The Root Causes of Construction Project Failure

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Abstract

Construction projects play an important role in the economic development of every country. Nevertheless, review of projects documents indicates that in most cases, the projects are not finished on schedule and on assigned budget, such that they sometimes loss their economic justification, and simply fail. Consequently, devising suitable solutions is essential to prevention of such failures. This is impossible without identifying the foremost causes of failure. In this study, first, all factors of failure are identified using Fault Tree Analysis (FTA). FTA as a diagnostic tool allows us to efficiently isolate root causes of failure. To rank these factors, dedicated specialists are requested to assess the risk of each cause using linguistic terms; thereby relevant calculations are carried out using the Linguistic Weighted Average (LWA). Undeniably, considering the complexity of construction projects and incomplete expert knowledge, judgments must not be made using crisp value conception. Hence, fuzzy theory is utilized to achieve more accurate results. Results indicate that the majority of problems in projects stem from financial

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concerns and shortcoming of bidding process. In the last section, an actual case study is used to validate our results.

Key words: construction project failure, decision making, fault tree analysis, interval type-2 fuzzy sets, uncertainty.

1. Introduction

Construction projects play a significant role in the economic development of every nation. In most countries, construction projects absorb large sums of the capital asset investment in the state budget, and the construction industry in Iran is no exception [1]. According to Iran official statistics published in 2015, a total sum of 597 thousand billion Rials was invested exclusively in construction projects [2]. Though, regrettably, the majority of these projects failed to finish, and many others incurred cost and time overruns. Furthermore, the Research Center of the parliament of the Islamic Republic of Iran reported that no benefits of current unfinished projects annually damage to the national economy over 200 thousand billion Rials (i.e. more than one-third of the country's annual development budget) [2]. Therefore, considering such outcomes, it is obvious that identifying, and subsequently, circumventing project failure in the construction industry is of utmost importance for the Iranian economy.

We should note that in this study, project failure is defined as follows:

1- Time and cost overrun such that the project losses economic justification, or

2- The project is not completed.

In order to solve any special problem, the first step is to identify the main factors leading to that problem. This is only possible, provided the effective tools are in place. The aim of this study is to emphasize on the main causes of construction project failure using two different tools: 1) FTA, and 2) LWA.

2. Literature review

In literature, many researchers have recognized the main causes of project failure by applying different approaches. We address some of the recently published.

Han et al. [3] assessed challenges, obstacles, and performances of the Korea Train eXpress (KTX) project. First, critical sections in the railway route that incurred considerable delays to project completion were recognized. After that, the causes of these critical sections were examined carefully. Analysis revealed five major delay causes for the KTX project, which are lack of owner's abilities and strategies to manage hi-tech-oriented mega projects, frequent changes of routes caused by struggles between public agencies and growing public opposition from environmental concerns, an unsuitable project delivery system, lack of suitable scheduling tools custom-made for a linear mega project, and redesign and change orders of the main structures and tunnels for high-speed railways, which is essentially unalike traditional railway structures. Abdul-Rahman et al. [4] addressed the matters pertaining to financial-related delays in construction projects. They recognized the core causes and studied the appropriate alleviation actions required to remedy financial-related project delays. Primary data were composed by means of an initial interview, questionnaire survey, and in-depth structured interviews. A total of 110 responses were acquired from a group of clients, contractors, consultants, and bankers. Results exposed poor cash flow management as the most important factor that leads to a project's delay followed by late payments, inadequate financial resources, and volatility in financial markets. Yang and Wei [5] found 35 delay factors. Fifteen factors were related to the planning phase, and 20 others were related to the design phase. Using the importance-frequency matrix, they concluded that change in owner requirements is the predominant cause of project delay. Soliman [6] recognized 29 causes of delay in construction projects in Kuwait, and then characterized them in six groups. The causes were graded based on the Relative Importance Index (RII). He demonstrated that financial and design problems are the main factors behind delay. Hasseb et al. [7] scrutinized the dynamics behind delay of construction projects in Pakistan. First, they identified 37 delay factors. To rank these factors, they distributed 200 questionnaires among construction firms and inquired about the importance of each factor. Lastly, the factors were weighed by critical assessment criteria. The results indicate that client factors are the key sources of delay. Doli et al. [8] explored the delay causes of construction projects in India. Using a selected set of 45 attributes, this study identified the key factors affecting delay in the Indian construction industry, and then established the relationship between the critical attributes for developing prediction models for measuring the impacts of these factors on delay. A questionnaire and personal interviews formed the foundation of this research. Factor analysis and regression modelling were employed to study the implications of the delay factors. From the factor analysis, the major critical factors of construction delay were identified as (1) lack of commitment; (2) inefficient site management; (3) poor site coordination; (4) improper planning; (5) lack of clarity in project scope; (6) lack of communication, and (7) substandard contracts. The regression model specified slow owner decision-making process, poor labor productivity, architects' reluctance for change and rework due to mistakes in construction are the reasons that significantly affect the overall delay of the project. Ezeldin and Abdel-Ghany [9] found the main reasons of delay through interview with stakeholders; thereafter, for each reason, they determined one party responsible. The latter was conducted using a modified questionnaire. Based on their results, the leading five categories led to the causes of delay: 1) Construction; 2) Managerial; 3) Political; 4) Financial, and 5) Technical factors. Rahsid et al. [10] identified the causes of delay using structured questionnaires distributed among construction firms. To find the main causes, they used several statistical instruments including reliability test, factor analysis, and regression. Their conclusions indicate that the existence problems are associated to contractor, client, consultant, material, and equipment factors. Marzouk and El-Rasas [11] analyzed causes of delay in Egyptian construction projects. They offered a list of construction delay causes retrieved from literature. The feedback of construction experts was acquired through interviews. Next, a questionnaire survey was prepared and distributed between thirty-three construction experts who represent owners, consultants, and contractor organizations. Frequency Index, Severity Index, and Importance Index were calculated, and according the highest values, the top ten causes of delay in construction projects in Egypt were determined. Similarly, a case study was analyzed and compared to the most important delay causes in their research. Statistical analysis was conducted using analysis of variance ANOVA to test delay causes obtained from the survey. Ruqaishi and Bashir [12] explored the factors behind failure in the oil and gas industry, in Oman. They circulated 59 questionnaires among project managers to find the major causes of project delay. They concluded that poor interaction with vendors is the central cause of delay.

Remon et al. [13] studied the causes of delay in road construction projects in Egypt. They distributed 500 questionnaires among construction companies. They employed RII in order to rank the delay factors, and the top twenty factors were recognized. A real case study was used to confirm the results.

As it can be observed, all mentioned studies investigated the causes of delay through crisp value conceptions. However, due to complexity of construction projects and expert knowledge deficiencies, using crisp values cannot be corrected. In this condition, fuzzy theory aids us to acquire more accurate results. In this course, Gunduz et al. [14] explored the key dynamics of failure using the Fuzzy Type-1 (FT1) approach. They initially found 83 delay factors and classified them into nine groups through a field study. Then, the experts were requested to provide an answer for the importance of each factor. Lastly, the related calculation was performed Fuzzy Type-1 Sets (FT1Ss).

Yet, in group decision making, due to lack of agreement about linguistic terms among experts, Fuzzy Type-2 (FT2) performs better than its predecessor. Thus, in this paper we employ the FT2 approach.

3. Methodology

In order to ascertain the key causes of project failure, the proposed framework has been presented in Fig. 1 and includes three main steps:

Step 1. Identification of basic events

In this paper, FTA is proposed to identify the root causes of failure. This analysis is carried out via interview with experts and review of literature. FTA as a diagnostic tool enables us to find the main causes of different problems more efficiently using hierarchical analysis. Additionally, understanding a problem is easy since the results of FTA are demonstrated in graphical form within a fault tree diagram. The fault tree diagram is a graphical model of various parallel and sequential arrangements of faults that can result in incidence of undesired events. The faults may comprise human errors, software errors, or any other errors, which can lead to undesired events [15]. In fault tree diagram, the undesired event is called top event, and the immediate causes of top events are called gate events. The analysis of a fault tree diagram should be continued to reach primary events, namely, basic events. The basic events are not further developed, and by using logical gates (AND or OR gates), the basic events connect to the top event [16]. When the "AND gate" is utilized, the upper event cannot follow unless all of its lower events occur. The "OR gate" specifies that the incidence of any of lower events is sufficient for the upper event to occur. The gates and their representative shapes are presented in Table 1 [16].

Using existing literature and interview with experts, the fault tree diagram for construction projects is drawn (see Fig. 2). As can be seen, the factors of failure have been categorized in four groups:

1- Contractor related factors;
2- Client related factors;
3- Consultant related factors, and
4- External factors.

Then, in each group, three phases of a project have been independently surveyed through FTA.

In Fig. 2, contractor, client, consultant and external factors are gate events, and regarding the gate events, 75 basic events have been found. These rudimentary events are the core factors behind construction project failure.

Step 2. Evaluation of basic events

In this step, the experts were requested to assess the risk of each basic event through linguistic terms defined in nine levels: {Extremely Low, Very Low, Slightly Low, Low, Medium, Slightly High, High, Very High, and Extremely High}. It has been proven in psychology that number of objects an average human can hold in working memory is 7±2. For this reason, nine levels of linguistic terms were selected [17].

Since the experts are not at the same level, their weight must be considered in risk evaluation. We recognize that an expert is described based on two qualities: 1) expertise and 2) experience. Therefore, three criteria are considered: 1) Educational level; 2) Profession, and 3) Service time (see Table 2). Based on a number of interviews, seven linguistic terms are defined for assessment of each expert in each one of the criteria: {Inferior, Very Poor, Poor, Fair, Good, Very Good, and Superior}. Hence, three linguistic terms are assigned to each expert. Then, the final weight of each expert is processed through Weighted Average (WA) of linguistic terms (Eq. 1) allocated to each expert.

$$\tilde{W}_j = \frac{w_j^1 \oplus w_j^2 \oplus w_j^3}{3} \qquad (1)$$

Where W_j is the WA of expert j and w_j^q is the linguistic term assigned to each expert j in criterion q (q= {1, 2, 3}).

Since the population size of this research is very large, for economical reason, a subset of them using the sampling method is selected. Sampling is basically concerned with selection of an appropriate subset of the whole population, which statically represents its characteristics. Human resources in construction companies of Iran comprise the population under study; accordingly, clustering sampling technique is employed for sampling, because it is best suited when there are homogeneous groupings. In this technique, clusters are selected randomly, and we need to apply it for selecting construction companies. Then, experts within responsive companies are surveyed. In addition to ease of implementation, this technique is more economical. The correct combination and estimation of sample size have a pivotal role in minimizing sampling bias. There are different ways to calculate appropriate sample size. These include using a census for small populations, imitating a sample size of similar studies, using published tables, and applying formulas to calculate a sample size. In this study, the sample size is estimated by the formula developed by Cochran [18] (Eq. 2).

$$n = \frac{N Z_{\alpha/2}^2 P(1-\mathrm{P})}{\varepsilon^2 (\mathrm{N}-1) + \mathrm{Z}_{\alpha/2}^2 P(1-\mathrm{P})} \qquad (2)$$

where n is the sample size, N is the size of population, P is the estimated proportion of an attribute that is present in the population, Z is a standard normal quantile, α is the confidence level and finally ε is the level of precision.

The first stage of clustering involves choosing a subset of first rate construction companies according to strategic planning and monitoring section of government. Size of the population (N) in this stage is 235. The companies which hold the first rank in the fields of construction, roads and transportation and water transmission are desired (23 companies). As a result, the desired proportion of attribute (P) equals to 23/235. The confidence level is considered 95%. The level of precision is equal to 10%. The value of Z according to 95% confidence level is equal to 1.96. Finally, the sample size (n) based on Cochran formula is estimated to be 8. It is worth mentioning that the result indicates the minimum required number of responses. To achieve at least 8 responses, more than 20 inquiries were made, but only 10 inquiries were answered which is the sample size of this study.

Step3. Combination of experts' judgments

The judgments made by different experts needs to be combined single one in order to obtain the risk of each basic event. LWA is used for this purpose (Eq. 3).

$$\tilde{R}_i = \frac{\sum_{j=1}^{10} \tilde{W}_j \times \tilde{X}_{ij}}{\sum_{j=1}^{10} \tilde{W}_j} \qquad (3)$$

in which, R_i is the overall risk of basic event i, W_j is the WA of expert j and X_{ij} is the response of expert j about the risk of basic event i.

Nonetheless, we cannot use equations 1 and 3 until the inputs are the linguistic terms. Therefore, the fuzzy engine is utilized for this purpose. As can be seen in Fig. 3, the linguistic terms are initially converted to fuzzy sets. Then, the associated calculations are carried out; and lastly, the output fuzzy sets are once again transformed into linguistic terms. Using these outputs, we can decide reliability.

4. Interval type-2 fuzzy sets

Considering complexity of construction projects and extensive interaction of events, using precise numerical evaluations is inconsistent [19], and evaluations are conducted based on linguistic terms. Though, a natural language is imprecise, uncertain, and partially true [20]. To evaluate basic events, it is crucial to convert linguistic terms into mathematical concepts. T2FSs are selected for this purpose. With this selection, the ambiguity inherent to a natural language is minimized [21]. In literature, FT1 is commonly suggested to answer these problems. Yet, linguistic words of experts are very unclear, and thus, it is very hard to handle and estimate them using T1FSs; because Type 1 representation is a reductionist approach and its Membership Functions (MFs) are totally crisp rather than fuzzy [21]. Furthermore, Mendel [22] established that employing T1FSs to model linguistic words is scientifically inappropriate. T2FSs have elucidated this problem by offering us more degrees of freedom for handling uncertainties. T2FSs are 'fuzzy fuzzy' sets (i.e., they are T1FSs that their grades of membership are also T1FSs). As the computational complexity of general T2FSs is severe, the Interval Type-2 Fuzzy Set (IT2FS) is used, which is a special case of generalized T2F. In [17], Wu and Mendel offered a technique using the LWA and IT2FSs by which the views of experts are aggregated. In this paper, Wu and Mendel's [17] approach is used to rank the core factors of construction project failure.

This section offers the definition of the mathematics behind IT2FSs; including calculation on fuzzy sets by means of α-cuts and WA. Fundamentally, T2FSs are fuzzy sets that exhibit uncertainty in their MFs. These types of sets are convenient in conditions where defining a precise fitness function is hard or impossible. The mathematical definitions of the T1FSs and T2FSs and their arithmetic are as follows:

Definition 1. A T1FS $\tilde{A}$ in a universe of discourse *X* is characterized by a Membership Function (MF) $\mu_{\tilde{A}}(x)$. This MF denotes the membership value of member *x* in the set $\tilde{A}$, and takes values in the interval [0, 1] [23].

Definition 2. The α-cut of a T1FS $\tilde{A}$ is a crisp set that contains all the elements in *X* that their membership values are greater than or equal to α, i.e.,

$$A(\alpha)=\left\{x \middle| \mu_A(x)>\alpha\right\} \quad \forall x\in X, 0\leq\alpha\leq 1 \qquad (4)$$

In order to calculate the addition, subtraction, multiplication, and division of a type 1 fuzzy number, it is necessary to obtain the α-cut of fuzzy numbers. Then, calculations are implemented as Definition 3 [23].

Definition 3. Suppose that [a, b] and [d, e] are the α-cut of FT1Ss $\tilde{A}_1$ and $\tilde{A}_2$, respectively (for $0\leq\alpha\leq 1$), multiplication and division of the α-cut of fuzzy set A_1 and A_2 will be defined as follows [24]:

$$\tilde{A}_1 \oplus \tilde{A}_2=[a,b]+[d,e]=[a+d,b+e] \qquad (5)$$

$$\tilde{A}_1 - \tilde{A}_2=[a,b]-[d,e]=[\min(a-d,b-e),\max(a-d,b-e)] \qquad (6)$$

$$\tilde{A}_1 \otimes \tilde{A}_2=[a,b].[d,e]=[\min(ad,ae,bd,be),\max(ad,ae,bd,be)] \qquad (7)$$

$$\tilde{A}_1 / \tilde{A}_2=[a,b]/[d,e]=[\min(a/d,a/e,b/d,b/e),\max(a/d,a/e,b/d,b/e)] \qquad (8)$$

Definition 4. Equation 6 is one of the defuzzification methods for T1FSs and is used to find the centroid of a T1FS [24].

$$c(A)=\frac{\sum_{i=1}^{N} x_i\mu_A(x)}{\sum_{i=1}^{N}\mu_A(x)} \qquad (9)$$

Definition 5. A general type-2 fuzzy set A in the universe of discourse *X*, can be presented by a type-2 MFs μ_A, shown as follows [24]:

$$\tilde{\tilde{A}} = \left\{((x,u), \mu_{\tilde{\tilde{A}}}(x,u)) \middle| \forall x \in X, \forall u \in J_x \subseteq [0,1], 0 \leq \mu_{\tilde{\tilde{A}}}(x,u) \leq 1 \right\} \quad (10)$$

where *x* is a primary variable, J_x is a primary MF, *u* is a secondary variable, and $\mu_A(x,u)$ is a secondary MF [24].

Another representation form of a T2FS is:

$$\tilde{\tilde{A}} = \int_{x \in X} \int_{u \in J_x} \frac{\mu_{\tilde{\tilde{A}}}(x,u)}{(x,u)} \quad (11)$$

where $J_x \subseteq [0,1]$ and $\iint$ denotes the union over all permissible *x* and *u*.

Definition 6. When $\mu_A(x,u) = 1, \forall \mu \in J_x \subseteq [0,1]$, we have an IT2 FS, shown as follows:

$$\tilde{\tilde{A}} = \int_{x \in X} \int_{u \in J_x} \frac{1}{(x,u)} \quad (12)$$

Though the third dimension of IT2 FSs, which is the value of secondary MF, always equals one (i.e., the third dimension is ignored), it is still enough powerful to accurately cover uncertainty of words [24].

As it can be seen in Fig. 4, the Union of all the primary memberships of an IT2FS is represented by a two-dimensional domain, which is called the Footprint Of Uncertainty (FOU) of A.

$$FOU(\tilde{\tilde{A}}) = \bigcup_{x \in X} J_x \quad (13)$$

$$\tilde{\tilde{A}} = \frac{1}{FOU(\tilde{\tilde{A}})} \quad (14)$$

In other words, the FOU is completely described by its two bounding functions. The upper bound is called Upper Membership Function (UMF), denoted as $\bar{\mu}_{\tilde{\tilde{A}}}(x)$, and the lower bound is called Lower Membership Function (LMF), denoted as $\underline{\mu}_{\tilde{\tilde{A}}}(x)$ i.e.,

$$\bar{\mu}_{\tilde{\tilde{A}}}(x) = \overline{FOU(\tilde{\tilde{A}})} \qquad (15)$$

$$\underline{\mu}_{\tilde{\tilde{A}}}(x) = \underline{FOU(\tilde{\tilde{A}})} \qquad (16)$$

In the following, some of the arithmetic operations between IT2FSs are presented. To start, suppose A_1 and A_2 are two IT2FSs:

$$\tilde{\tilde{A}}_1 = (\tilde{\tilde{A}}_1^U, \tilde{\tilde{A}}_1^L) = ((a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; h_{11}^U, h_{12}^U), (a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; h_{11}^L, h_{12}^L))$$

$$\tilde{\tilde{A}}_2 = (\tilde{\tilde{A}}_2^U, \tilde{\tilde{A}}_2^L) = ((a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U; h_{21}^U, h_{22}^U), (a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L; h_{21}^L, h_{22}^L))$$

Definition 7. In IT2Fs, the aforesaid calculations for T1FSs in definition 3 are separately carry out for its upper bound and lower bound and the result of addition, subtraction, multiplication, or division is found. For example, the addition operation between above IT2FSs is defined as follows [17]:

$$\begin{aligned}\tilde{\tilde{A}}_1 \oplus \tilde{\tilde{A}}_2 = ((&a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; \min(h_{11}^U, h_{21}^U), \min(h_{12}^U, h_{22}^U)),\\ &(a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; \min(h_{11}^L, h_{21}^L), \min(h_{12}^L, h_{22}^L))\end{aligned} \qquad (17)$$

Definition 8. A crisp value λ is multiplied by an IT2FS as the following equation [17]:

$$\lambda\tilde{\tilde{A}}_1 = ((\lambda a_{11}^U, \lambda a_{12}^U, \lambda a_{13}^U, \lambda a_{14}^U; h_{11}^U, h_{12}^U), (\lambda a_{11}^L, \lambda a_{12}^L, \lambda a_{13}^L, \lambda a_{14}^L; h_{11}^L, h_{12}^L)) \qquad (18)$$

Definition 9. To obtain the centroid of an IT2FS A, the average centroid between the centroid of UMF and centroid of LMF can be used [17]:

$$c(\tilde{A}) = \frac{c(UML(\tilde{A})) + c(LMF(\tilde{A}))}{2} \qquad (19)$$

4.1.MFs definition

For the purpose of determining the MFs of linguistic terms defined in Step 2, the experts were initially requested to say interval endpoints of each linguistic term. Then, the Enhanced Interval Approach (EIA) [19] was utilized to find all MFs. EIA determines MFs by means of the mean and variance of the interval endpoints. The obtained MFs are presented in figures 5 and 6. Similarly, their FOUs are given in Tables 3 and 4.

Ten experts that had been nominated as a suitable subset of the whole statistical population of this research have been assessed in Table 5 and using Eq. 1 and Definitions 7 and 8, their Weighted Averages (WAs) has been reflected in Table 6. Correspondingly, the MFs associated to the WAs of Expert 1, 3, and 10 are shown in Fig. 7. For example, the output MF of Expert 1 (the left picture of Fig. 7) shows that he has satisfactory expertise and experience in the construction project.

On the other hand, the judgments of experts about the risk of each basic event have been reflected in Table 7. As can be seen in this table, roughly all experts (except Expert 9) have considered that the basic event 19 is the most significant factor of project failure, and they considered further risk for this basic event. This issue presents that there is no suitable planning for allocation of financial resources. Thus, the project will be stopped and failure has occurred.

5. Results and discussion

Established on the stated descriptions of Step 3, the risk of each basic event is calculated. Then, the average centroid ranking method (Eq. 19) is used to obtain the centroid of all risks. The results are revealed in Table 8.

The most important factors have the bigger centroid. MFs associated to the top ten most important factors of failure are shown in Fig. 8. As can be seen in this figure, the acquired results exemplify more information about the uncertainties of linguistic words. Hence, consuming this additional information provided by IT2FSs, from the beginning of the calculations up to the time when final results are obtained, our proposed procedure benefits decision makers in making more reliable choices.

The top ten most important causes of failure are discussed as follows:

The basic event 19, 8, 18, and 11 are related to financial problems. It is clear that this problem leads to delay in work progress, because there will be insufficient cash flow to support construction expenditures. This issue increases financial problems of the contractor. In particular, in Iran, financial problems of contractors are more than other countries, since most Iranian contractors are small in size and independent, and they have limited access to credit facilities.

The basic events 72 and 75 are about the contractor selection process. We know that every construction project comprises initial planning, design, and construction stages. In terms of spending, the construction stage is the most outstanding one, because about 90 percent of total project funding is expended throughout the construction stage. Consequently, choosing a suitable contractor definitely helps to achieve overall success and good performance. In Iran and many other countries, contracts are normally awarded to the lowest bid price. It is understandable that with the simple selection of cost minimization, the objectives such as construction time and final quality of a project are overlooked, while these objectives are generally more desirable and appropriate. Thus, the lowest bidder is not always the most economic choice, and with it, rises the risk of poor performance. With the accurate selection of pre-qualified contractors, the above-mentioned problem will be significantly reduced. In the prequalification method, first, the pool of contractors is examined and then the short list of contractors is requested to contribute in the bidding process. If this process is conducted properly, the selected contractor likely complete the project satisfactorily.

The basic event 27 as the third important factor of failure is justified as follows:

Changes and/or additional works stem from uncertainties, faults, and discrepancies in specifications and drawings. The order of changes has remarkable effect on the financial performance of a construction project. These change orders can be reduced, if the following conditions are considered:

a) Carrying out precise preliminary studies of the project by consultants;
b) Allocation of adequate time for preliminary studies;
c) Clear and continuous discussion about the objectives of a project between the consultant and the client, and
d) Establishment of correct descriptions of client requirements by consultants.

6. Case study

In order to validate the results of the current study, in this section, a real case study leaded to failure is investigated.

The project in question is the construction of the second lane of Miandoab-Kermanshah highway that is located in three different provinces: West Azarbayjan, Kurdestan, and Kermanshah. With a length of 440 Km, it was divided into eleven parts such that each part was awarded to one independent contractor. Furthermore, it has a width of 7.30 meters. The main objective of this project is to increase transportation capacity. Safety improvement and reduction of accidents are the other aims of this project. The longest part of this project belongs to part 11 with an allotted time of 30 months in the related contract. Since construction of different parts was independent, the construction of all parts must be completed in 30 months. Conversely, after 12 years, the construction of this project is yet to reach completion, and construction cost has reached five times the estimated sum, such that the project has lost its economic justification.

In order to survey the causes of failure, eleven project managers of the case study were asked to help us to find the key factors of failure. First, through FTA and interview with the project managers, forty two basic events were identified. Twenty one identified basic events are the basic events 2, 5, 6, 8, 11, 15, 19, 20, 24, 27, 31, 35, 37, 42, 45, 50, 52, 53, 55, 56 and 57 of Fig. 2. Other identified basic events have been listed in Table 9. As it can be seen, the risks of rows 1 and 4 in this table are only related to road construction projects and other risks can be occurred in each construction project.

To rank the basic events, the project managers were asked to response about risk of each basic event. Then, the proposed methodology outlined in section 3 was used to identify key factors of cases study project failure. The MFs results of top three key factors of the project failure have been presented in Fig. 9. As it can be seen, the case study also confirms that financial problems are the most important factors of construction project failure. In the case study, these issues caused that the project was stopped several times.

Also, the Research Center of the Islamic Republic of Iran's parliament has been investigating the causes of this failure. Its reports present that in the tender stage, none of the contractors were qualified and all contracts were awarded to the lowest bids. On the other hand, in the construction stage, due to payment delays to the contractor, in most cases, the project had been stopped. Likewise, path changes in some parts of the project have led to a continuous design stage. As can be seen, this actual case study validates the obtained results.

7. Conclusion

In most countries, public sector projects absorb a high percentage of the capital asset investment in the state budget. Reports indicate that failure is the predominant fate of most of them.

Consequently, many researchers have attempted to investigate the key factors behind project failure, and for this purpose, most of them have used crisp value conceptions. Nonetheless, due to the complexity in construction projects, using this tool is inappropriate and results in unreliable outcomes. When we are confronted with uncertainties, undeniably, one of the best methods is employing fuzzy concepts. We recognize that FT1 is only applicable in one-person decision making problems. In multi-person decision making, since experts have no unified agreement on MFs, then, applying FT2Ss is more justifiable. Consequently, in the current study, the root factors of project failure were initially identified through FTA. Then, we ranked them using the T2FSs approach. In the last section, a case study was provided to validate our results.

Future studies could focus on exploring inadequacies of construction bidding procedures of public sector projects. Furthermore, proposing a decision making model for contractor prequalification using T2FSs could be another topic for future studies.

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Figure captions

Fig.1. The proposed framework for finding the key causes of project failure.

Fig. 2. Fault tree diagram for construction project failure,

Fig. 3. Fuzzy engine.

Fig. 4. FOU, LMF, and UMF of a T2 FS [24].

Fig. 5. MFS of the linguistic terms for evaluation of each expert.

Fig. 6. MFS of the linguistic terms for evaluation of each basic event.

Fig. 7. MFs of the WAs of expert 1, 5 and 10.

Fig. 8. Overall risks of the top ten causes of projects failure.

Fig. 9. MFs results of top three key factors of the project failure (related to case study).

Table captions

Table 1. The related shapes for "AND gate" and "OR gate" in fault tree diagram.

Table 2. Linguistic terms for different experts.

Table 3. Linguistic terms and their corresponding FOUs for evaluation of each expert.

Table 4. Linguistic terms and their corresponding FOUs for evaluation of each basic event.

Table 5. Attributed scores to each expert based on his/hers knowledge and experiment.

Table 6. FOUs result for WAs of experts.

Table 7. Linguist terms given by experts to each basic events,

Table 8. The obtained centroid for overall risk of each basic event.

Table 9. Some of the basic events related to the case study failure.

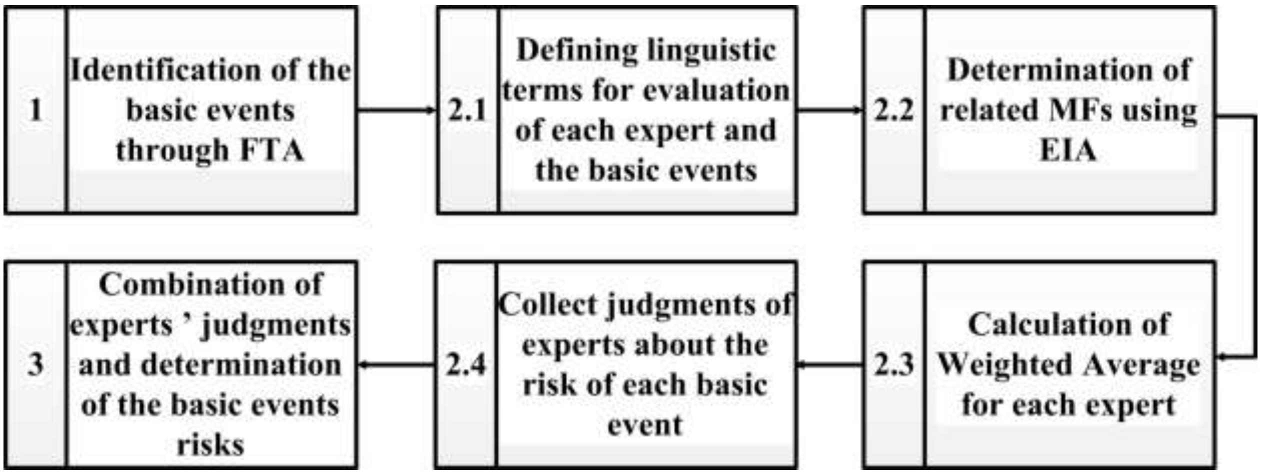
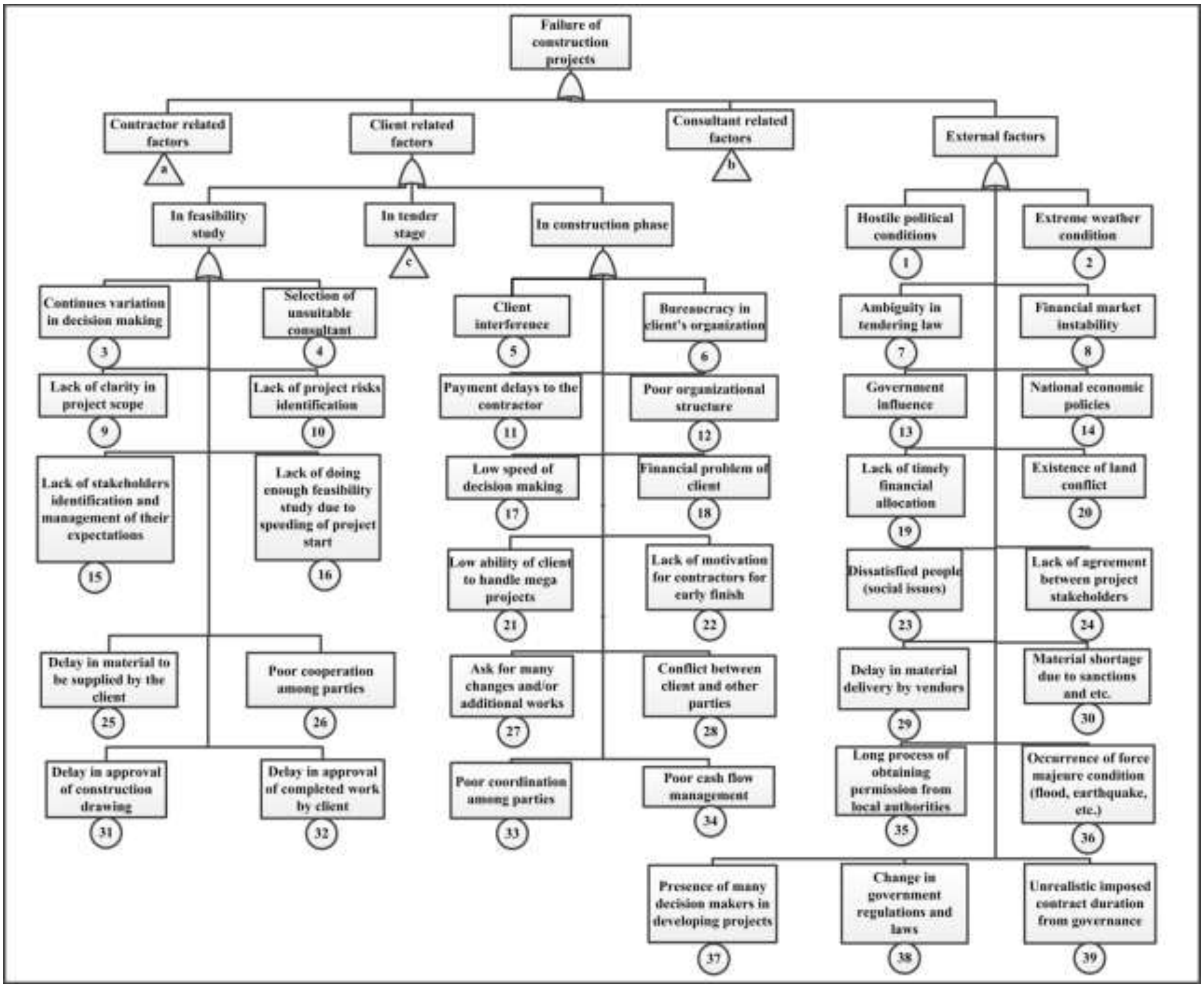

1
Identification of the basic events through FTA
2.1
Defining linguistic terms for evaluation of each expert and the basic events
2.2
Determination of related MFs using EIA
2.3
Calculation of Weighted Average for each expert
2.4
Collect judgments of experts about the risk of each basic event
3
Combination of experts ' judgments and determination of the basic events risks

Fig.1.



Failure of construction projects
Contractor related factors
a
Client related factors
Consultant related factors
b
External factors
In feasibility study
In tender stage
c
In construction phase
Hostile political conditions
1
Extreme weather condition
2
Continues variation in decision making
3
Selection of unsuitable consultant
4
Client interference
5
Bureaucracy in client's organization
6
Ambiguity in tendering law
7
Financial market instability
8
Lack of clarity in project scope
9
Lack of project risks identification
10
Payment delays to the contractor
11
Poor organizational structure
12
Government influence
13
National economic policies
14
Lack of stakeholders identification and management of their expectations
15
Lack of doing enough feasibility study due to speeding of project start
16
Low speed of decision making
17
Financial problem of client
18
Lack of timely financial allocation
19
Existence of land conflict
20
Low ability of client to handle mega projects
21
Lack of motivation for contractors for early finish
22
Dissatisfied people (social issues)
23
Lack of agreement between project stakeholders
24
Delay in material to be supplied by the client
25
Poor cooperation among parties
26
Ask for many changes and/or additional works
27
Conflict between client and other parties
28
Delay in material delivery by vendors
29
Material shortage due to sanctions and etc.
30
Delay in approval of construction drawing
31
Delay in approval of completed work by client
32
Poor coordination among parties
33
Poor cash flow management
34
Long process of obtaining permission from local authorities
35
Occurrence of force majeure condition (flood, earthquake, etc.)
36
Presence of many decision makers in developing projects
37
Change in government regulations and laws
38
Unrealistic imposed contract duration from governance
39

Fig. 2,

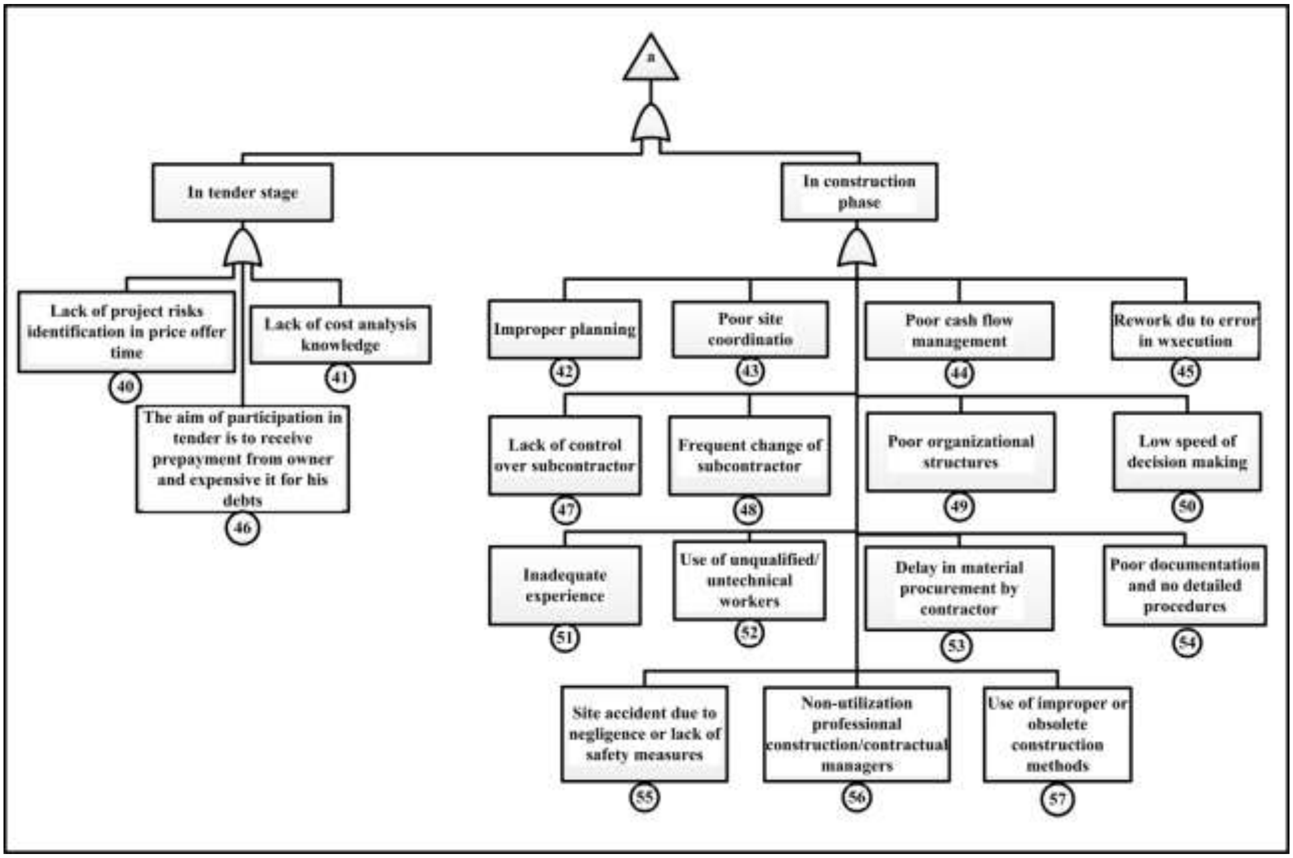


Fig. 2 (continued),

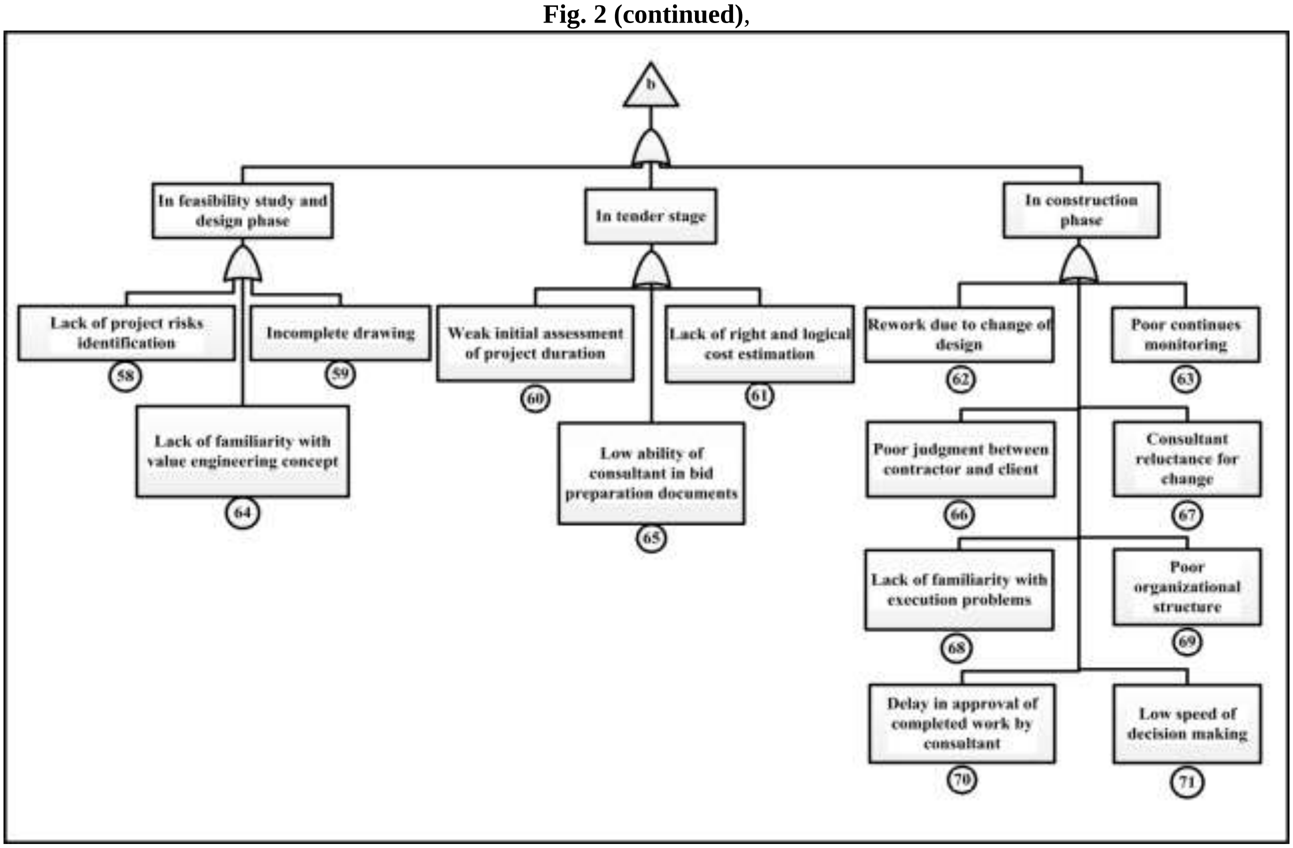


Fig. 2 (continued),

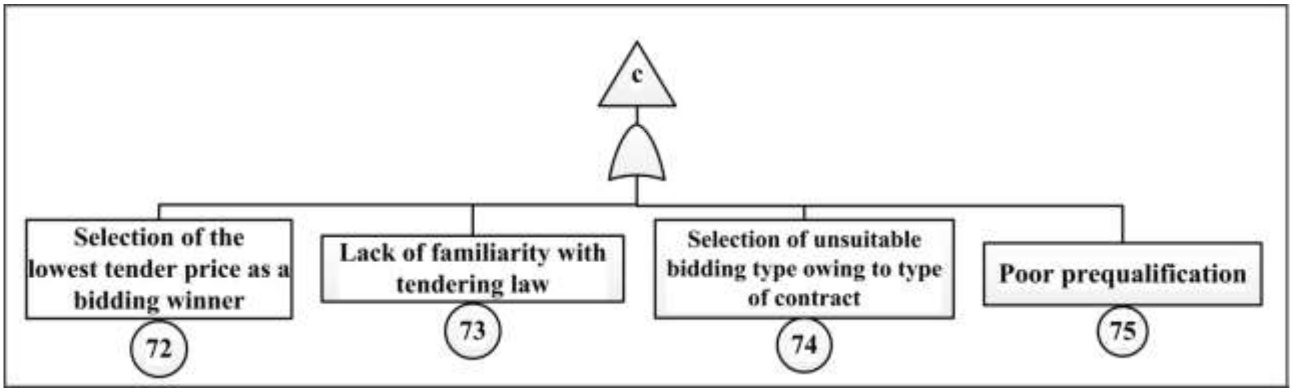


Fig. 2 (continued).

Fig. 3.

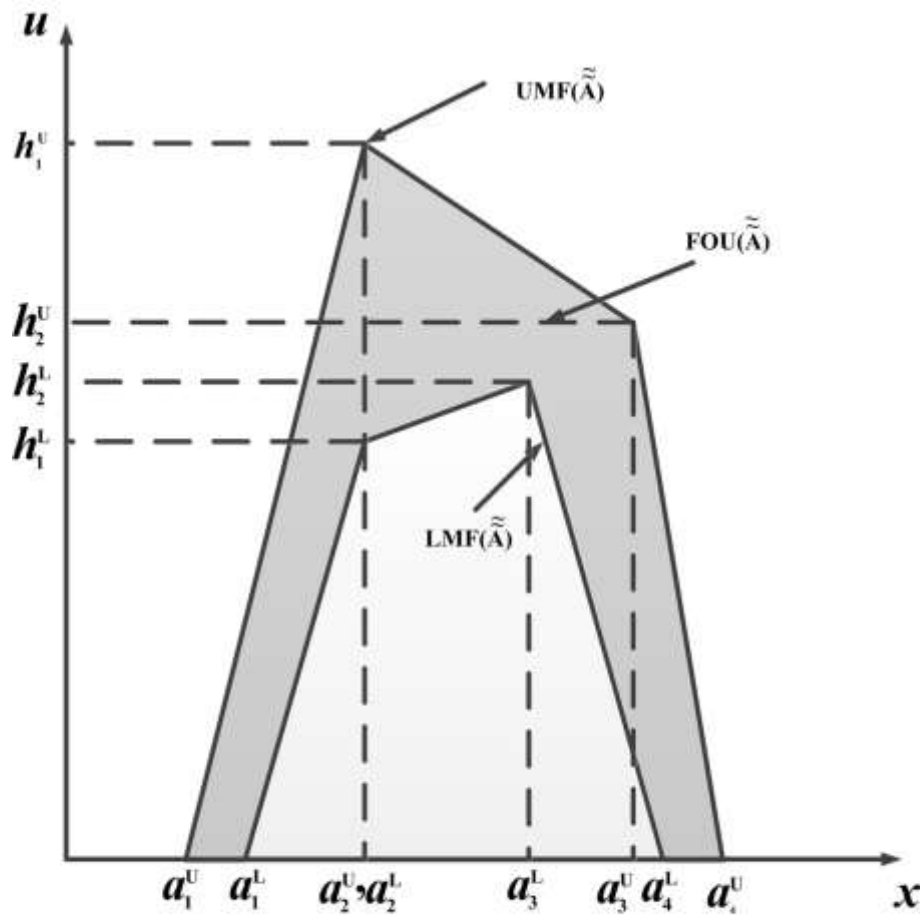

u
UMF($\tilde{\tilde{A}}$)
FOU($\tilde{\tilde{A}}$)
LMF($\tilde{\tilde{A}}$)
h_1^U
h_2^U
h_2^L
h_1^L
a_1^U
a_1^L
a_2^U,a_2^L
a_3^L
a_3^U
a_4^L
a_4^U
x

Fig. 4.

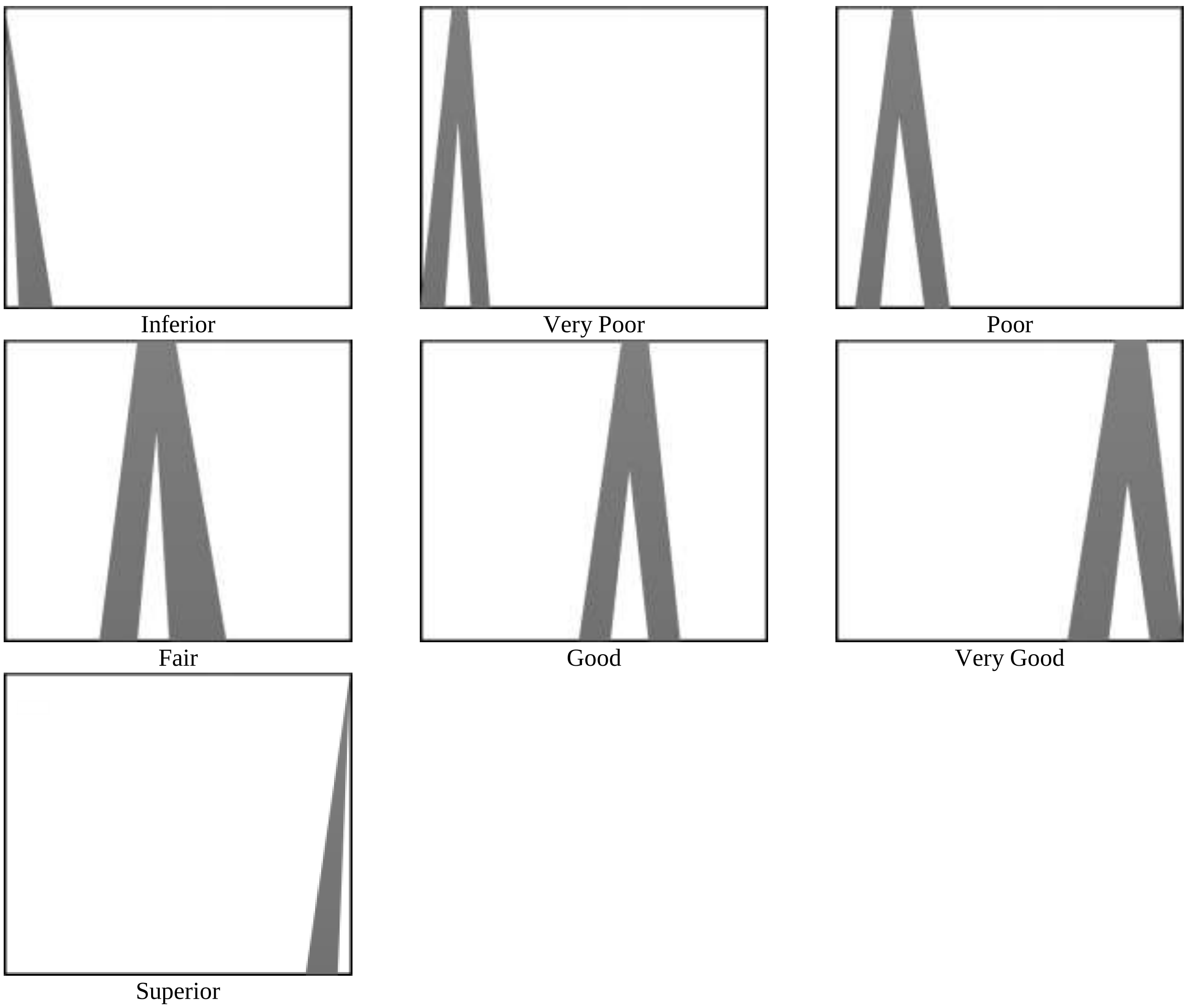


Fig. 5.

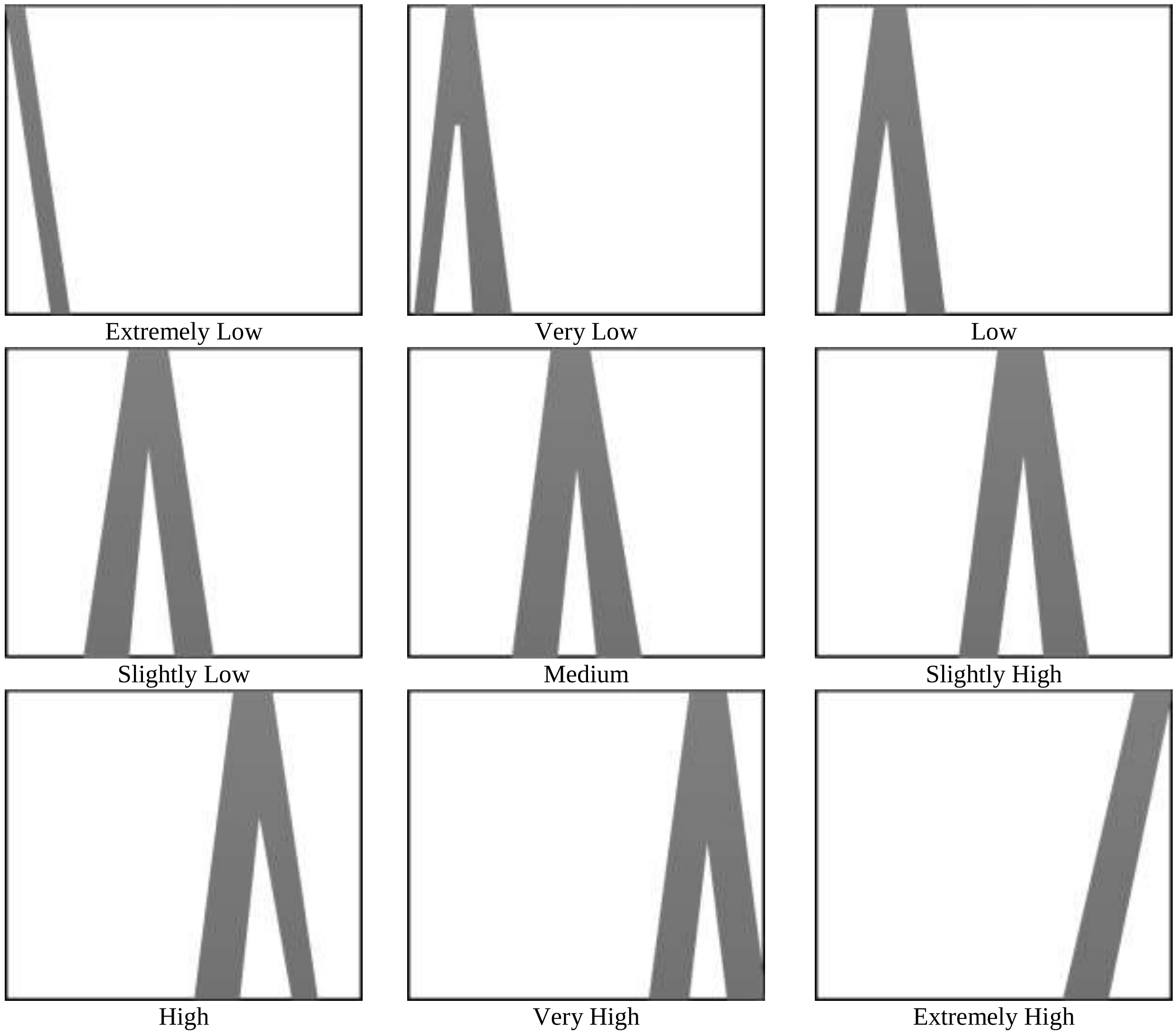

Extremely Low
Very Low
Low
Slightly Low
Medium
Slightly High
High
Very High
Extremely High

Fig. 6.

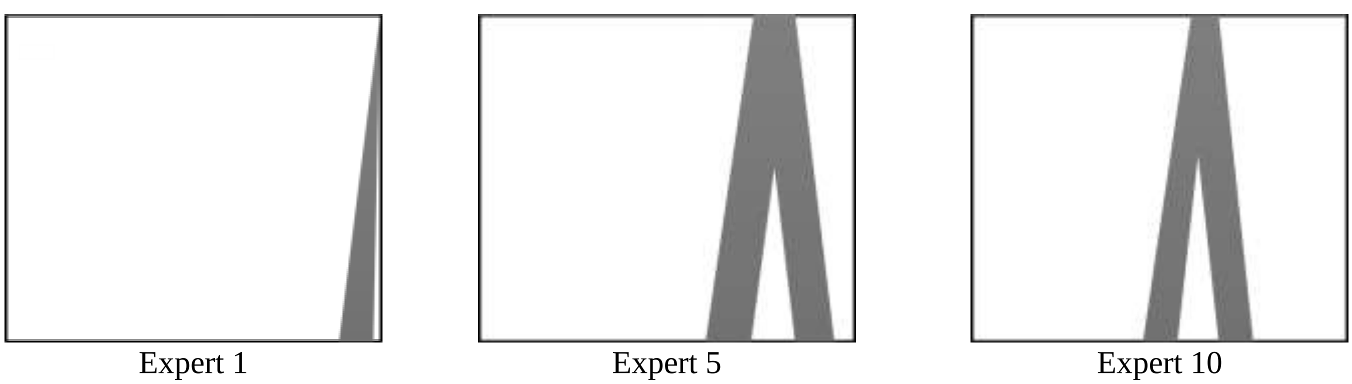

Expert 1
Expert 5
Expert 10

Fig. 7.

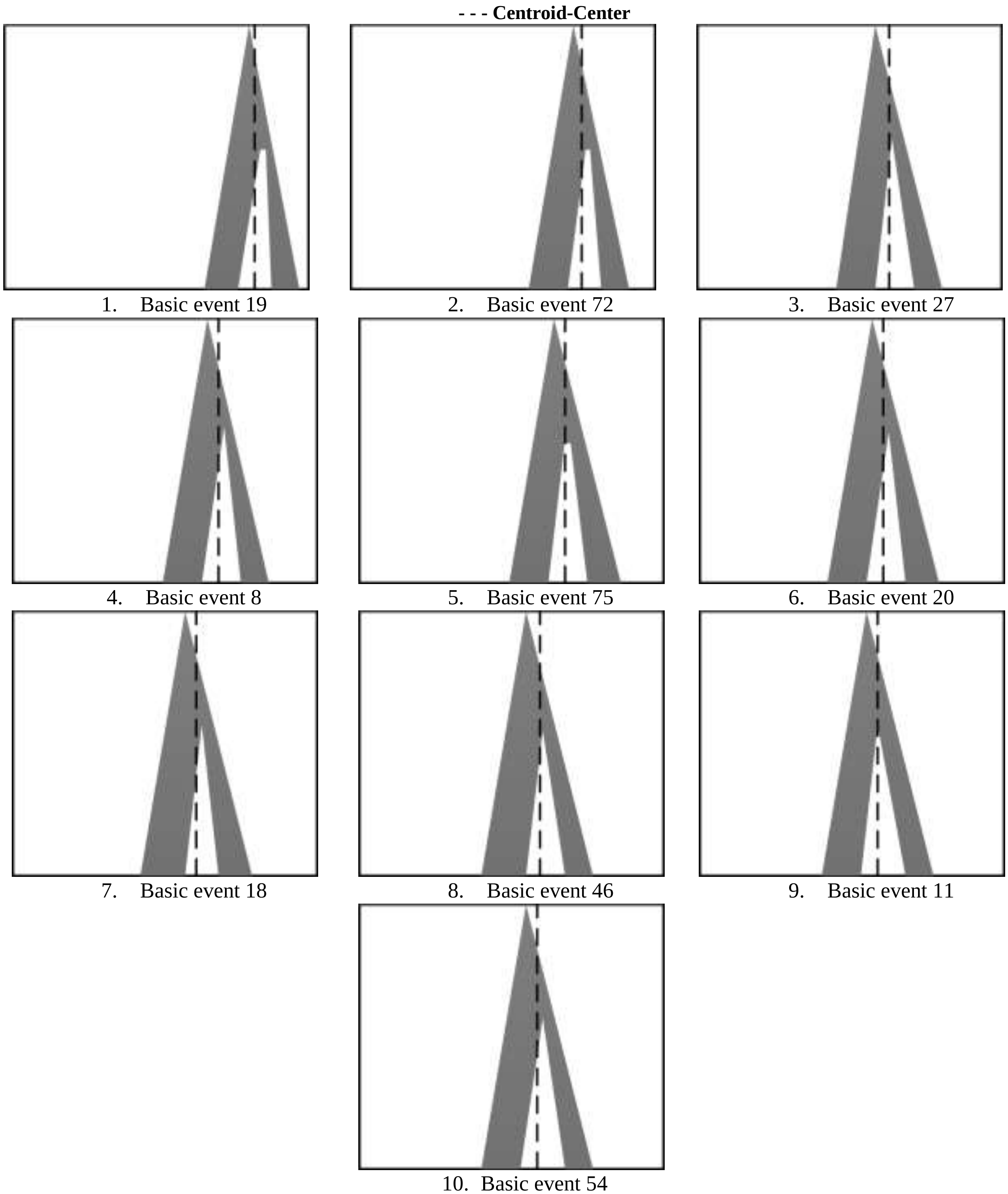
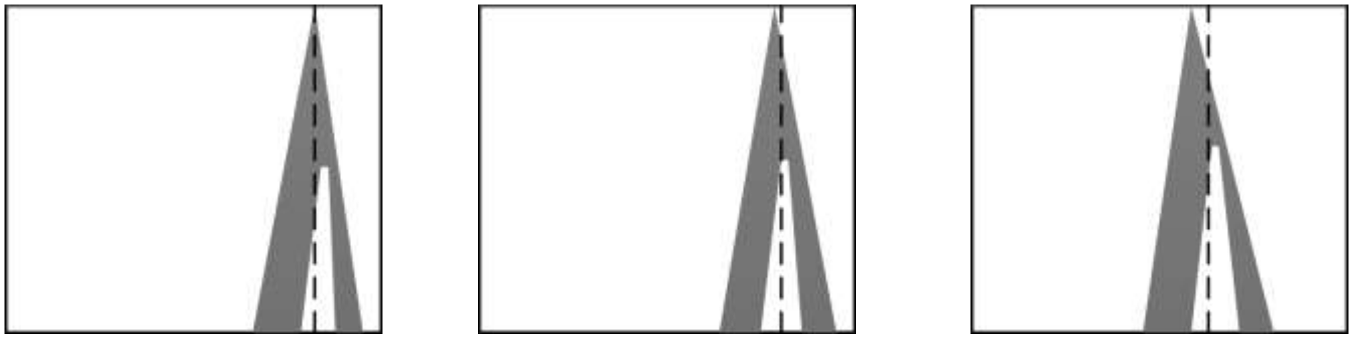

- - - Centroid-Center
1. Basic event 19
2. Basic event 72
3. Basic event 27
4. Basic event 8
5. Basic event 75
6. Basic event 20
7. Basic event 18
8. Basic event 46
9. Basic event 11
10. Basic event 54

Fig. 8.



---- Centroid-Center = 8.2

1. **Lack of timely financial allocation**

---- Centroid-Center = 8.1

2. **Payement delays to the contractor**

---- Centroid-Center = 6.3

3. **Changes and/or additional works**

Fig. 9.

Table 1.

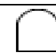
AND gate	
OR gate	

Table 2.

Constitution	Classification		Linguistic terms
Educational level	Ph.D.	Professor	Superior
		Assistant professor	Very Good
		Associated professor	Good
	M.Sc.		Fair
	B.Sc.		Poor
	Junior college level		Very Poor
	School level		Inferior
Profession	Project manager	With more than ten times experience	Superior
		With between five times and nine times experience	Very Good
		With between two times and four times experience	Good
		With One time experience	Fair
	Engineer		Poor
	Technician		Very Poor
	Laborer		Inferior
Service time	>30 years		Superior
	25-30		Very Good
	20-25		Good
	15-20		Fair
	10-15		Poor
	5-10		Very Poor
	<5		Inferior

Table 3.

Linguistic terms	FOUs
Superior	EL = ((0.00,0 .00,0.14,1.97;1,1),(0.00,0.00,0.05,0.66;1,1))
Very Good	VL = ((0.00,1.00,1.50,2.31;1,1),(0.80,1.25,1.25,1.71;0.64,0.64))
Good	L = ((0.83,2.25,3.25,4.66;1,1),(1.84,2.75,2.75,3.66;0.64,0.64))
Fair	M = ((2.89,4.05,5.30,6.71;1,1),(4.09,4.60,4.60,5.01;0.7,0.7))
Poor	H = ((4.75,6.17,6.92,7.98;1,1),(5.96,6.47,6.47,6.87;0.58,0.58))
Very Poor	VH = ((6.75,7.92,8.92,10;1,1),(7.85,8.42,8.41,8.97;0.53,0.53))
Inferior	EH = ((8.68,9.91,10,10;1,1),(9.61,9.97,10,10;1,1))

Table 4.

Linguistic terms	FOUs
Extremely low	EL = ((0,0,0.59,1.81;1,1),(0,0,0.09,1.16;1,1))
Very low	VL=((0.18,1,1.50,2.80;1,1),(0.79,1.25,1.25,1.90;0.65,0.65))
Low	L = ((0.83,1.70,2.50,3.66;1,1),(1.54,2.04,2.04,2.45;0.56,0.56))
Slightly low	SL = ((1.58,3.00,4.00,5.41;1,1),(2.58,3.5,3.50,4.41;0.65,0.65))
Medium	M = ((3.33,4.50,5.25,6.66;1,1),(4.54,4.95,4.95,5.45;0.58,0.58))
Slightly high	SH = ((4.33,5.75,6.75,8.16;1,1),(5.33,6.25,6.25,7.16;0.65,0.65))
High	H = ((6.10,7.25,8.10,9.01;1,1),(7.53,7.89,7.89,8.31;0.64,0.64))
Very high	VH = ((7.15,8.48,9.32,10;1,1),(8.25,8.81,8.81,8.97;0.53,0.53))
Extremely high	EH = ((8.03,9.41,10,10;1,1),(8.94,9.92,10,10;1,1))

.Table 5.

Experts	Weights						
	EL	VL	L	M	H	VH	EH
1	0	0	0	0	0	0	3
2	0	0	0	0	0	2	1
3	0	0	0	0	1	1	1
4	0	0	0	0	0	1	2
5	0	0	0	0	1	2	0
6	0	0	0	0	2	1	0
7	0	0	0	0	1	0	2
8	0	0	0	0	0	3	0
9	0	0	0	0	0	3	0
10	0	0	0	0	3	0	0

Table 6.

Experts	Final IT2 FS of weights $((a^U_{i1}, a^U_{i2}, a^U_{i3}, a^U_{i4}; H^U_{i1}, H^U_{i2}), (a^L_{i1}, a^L_{i2}, a^L_{i3}, a^L_{i4}; H^L_{i1}, H^L_{i2}))$
1	(8.68, 9.91, 10.00, 10.00; 1.00, 1.00), (9.61, 9.970, 10.00, 10.00; 1.00, 1.00)
2	(7.39, 8.58, 9.28, 10.00; 1.00, 1.00), (8.44, 8.94, 8.94, 9.31; 0.53, 0.53)
3	(6.73, 8.00, 8.61, 9.33; 1.00, 1.00), (7.81, 8.29, 8.29, 8.61; 0.53, 0.53)
4	(8.04, 9.25, 9.64, 10.00; 1.00, 1.00), (9.02, 9.45, 9.47, 9.66; 0.58, 0.58)
5	(6.08, 7.34, 8.25, 9.33, ; 1.00, 1.00), (7.22, 7.77, 7.76, 8.27; 0.53, 0.53)
6	(5.42, 6.75, 7.59, 8.65; 1.00, 1.00), (6.59, 7.12, 7.12, 7.57; 0.58, 0.58)
7	(7.37, 8.66, 8.97, 9.33; 1.00, 1.00), (8.39, 8.80, 8.82, 8.96; 0.58, 0.58)
8	(6.75, 7.92, 8.92, 10; 1.00, 1.00), (7.85, 8.42, 8.41, 8.97; 0.64, 0.64)
9	(6.75, 7.92, 8.92, 10; 1.00, 1.00), (7.85, 8.42, 8.41, 8.97; 0.64, 0.64)
10	(4.75, 6.17, 6.92, 7.98; 1.00, 1.00), (5.96, 6.47, 6.47, 6.87; 0.64, 0.64)

Table 7,

Basic events	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10
1	M	SL	L	VL	L	SL	SL	L	VL	M
2	VL	SL	VL	VL	SL	VL	VL	SL	M	H
3	VL	H	H	SL	VL	SL	VL	L	M	M
4	SL	SH	M	SL	SH	M	SL	L	VL	VL
5	L	M	SL	SL	L	M	M	M	SL	L
6	VH	M	L	M	VL	H	VL	L	SL	L
7	VL	VL	VL	VL	SL	M	SL	M	VL	VL
8	H	SH	H	H	SH	H	M	SH	H	M
9	SH	M	SL	SL	SH	M	SL	M	M	M
10	SH	M	M	M	SH	M	M	H	SH	SH
11	SH	M	H	M	SH	M	SH	SH	H	SL
12	VL	L	VL	VL	L	L	VL	EL	L	L
13	VL	M	VL	EL	M	VL	EL	M	VL	M
14	L	L	VL	EL	SL	EL	L	L	VL	SL
15	SH	M	L	VL	SL	M	SL	VL	L	SL
16	H	SH	SL	M	H	SH	H	M	SL	SL
17	M	VL	L	SL	SL	VL	L	L	SL	VL
18	H	M	M	M	SH	SH	H	M	M	H
19	EH	EH	VH	VH	EH	SH	H	VH	M	VH
20	H	SH	M	M	M	M	SH	H	H	M
21	SL	M	VL	VL	M	M	M	L	SL	VL
22	VL	L	EL	VL	L	EL	EL	VL	SL	SL
23	VL	L	VL	SL	SL	L	SL	VL	L	VL
24	L	M	L	SL	SL	SL	L	M	L	M
25	L	L	SL	VL	M	VL	VL	SL	L	M
26	SL	SL	M	SL	L	M	M	SL	SL	L
27	VH	VH	H	M	SH	H	H	SH	M	M
28	SL	SL	M	SL	M	SL	L	SL	VL	VL
29	L	L	SL	VL	SL	L	L	VL	SL	L
30	M	H	H	M	SH	M	M	L	H	SL
31	VL	L	SL	SL	M	SL	SL	L	L	VL
32	M	SL	SL	SL	L	M	M	SL	L	L
33	SL	SL	M	SL	L	M	SL	M	M	L
34	VL	VL	VL	SL	SL	VL	VL	L	SL	SL
35	SL	SL	M	M	L	L	M	SL	SL	L
36	VL	L	L	VL	SL	VL	SL	L	VL	L
37	L	L	L	M	SL	SL	M	M	SL	H
38	VL	M	SL	VL	M	SL	SL	L	VL	M
39	SL	M	M	M	SL	L	L	VL	SL	M
40	SH	M	M	M	H	H	M	SL	M	H
41	L	H	SH	M	SL	H	H	SL	H	L
42	M	H	SH	SL	M	SH	M	M	H	SH
43	SL	M	M	SL	M	M	SL	SL	M	M
44	VL	VL	VL	SL	L	VL	SL	SL	VL	L
45	SL	M	SL	VL	M	L	SL	M	VL	L
46	H	H	M	L	SL	M	H	H	SH	H
47	M	M	SL	VL	L	VL	L	M	SL	M
48	M	M	SL	VL	M	VL	SL	L	M	SL

Table 7 (continued).

Basic events	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10
49	VL	L	VL	VL	VL	L	SL	L	VL	M
50	M	VL	L	SL	SL	M	SL	SL	VL	SL
51	M	M	M	M	SL	L	SL	VL	L	M
52	SL	L	VL	VL	VL	L	L	SL	SL	L
53	SL	L	SL	VL	VL	SL	L	VL	M	VL
54	SH	H	SL	M	H	H	H	H	VL	M
55	M	M	SL	SL	SL	M	M	SL	SL	L
56	H	SL	M	SL	M	M	M	SL	SL	L
57	L	M	VL	L	L	L	VL	SL	M	M
58	SH	M	M	M	SH	M	M	VL	L	SL
59	SL	M	L	VL	M	M	M	SL	L	VL
60	SL	M	M	M	M	M	M	SL	SL	L
61	SL	SL	SH	M	SL	H	M	SH	M	M
62	L	M	L	VL	L	L	L	M	SL	L
63	L	M	L	VL	SL	M	M	L	SL	VL
64	M	M	M	SL	L	M	SL	L	SL	L
65	L	VL	EL	VL	EL	EL	L	EL	L	M
66	VL	L	VL	VL	SL	L	L	SL	L	SL
67	VL	M	M	SL	SL	M	M	SL	L	M
68	M	H	M	M	SH	M	M	H	SH	SH
69	VL	L	VL	VL	SL	VL	VL	L	SL	L
70	M	SL	SL	SL	L	M	M	SL	M	VL
71	M	VL	L	VL	VL	M	M	VL	L	SL
72	VH	VH	EH	VH	VH	H	M	M	VH	SH
73	VL	VL	L	M	M	M	SL	L	SL	SL
74	SL	VL	L	VL	L	L	SL	SL	L	VL
75	SH	H	SH	M	H	SH	H	M	M	H

Table 8.

Basic event	Centroid	Basic event	Centroid	Basic event	Centroid
1	2.9	26	3.6	51	3.7
2	2.8	27	6.3	52	2.3
3	3.8	28	3.2	53	2.5
4	3.7	29	2.3	54	5.9
5	3.6	30	5.7	55	3.9
6	3.9	31	2.8	56	4.4
7	2.4	32	3.5	57	2.9
8	6.7	33	3.8	58	4.4
9	4.7	34	2.2	59	3.3
10	5.7	35	3.6	60	4.2
11	5.9	36	2.0	61	4.9
12	1.6	37	3.8	62	2.7
13	2.5	38	3.0	63	3.1
14	1.9	39	3.6	64	3.7
15	3.3	40	5.6	65	1.6
16	5.6	41	5.3	66	2.2
17	2.6	42	5.7	67	3.7
18	6.0	43	4.3	68	5.7
19	8.1	44	2.1	69	2.0
20	6.1	45	3.2	70	3.8
21	3.3	46	6.0	71	2.8
22	1.6	47	3.4	72	7.6
23	2.2	48	3.5	73	3.1
24	3.3	49	2.1	74	2.2
25	2.6	50	3.2	75	6.8

Table 9
Some of the basic events related to the case study failure.

1	Incensement of tar price
2	Asphalt batching plant stopping
3	Subsoil Conditions
4	Traffic control and restrictions on the job site
5	Machines stopping
6	Increment of material and laborer price (except tar)
7	Lack of coordination among different governmental organization (stakeholders)
8	Lack of timely equipment and material procurement
9	Lack of suitable planning and scheduling for used machines
10	Lack of selection of unsuitable construction method
11	Prolongation of Conflict Resolution
12	Conflicts in work schedules of subcontractors
13	mistake in design
14	design changes
15	inappropriate design
16	late inspection
17	insufficient inspectors
18	Ambiguities, mistakes, and inconsistencies in contract specifications and drawings
19	Severe weather conditions on the job site
20	incapable inspectors
21	Poor qualification of the contractor's technical staff

Appendix I

List of abbreviations and symbols used in this paper:

FTA	-	Fault tree analysis	$\boldsymbol{\varepsilon}$	-	The level of precision
LWA	-	Linguistic Weighted Average	$\tilde{\boldsymbol{R}}_{\boldsymbol{i}}$	-	The overall risk of basic event i
IT2FSs	-	Interval Type-2 Fuzzy Sets	$\tilde{\boldsymbol{X}}_{\boldsymbol{ij}}$	-	The response of expert j about the risk of basic event i
KTX	-	Korea Train eXpress	**MFs**	-	Membership Functions
RII	-	Relative importance index	**MF**	-	Membership Function
FT1	-	Fuzzy Type-1	$\tilde{\boldsymbol{A}}$	-	A type-1 fuzzy set
FT1Ss	-	Fuzzy Type-1 Sets	$\boldsymbol{\mu}_{\tilde{\boldsymbol{A}}}(\boldsymbol{x})$	-	MF of $\tilde{A}$
FT2	-	Fuzzy Type-2	$\boldsymbol{c}(\boldsymbol{A})$	-	Centroid of a T1FS
	-	AND gate	$\tilde{\tilde{\boldsymbol{A}}}$	-	A general type-2 fuzzy set
	-	OR gate	$\boldsymbol{\mu}_{\tilde{\tilde{\boldsymbol{A}}}}(\boldsymbol{x},\boldsymbol{u})$	-	Type-2 MFs
WA	-	Weighted Average	**FOU**	-	Footprint Of Uncertainty
$\tilde{\boldsymbol{W}}_{\boldsymbol{j}}$	-	weighted average of expert j	**UMF**	-	Upper Membership Function
$\boldsymbol{w}_{\boldsymbol{j}}^{\boldsymbol{q}}$	-	linguistic term assigned to each expert j in criterion q	**LMF**	-	Lower Membership Function
N	-	The sample size	$\boldsymbol{c}(\tilde{\boldsymbol{A}})$	-	Centroid of a T1FS
N	-	The population size	$\boldsymbol{c}(\boldsymbol{UML}\ (\tilde{\boldsymbol{A}}))$	-	the centroid of UMF
Z	-	Standard normal quantile	$\boldsymbol{c}(\boldsymbol{LMF}(\tilde{\boldsymbol{A}}))$	-	centroid of LMF
A	-	The confidence level	**EIA**	-	Enhanced Interval Approach
P	-	The estimated proportion of an attribute that is present in the population	**WAs**	-	Weighted averages

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