

1 **An improved decision model for evaluating risks in construction projects**

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Abstract

The paper develops an innovative risk evaluation methodology to address the challenges of multi-criteria decision-making problem of project evaluation and selection. The methodology considers Fuzzy Analytic Network Process (FANP) to incorporate the inter-dependencies of different risk factors, and Failure Mode and Effect Analysis to conduct the rating analysis of projects to develop the decision matrix. Finally, evaluation based on the distance from average solution compares alternative projects and reports the optimal solution. The proposed approach allows project managers to engage in the evaluation process and to use fuzzy linguistic values in the assessment process. A case study from the construction sector is selected to verify the efficacy of the proposed approach over other popular approaches in literature.

Keywords: Multi-criteria decisions; Failure mode and effect analysis; Fuzzy analytical network process; Risk assessment; Construction projects.

40 **Introduction**

41
42 In industrial projects, the risk assessment exercise has strategic importance, and can decide the success
43 or failure of the project. Risk assessment involves the analysis of the whole project in order to reduce
44 the impact of potential risk factors. It begins by identifying the potential risks that could influence the
45 project. During the project planning phase, the project manager usually forms a team of experts and
46 relevant stakeholders to assess the potential risk factors that could affect the successful completion of
47 the project. The team uses techniques like brainstorming, discussions and tools such as flowcharts, root
48 cause analysis, histogram and cause-effect analysis to release potential problems. Several tools are
49 utilized by different risk management teams to develop the risk-breakdown structure and risk-profile.
50 This paper is primarily focused on the risk evaluation and assessment of construction projects.

51 Scenario analysis is one of the most popularly used techniques for evaluating project risks. The project
52 team evaluates the impact of each risk factor in terms of the probability of its occurrence and the
53 influence on the project. A structured approach is needed to recognize potential / known failure modes
54 at different levels of the project and investigate the effect on the next sub-system level (Sharma et al.
55 2005). Failure Mode and Effect Analysis (FMEA) is considered as a fundamental tool and a part of the
56 risk assessment methodology in several studies, and is established as one of the most reliable
57 techniques (Dinmohammadi and Shafiee, 2013). This technique can help in understanding different
58 failure modes within a system, evaluating their impacts, and deciding for corrective actions
59 (Abdelgawad and Fayek, 2010). However, reported applications of this technique in the construction
60 industry are limited (Andery et al., 2000; Nielsen, 2002). Evaluating different risk factors in
61 construction projects is a complex task since the objective functions may change during the project life
62 cycle (Dikmen et al. 2008). Further, Tserng et al. (2009) discussed an ontology based risk management
63 framework for construction projects based on the project life cycle variance and covariance. However,
64 FMEA provides a better approach to assess the severity of a potential risk, and by identifying the “risk
65 priority” of a project, the key stakeholders can adopt a suitable risk management strategy to manage

66 potential risks (Safari et al. 2016). In practice, it is necessary to address technical, external and internal
67 (organizational) issues through a risk breakdown structure. When developing this structure, it is
68 important to reduce the chance of a risk event being missed, and to develop a comprehensive view of
69 the project.

70 ***Research significance***

71
72 Multi-criteria decision-making (MCDM) techniques are amongst the most efficient approaches to
73 evaluate risk factors and assist in real-life decision problems. In recent years, there is growing trend in
74 integrating different MCDM approaches to develop hybrid techniques with better performance to
75 address risk assessment problems in different projects (Chan and Kumar 2007; Chan et al. 2008; Chang
76 2013; Prakash and Barua, 2016). It enables experts to be flexible in choosing relevant methods and
77 creating integrated structures. Past literature (such as Gu and Zhu 2006; Tzeng et al. 2007; Yang and
78 Tzeng, 2011; Liu et al. 2012; Liu et al. 2013) have provided further evidence to support the novelty of
79 integrated and hybrid methods in order to take the advantage of two or more decision making
80 approaches.

81 Moreover, Franceschini and Galetto (2001) presented a multi-expert MCDM model to analyze the risk
82 preferences of failures in FMEA. In this model, risk factors were transformed as evaluation criteria,
83 while failure modes were considered as different alternatives to be decided. This method contemplated
84 each decision-making criterion as a fuzzy subset over the set of alternatives. Chin et al. (2009)
85 discussed a FMEA model using the group-based evidential reasoning (ER) approach to collate diverse
86 opinions and prioritize failure modes under uncertainties such as incomplete assessment, ignorance
87 and intervals. Hu et al. (2009) developed a green component risk priority number to analyze the risks
88 involved due to hazardous substances. In their study, Fuzzy analytic hierarchy process (FAHP) was
89 used to identify the relative weights of risk factors. Then the green component risk priority number
90 (RPN) was calculated for each component to assess the risks derived from them. In this study, the

91 application of fuzzy value FMEA in the context of risk evaluation is discussed, where FMEA forms
92 an initial decision matrix for evaluation process.

93 The novelty of the proposed approach lies in the way it analyzes the anatomy of a project framework.

94 One of the important activities in decision modelling is to find logical ways to weigh different decision

95 attributes. In past literature, mostly Analytic hierarchy process (AHP), Delphi and entropy based

96 approaches are used to determine the weights of different influencing factors. However, in many

97 decision problems, the decision criteria are strictly dependent on each other. Analytic network process

98 (ANP) is the method that undertakes the interrelationship of risk factors in a ratio scale and aids in

99 overcoming the drawbacks of the decision levels and clusters (Tavana et al. 2016). The advantages of

100 ANP can be summarized as follows (Ignatius et al. 2016) : 1) ANP converts qualitative values into

101 numerical values for relative analysis of preferences, 2) It has a simple and intuitive structure, and 3)

102 it allows the participation of stakeholders and experts in the decision process.

103 In addition, risk evaluation in real life problems usually confronts low levels of information and

104 certainty. In the literature, the *fuzzy approach* is recognized as an effective tool for tackling uncertainty

105 stemming from inaccurate information (Wang et al. 2009). In multi-criteria decision-making problems,

106 where some of the criteria cannot be quantitatively represented, the fuzzy set theory can be helpful to

107 enable project assessors to express their linguistic preferences, and to convert those preferences into

108 numerical values for comparative analysis (Ho et al. 2012). He et al. (2015) studied the complexity of

109 mega construction projects in China using Fuzzy ANP methodology and argued that the methodology

110 can help decision makers to develop effective strategy for the project execution.

111 In this paper, an integrated decision-making approach, combining ANP and FMEA in a fuzzy

112 environment is proposed for the risk evaluation process. Very limited studies are available in the

113 literature which attempt to integrate FMEA and ANP with fuzzy variables for risk assessment.

114 Additionally, the ‘evaluation based on the distance from the average solution’ (EDAS) method is

115 adopted to compare alternative projects and rank them based on risk priority. A case study is also
116 discussed to explain the implementation process of the proposed approach.

117 The rest of the paper is organized as follows: Next section discusses the proposed integrated approach
118 (combining fuzzy set theory, ANP and FMEA) for risk assessment. Further, the case study and risk
119 management methodology are presented, along with the analysis and findings. The managerial
120 implications of the proposed approach is also discussed. At the end, paper concludes with a discussion
121 on future research directions.

122 **Research Background**

123 This section discusses different methods for addressing multi-criteria decision-making problems.
124 Particular attention has been given to approaches that are closely related to the integrated approach for
125 risk evaluation proposed in this paper.

126 ***Fuzzy set theory***

127 In real world decision problems, there are many instances where decision makers are faced with
128 multiple criteria when reaching to a decision. However, estimating the impact of these criteria on
129 potential decision outcomes is cumbersome, and this sometimes results in extremely pessimistic or
130 optimistic decisions being made. In every decision environment two types of systems can be proposed
131 based on the availability of information. In white systems, all internal information is completely
132 known, whereas in a black system, it is difficult to obtain any information and characteristics about the
133 system (Zavadskas et al. 2010). Saaty (1980) introduced the analytic hierarchy process (AHP) to
134 accurately represent the consensus of experts and is one of the most widely applied methods in practical
135 applications. In his study, the geometric mean is used as the reference for triangular fuzzy numbers.
136 Zadeh (1965) provided the fuzzy set theory for dealing with the uncertainty due to imprecise and vague
137 information. The theory also allows mathematical operations and programming to be applied in the
138 fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership (degree of
139 compatibility) (Peng and Selvachandran 2017). Such a set is characterized by a membership function,

140 which reflects the degree of compatibility assigned to each object with the grade of membership
 141 between 0 and 1.

142 A triangular fuzzy number (TFN) is defined simply as (l, m, u) where parameters l , m , and u represent
 143 the smallest possible value, the most promising value and the largest possible value that denotes a
 144 fuzzy event. The triangular fuzzy numbers \tilde{a}_{ij} can be established as:

145
$$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \tag{1}$$

146
$$l_{ij} \leq m_{ij} \leq u_{ij}, l_{ij}, m_{ij}, u_{ij} \in (0,1) \tag{2}$$

147 To establish the fuzzy pair-wise comparison matrix, the following procedure must be followed:

148 Suppose $\tilde{A} = [\tilde{a}_{ij}]$ denotes a triangular fuzzy number for depicting the relative importance of criteria C_1
 149 , C_2, \dots, C_n . In this way, \tilde{a}_{ij} represents a matrix constructed by triangular fuzzy numbers.

150
$$\tilde{A} = [\tilde{a}_{ij}] = \begin{matrix} & C_1 & & & \\ C_1 & \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \frac{1}{\tilde{a}_{12}} & 1 & & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{\tilde{a}_{1n}} & \frac{1}{\tilde{a}_{2n}} & \dots & 1 \end{bmatrix} & & & \\ C_2 & & & & \\ \vdots & & & & \\ C_n & & & & \end{matrix} \tag{3}$$

151 Defuzzification is a technique to convert the fuzzy number into crisp real numbers and the procedure
 152 of defuzzification is to locate the Best Non-fuzzy Performance (BNP) value (Tsaur and Wang 2007).
 153 Methods such as the Mean-of-Maximum, the Centre-of-Area, and the α -cut method are the most
 154 common defuzzification approaches. In this research, fuzzy risk criteria are defuzzified with the help
 155 of the Centre-of-Area method. This was chosen due to its simplicity and its less reliance on the personal
 156 judgement of analysts. A defuzzified value of a TFN can be produced using the equation below:

157
$$BNP = [(U_{ij} - L_{ij}) + (M_{ij} - L_{ij})] / 3 + L_{ij} \tag{4}$$

158
 159 **Fuzzy ANP**

160 ANP is a popular MCDM technique useful to deal with interdependency of complex decision factors.
 161 It helps decision makers (DMs) to define complex relationships among several decision levels and

162 their corresponding attributes (Saaty 1996). It helps in overcoming the drawbacks of AHP in
163 addressing interrelationships issues among different decision levels using a super-matrix which detects
164 the composite weights (Shyur, 2006; Kang et al. 2012).

165 By structuring the problem as an ANP model, the uncertain vague elements of matrix A used for pair-
166 wise comparisons can be redefined by fuzzy membership functions reflecting the degree of
167 compatibility for both the quantitative and the qualitative criteria. By pair-wise comparisons using a
168 fuzzy membership function e.g. with triangular fuzzy numbers, the fuzzy pair-wise comparison matrix
169 \tilde{A} with elements \tilde{a}_{ij} , is constructed where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ reflects the influence of element i over
170 element j that could be a criterion/alternative in the network with lower (l_{ij}), mean (m_{ij}) and higher
171 u_{ij} values respectively. The value $u_{ij} - l_{ij}$ could reflect the domain/degree of fuzziness. The greater
172 that $u_{ij} - l_{ij}$ is, the fuzzier the degree is. When $u_{ij} - l_{ij} = 0$, the judgment is a non-fuzzy number (crisp

173 value) with m_{ij} importance value. Contrarily, assuming that \tilde{A} is a positive $n \times n$ reciprocal matrix,

174 $\tilde{a}_{ij} = \tilde{a}_{ij}^{-1} = (\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}})$ that represents influence of element j over element i with lower $\frac{1}{u_{ij}}$, mean $\frac{1}{m_{ij}}$

175 , and higher $\frac{1}{l_{ij}}$ values respectively. As a result, the fuzzification increases the complexity of the

176 computation for synthesis judgments based on the fuzzy elements a_{ij} s. To be able to evaluate a fuzzy

177 ANP model through standard pair-wise comparisons, the fuzzy values are standardized into a single-

178 pattern fuzzy set dealing with both linguistic and/or quantifiable criteria (Abdi, 2009). Accordingly,

179 the importance weights are defined with five triangular fuzzy sets: $\hat{1}, \hat{3}, \hat{5}, \hat{7}, \hat{9}$ with their

180 corresponding lower, mean, and upper values defined in equation (5) and represented in **Table 1** (Abdi

181 and Labib, 2004).

$$\tilde{a}_{ji} = \begin{cases} \hat{1} & ; \in (1, 1, 3) \\ \hat{x} & ; \in (x-2, x, x+2) \\ \hat{9} & ; \in (7, 9, 9) \end{cases} \quad (5)$$

<< Insert Table 1 about here >>

The fuzzy range of ($\hat{1}, \hat{3}, \hat{5}, \hat{7}, \hat{9}$) are used to express linguistic preferences for evaluation criteria in terms of Equal (EQ), Low (L), Medium (M), High (H), and Very High (VH) as decision linguistic variables (**Table 1**), respectively. EQ can also represent equal to very low importance. If criterion (c_i) is assigned one of the fuzzy numbers above when compared with criterion (c_j), then c_j has the reciprocal value when compared with c_i . To simplify the weighting process, the priority values are put in a reciprocal comparison bar for each pair of attributes with respect to a criterion/alternative. For example, if value 5 is assigned on the right-hand side criterion (c_j), then criterion c_j is more important than c_i with a moderate degree. Similarly, if value 5 is assigned on the left criterion (c_i), then the criterion c_i is more important than c_j with a moderate degree (Abdi and Labib, 2004).

The synthesized fuzzy degree of criterion i influenced by criterion j , where $i, j = 1, 2, \dots, n$, each with a triangular fuzzy number \tilde{a}_{ij} in an ANP structure, can be derived from formula (5). In the ANP with a ($n \times n$) super-matrix, in which any element can influence on another element based on the influence flow from a component/cluster to another component/cluster, or from a component to itself (inner dependency loop), the number of elements influencing on or being influenced by criterion i could be up to n elements. In the fuzzy environment, the comparison ratios \tilde{a}_{ij} are represented by the membership functions that indicate the degree of compatibility/possibility.

206 **Fuzzy FMEA**

207 Failure mode and effects analysis (FMEA) is a risk measurement tool, which is used in various
208 engineering and management problems such as project risk management. Accordingly, a risk priority
209 number (RPN) is constructed for measuring key risk elements and prioritizes several risky
210 problems/projects, for which the largest RPN corresponds to the riskiest problem/project being
211 considered. The purpose of this section is to explain the logic and shortcomings of RPN values.

212 In the FMEA, risk value is evaluated by grading the data according to key risk elements: 1) severity of
213 effect (S), 2) frequency of occurrence (P), and 3) detectability (D). The multiplied sum of these figures
214 produces the risk priority number. Failure mode and effects analysis extends the risk priority matrix
215 that includes RPN for each project:

$$216 \quad RPN = \text{Severity} \times \text{Probability} \times \text{Detection} \quad (6)$$

217 In typical RPN problems, a rating of 1 to 10 on each scale will be assigned to each risk element, with
218 10 being severe, very likely to occur, and impossible to detect. These ratings are then multiplied
219 together to obtain RPN values, which are used to assess the projects. The idea is that the problem with
220 the highest *RPN* value is the critical one (with a highest priority) that needs to be focused on. However,
221 there are two logical difficulties with calculating the RPN. As argued by Wheeler (2011),
222 multiplication of the RPN elements is nonsense; with having assigned a range of 1 to 10 to each
223 element, RPN varies from 1 to 1,000 with only 125 possible values, which are not uniformly distributed
224 between 1 and 1,000. In the typical RPN, the three elements are assumed to be of the same importance
225 while being given crisp values ranging from 1 to 10. RPN values gained from multiplication of the
226 three elements are not meaningful because each value is an interval scale and not a ratio scale as a
227 requirement for multiplication. However, in a ratio scale, the values can be ordered with consistently
228 identical distance between two values (the distance between 1 and 3 is the same of the distance between
229 5 and 7, and etc.), and with an absolute zero point (starting from zero rather than 1).

230 To overcome the shortcomings of using certain value and illogical multiplication, the elements can be
 231 considered as linguistic values ranging from Very Low (VL), Low (L), Medium (M), High (H), and
 232 Very High (VH) respectively. By using RPN linguistic scores, 125 problem descriptions (5^3) can be
 233 obtained; each with the 5 options above e.g. a risk score of HMH (High, Medium High) reflect values
 234 of (Severity, Occurrence, Detectability) respectively. So far, all the values for RPN elements are
 235 assumed to be crisp ranging in [1,5]. Conversely, the elements can be considered as criteria with fuzzy
 236 number as described earlier. Therefore, the fuzzy range of $(\hat{1}, \hat{3}, \hat{5}, \hat{7}, \hat{9})$ can be used to express
 237 linguistic priorities. Using fuzzy number ranging from $\hat{1}, \hat{3}, \hat{5}, \hat{7}$, to $\hat{9}$, each problem description can
 238 be seen as a fuzzy linguistic value, and a ratio fuzzy scale can be achieved by a synthesized fuzzy
 239 number. Adopting from the extent analysis (Chang, 1996), the synthesized result for criterion i will
 240 remain fuzzy as shown in formula (7).

$$241 \quad S_i = \sum_{j=1}^n \tilde{a}_{ij} \otimes \left(\sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{ij} \right)^{-1} = (l_{si}, m_{si}, u_{si}); \quad i, j = 1, 2, \dots, n \quad (7)$$

$$242 \quad V(M \geq L) = \sup_{x \geq y} [\min \mu_L(x), \mu_M(y)] \quad (8)$$

243 Where V is the possibility of $M \geq L$ and a pair (x,y) exists, If $x \geq y$ and $\mu_L(x) = \mu_M(y) = 1$, then $V(M$
 244 $\geq L) = 1$ where V is the possibility distribution. Considering M and L are convex fuzzy numbers

245 (l, m, u) and $L = (1, 3, 5)$ and $M = (3, 5, 7)$:

$$246 \quad V(M \geq L) = 1 \quad \text{as } m_M = 5 \text{ and } \geq m_L = 3 \quad (9)$$

$$247 \quad V(L \geq M) = \mu_L(d) = D = 0.5 \quad (10)$$

248 D is equal to $\mu(d)$, and d is the intersection point of two sides of triangles of fuzzy number M and L .

249 we have:

$$250 \quad \text{Line 1: } p_1: (5,0), p_2: (3,1) \text{ then } (Y-0)/(1-0) = (X-5)/(3-5) \text{ then } -2Y = X-5 \quad (11)$$

$$251 \quad \text{Line 2: } p_1: (3,0), p_2: (5,1) \text{ then } (Y-0)/(1-0) = (X-3)/(5-3) \text{ then } 2Y = X-3 \quad (12)$$

252 Value 'd' can be found by equalizing the simultaneous equations by adding equations for Line 1 and
253 line 2, therefore:

254 $0 = 2X - 8$, then $X = 4$ so, $d = 4$, and therefore by substituting d in Line 1 or Line 2:

255 $Y = D = 0.5$, therefore:

256 $V(L \geq M) = 0.5$

257 Interestingly, the degree possibility for $M \geq L$ equals 1 whereas it is 0.5 for $L \geq M$.

258 We also have:

259 $V(L \geq M, H, VH) = V(\hat{1} \geq \hat{3} \text{ and } \hat{5} \text{ and } \hat{7} \text{ and } \hat{9}) = \text{Min}(V(L \geq M), V(L \geq H) \text{ and } V(L \geq VH) = V(L \geq M) = V(\hat{1} \geq \hat{3}) = 0$ (13)

261 That means the fuzzy number $\hat{1}$ (Low) cannot be greater than fuzzy values (M, H, VH) at once as the
262 degree possibility is zero.

263 The synthesized fuzzy number for comparison matrix \tilde{A} can be derived using formula (14):

264 Fuzzy RPN = Fuzzy Severity (S) * Fuzzy Occurrence (P) * Fuzzy Detection (D) (14)

265 To avoid the logical failure of the multiplication of the three risk elements Severity (S), Occurrence
266 (P), and Detection (D) in obtaining RPN the linguistic scales can be replaced for ranking projects with
267 regards to their risks and the impacts. As shown in **Table 2**, the risk values can be classified to 5 fuzzy
268 numbers which reflect the linguistic scales with fuzzy range possibility for each scale. By ordering of
269 these three risk aspects, a fuzzy RPN value for each project with combination of three fuzzy numbers
270 for three risk elements is allocated. All the possible combinations will be 125 (= 5*5*5) with different
271 scores which can be ordered based on their centred average in a descending order to see the most
272 critical (risky) projects at the top of the table. In this approach, equal importance is given to each risk
273 element.

274 The final rating will range from extremely high (EXH), very high (VH), high (H), medium (M), low
275 (L) and very low (VL). The combinations of the three elements in a descending order from EXH, VH,

276 to H are presented in Appendix 1. combinations from 125 possible combinations are ranked from H to
277 EXH. The same combination of elements is defined for medium (M), low (L) and very low (VL). The
278 table presented in Appendix 1 facilitates the collection of data related to pair-wise comparison of risks
279 factors and sub-factors from the group of experts and decision makers.

280

281 ***Evaluation based on distance from average solution (EDAS) method***

282 In order to solve the MCDM problems, the alternatives must be ranked by computing the distance of
283 the possible solutions from the ideal and worst solutions using the EDAS tool (Ghorabae et al. 2015).
284 The most preferred alternative will have the lowest distance from ideal solution and the highest distance
285 from the nadir solution in VIKOR and TOPSIS methods (Yazdani and Payam, 2015). However, in the
286 proposed approach, the best alternative is related to the distance from the average solution (*AV*). This
287 method does not need to calculate the ideal and the nadir solution, instead two measures dealing with
288 the desirability of the alternatives will be computed. The first measure is the positive distance from
289 average (PDA), and the second is the negative distance from average (NDA). These measures can
290 illustrate the difference between each solution (alternative) and the average solution. As suggested by
291 Ghorabae et al. (2016), the evaluation of alternatives is made according to the higher values of PDA
292 and lower values of NDA.

293

294 << *Insert Table 2 about here* >>

295

296 The EDAS ranking score can be obtained as follows (Ghorabae et al. (2016):

297 *Step 1* – Select the most relevant attributes, which describe the alternatives for the specific decision
298 problem.

299 *Step 2* - Let x_{ij} be the performance rating of i^{th} alternative $A_1, A_2, \dots, A_n, (i = 1, 2, \dots, n)$ with respect to the
 300 j^{th} criterion $C_1, C_2, \dots, C_m (j = 1, 2, \dots, m)$. Form the interval decision matrix X and weight of each
 301 criterion W as follows:

$$302 \quad X = [x_{ij}]_{n \times m} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix}, \quad (15)$$

$$303 \quad W = [w_1, w_2, \dots, w_m]$$

304 For $(i = 1, 2, \dots, n)$ and $(j = 1, 2, \dots, m)$

305 where w_j is the weight of criterion j^{th}

306 *Step 3* - The average solution with respect to all criteria must be determined as shown following the
 307 formula:

$$308 \quad AV_j = \frac{\sum_{i=1}^n x_{ij}}{n}; \quad (16)$$

309 *Step 4* - The positive distance from average (*PDA*) and the negative distance from average (*NDA*)
 310 matrices can be calculated as:

$$311 \quad PDA_{ij} = \frac{\max(0, (x_{ij} - AV_j))}{AV_j} \quad (17)$$

$$312 \quad NDA_{ij} = \frac{\max(0, (AV_j - x_{ij}))}{AV_j} \quad (18)$$

313 In this way PDA_{ij} and NDA_{ij} represent the positive and negative distance of the i^{th} alternative from the
 314 average solution in terms of the j^{th} criterion for the lower level of decision matrix, respectively.

315 *Step 5* – Compute the weighted summation of the positive and negative distances from the average
 316 matrix:

317
$$SP_i = \sum_{j=1}^m w_j PDA_{ij} \quad (19)$$

318
$$SN_i = \sum_{j=1}^m w_j NDA_{ij} \quad (20)$$

319 *Step 6* – Find the normalized values of SP_i and SN_i for all alternatives as follows:

320
$$NSP_i = \frac{SP_i}{Max_i(SP_i)} \quad (21)$$

321
$$NSN_i = 1 - \frac{SN_i}{Max_i(SN_i)} \quad (22)$$

322 *Step 7* – Calculate the appraisal score AS for all alternatives as:

323
$$AS = \frac{1}{2}(NSP_i + NSN_i), \quad (23)$$

324 where $0 \leq AS \leq 1$

325 *Step 8* - Rank the alternatives according to the decreasing values of the appraisal score (AS). The
326 alternative with the highest AS is the best choice.

327

328 **Problem context and proposed approach**

329 Projects' failure could be the result of poor planning of risk management and a lack of proper risk
330 analysis (Kerzner, 2001). On the other hand, risk management could be seen as a cost-containment tool
331 rather than a systematic process and technique for handling various aspects of the projects (Zwikael
332 and Globerson, 2006). It has been shown that risk management incorporates cost, time, quality and
333 scope are unavoidably connected and interdependent (Lavender 2013, Mantel et al. 2011; Chan et al.
334 2004). Therefore, if the risk management is considered for controlling cost, then it is similarly
335 concerned with controlling time, quality and scope that could result in successful project delivery.

336 In the past, clients or contractors rarely formally requested risk analysis for their projects (even for
337 infrastructural projects) (Akintoye and MacLeod 1997). An independent investigation undertaken by

338 British Airports Authority (BAA) indicates that any UK construction project with over £1 billion in
339 value for construction over 10 years, in addition to all international airport projects completed in the
340 previous 15 years, had not been delivered on time, on budget, safely or met their specified quality
341 standards (Lowe 2013). Due competitive environment for contracting projects, customers are now able
342 to get involved with project, insisting contractors to assume higher levels of risk through various types
343 of contracts: Lump sum, Guaranteed Maximum Price (GMP), or Not-To-Exceed price (NTE). With
344 increasing project size, complexity and competition, the management of risks, particularly at the early
345 stage of the project is becoming an ever more important challenge (Maytorena et al. 2007). Therefore,
346 it is crucial to improve both organizational and project performance with developing risk assessment
347 methodologies that can be mutually accepted as a critical component of successful project delivery
348 (PwC, 2013; KPMG and PMI 2012).

349 The proposed model integrates analytical network process (ANP) and, failure mode and effect analysis
350 (FMEA) with fuzzy approach in order to develop a meaningful and practical solution to the project
351 risk evaluation problem. These three methods have been integrated to complete three tasks: ANP to
352 weight decision criteria, FMEA to shape the performance-rating matrix (decision table), and the
353 outputs of these two methods are used as input to EDAS (third method) which produces the ranking of
354 the projects considering the risk factors. Each method has its particular advantage, and the intelligent
355 integration of them provides a robust methodology for risk evaluation.

356 The proposed model to evaluate construction projects based on risk variables can be presented in
357 three phases (**Figure 1**):

358 **Phase I** - In the first phase, a team of experts will define the risk attributes, decision alternatives and
359 level of complexity. In this phase, the proposed integrated model will be explained to the experts.

360 **Phase II** - The second phase based on the ANP principles represents the relationship and interaction
361 among the decision variables and constructs the pairwise comparison matrix (shown in **Figure 2**). The
362 fuzzy ANP utilizes this matrix to estimate weights of the decision factors and sub-factors. Further in

363 this phase, the initial risk matrix for alternative projects is decided through a new fuzzy FMEA scoring,
364 Three decision makers (DMs) present their views over projects considering risk determination values.
365 The fuzzy FMEA procedure is explained earlier in the paper. The outputs of this phase will be the input
366 (weights of the attributes and performance rating of projects) of phase III.

367

368 << *Insert Figure 1 about here* >>

369

370 **Phase III** - At last, in the third phase, the EDAS method (as described earlier) evaluates projects and
371 ranks them from the best to worst. Comparisons with other MCDM methods and sensitivity analysis
372 are performed in order to test the consistency and stability of the results.

373

374 **Implementation of the proposed approach**

375 In this section, the implementation process of the proposed approach is discussed. Six projects
376 considered in this study are medium to large scale construction projects. These projects are related to
377 building water reservoirs and dams in one of the European countries. Due to the lack of rain and
378 decreasing water resources, the need to construct water reservoirs and dams to improve water
379 availability for agriculture is one of the important issues in this country. All of these projects are from
380 different regions of the country with varying degree of resources availability, weather conditions,
381 geographical features and political situations. Assessing and measuring the risks in developing these
382 construction projects are vital for the successful completion of the projects. Also for planning purpose,
383 it is important to understand the risks involved due to limited resources available for these projects.
384 The risk evaluation of these construction projects in this study is based on measuring the risks with the
385 help of the proposed decision analysis model and then rate them according to different risk parameters.
386 The proposed approach is implemented in consultation with the practitioners and planners to
387 understand the real -life challenges in risk evaluation of constructions projects.

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<< Insert Figure 2 about here >>

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Phase I - This study examines the hierarchical risk breakdown structure (RBS) for risk assessment of construction projects. Organizations use RBS in conjunction with Work Breakdown Structure (WBS) to help management team and eventually analyze risks (Mantel et al. 2011). For the six construction projects, specific risks must be identified and analyzed. In this phase, ANP tool is used to produce the weights of risk factors and sub factors. ANP is an applied tool in MCDM which considers the inter-relationship among risk elements using pairwise comparison. The ANP network (**Figure 2**) presents the criteria and sub-criteria for the risk assessment of the construction projects. Different decision variables for risk evaluation in construction projects are identified based on past literature such as Antuchevičiene et al. (2010) and Zavadskas et al. 2010). However, these factors and sub-factors are later verified during the interviews with the key decision makers in the construction projects. The risk factors in this study are classified into three groups : a) *Technical*, b) *External* and c) *internal / organisational* risk factors. The *technical* factors include: C₁) construction requirements; C₂) technology; C₃) complexity and interfaces; C₄) quality and C₅) cost; *external* factors include C₆) subcontractors and suppliers; C₇) economic and market; C₈) weather; and C₉) political; and *internal* factors include C₁₀) resources; C₁₁) funding; and C₁₂) project site.

Later on, the pairwise comparisons among different decision factors and sub-factors are performed, which help to get global weighs of each factors and sub-factors to decide the final risk assessment of the projects. The project risk ratings are determined using fuzzy linguistic variables.

Phase II - In order to obtain the weights of factors and sub-factors using ANP, the pairwise comparison matrix must be performed between factors and sub-factors. To shape the global weight matrix for all the factors, primarily pairwise comparison must be made between each factor and sub-factors based on the defined inter-dependency.

414 For the FMEA process, three experts / decision makers (DM) deliver their judgments for six projects
415 regarding each decision variable. These decision makers were selected based on their wide experience
416 in managing large scale construction projects. The decision makers selected for this study for providing
417 pairwise comparison of different risk factors and sub-factors have more than 20 years of working
418 experience. **Appendix 1** shows the fuzzy FMEA pre-defined values (FMEA reference rating scales).
419 In this phase the experts carefully consider probability, severity and number of detection parameters
420 using fuzzy linguistic variables. For example DM₁ explains for project 1 corresponding C₂ the severity
421 (S), probability of happening (O) and detection are (1,1,3), (3,5,7) and (1,1,3), respectively. **Appendix**
422 **2** presents the information of projects expressed by decision experts. Then linguistic variables are
423 translated to fuzzy values and also the defuzzification process is established.

424

425 With the help of the decision makers, pairwise comparisons are performed for the three factors to find
426 independent weights of factors (shown in **Table 3**). To design Table 3, experts are asked to compare
427 three factors to realize their influence. This task is done using reference scales in Table 1. After that
428 comparison between each factor is performed with regard to the single factor. Table 3 is developed
429 based on the experts' judgment over the importance of different risk factors. For example, as the
430 external factors were identified 5 times more important than technical factors. Therefore, the priority
431 of technical factors over external are 0.2 times. After the pair wise comparison of each factor, sum of
432 each column is obtained. Then, each element is divided by the sum of the column. Finally, average of
433 each row produces the weights which are seen in the last column. Similar process is followed for each
434 pairwise matrix of the decision variables.

435

436

<< *Insert Table 3 about here* >>

437

438 In ANP, when decision system contains factors and sub-factors, pairwise comparisons must be
 439 performed in order to find importance (weight) of one over another. The weight of different factors are
 440 obtained through multiplication of factors inter-dependence vector and the vector of factors
 441 interrelationship with respect to each one. As there are three key decision factors (Technical, External,
 442 and Internal) in this study, four vectors (one for inter dependence and one each for three factors) should
 443 be multiplied to calculate the final weight of the factor (as shown in equation 24).

$$444 \quad w_{factors} = \begin{bmatrix} 0.667 & 0.245 & 0.525 \\ 0.15 & 0.428 & 0.334 \\ 0.183 & 0.327 & 0.142 \end{bmatrix} \times \begin{bmatrix} 0.102 \\ 0.686 \\ 0.211 \end{bmatrix} = \begin{bmatrix} 0.347 \\ 0.38 \\ 0.273 \end{bmatrix} \quad (24)$$

445
 446 Similarly, the pair-wise comparison of 12 sub-factors are performed to find the local-weight of each
 447 sub-factor. It is then multiplied to the weight of the corresponding risk factor (Technical, External, or
 448 Internal - as calculated in equation 24) to generate the global weights of each sub-factors. Finally, the
 449 normalised weights of each sub-factor are presented in Table 4. The normalized global weights of sub-
 450 factors are utilized in the project evaluation process by EDAS in Phase III. EDAS needs the weights
 451 of decision factors and sub-factors to find the final ranking of the projects.

452 *<< Insert Table 4 about here >>*

453
 454
 455 **Phase III** - This section ranks projects using the EDAS method. The aggregated defuzzified matrix
 456 (Appendix 3) is used as the initial decision matrix for the EDAS method. The process of ranking
 457 alternative projects using EDAS first involves developing the positive distance from average (PDA)
 458 and negative distance from average (NDA) matrices as described in equation 17 and 18 (See Appendix
 459 4). Then, the weighted summation of the positive distance (SP) and negative distance (SN) from the
 460 average matrix are obtained (as shown in equation 19 and 20). Further, the normalised values of SP
 461 and SN for all alternatives (NSP and NSN) are calculated. Finally the appraisal scores (AS) of each
 462 alternative are computed according to equation 23. The project with highest appraisal score is

463 considered as the riskiest project. The summary results obtained by the EDAS method and the ranking
464 of the projects are presented in **Table 5**.

465 << *Insert Table 5 about here* >>
466

467 The ranking of projects based on EDAS shows this arrangement:

468 Project 4 > Project 6 > Project 1 > Project 3 > Project 5 > Project 2

469 Therefore, it is observed that project 4 is the riskiest project based on the judgments of experts and
470 corresponding risk factors. Project 2 is considered as the least risky project among all. It is observed

471 Appendix 3), that Project 4 has the maximum value regarding the criteria “subcontractors and
472 suppliers” (C₆) which is the most important criterion among all. Also, this project has considered as

473 one of the low cost project among others. The results are confirmed through observing the initial data.

474 In this phase, to check the consistency and the accuracy of the obtained ranking outcomes, a
475 comparison of the proposed approach with other popular methods is conducted. EDAS ranking scores

476 are compared with other MCDM tools such as SAW, TOPSIS, VIKOR, COPRAS and WASPAS. The
477 consistency of the proposed method is evident among the ranking orders of the different methods.

478 **Table 6** shows the comparative results, and tests the stability of the model.

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481 << *Insert Table 6 about here* >>
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484 Further, sensitivity analysis is conducted on the decision parameters to study the changes in the ranking

485 of the projects. To conduct the sensitivity analysis, relative preferences of experts over the risk factors

486 and sub-factors are altered and weights of decision variables are replaced by random weights. The

487 performance of proposed approach has been then compared and analyzed for each scenario. Each

488 scenario is represented by a “set” of alternative sub-factors weights. In total, 12 sets of weights are

489 generated to analyze the impact on project ranking (as shown in figure 3). **Table 7** shows the weight
490 replacement scenarios for six projects with respect to the decision variables. Figure 3 shows that
491 significant changes were observed in the ranking orders of the projects. Based on the sensitivity
492 analysis outcomes, it could be concluded that on average, Project 1, Project 4, and Project 6 are the top
493 3 riskiest projects.

494 << *Insert Table 7 about here* >>

496 << *Insert Figure 3 about here* >>

498 **Discussion**

499 The approach proposed for the risk evaluation of projects in this study embraces multi-level internal,
500 external and organizational factors. The proposed decision framework can help to provide suggestions
501 and improvements for practitioners to improve their decision making capabilities. Generally the
502 interrelationships among different levels of project evaluation are not considered by project managers.
503 This partially blocks the decision-making process from its most accurate route and enhances the
504 complexity of the computations. This paper essentially insists on the importance of taking into
505 consideration such interrelationships and shows how it can be done though utilizing ANP. The
506 proposed approach offers the additional opportunity for practitioners to express their comparisons
507 using fuzzy linguistic values with ANP.

508 This paper introduces a new FMEA structure utilizing fuzzy linguistic variables. The paper argues that
509 this novel pattern offers a unique anatomy, which increases judgment's preciseness and facilitates
510 efficient decision-making procedure. The FMEA rating classification easily converts solid fuzzy values
511 to the meaningful and informative codes that are exhibited in **Appendix 1**. Moreover, it gives reliable
512 combination of fuzzy scales to constant alarm codes (EXH as extremely high, VH as very high). This

513 will decrease the complexity of the judging process and allow the DM to perform a better analysis of
514 the existing project.

515

516 **Conclusion and future research direction**

517

518 Project risk management is increasingly becoming challenging due to the number of variables and
519 parameters with quantitative and qualitative characteristics. Uncertainty and impreciseness have
520 emerged as influential factors at the core of risk evaluation computations. Mitigating complexity,
521 interrelationship and transaction among risk variables is a serious concern for project managers. In this
522 paper, a new integrated model of combining FANP and FMEA in a fuzzy decision-making
523 environment has been proposed to evaluate the potential risks of projects considering internal /
524 organizational, external and technical factors. The ANP with fuzzy linguistic scales is applied in order
525 to obtain relative weights of the sub-criteria and to resolve internal dependencies. In addition, failure
526 mode and effect analysis (FMEA) has been conducted to comprehensively measure fundamental
527 factors such as the likelihood, severity and detection of potential risk for each project. Explaining and
528 rating these factors by verbal codes is crucial. Therefore, the utilization of fuzzy linguistic scales is
529 appropriate to deal with such vagueness and uncertainty in comparing the priority of variables. The
530 proposed FMEA coding improves the decision process and increases the flexibility and efficiency of
531 risk evaluation. In this paper, decision makers offered their opinions regarding FMEA codes and then
532 through defuzzification process, the consequences assessed by them provided the main decision matrix
533 for MCDM process. The proposed framework provides a robust decision-making tool which can aid
534 project managers and investors to analyze different risk factors in multiple levels of a project.

535 The paper contributes in developing the body of knowledge in MCDM field. A new feature is the
536 integration of the EDAS method in to the risk evaluation process – something that was not considered
537 in past studies. However, the study is highly reliant on the experts' opinions over the priority of the

538 decision variables. Depending on the dimensions and levels of decision, a large pairwise comparison
539 needs to be carried out and, in such cases; fatigue is a serious concern that may cause some reliability
540 issues. In this situation, involving more decision makers in the research could be advantageous.
541 The proposed integrated MCDM model for risk evaluation can be applied to other decision-making
542 problems such as supply chain risk assessment, productivity and ergonomic risk evaluation in human
543 resource management studies. Although, ANP is a method which analyzes the interactions among
544 decision variables, it cannot recognize the direction of that interaction. In order to tackle that
545 shortcoming future research could expand the scope of this study by addressing the inter-relationships
546 among the criteria using Decision Making Trial and Evaluation Laboratory (DEMATEL) or
547 interpretive structural modeling (ISM) (Hashemi et al. 2015). Another potential improvement in the
548 project evaluation exercise could be the consideration of the risk of investment and, the satisfaction of
549 stakeholders and external customers. Integration of MCDM methods with Quality Function
550 Deployment (QFD) could be considered in future research to address this issue. Moreover, due to the
551 increasing awareness of environmental and social issues, incorporating ecological and sustainability
552 factors in the risk measurement model could be included in the proposed model.

553

554 **Data Availability Statement**

555 Data generated or analyzed during the study are available from the corresponding author by request.

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693 **List of Figures**

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695

696 **Figure 1.** Three phase MCDM model for project risk evaluation problem

697 **Figure 2.** Risk factors and sub-factors relationship and network diagram for ANP

698 **Figure 3.** EDAS ranking outcomes based on different scenarios of sensitivity analysis

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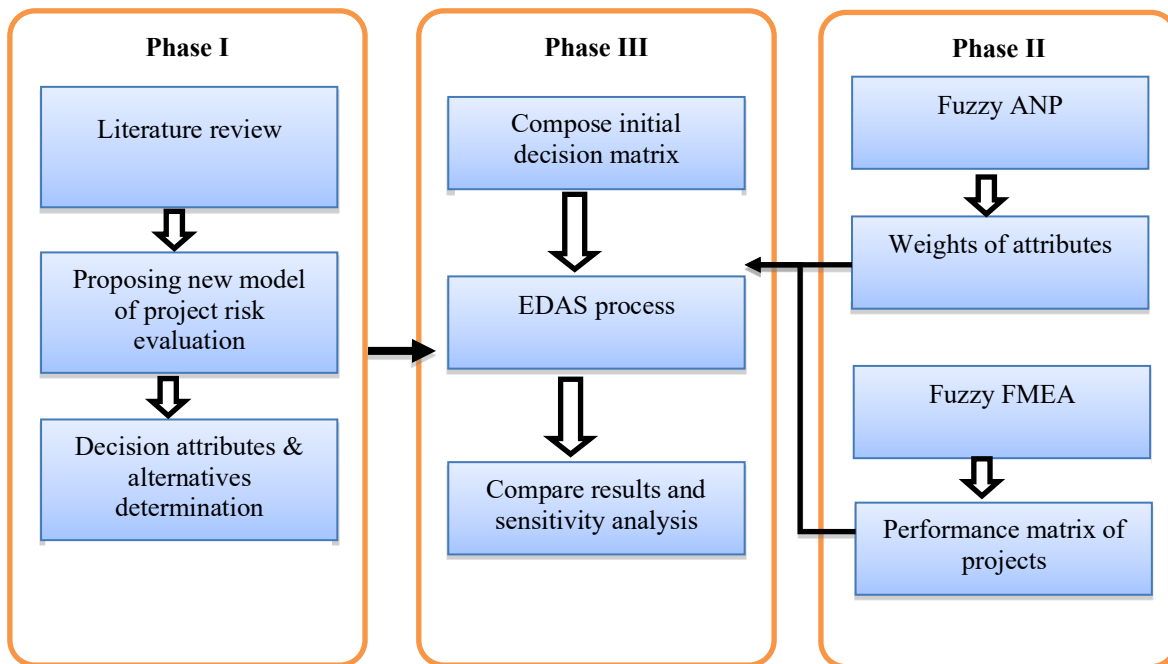
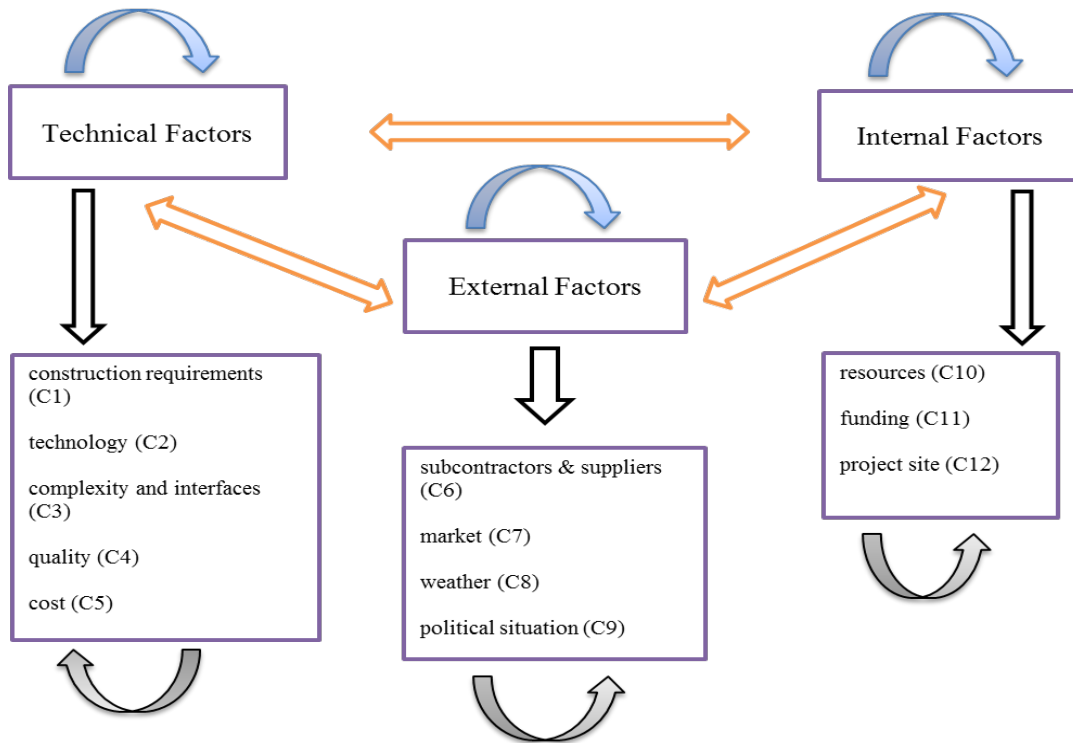


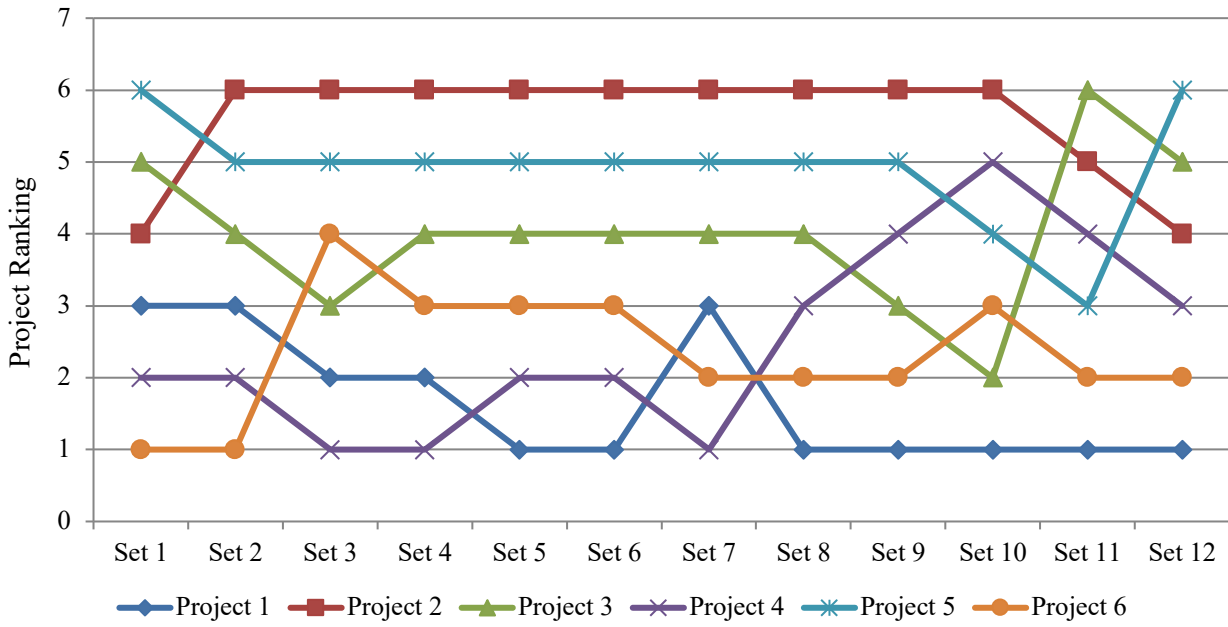
Figure 1. Three phase MCDM model for project risk evaluation problem



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Figure 2. Risk factors and sub-factors relationship and network diagram for ANP

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Figure 3. EDAS ranking outcomes based on different scenarios of sensitivity analysis

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Table 1. Fuzzy scale for pairwise comparisons

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Fuzzy number	Linguistic variables	Triangular fuzzy number
$\tilde{9}$	Extremely important/preferred	(7,9,9)
$\tilde{7}$	Very strongly important/preferred	(5,7,9)
$\tilde{5}$	Strongly important/preferred	(3,5,7)
$\tilde{3}$	Moderately important/preferred	(1,3,5)
$\tilde{1}$	Equally important/preferred	(1,1,3)

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Table 2. Classification of fuzzy linguistic variables for RPN scoring

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Linguistic Term	Fuzzy Number	Severity	Occurrence	Detection
Very Low	$\hat{1}$	A failure that has no/ minor effect on the system performance, the operator probably will not notice.	It would be very unlikely for these failures to be observed.	Defect remains undetected until the system performance degrades to the extent that the task will not be completed.
Low	$\hat{3}$	A failure that would cause slight annoyance to the operator, but that cause no deterioration to the system.	Likely to occur once, but unlikely to occur more frequently.	Defect remains undetected until system performance is severely reduced.
Medium	$\hat{5}$	A failure that would cause a high degree of operator dissatisfaction or that causes noticeable but slight deterioration in system performance.	Likely to occur more than once.	Defect remains undetected until system performance is affected.
High	$\hat{7}$	A failure that causes significant deterioration in system performance and/or leads to minor injuries.	Near certain to occur at least once.	Defect remains undetected until an inspection/test is carried out.
Very High	$\hat{9}$	A failure that would seriously affect the ability to complete The task or cause damage, serious injury or death.	Almost certain to occur several times.	Failure remains undetected, until a full inspection and test is completed.

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Table 3. Pairwise comparison matrix for decision variables

Comparative rating of all factors							
Factors	Technical	External	Internal				weight
Technical	1	0.2	0.33	0.1111	0.1429	0.0526	0.102
External	5	1	5	0.5556	0.7143	0.7895	0.686
Internal	3	0.2	1	0.3333	0.1429	0.1579	0.211
	9	1.4	6.3				
Relative importance of all factors with respect to technical factor							
Technical	Technical	External	Internal				weight
Technical	1	3	7	0.6774	0.5	0.8235	0.667
External	0.33	1	0.5	0.2258	0.1667	0.0588	0.150
Internal	0.14	2	1	0.0968	0.3333	0.1176	0.183
	1.48	6	8.5				
Relative importance of all factors with respect to external factor							
External	Technical	External	Internal				weight
Technical	1	0.14	2	0.1176	0.0455	0.5714	0.245
External	7	1	0.5	0.8235	0.3182	0.1429	0.428
Internal	0.5	2	1	0.0588	0.6364	0.2857	0.327
	8.5	3.1	3.5				
Relative importance of all factors with respect to internal factor							
Internal	Technical	External	Internal				weight
Technical	1	2	3	0.5455	0.6	0.4286	0.525
External	0.5	1	3	0.2727	0.3	0.4286	0.334
Internal	0.33	0.33	1	0.1818	0.1	0.1429	0.142
	1.8	3.3	7				

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Table 4. ANP global weights assigned for each sub-factors

Factors	Sub-factors (Indicators)	Sub-factors local weight	Factors weight	Sub-factors global weights	Normalized global weight
Technical	construction requirements (C ₁)	0.0621	0.347	0.0215	0.063
	technology (C ₂)	0.1093		0.0379	0.11
	complexity and interfaces (C ₃)	0.0867		0.0301	0.088
	quality (C ₄)	0.0446		0.0155	0.045
	cost (C ₅)	0.0599		0.0208	0.061
External	subcontractors & suppliers (C ₆)	0.1235	0.380	0.0469	0.137
	market (C ₇)	0.1067		0.0405	0.118
	weather (C ₈)	0.1006		0.0382	0.111
	political situation (C ₉)	0.0774		0.0294	0.086
Internal	resources (C ₁₀)	0.0736	0.273	0.0201	0.058
	funding (C ₁₁)	0.0963		0.0263	0.077
	project site (C ₁₂)	0.0594		0.0162	0.047

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Table 5. Ranking of projects based on EDAS method

	SP	SN	NSP	NSN	AS	RANK
Project 1	0.514	0.366	0.891	0.477	0.684	3
Project 2	0.200	0.699	0.347	0	0.174	6
Project 3	0.317	0.377	0.549	0.461	0.505	4
Project 4	0.576	0.294	1	0.580	0.790	1
Project 5	0.320	0.406	0.555	0.420	0.487	5
Project 6	0.525	0.310	0.911	0.557	0.734	2

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Table 6. Comparison of other MCDM techniques with EDAS

	SAW	WASPAS	COPRAS	TOPSIS	VIKOR	EDAS
Project 1	3	3	3	3	4	3
Project 2	6	6	6	6	6	6
Project 3	4	4	4	5	5	4
Project 4	1	1	1	1	1	1
Project 5	5	5	5	4	3	5
Project 6	2	2	2	2	2	2

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Table 7. Twelve scenarios for sensitivity analysis

Scenarios	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀	C ₁₁	C ₁₂
Set 1	0.045	0.0472	0.0585	0.0605	0.0627	0.0765	0.0856	0.0877	0.1104	0.1113	0.1179	0.1366
Set 2	0.0472	0.0585	0.0605	0.0627	0.0765	0.0856	0.0877	0.1104	0.1113	0.1179	0.1366	0.045
Set 3	0.0585	0.0605	0.0627	0.0765	0.0856	0.0877	0.1104	0.1113	0.1179	0.1366	0.045	0.0472
Set 4	0.0605	0.0627	0.0765	0.0856	0.0877	0.1104	0.1113	0.1179	0.1366	0.045	0.0472	0.0585
Set 5	0.0627	0.0765	0.0856	0.0877	0.1104	0.1113	0.1179	0.1366	0.045	0.0472	0.0585	0.0605
Set 6	0.0765	0.0856	0.0877	0.1104	0.1113	0.1179	0.1366	0.045	0.0472	0.0585	0.0605	0.0627
Set 7	0.0856	0.0877	0.1104	0.1113	0.1179	0.1366	0.045	0.0472	0.0585	0.0605	0.0627	0.0765
Set 8	0.0877	0.1104	0.1113	0.1179	0.1366	0.045	0.0472	0.0585	0.0605	0.0627	0.0765	0.0856
Set 9	0.1104	0.1113	0.1179	0.1366	0.045	0.0472	0.0585	0.0605	0.0627	0.0765	0.0856	0.0877
Set 10	0.1113	0.1179	0.1366	0.045	0.0472	0.0585	0.0605	0.0627	0.0765	0.0856	0.0877	0.1104
Set 11	0.1179	0.1366	0.045	0.0472	0.0585	0.0605	0.0627	0.0765	0.0856	0.0877	0.1104	0.1113
Set 12	0.1366	0.045	0.0472	0.0585	0.0605	0.0627	0.0765	0.0856	0.0877	0.1104	0.1113	0.1179

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760 **Appendices:**

761 **Appendix 1:** Fuzzy FMEA rating reference for projects and assigned defuzzified values

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S	P	D	SPD	Code	Defuzzified Value
(7,9,9)	(7,9,9)	(7,9,9)	(343,729, 729)	EXH1	600.33
(7,9,9)	(5,7,9)	(5,7,9)	(175,441, 729)	EXH2	448.33
(5,7,9)	(7,9,9)	(5,7,9)	(175,441, 729)	EXH2	448.33
(5,7,9)	(5,7,9)	(7,9,9)	(175,441, 729)	EXH2	448.33
(5,7,9)	(5,7,9)	(5,7,9)	(45,343, 729)	EXH3	372.33
(5,7,9)	(3,5,7)	(3,5,7)	(125,175, 441)	VH1	247
(3,5,7)	(5,7,9)	(3,5,7)	(45,175, 441)	VH2	220.33
(3,5,7)	(3,5,7)	(5,7,9)	(45,175, 441)	VH2	220.33
(3,5,7)	(3,5,7)	(3,5,7)	(27,45,343)	H1	138.33
(1,3,5)	(1,3,5)	(3,5,7)	(1,45,175)	H2	74.33
(3,5,7)	(1,3,5)	(1,3,5)	(1,45,175)	H3	73.00
(1,3,5)	(3,5,7)	(1,3,5)	(3,45,175)	H3	73.00
(1,3,5)	(1,3,5)	(1,3,5)	(1,27,125)	M1	51
(7,9,9)	(1,1,3)	(1,1,3)	(7,9,81)	M2	32.33
(1,1,3)	(7,9,9)	(1,1,3)	(7,9,81)	M2	32.33
(1,1,3)	(1,1,3)	(7,9,9)	(7,9,81)	M2	32.33
(3,5,7)	(1,1,3)	(1,1,3)	(3,5,63)	L	23.67
(1,1,3)	(3,5,7)	(1,1,3)	(3,5,63)	L	23.67
(1,1,3)	(1,1,3)	(3,5,7)	(3,5,63)	L	23.67
(1,3,5)	(1,1,3)	(1,1,3)	(1,3,45)	VL1	16.33
(1,1,3)	(1,3,5)	(1,1,3)	(1,3,45)	VL1	16.33
(1,1,3)	(1,1,3)	(1,3,5)	(1,3,45)	VL1	16.33
(1,1,3)	(1,1,3)	(1,1,3)	(1,1,9)	VL2	3.67

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Appendix 2: Decision makers rating over risk factors of projects using FMEA codes

DM₁	C₁	C₂	C₃	C₄	C₅	C₆	C₇	C₈	C₉	C₁₀	C₁₁	C₁₂
Project 1	EXH2	L	H3	M2	VL2	L	VH2	M1	L	M1	M2	M2
Project 2	VL1	L	M1	M1	VH1	M1	M2	VL2	VL2	VH2	M1	H2
Project 3	M1	M1	EXH2	L	M2	L	M1	M2	H1	H2	L	L
Project 4	H2	L	M2	H3	L	EXH3	M1	H2	H2	M1	L	M2
Project 5	M2	VH1	M2	L	M2	M1	M2	M1	M1	M1	M1	L
Project 6	L	M2	H1	M1	L	VH2	VL1	H3	L	H3	EXH3	VL2
DM₂												
Project 1	EXH3	L	H2	M1	VL1	VL2	VH1	M2	VL1	M2	M1	M1
Project 2	VL2	VL1	M2	M2	VH1	M1	M1	VL1	VL2	VH1	M1	H1
Project 3	M1	M2	EXH2	L	M1	VL1	M2	M1	H2	H2	VL2	VL1
Project 4	H3	L	M1	H3	VL1	EXH2	M2	H2	H1	M2	VL1	M2
Project 5	M1	VH2	M2	VL2	M1	M2	M1	M2	M1	M2	M2	VL2
Project 6	VL1	M2	H2	M1	L	VH1	VL2	H2	VL1	H2	EXH2	L
DM₃												
Project 1	VH1	VL2	H1	M1	VL1	VL1	VH2	M1	VL2	M1	M1	M2
Project 2	VL1	VL1	M2	M1	VH2	M2	M1	VL1	VL2	VH1	M2	H1
Project 3	M1	M1	EXH3	VL2	M1	VL1	M1	M2	H3	H3	VL2	VL2
Project 4	H2	L	M1	H1	VL2	EXH3	M2	H3	H1	M2	VL2	M2
Project 5	M2	VH1	M1	VL1	M1	M2	M2	M2	M2	M1	M1	VL1
Project 6	VL2	M1	H3	M2	VL1	VH2	VL1	H1	VL2	H2	EXH1	VL1

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768 **Appendix 3:** Defuzzified aggregated decision makers judgment table (Initial decision matrix)

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	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀	C ₁₁	C ₁₂
Project 1	355.89	17	95.22	44.78	12.11	14.56	229.22	44.78	14.56	44.78	44.78	38.55
Project 2	12.11	18.78	38.55	44.78	238.11	44.78	44.78	12.11	3.67	238.11	44.78	117
Project 3	51	44.78	423	17	44.78	18.78	44.78	38.55	95.22	73.89	10.34	14.56
Project 4	73.89	23.67	44.78	94.78	14.56	397.66	38.55	73.89	117	38.55	14.56	32.33
Project 5	38.55	238.11	38.55	14.56	44.78	38.55	38.55	38.55	44.78	44.78	44.78	14.56
Project 6	14.56	38.55	95.22	44.78	21.22	229.22	12.11	95.22	14.56	73.89	473.66	14.56

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774 **Appendix 4:** Matrices of the positive distance from average (PDA) and the negative distance from
 775 average (NDA)

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PDA	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Project 1	2.9109	0	0	0.0307	0.8065	0	2.371	0	0	0	0	0
Project 2	0	0	0	0.0307	0	0	0	0	0	1.7795	0	2.0317
Project 3	0	0	2.4515	0	0.2846	0	0	0	0.9716	0	0	0
Project 4	0	0	0	1.1816	0.7674	2.2089	0	0.4626	1.4225	0	0	0
Project 5	0	2.7508	0	0	0.2846	0	0	0	0	0	0	0
Project 6	0	0	0	0.0307	0.6609	0.8497	0	0.8849	0	0	3.4905	0

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NDA	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Project 1	0	0.7322	0.223	0	0	0.8825	0	0.1136	0.6986	0.4773	0.5755	0.001
Project 2	0.8669	0.7042	0.6854	0	2.8041	0.6387	0.3415	0.7603	0.924	0	0.5755	0
Project 3	0.4396	0.2947	0	0.6086	0	0.8485	0.3415	0.2368	0	0.1375	0.902	0.6228
Project 4	0.188	0.6271	0.6346	0	0	0	0.433	0	0	0.55	0.862	0.1623
Project 5	0.5763	0	0.6854	0.6649	0	0.6889	0.433	0.2368	0.0729	0.4773	0.5755	0.6228
Project 6	0.84	0.3927	0.223	0	0	0	0.8219	0	0.6986	0.1375	0	0.6228

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