International Construction Projects’ Risk Cost Estimation: Fuzzy Logic and AHP in Application (Real Case Studies)

Hesham Abd El Khaleka, Remon F. Azizb, Hamada Kamelc

aProfessor of Construction Engineering and Management, Faculty of Engineering, Alexandria University, Egypt
bAssociate Professor of Construction Engineering and Management, Faculty of Engineering, Alexandria University, Egypt
cPhD Candidate, Faculty of Engineering, Alexandria University, Egypt

ABSTRACT

A myriad of construction companies operating in the global construction industry aim at maximizing their profitability by shouldering international projects making use of such new attractive markets, and thus they reduce the dependency upon local markets. Due to the risky and uncertain nature of construction works, the company and project’s conditions should be accurately monitored; thus, the need to assess risk sensitivity of projects costs in a realistic manner arises. The comprehensive risk assessment is a method introduced as a decision making supporting tool through outlining a risk model that is, if applied, will aid the procedures of risk evaluation and prioritization of such projects, and assessment of risk contingency value. There are two approaches used for developing the risk model: first, the Analytic Hierarchy Process (AHP) which is applied for evaluating risk factors weight (likelihood); second Fuzzy Logic approach which is applied for evaluating risk factors influence (Risk consequences). Software aids were also employed to develop such model. The developed software has been proved reliable after having been applied on real construction projects. The outcome of using the proposed methodology and the tool of decision support for estimation of cost overrun resulting from risk has been proved reliable too, as it has been based on actual final reports on realistic projects. For the aim of the study, six case studies from varying countries were selected on the common basis of being actual projects. In these six cases the highest risk factors are determined, through applying the designed models, testing their results and evaluating risk cost impact. The proposed models in application showed that: the highest and lowest risk contingency of 49 % and 16 % were in Project no (5), (6) respectively in Egypt, where the projects no (1, 2, 3,4) in Algeria, Oman, Jordan and Emirates had risk contingency of 38%, 17%, 28%, 40% respectively. The actual results are adjacent to those proposed in the program.

Keywords: Risk Management, International construction, risk factors, Analytic hierarchy process (AHP), Fuzzy Logic approach, MATLAB software and Validation process.

1. Introduction

One of the factors resulting in cost overrun and delays of schedules in many projects is risk. The risk management effectiveness is a major aspect in project management (Ming and Hui 2003). We cannot rely on subjective judgement to determine the exact impact of qualitative decision factors on the project risk, yet we can only rely on it to constrain or exclude possible strategies for improving the qualitative decision. Considering participation in an international construction project required a thorough study of many dimensions simultaneously; for instance, project revenues maximization, project risks allocation and minimization, funds availability, etc. Thus, in order to assess the factors influencing the company’s analysis a multi factor decision making methodology should be applied (Dias and Ioannou 1996, Ludovic et al 2011, Antonio et al. 2011, John et al 2003). Due to the fact that there are many subjective and non-quantifiable parameters deeply affecting these decisions, they are extremely complex to make. Dias (1995) covered the issue of infrastructure projects evaluation from the perspective of contractors, and managed to reach main objectives of a risk model: 1. providing a logical, reliable and consistent process to facilitate a company’s decision making to carry on with a project through analyzing different parameters, 2. Allowing the performance of a sensitivity
analysis so companies will be able to assess and examine different scenarios; e.g., strategies of risk mitigation (Dias and Ioannou 1996, Ludovic et al 2011, Enrique et al 2011, Garshasb et al 2012).

The tool described in this study represents a system which is capable of finding the correlations between factors of decision making, as well as, the impact each factor introduces to the overall project risk. It deploys a modeling technique operating on the basis of Analytical Hierarchy Process (AHP), Fuzzy logic. The researcher uses statistical methods with the aim to verify the model. The results were compared to the actual outcomes from projects’ final reports.

2. Background

Construction projects, being huge in size, are usually influenced by uncertain environment (physical, required manpower and fiscal value), complex designs and an array of external elements involvement. With all such uncertainties which are facing the projects, many changes in the projects’ scopes happen during the execution phase. If such changes were not properly controlled; goals such as time, cost and quality would never be accomplished (Prasanta 2002).

Any managerial work requires some essential elements such as the ability to analyze situation and make decisions. Making decisions as a project includes a number of tasks; planning, finding alternatives, defining priorities, selecting the best policy, allocating resources, identifying requirements, anticipating outcomes, designing systems, evaluating performance, securing system stability and settling conflicts (Saaty 1980, Saaty 1985, Saaty 1990, Saaty and Kearns 1991).

The Decision Support System (DSS) was early defined as a system aiming to support managerial decision makers in semi-structured decision situations. DSS is associated with decision makers, in a way to expand their abilities and not to substitute their decision maker's judgment (Dias and Ioannou 1996). A DSS is an interactive, flexible, and adaptable Computer Based Information System (CBIS) that employs decision rules, models, and model base with a comprehensive database (Enrique et al 2011, Garshasb et al 2012, Liu et al 2011, Prasanta 2010). The decision makers are often reluctant towards alternative selection because of the complicated nature of construction engineering. Fuzzy risk assessment is a promising tool which measures risk ratings in the event that the risk consequences are not clear, and their definition is based on subjective judgment instead of objective data. Moreover, Fuzzy is an optimum technique which can handle the uncontrolled factors such as; location, manpower, equipment, weather, unpredictable circumstances, time- based situations and rules (Mag 2000).

Therefore, Fuzzy logic and computation are employed in numerous engineering tasks such as risk evaluation, risk pricing algorithm, construction time- cost trade off and the building elements’ whole life costs. The following sections specify examples for application of fuzzy theory in construction industry:

Hyun-Ho et al., (2004) develops a risk assessment method for handling underground construction projects. The key tool of this method was a software of risk analysis. This risk analysis software was based on an uncertainty model established by fuzzy concept. The Fuzzy-based uncertainty model was designed in order to closely examine the uncertainty range of degrees related to: 1. the estimations of probability parameter, and 2. Subjective judgments. They also arrived at the conclusion that the proposed method for risk assessment provides the insurance companies as well as contractors with process and tools that are of flexible and easy to follow nature and improves the ability to outline an uncertainty model. An optimal construction time-cost trade-off method was proposed by Sou et al (2001), it was concerned with the time period of the uncertain activity and the time- cost trade off. The uncertainties of activity durations were modeled based on the Fuzzy set theory. The perfect balance of time and cost was shown by this method in the presence of different risk levels according to decision makers (Sou et al 2001).

A generic elemental model which cost him his whole life was developed by Wang et al. (2004). The model used the fuzzy logic concept. Experts’ linguistic data were employed to model the correlation between both the context of application and the cost items. Fuzzy logic approach uses experts’ knowledge. It proved that fuzzy manages to resolve problems of lacking data and prediction of uncertain future events.

Dikmen I et al (2007) developed a model based on Fuzzy rating approach used to estimate cost overrun risk in international projects during the stage of bidding. That stepwise procedure was developed for this approach and this procedure was applied during the development of the tool of fuzzy risk rating (Dikmen et al. 2007).
Carreño et al. (2004) proposed linguistic values based on fuzzy that represent risk performance factors. Such linguistic values are the same as a fuzzy set that have a membership function of the bell function. They also suggested the defuzzification of the linguistic values provided effectiveness that has the same sigmoidal function. Therefore, the risk effectiveness is nonlinear; due to its complexity.

Bu-Qammaz (2007) maintained “Structure of the International Construction Project Risk (ICPRR) Software Application, an application that was composed using "Oracle Forms". (Dias 1995), (Salman 2003) and (Zayed 2008) introduced risk models on the two levels of company and project based on equation (1) which represents the probability multiplied by consequences. They used a questionnaire to identify the expected risk performance of every factor and every linear equation for assessing risk effectiveness. Salman (2003) managed to prove that the risk consequences drive the action, as the model results are extremely sensitive to any variation in risk effectiveness more than importance weight. The conclusion was that the value scores are the driving forces of that model rather than the importance weights, therefore this paper applies fuzzy logic for the evaluation of risk performance and nonlinear Function (sigmoidal function) to evaluate risk effectiveness.

3. Study Objectives

The objectives of the current study are:

1) Determining main risk and uncertainty factors and their sub-factors influencing projects on the company level and the project level in international projects.

2) Determining both risk and uncertainty values for each factor via an evaluation model based on analytic hierarchy process (AHP), determining the risk performance for each factor based on a developed program based on (fuzzy logic approach) instead of just depending on questionnaire used in the previous methods

3) Determining the value score (the effectiveness) of each of the risk factors applying nonlinear function.

4) Designing a flexible assessment model to measure the cost impact of risk and to measure the proposed appropriate risk contingency value.

5) Applying the proposed model on real construction projects for the assessment of the proposed risk contingency value and the comparison between the proposed risk contingency value and its actual risk value.

4. Study Method

This study has different method stages to fulfil its goals to determine the risk index (R). Figure 1 shows those stages along with their correlation. The stages are fully described in detail throughout the whole paper and they are briefly listed as the following:

Stage 1. Review of the Literature

This stage focuses on exploring the previous decision making supporting systems in the field of risk assessment, as well as, the components of risk models.

Stage 2. Analytical study

The following stage consists of:

1) Exploring the risk evaluation models for both the company level and the project level. (developing a Risk hierarchy model)

2) Two models of risk index (R), on both the company level and project level, developed to evaluate the influence of risk sources and uncertainty on construction project on based on equation (1) probability theory adapted from (Dias and Ioannou 1996).
Final project Risk Index (R) = Risk Index for Company level (R1) * Risk Index for project level (R2)

\[
R_{1,2} = \sum_{i=1}^{n} W(xi) \times E(xi)
\]

Equation (1)

3) There are two models composed to define the risk index (R) and the risks factors are distributed among the two levels (both the company level and the project level). Each model consists of two main parts: risk factors weights (W) and their value score (E).

AHP will be used to determine risk factors weights; meanwhile four different approaches are applied to assess the risk impact; Dias approach (Dias and Ioannou 1996), Value curve approach of Zayed (Zayed et al. 2008), New approach of Salman (2003) and proposed model which is using Fuzzy logic approach to evaluate Expected risk performance and sigmoidal function to evaluate risk factors effectiveness.

4) A new software, using excel sheet, was developed to evaluate the risk factors weights busing AHP concepts and Eigenvalue method. Also, excel software will receive Expected Risk Performance (P_{Expected}) value from fuzzy program for calculating risk effectiveness using sigmoidal function hence the total risk could be determined through equation (1) on both the company level and the project level too.

Stage 3. Case studies (Processes of Verification, validation and application)

1) This study utilizes six case studies in order to verify the proposed model through making a questionnaire as a data collecting tool, for collection of data about sources of risk in international projects for construction and risk factors from a study group.

2) Validation was undertaken to assess different methods through comparing results via applying four statistical evaluation methods.

3) The application of the suggested model assesses the proposed risk contingency value in real construction projects and matches both the proposed risk contingency value and actual risk value together from close out reports of the projects.

5. Models Developed Through research

Four models were developed throughout research stages. Table 1 constitutes the description and the objectives of each model. Hierarchy risk models on both the company level and the project level are displayed in Figure 2, 3, 4 that will be referred to throughout the study for the evaluation of the project's risk. The main Hierarchy risk model shown in figure (2) represents level 1 as divided into two main groups: company and project, each class is divided into main categories representing main risk factors, which is also divided into sub factors shown in figures (3,4).
Figure 1. Study method flowchart.
In order to assess the risk sources impact, and to assess the uncertainty in a construction project from contractor’s (company) perspective a risk index (R) model was designed. Such model offers a logical, reliable and consistent tool for the evaluation and prioritization of potential projects, in addition to, the facilitation of the process of decision making on the company’s part. The various risk sources and uncertainty of the project can be characterized through the risk index (R) based on equation 1. The R-index has two parts; weights of risk factors and sub factors along with their impact score. AHP developed by Saaty shall determine Weights of risk areas (Saaty 1980, Saaty 1985, Saaty 1990, Saaty and Kearns 1991), while, the impact score is assessed using utility function for previous approaches as well as fuzzy logic approach for the suggested model. To develop risk worth score (Impact) of the risk factors four approaches are used; such approaches are shown in table 2.

Table 2. Performance and Effectiveness evaluation approaches.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Performance evaluation</th>
<th>Effectiveness evaluation</th>
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<tbody>
<tr>
<td>Diaz Approach</td>
<td>Questionnaire-based</td>
<td>Diaz value curve</td>
</tr>
<tr>
<td>P2=100 Approach</td>
<td>Questionnaire-based</td>
<td>According to Zayed value curve P2 = 100</td>
</tr>
<tr>
<td>P2 Only Approach</td>
<td>Questionnaire-based</td>
<td>According to Salman, A. value curve P2 = 100</td>
</tr>
<tr>
<td>Proposed model based on Fuzzy Logic and Sigmoidal Function Approach</td>
<td>Based on Fuzzy Logic</td>
<td>Sigmoidal function</td>
</tr>
</tbody>
</table>
● Diaz Value Curve deploys the two points P1, P2’s for describing the value curve. P1 is the minimum risk performance level, while P2 is the maximum risk performance level. These questionnaire abstracted the following two points; feature the generic form of a value curves through dividing the performance scale into three regions (Dias and Ioannou 1996).

● P2= 100 Value Curve. The performance value of P1 was always zero in P2 =100 approach in contrast of the approach of Dias and Ioannou. This result we get here from considering project’s decision factors significant and influencing the total project’s risk outcome. According to Zayed approach (Zayed et al. 2008), even though there is a minimum impact of the decision, performance should be taken into consideration in evaluation.

● P2 Only Value Curve. P2 Only Approach” which deploys P2 value provided by the respondents as the maximum performance and P1 shall be totally neglected. (Salman 2003).

● A suggested Model for assessment of Expected Risk Performance According to Fuzzy Logic

● The new proposed model to evaluate the Expected Risk Performance will be deployed and shall be explained in the following sections (Expected Risk Performance according FUZZY approach section and System Developing using MATLAB Software section). This will be carried out applying Fuzzy Logic and MATLAB software.

6. Collection Data

Data was collected through personal interviews; a questionnaire survey was conducted, on 93 respondents, to identify the risk factors and subfactors in international projects. 36 respondents provided positive responses. Those experts were selected according to certain criteria, based on their participation in pipeline projects throughout the country, along with, their actual or intended participation in international projects. Experts’ positions and titles vary among project manager, project planner, proposal developers, quality control officials, estimators and site and cost control engineers. Table (3) shows the two phases of research data collection process.

<table>
<thead>
<tr>
<th>Questionnaire No</th>
<th>Description</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A. General Data</td>
<td></td>
</tr>
<tr>
<td>Questionnaire 1</td>
<td>Criteria Development</td>
<td>Developing a risk model</td>
</tr>
<tr>
<td></td>
<td>B. focused Data</td>
<td></td>
</tr>
<tr>
<td>Questionnaire 2</td>
<td>1. AHP, Risk Performance surveys for six projects on company level.</td>
<td>Model verification and application</td>
</tr>
<tr>
<td></td>
<td>2. AHP, Risk Performance surveys for six projects on project level.</td>
<td>Model verification and application</td>
</tr>
<tr>
<td>Questionnaire 3</td>
<td>comprehensive evaluation surveys for six projects</td>
<td>Model Validation</td>
</tr>
<tr>
<td>Questionnaire 4</td>
<td>Company and projects risk matrix</td>
<td>Fuzzy Risk contingency model</td>
</tr>
</tbody>
</table>

A. First general data

Based on opinions of managers, users and experts, developing a model of risk factors, as presented in questionnaire No. 1. The first questionnaire focuses on the general data for setting criteria for developing risk hierarchy models. The first stage was to specify the numerical and linguistic variables that are affecting the project. This was achieved by gathering all the related variables from database of previous projects and the project environment (conditions of host country, characteristics of the project and location of the project). The process of project risk decision factors collection was based upon assessing a wide range of factors of risk decision and their sub factors extracted from the literature.

The second stage aimed at identification of such variables, exclusion of the redundant variables, and their classification. Then, came the categorization of these decision factors into main relevant categories to save both efforts and time spent to determine their interrelationships and evaluate them. This definitely requires a group of experts in the field. With regards to the third stage, it is dedicated to applying mathematical methods to process the data. Sample of data analysis showed a wide variety in estimating the important weights in each of the factors. This is due to the fact that each project has its own unique risks and different policies may be applied to allocate and mitigate the same risks among different projects due to the different countries’ conditions. Thus, this is the main reason that led to including all the factors in both models and categorizing the attributes. This in order to compare these attributes in a
more meaningful manner by comparing attributes of the same nature and also to reduce the size of comparison matrix. Figures 2, 3, 4 show final risk hierarchy models.

Figure 3. Risk factors on company Level.

B. Second focused data

The following are measurements taken for evaluation of the whole performance of this model based on six case studies of six different projects.

1. Questionnaire No. 2, is essential for verification, validation of model and application processes. Each project questionnaire consists of two parts
   - Part 1. Factors and sub factor weights (AHP survey) for company risk level.
     Factors and sub factor risk Performance (Impact) for company risk level.
   - Part 2. Factors and sub factor weights (AHP survey) for project risk level.
     Factors and sub factor risk Performance (Impact) for project risk level.

2. Questionnaire No. 3, Holistic evaluation for both company and project level, essential for the process of model validation.

3. Questionnaire No. 4, impact of company and project Risk on the overall project risk (Risk matrix), essential for Risk contingency model.
7. **Suggested Expected Risk Performance Assessment Model According to Fuzzy Logic**

The fourth approach presents a new model to determine the expected risk factors performance according to fuzzy logic approach. It does not apply a questionnaire as in the previous method. It aims at determining risk factors effectiveness according to sigmoidal function instead of linear functions deployed in the previous methods. The reason why Fuzzy logic was used is that it is conceptually easy to understand because of the simple mathematical concepts behind fuzzy reasoning, due to its flexibility with any system and its capability of modeling nonlinear functions of arbitrary complexity. Fuzzy logic can be developed based on experts’ experience, as contrasting to neural networks that is responsible for taking training data and generating opaque, impenetrable models, fuzzy logic depends on the experiences of people who already understand that system. The basis for fuzzy logic is the same as for human communication. (Lotfi 2002, Sou et al 2001). In other words, Fuzzy logic is based on natural language.
7.1 Modeling a Fuzzy Problem

The first Fuzzy model was developed in order to evaluate expected risk performance. Input data were two elements (minimum risk performance and maximum risk performance). The inputs are crisp (non-fuzzy) numbers limited to a specific range provided through questionnaire No. 1. All the results were evaluated in parallel by fuzzy reasoning using 10 rules system. The results of the rules were combined and defuzzified, the result is a crisp number representing the output expected risk performance.

7.2 Fuzzy Inference Process

The process of the mapping formulation from certain input into output using fuzzy logic is called inference. The process of mapping presents the basis upon which decisions making or patterns discerning can depend on. As per Fuzzy Logic, there are five parts of the fuzzy inference process: (Abdel Khalek 2016)

1. Step one Fuzzifying Inputs: to fuzzify the input variables and to determine the membership function of the input and output variables, for instance; the input and output Membership functions are shown in figure 6.
2. Step two. Application of Fuzzy operator: applying the fuzzy operator AND/OR to the antecedent.
3. Step three. Applying implication method, from the antecedent to the consequent.
4. Step four. Aggregate All Outputs in other words aggregation of the consequences across the rules.

![Figure 5. Expected Risk Performance model (Pexp).](image-url)

![Figure 6. Membership functions of input variables.](image-url)
8. System Developing using MATLAB Software

A new model was presented to determine anticipated risk factors performance, in this way representing ultimate estimation of risk impact according to fuzzy logic approach instead of traditional questionnaire used in previous methods. Membership functions for fuzzy sets can be defined, representing the levels of performance for the input factors (P1, P2) and they are used in processing of information. P1 represents Minimum Risk Performance, representing maximum ineffective risk performance, while P2 represents maximum risk performance, representing maximum effective risk performance. These two aspects were explained by experts in the questionnaire method. The x-axis shows the performance values of factors, and the y-axis shows the membership degree for each level of performance, where 1 is the total membership and 0 is the non-membership. Equation No. 2 presents Membership functions as represented by bell function, as proposed by Carreno (2004).

\[
bell(x, a, b, c) = \frac{1}{1 + \left| \frac{x - c}{a} \right|^b}
\]

*Equation 2* Where the parameter b is usually positive.

Figure 7 presents input Membership Function for point P1 and another input P2 and output Membership Function for the same membership function. The Rule Editor represented with if...and then.... As for the rule variables, they are considered independent of each other in order to simplify the procedure. The steps followed to develop the program are based on fuzzy approach using MATLAB software are presented in detail (Abdel Khalek 2016).

![Figure 7. Anticipated risk performance according to FUZZY LOGIC approach using MATLAB software. (Expected risk performance).](image)
9. Determining Risk Effectiveness

Equation No. 3 presents the Effectiveness for the value Obtained by defuzzifying the linguistic values ($P_{Expected}$) i.e. the value obtained by sigmoidal function type [2].

Figure 8 shows the degree of Effectiveness of the risk performance value according to (Carreno 2004) using sigmoidal function type.

\[
\text{sigmoidal}(x, a, c) = \frac{1}{1 + \exp[-a(x-c)]} \quad \text{Equation. (3)}
\]

Where $a$: controls the slope at the crossing point, 0.5 of membership and equal 0.104, $X$ is Performance at X axis and $C = 50$.

According to Carreño et al (2004) in order to characterize performance shape which corresponds to the sigmoidal function (Figure 8), the coverage and form of these membership functions follow a non-linear behavior in a sigmoidal form. According to figure (4) the effectiveness of the risk is represented as a function of the performance level.

10. Developing an Excel Spread Sheet Program

The model put forward was designed using Excel Software Program to include the following features;

1. The model presents all input data collected through a pair-wise process.
2. It is designed to resolve the matrices with AHP concepts and Eigen value method of assessing risk factors weights.
3. The model calculates risk performance against each risk factor on the basis of each approach.
4. The results from fuzzy program are (Expected Risk Performance ($P_{Expected}$)) put in the Excel sheet (Column 23) to calculate risk effectiveness as per sigmoidal function.
5. As a result, the total risk index is determined through equation No. (1), for both company level and project level. Figure 9 represents the Excel Software sheet with the description of the functions and properties of each column. The right lower corner presents risk index of each approach.
6. The main characteristic of the suggested model, it has unlimited number of risk factors.

11. Verification of suggested Model results

Six projects are from different countries, presented in table (4). They were selected to verify model application according to study methodology flow chart of figure (1), the steps are as follows.

11.1 Part 1. Assigning Risk factors weights (AHP Survey)

Respondents were asked to make a pairwise comparison between risk factors and risk sub factors representing the relative significance between them of the basis of the numerical scale (1-9) using Analytical Hierarchy Process (AHP). Figure 10 provides an example to explain the pair wise process. The assignment of weights requires logical and analytical thinking, so it is preferred to focus on the respondents with good experience and knowledge as per each case study to participate in the AHP survey questionnaire as a guarantee that only valid and good quality data are collected. The group members should hold brainstorming sessions seeking consensus regarding the required tasks.
Figure 9. Screen shot for Excel sheet program explaining each columns identification and demonstrate the input data and output results of the program for risks in the company level in the project 5.
In other words, instead of asking the same questions to individual members separately, the group shall provide only one response which represents the democratic majority point of view of the group. (Saaty and Kearns 1991, Prasanta 2010).

11.2 Part 2. Assigning Risk factors weights (AHP Survey)

Respondents were asked to make a pairwise comparison between risk factors and risk sub factors representing the relative significance between them of the basis of the numerical scale (1-9) using Analytical Hierarchy Process (AHP). The challenges of using the AHP approaches is the small size of the positive sample responses is due to the following reasons:
1. Difficulty of finding participants who are knowledgeable and capable of giving important opinions in this field.
2. The volume of the proposed questionnaires is too large.
3. The assignment of weights requires logical and analytical thinking.

Hence, it is preferred to focus on the respondents with good experience and knowledge as per each case study to participate in the AHP survey questionnaire as a guarantee that only valid and good quality data are collected. The group members should hold brainstorming sessions seeking consensus regarding the required tasks. In other words, instead of asking the same questions to individual members separately, the group shall provide only one response which represents the democratic majority point of view of the group. (Saaty and Kearns 1991, Prasanta 2010).

11.3 Part 3. Allocating Performance of Risk factors

Respondents were required to allocate 3 points, the first is to represent low risk performance (P1), the second is to represent high point of risk performance (P2) and the third is to represent Expected risk performance (P_{Expected}) for all sub factors on both company and project risk factors on the basis of the numerical scale (1 to 9). Figure 10 provides an example explaining Allocating Risk Performance for each risk factor.

The performance scale has these main points:

- Minimum Risk Performance (P1): this is the point at which exists maximum Ineffective risk performance. It also reflects the impact of risk factor in the condition at which things go well (optimistic Impact).
- Maximum Risk Performance (P2): this point refers to maximum effective risk performance. It also refers to the influence of risk factor when things are not alright (pessimistic Impact).
- Expected Risk Performance (P_{Expected}): This point represents best estimate of the risk impact (likely impact). This point is determined using Fuzzy logic in the new software instead of using the traditional questionnaire aspect in previous methods.
Ineffective point: It is the point of normal risk performance, it means that the risk is the same as previous projects.

Extremely Ineffective: it is the lowest risk point on performance scale, it means that there is no risk at all.

Absolutely Effective: it is the highest risk point on the performance scale which means that there is an extremely high risk.

11.4 Part 4. Assessing effectiveness of risk factors

Expected risk performance of risk factors was evaluated according to previous approach applying questionnaire and MATLAB software for proposed FUZZY model table (2), (Expected Risk Performance according FUZZY approach section and System Developing using MATLAB Software section). Effectiveness of risk factors was assessed using relevant utility function for the previous methods (Dias, P2=100 and P2 Only approaches) and sigmoidal function to evaluate the effectiveness of Expected risk performance (P\text{Expected}) retrieved by the new fuzzy model. (Dias and Ioannou 1996, Salman 2003, Zayed et al. 2008, Abdel Khalek 2016).

12. Risk Models Results and Analysis

The assessment of the four (Diaz, P2 Only, P2=100 and new software on the basis of FUZZY Logic) approaches for each project profile is shown in table 4 in details. The calculations of the projects’ detailed profiles evaluation results were undertaken in terms of the four approaches for each of the case studies. They were also organized according to comprehensive evaluations of the final risk index of the project. Figure 11 shows the results.

Table 4. Company and project risk indexes and contingency value for each project conjunction with each approach.

<table>
<thead>
<tr>
<th>El Merk - ALGERIA</th>
<th>KCP - OMAN</th>
<th>Disi - JORDAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp</td>
<td>Dias</td>
<td>P2=100</td>
</tr>
<tr>
<td>Proj</td>
<td>Dias</td>
<td>P2=100</td>
</tr>
<tr>
<td>Risk index</td>
<td>Dias</td>
<td>P2=100</td>
</tr>
</tbody>
</table>

The figure shows that in P2 Only and P2=100 approaches, most of detailed evaluations were greater than Diaz approach evaluations. This resulted from the assumption that performance level point P1 was controlled to remain equal zero in the mentioned two approaches, so that any factors performance less than P1 and bigger than zero had a worth score value and shall be included in the evaluation of the overall value of the project (eq. 1) while in Diaz approach; the factors performance level point P1 was considered in the evaluations so that all the factors performance levels located behind P1 had zero worth score resulted in zero worth value and it is to be excluded from the equation no 1.

Moreover, the figure shows that approach P2 only had higher values than P2 =100 approach, mentioned in P2 Only approach. The performance level points P2 provided by respondents as extreme points of risk performance and worth 100 points even if it was not at the extreme end of the performance scale and all the attributes performance levels.
located after this point shall have the same worth score. While in P2 = 100 approach the point of attributes performance P2 was always kept at the end of the scale of performance.

So as for the attributes of performance point P was bigger than point P2 as estimated by respondents. Their worth scores were less than 100 points therefore resulting in worth values less than those of P2 only approach.

The figure also included the curve of holistic evaluation, used to compare between the differences in the results of the five approaches and their holistic evaluations. Figure 11 shows that P2=100 approach curve and fuzzy approach were the closest to each other moreover they are the closest to the holistic curve which means that they are the best approaches seeking the holistic approach.

The Fuzzy approach model is more accurate than other models due to the fact that:

1. It deploys fuzzy program for evaluation of the minimum and maximum risk performance to estimate expected risk performance instead of using traditional questionnaire as per previous method.
2. The new model applies nonlinear function in assessment of effectiveness of risk factors instead of linear functions used in previous approaches.
3. Fuzzy approach is the closest to the holistic approach as represented in figure 11.

Figures 12, 13 present the results of risk factors on the company level and projects level based on model of fuzzy approach and the data collected from excel spreadsheets. With regards to the risk indices, they are provided in table (4). As seen on Figures 12, 13 the Change of regulation or laws, past experience in host country, conflicts/tension/terrorism, have the highest risk value in project no (1) in Algeria. On the other hand, the highest risk values on project level were for these factors: lack of skilled workers, unavailability of subcontractors or poor performance and poor productivity of project. These factors had the highest risk values on the company level in project No. 2 in Oman: past experience in host country, Obstacles and Geographical Distance and Interaction between management and local contracts. On the other hand, and with regard to the project level; poor productivity of project, unforeseen adverse ground conditions and lack of skilled workers have the highest risk values.
In project No. 3 in Jordan, Interaction between management and local contracts, volume of future market and competitors and Obstacles and Geographical Distance have the highest risk values on the company level, while Weather and natural Causes of delay, Availability of special Equipment and lack of skilled workers have the highest risk values on the project level.

In relevance to company level the Change of regulation or laws, dependence on or significance of major power, size and volume of future market and competitors, size of current market and competitors and geographical distance have the highest risk value in project no (4) in Emirates, moreover; lack of skilled workers, delay in delivery of supplying materials and cost overrun have the highest risk value on the project level.

The highest risk values on the company level in Project 5 (WND) in Egypt were for; the Change of regulation or laws, unstable economic conditions and rates of Currency exchange, besides on the project level the highest risk values
were due to delay in materials supplying, Availability of special Equipment and Strict Safety and Health Requirements.

On the other hand, the highest risk values on the company level in project no 6 in Egypt were due to payment risk and unstable economic conditions while on the project level the highest risk values were due to; delay of materials supplying and delay in design and regulatory approvals and cost overrun.

![Figure 13. Risk factors values on project level for each project (Model based on fuzzy approach).](image)

The previous analysis shows that the following factors; past experience in host country attribute, the size of current market and competitors, changes of regulation or laws, dependence or significance of major power, payment risk and instability are considered high risk in the five profile projects. In other words; decision makers should focus well on such factors to decrease their risk before they proceed with similar projects. Also the previous analysis shows that the factor of resources availability is of high risk in most of the existing profile projects. As a result, decision makers shall focus well on such attributes to decrease their risk before they proceed with the project by insuring settling the
following items in the phase of feasibility study; the availability of local resources required for the project, as well as, the availability of imported resources required for the project with their paper works (types, costs, importation licenses, taxes, delivery time, etc.). Moreover, figures (12,13) show that it is worth mentioning that some factors have low risk value while in another project have high risk relevant to conditions of each project.

13. Model Validation

The ultimate aim of the model validation process is introducing statistical methods for validation of the results of risk evaluation model. As a result, the validated results are used in estimating the overall risk contingency using MATLAB software based in FUZZY logic approach.

Dias and Ionone, 1996 mentioned that using external criteria to objectively assess the validity of the evaluation models is a difficult matter because of the subjective nature of the multi attribute decision models. Therefore, past research depended on indirect approaches, such as convergent validation method, predictive validation method, and axiomatic validation method.

13.1 Holistic Assessment

Holistic assessment is also called 'integrated assessment' focuses on the evaluation of the whole work activities rather than just specific elements. Holistic assessment is a direct evaluation done by the professional decision makers.

13.2 Convergent Validation

Convergent validation consists of comparing between the results obtained by a fuzzy model and the holistic one; that is a direct evaluation made by the decision makers (average, average plus standard deviation, and average minus standard deviation values. Figure (14) represents the developed fuzzy model results, in addition to the holistic evaluation for risks of company level and project level. It is worth mentioning that the results of the developed fuzzy model are within the range of average plus standard deviation, and average minus standard deviation values.

![Figure 14. Convergent validation of developed fuzzy model results for project risk.](image-url)
13.3 Correlation Coefficient, R (Pearson Product Moment Correlation)

Correlation is a technique used for examining the relationship between two quantitative and continuous variables. The quantity r, is called the linear correlation coefficient, it measures the strength and the direction of a linear relationship between two given variables. The linear correlation coefficient can also be referred to as the Pearson product moment correlation coefficient

\[
r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{n(\Sigma x^2 - (\Sigma x)^2)} \sqrt{n(\Sigma y^2 - (\Sigma y)^2)}}
\]

Eq. (4) (Jessica 2014)

The correlation estimation was obtained by the calculation of the Pearson’s product-moment correlation coefficients between the holistic approach and the detailed approaches for each project profile for both the company and the project levels results; to verify the validity of fuzzy model and to pinpoint which approach was the closest to the holistic one. The results shown in table (5) indicate that the Pearson correlation coefficients in the four approaches proved that fuzzy approach was the one that nearly matched the holistic approach.

<table>
<thead>
<tr>
<th>Pearson Coefficient</th>
<th>Risk assessment model</th>
<th>Holistic</th>
<th>Diaz</th>
<th>P2=100</th>
<th>P2 Only</th>
<th>FUZZY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company level</td>
<td>100%</td>
<td>48%</td>
<td>97%</td>
<td>82%</td>
<td>97%</td>
<td></td>
</tr>
<tr>
<td>project level</td>
<td>100%</td>
<td>26%</td>
<td>79%</td>
<td>59%</td>
<td>88%</td>
<td></td>
</tr>
</tbody>
</table>

13.4 Test factor

Test factor validation is a step applied for testing the exact model and verifying its strength in predicting risk in construction project. The results obtained from the model and the holistic evaluation were compared with the test factor in model as follows:

Test Factor (TF) = RMR/RHE  
Equation (5), (Zayed et al. 2008)

Table 4 shows the results of test factor of the holistic and detailed evaluations of models in terms of the risks on both the company level and the project level. This shows that fuzzy is the closest approach to the holistic, which means that it is the closest to match the Holistic. The previous test factor uncovers that the accuracy and robustness of FUZZY model on company level have been tested by holistic evaluation, which proves its strength in assessment of risk (92%) on both the company level and on project level as shown in table 6.

<table>
<thead>
<tr>
<th>Test factor</th>
<th>Risk assessment model</th>
<th>Holistic approach</th>
<th>Diaz approach</th>
<th>P2=100 approach</th>
<th>P2 Only approach</th>
<th>FUZZY approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company level</td>
<td>100%</td>
<td>129.47%</td>
<td>117.20%</td>
<td>203.22%</td>
<td>92.65%</td>
<td></td>
</tr>
<tr>
<td>project level</td>
<td>100%</td>
<td>80.80%</td>
<td>93.30%</td>
<td>132.72%</td>
<td>92.59%</td>
<td></td>
</tr>
</tbody>
</table>

13.5 Coefficient of determination r²

The coefficient of determination measures the regression line representation of the data. In cases at which the regression line passes through every point on the scatter plot, it then shall be capable of explaining all the variation. The farther the line gets away from the points, the less able to explain it becomes. The coefficient of determination, r² provides the proportion of the variance (fluctuation) of one variable that is predictable from the other one. It allows users to determine how certain the predictions they made from a certain model/graph are. It is useful because it gives the proportion of the variance (fluctuation) of one variable that is predicted from the other variable.

The correlation was made between both the holistic and detailed evaluations for each of the four approaches in terms of the results of the company Risk model. Figures (15,16) present the correlations between risk attributes of both holistic and detailed evaluations of the project profile for the four alternative approaches and their regression lines. This shows that the trend line of fuzzy approach is the closest one to the 45-degree line and the detailed evaluations values in this approach are the closest values to the holistic evaluation values (correlations for Diaz, P2=100, P2 Only, and fuzzy approaches are 0.232, 0.942, 0.678, 0.943 respectively) Company Risk model results.
while (Correlations for Diaz, P2=100, P2 Only, and fuzzy approaches are 0.67, 0.627, 0.351, 0.777 respectively) project risk model results.

Figure 15. The correlations between risks attributes holistic and detailed evaluations of the project profile for the four alternative approaches (company level risk).
Figure 16. The correlations between risks attributes holistic and detailed evaluations of the project profile for the four alternative approaches (project level risk).
14. Suggested Final Risk Value (Suggested Project Risk Contingency Value)

Cost overhead can be estimated through aggregation and defuzzification of final risk ratings of the company and the project. Figure no 17 shows FUZZY risk contingency model (Abdel Khalek et al, 2016). Figure no 18 shows Membership functions for company and project risk indices’ input retrieved from excel program with regard to fuzzy approach. Figure no 19 shows Membership functions for final risk output.

Table 7 shows the rules of decision matrix as aggregation rules. They combine both company risk with project’s risk with the goal to estimate and evaluate total project risk value. The opinions of the experts taking part in brainstorming sessions are reflected through such rules. The rules might differ according to the risk attitude of experts and corporate policies, as such policies can be company specific, in other words, each company has its own risk knowledge, in that case leading to different fuzzy rules and therefore different risk attitudes. (Cooper et al. 2007) have managed to comply the philosophy of aggregated rules the closest to risk priorities for water pipelines.

The importance of risk evaluation lurks in determining the maximum point in the output membership function representing the percentage that should be added to the budget of the project in cases of extremely high risks on both levels of company and project. Such points are company specific and every corporate has a unique knowledge based on its conditions. The percentage varies according to some issues like the project and the point of view of its decision makers and estimators. Figure 19 represents membership function of final cost shows that as for the current projects currently being studied, the experts, decision makers and estimators decided that in the event of extremely high project risk and high company risk as well, then the percentage of risk shall be in proportion with to total budget and not less than 100% of the entire budget (This is extreme point in X axis). For project (5) WND (Egypt), company risk is 0.70 and project risk 0.52 (based on fuzzy approach), the final risk cost is the output of the fuzzy risk evaluation procedure calculated to be 0.49 from the total budget as shown in (figure 21). Table (8) shows Fuzzy risk contingency for each project based on program.
Table 1. Project Risk

<table>
<thead>
<tr>
<th>Company Risk</th>
<th>Project Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Slightly</td>
<td>Low</td>
</tr>
<tr>
<td>Substantially</td>
<td>Slightly</td>
</tr>
<tr>
<td>High</td>
<td>Substantially</td>
</tr>
<tr>
<td>Extremely High</td>
<td>High</td>
</tr>
</tbody>
</table>

Figure 18. Shows Screenshot of Membership functions for company and project risk.

Figure 19. Shows Screenshot of output Membership functions for final risk.
Figure 20. Shows Aggregation rules combining company risk with project risk producing total project risk value.
15. Model Application

The data available in close out reports of the six projects were the source from which actual risk values of these projects were retrieved. Then a comparison was drawn between the results and risk values according to FUZZY program which is discussed in section 14 and the results are shown in table 8.

Figure 22, table 8 shows project 6 in Egypt has low risk value percentage, according to FUZZY LOGIC program equals to 16% the actual value decreased slightly to about 5%. On the other hand the suggested risk value percentage according to FUZZY LOGIC program soared with maximum risk value of 49% in project no 5 in Egypt, while the actual risk value percentage increased slowly with maximum increase of 6%.
On the other hand, project 2 in Oman, the FUZZY LOGIC program proposed risk value up to 17% while the actual value was 10% representing the lowest proposed value: a slight increase in actual risk value of about 7% in project no 3 in Jordan.

On the other hand, the actual risk value percentage increase significantly in risk value in project no 4 in UAE and project no 1 in Algeria with 34.3%, 47% respectively while the proposed risk value percentage was 40.4%, 38.6% respectively.

<table>
<thead>
<tr>
<th>Project No 1</th>
<th>Project No 2</th>
<th>Project No 3</th>
<th>Project No 4</th>
<th>Project No 5</th>
<th>Project No 6</th>
<th>Pearson</th>
<th>R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Risk value</td>
<td>47.0%</td>
<td>10.6%</td>
<td>18.0%</td>
<td>34.3%</td>
<td>55.0%</td>
<td>11.0%</td>
<td>1</td>
</tr>
<tr>
<td>Risk value according FUZZY program</td>
<td>38.6%</td>
<td>17.0%</td>
<td>28.5%</td>
<td>40.4%</td>
<td>49.0%</td>
<td>16.1%</td>
<td>94.95%</td>
</tr>
</tbody>
</table>

Table 8 and figure 22 show that according to FUZZY program the results of the risk value are close to those of the actual risk value with coefficient (Pearson Product Moment correlation) of 0.949 and coefficient of determination of 0.902.

![Project Risk contingency](image)

**Figure 22.** Fuzzy risk contingency for each project on the basis of fuzzy program compared with actual risk results percentage.

16. Conclusion

The international markets witness growing willingness; among most of construction companies to enter those international markets; seeking the maximization of profits and growth potentials Concerning the high risk involved in international construction projects, it has led to a lot of cost overruns throughout the history of the industry. Therefore, contractors should follow a systematic approach to risk management of projects. The current research presents a risk index (R) with three main functions; first, estimation of risk sources and uncertainty, second, prioritization of international construction projects and finally evaluation of project risk contingency value.
A calculation model design for the R-index was developed by an application of analytic hierarchy process (AHP) with the purpose of risk factors weights estimation (likelihood). the Fuzzy Logic approach was applied, in order to, evaluate the impact of risk factors (Risk Consequences) with aiding software tools like Excel and Matlab software. A promising risk quantification tool was introduced through “Fuzzy Risk Assessment” to quantify risk ratings; in case of risk impact that are vague and defined by subjective judgment rather than objective data.

The challenges of using the AHP approaches is the small size of the positive sample responses due to Difficulty of finding participants who are knowledgeable and capable of giving important opinions in this field, the volume of the proposed questionnaires is too large and the assignment of weights requires logical and analytical thinking, so it is preferred to focus on the respondents with good experience and knowledge as per each case study as a guarantee that only valid and good quality data are collected. The group members hold brainstorming sessions; the group shall provide only one response which represents the democratic majority point of view of the group.

The present study has tackled and discussed the components of the model in details. It has also tested the applicability of the proposed methodology on actual cases. Five actual case studies from five different countries were chosen to apply the developed models and test their results. The model components were explained and discussed in detail throughout this paper. Applicability of the proposed methodology has been tested on real cases. Six case studies in different countries were selected to implement the designed models and test their results.

According to the risk factors results on the company level using software aids (fuzzy Logic approach model), the Change of regulation/laws, previous experience in host country, tension/conflicts/terrorism, have the highest risk value in project no (1) in Algeria. While on the project level, the lack of skilled workers, unavailability subcontractor or poor performance and poor project productivity were of the highest risk value. These factors had the highest risk values on the company level in project No. 2 in Oman: experience in host country, limitation of Geographical Distance Obstacles and Interaction between management and local contracts. On the other hand, for the project level; poor productivity of project, unforeseen adverse ground conditions and lack of skilled workers are causes of the highest risk values.

In project No. 3 in Jordan Interaction between management and local contracts, volume of Future market and competitors and Geographical Distance Obstacles have the highest risk values on the company level. Whereas weather and natural Causes of delay, Availability of specific Equipment and lack of skilled workers have the highest risk values on the project level. Regarding the company level in project No. 4 in Emirates, the change of regulations/ laws, dependence of major power, the size of future market and competitors, the size of current market and competitors and geographical distance were of the highest risk value and on the project level; the lack of skilled workers, delay in materials supplying and cost overrun had the highest risk value.

The highest risk values on company level in Project 5 (WND) in Egypt were for; the Change of regulation or laws, Instability of economic conditions and Currency exchange rate, besides on the project level the highest risk values were of; delay in materials supplying, Availability of special Equipment and Strict Safety and Health Requirements. On the other hand, the highest risk values on the company level in project 6 in Egypt were for; payment risk and unstable economic conditions. On the project level, the highest risk values were due to; delay in supply of material and delay in designing and regulatory approvals and cost overrun.

The developed model could be of use in sorting projects on the basis of risk, aiding decision-making process on company’s part in terms of the projects they undertake. The study has examined and tested that developed R model and proved it strong at-risk assessment (92%) on both the company level and (92%) project level as shown in the Test Factor section 13.4. It can be helpful also in sorting construction projects studied in the bids stage in order to take suitable preventive actions. The developed model enabled the evaluation of risk contingency values through aggregating rules merging both company risk index and project risk index through applying fuzzy logic approach and MATLAB software.

Rules of decision matrix as aggregation rules combining both company risk with project’s risk with the goal to estimate and evaluate total project risk value. The opinions of the experts taking part in brainstorming sessions are reflected through such rules. The rules might differ according to the risk attitude of experts and corporate policies, as such policies can be company specific, and in other words, each company has its own risk knowledge, in that case leading to different fuzzy rules and therefore different risk attitudes.
In addition, the importance of risk evaluation lurks in determining the maximum point in the output membership function representing the percentage that should be added to the budget of the project in cases of extremely high risks on both levels of company and project. Such points are company specific and every corporate has a unique knowledge based on its conditions. The percentage varies according to some issues like the project and the point of view of its decision makers and estimators.

According to the results of the proposed models, project No. 5 in Egypt had the highest percentage of risk contingency 49%, whereas the lowest percentage of risk contingency 16.2% where in project No. 6 in Egypt too. As for projects 1, 2, 3 and 4 in Algeria, Oman, Jordan and UAE respectively the percentage of risk contingency are 47%, 10.6%, 18% and 43.3% respectively. The actual results based on of the project’s final reposts were close to those of the proposed program.

The findings of case studies showed that the proposed model can be applied to quantify risk ratings. The tool provided the advantage of offering a guidance for the company concerning the amount of risk premium which should be included in markup. Thorough this model it has been proved that fuzzy logic approach which applies experts’ knowledge succeeded in overcoming the lack of data and uncertainty in predicting future events. It is expected that the proposed model shall offer a wide range of application in the estimation of whole life costs of public service.

REFERENCES


