE Assistant, Kayson PMO Manager, Quality Control and Assurance Manager, DCC/ICM (Internet Communication Manager) Manager, Site Manager, Head and Deputy of Electrical and Instrumentation Engineering Office participated in interviews. For calculating the importance weight of experts, the interviewees' attributes and FES are used. Finally, 49 risk events of EPC2 project are evaluated and the results are published. Table 4 shows 5 more critical risk of EPC2 project. It is difficult to demonstrate the effectiveness of risk management by assessing project performance and this is a major obstacle to implementing risk management for a project or a company (Kuo & Lou, 2012). However, it was decided using the "face validation" to check the validity of the findings. A meeting is arranged with a group of six experts consisting of project manager, project technical assistant, project HSE assistant, Kayson PMO manager and two PMO experts .The goal of the meeting is to present the traditional approach of applying FMEA, its drawbacks, review the results obtained from RMF and investigate the FES ability to incorporate the quality of experts in risks evaluation process. The expert group is encouraged to provide feedback. The feedback received on the RMF from all experts was positive. The expert group validated the results of implementation the proposed model on EPC2 project and they confirmed the usefulness of the results in practice. They noted several advantages of the RMF. They stated risk events which require corrective action can be tracked monthly and by focusing on them managers can achieve better performance from risk management plans. Furthermore, consideration experts' importance weight factor can lead the final result closer to opinion of top-level managers.

Table 4. A brief view of risk ranking list of EPC2 project

Ranking	**Risk Description**	**Likelihood**	**Impact**	**Detection**	**RPN**	**Recommended Action**
1	International sanctions	9	8	2	868.76	Avoidance
2	Scope changes	8	7	2	674.99	Avoidance/ transfer
3	Disqualification of subcontractor	8	7	3	558.41	Avoidance/ transfer
4	Delays in approval of design documents in the owner organization	8	7	3	558.41	Avoidance/ transfer
5	Problems in acquiring long-term work permit for foreign experts	8	7	4	449.99	Mitigation/ transfer

Conclusions

A Risk Management Framework (RMF) model is presented to overcome the limitations of the existing construction project risk management problems. The proposed RMF combines FMEA and Fuzzy Sets Theory to evaluate the risk events in the project. Fuzzy FMEA Risk Analyzer establishment and Risk Analyzer Application are two sections of the proposed framework. The RMF permits the experts in the project risk assessment team to calculate the likelihood (L), Impact (I), and detection (D) of risks by means of their judgments and experience. Experts make their judgments by using linguistic terms that are expressed in trapezoidal and triangular fuzzy numbers. Fuzzy set has been used to overcome the limitations of traditional FMEA. The RMF utilize seven linguistic terms of L, I and D in order to find more appropriate risk assessment results. Finally, a list of corrective action categories and recommended actions has been provided by RPN ranges. Considering importance weight of experts obtained by

FES is another advantage of RMF over existing risk management models. The RMF is applied to analysis a large scale project in oil and gas industry for verification. Risks are ranked and recommended actions lists are generated. It is shown that the proposed approach can efficiently help project management team to focus on high-priority risk events to make a suitable risk response and help them to solve risks management problems when there is inaccurate and incomplete information. This research has two main shortcomings; first the risk events are regarded as negative events. Second, this study used experts from Kayson Company and the results are only useful for this company. For each company and project the framework should be calibrated and each part of the RMF might have some changes to adopt project and company type. However, future researches can consider risk interactions or investigate risk factors at each step of project life cycle.

References

Abdelgawad, M., & Fayek, A.R. (2012). Comprehensive Hybrid Framework for Risk Analysis in the Construction Industry Using Combined Failure Mode and Effect Analysis, Fault Trees, Event Trees, and Fuzzy Logic. *Journal of Construction Engineering and Management*, *138(5)*, 642-651.

Ahmed, A., Kayis, B., & Amornsawadwatana, S. (2007). A review of techniques for risk management in projects. *Benchmarking: An International Journal, 14(1)*, 22 – 36.

Chang, K. H., & Cheng, C. H. (2011). Evaluating the risk of failure using the fuzzy OWA and DEMATEL method. *Journal of Intelligent Manufacturing, 22(2)*, 113–129.

Ezeldin, A.S. & Orabi, W. (2006). Risk Identification and Response Methods: Views of Large Scale Contractors Working in Developing Countries. *Advances in Engineering Structures, Mechanics &Construction*, *140*, 781–792.

Forbes, D., Smith, S., & Horner, M. (2008). Tools for selecting appropriate risk management techniques in the built environment. *Construction Management and economics*, *26*(11), 1241-1250.

Hu, A. H., Hsu, C. W., Kuo, T. C., & Wu, W. C. (2009). Risk evaluation of green components to hazardous substance using FMEA and FAHP. *Expert Systems with Applications*, *36*(3), 7142-7147.

Kuo, Y.C., & Lu, S.T. (2012). Using fuzzy multiple criteria decision making approach to enhance risk assessment for metropolitan construction projects. *International Journal of Project Management, 31(4)*, 602-614.

Liu, H.C., Liu, L., & Liu, N. (2013). Risk evaluation approaches in failure mode and effects analysis: A literature review. *Expert Systems with Applications, 40(2)*, 828-838.

Mohammadi, A., & Tavakolan, M. (2013, June). Construction project risk assessment using combined fuzzy and FMEA. IFSA World Congress and NAFIPS Annual Meeting (IFSA/NAFIPS), 2013 Joint (pp. 232-237). IEEE.

Nieto-Morote, A. & Ruz-Vila, F. (2011). A fuzzy approach to construction project risk assessment. *International Journal of Project Management, 29(2)*, 220-231.