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Research Paper

Identification and Prioritization of Road Project Risks using the Failure Modes and Effects Analysis Method in a Fuzzy Environment

Abdolreza Rezaee Arjroody[1], Seyed azim Hosseini[1,*], Mahdieh Akhbari[2], Ebrahim Safa[1], Jafar Asadpour[3]

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Abstract

A dynamic, efficient transportation network is an important index of country development and currently, major parts of infrastructure projects-related credits and budgets are allocated to road construction projects. Since several risks divert such projects, during their construction, from their main goals, proper risk identification and management are necessary to better implement infrastructure and road construction projects. As risks are changeable factors that differ from country/region to country/region, this research has reviewed the literature and used the experts' opinions to identify the most influential ones in Iran to eliminate or reduce their effects on the time and cost of road construction projects. To this end, a questionnaire was designed to identify the risks and prioritize them using the failure modes and effects analysis method in a fuzzy environment; defuzzification was done by MATLAB Software. Scores of the risks revealed that: 1) inflation (increased material price), 2) late financial provisions, 3) deficiency, failure, or defect of equipment/machinery, and 4) Maps and specification changes of more than 25% with respect to the values specified in the general conditions of contract due to the employer's incorrect studies/estimation of the project, were identified as the most important risks of road construction projects.

Keywords: Road Projects, Risk Identification, Prioritization, Failure Modes and Effects Analysis Method, Fuzzy Environment

[*] Corresponding author. E-mail: s.az.h.46@gmail.com
[1] Department of Civil Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran
[2] Department of Industrial Engineering, Electronic Branch, Islamic Azad University, Tehran, Iran
[3] Department of Mathematical, South Tehran Branch, Islamic Azad University, Tehran, Iran

1. Introduction

The construction industry plays a vital role in other industrial sectors and, hence, in the economic growth and social development of a country (Osei-Kyei and Chan, 2017). Since road infrastructures help reduce poverty and improve life quality and road transportation helps proper final-goods delivery to consumers, understanding their importance in economic growth and their efficient management are both important and necessary (Ben, 2019). Construction projects face many risks, especially related to infrastructures, which affect project performance negatively (El-Sayegh & Mansour, 2015) and cause highway projects not to be completed within the allocated budget (Larsen et al., 2016).

Project management means planning, organizing, monitoring, and directing its implementation, through proper use of resources, within a specified time-cost-quality framework so as to deliver the expected specific results in due time based on previously agreed costs. In other words, it means using skills, tools, techniques, and knowledge, all gathered in two powerful arms - planning and controlling - necessary to manage the flow of activities to meet what trustees need and expect from the project implementation; planning determines the sequence and balance of activities required to implement a project considering the time and quality determined for each activity. In the PMBOK Standard, which presents the 12-fold management principles that govern projects, risk management has received special attention today due to its importance (PMBOK guide, 2021).

In general, the risk is defined as the possibility that a certain action will lead to unexpected, unpleasant losses or consequences; it can also be defined as an unexpected event. Almost all human endeavors involve some risks, but some are more severe (Eunchang et al., 2009).

Although risk management, which is an integral part of project management aimed to deliver results conforming to the agreed plan, budget, and quality level, has experienced many analytical advances, still many projects fail to meet their goals revealing that this functional gap is quite important (Cox, 2021).

In the current research that has identified the risks related to road projects in Iran through a literature review, the most serious ones have been prioritized using the experts' opinions and a fuzzy FMEA questionnaire designed by the Delphi technique; defuzzification has been done by the MATLAB Software. Results of the present study can be used in the scheduling of road projects to evaluate the quantitative effects of risks and enable the related managers to have a more appropriate estimate of the time and cost price before starting the project.

2. Literature Review

In review research entitled the “effects of risks on the selection and design of highways”, results of 39 papers showed that no pre-construction risk management had been done causing increased delays in the projects (Tran and Molenaar, 2014).

In another research entitled “identifying factors affecting the cost of road projects”, the analyses result of 41 factors showed, from the contractors’ points of view, that internal administrative problems, delayed payments, poor constructor-employer communication, and 4) delayed decision-making were the factors that highly increased the costs of a road project in Saudi Arabia (Alhomidan, 2013).

In research entitled “examining the determining factors that increase costs in transportation infrastructure projects”, Cavalieri et al., 2019) reviewed the literature of 26 papers during 2000-2016 and showed that: 1) cost was a major factor and 2) accurate cost prediction planning reduced additional costs in infrastructure projects.

To estimate costs, assess risks and review current practices in early highway/bridge construction stages, Kermanshachi and Safapour (2020) showed, in a case study, that various opinions affected the project risk assessment, through which the additional costs were reduced greatly by defining the project scope and estimating the costs accurately.

Mohajeri Borje Ghaleh et al. (2020) addressed the identification and qualitative prioritization of delays in the implementation stage in the Garmsar - SiminDasht Road project from the risk management point of view where risks were identified through interviews and prioritized using the hierarchical analytical process method; their qualitative prioritization was based on experts' opinions. Qualitative delaying risks were prioritized by cause-and-effect diagrams and ranked by the Expert Choice Software, which showed: 1) financial/credit problems, 2) land acquisition, 3) management problems, 4) technical problems, and 5) natural disasters had the highest risks among the main criteria.

Islam and Nepal (2017) reviewed the literature on risk analysis methods during 2005-2017 and showed that various complex projects often used the fuzzy analytical network process (FANP), which is suitable for pairwise comparisons (due to tedious and long calculations) but is unable to integrate new data in the risk structure. To overcome this limitation for risk assessment, use has been made of the fuzzy Bayesian-based network (FBBN), a wider application of which requires specific studies. Beyond fuzzy methods, credal networks - extended forms of the FBBN - have proved capable of assessing risks under potential uncertainties.

As risks are variable factors that differ depending on the situation of each country/region (Ammar et al., 2022), the authors in this papaer have tried to review Iran's domestic research and identify the risks of road projects.

Dehghani and Keramati (2015) identified the risks of road construction projects and provided solutions to reduce them by categorizing them into external and internal risks. Reviewing and analyzing the risks related to road projects by fuzzy logic, Baghelani et al. (2013) identified and prioritized them using the experts' opinions and the fuzzy technique, respectively. Javadi et al. (2014) studied and ranked the internal risks in road projects with BOT contracts, used questionnaires to ask experts about their quality/time/cost effects in such projects, and categorized them into political, economic, and legal risks. In a case study on - Khorram Abad-Kohdasht Highway -, Soltanpanah and Sohrabi (2014) identified 49 risks of road construction projects based on the knowledge of experts and consultants. In a case study, Rajabinejad and Radkia (2016) addressed the management of the risks that caused delays in the "Ramhormoz-Behbahan Highway" construction project. Using the risk matrix in the Qom Province case study, Abbasian Jahromi et al. (2017) identified and classified risks as those related to the employer, consultant, and contractor, and then prioritized them to identify the critical ones that caused delays in road construction projects. Faraji et al. (2017) identified risk factors in a road construction project case study in Mazandaran Province and used the Topsis method for their prioritization. Through a library study, Basiri and Rahsepar (2017) examined the risks identified in road construction projects with BOT contracts, classified them as time, cost, and quality risks, and prioritized them by the Topsis method. Naghibi and Hasanpour (2017) evaluated the risks of road construction projects, analyzed them based on their occurrence probability, failure efficacy, and control level, and prioritized them using the FMEA method and RPN number. Using the fuzzy approach in a case study, Shariatnia and Riazi (2017) examined the factors that delayed the construction of roads leading to Dehdasht city, identified 30 related risks, and prioritized them

based on the opinions of 20 experts. Yazdani Mooneki and Ghahremanifar (2018) evaluated risk management in road projects, identified and grouped the related risks, and prioritized them by the FMEA method. Sadeghi Googhari and Mohamadizadeh (2019) identified and assessed the risks in road projects in Sirjan access roads, grouped them into political, economic, financial, developmental, social, organizational/management, and design risks, and then ranked them, through questioning, as qualitative, time and cost risks after determining their probabilities.

3. Research Methodology

FMEA[1] (Figure 1) is an analytical technique that tries to identify and rank the potential risks, in the desired risk-assessment range, and find their related causes and effects. It is a method that predicts breakdowns, defects, and deficiencies probable in the design of a product or in its production process; hence, it prevents such problems and reduces related costs. First, it was officially introduced in the US in the late 1940s for military purposes, then Ford Co. introduced it in the automobile industry in the late 1970s and today it is widely used in various industries. The steps of this technique are shown in (AIAG, 2008).

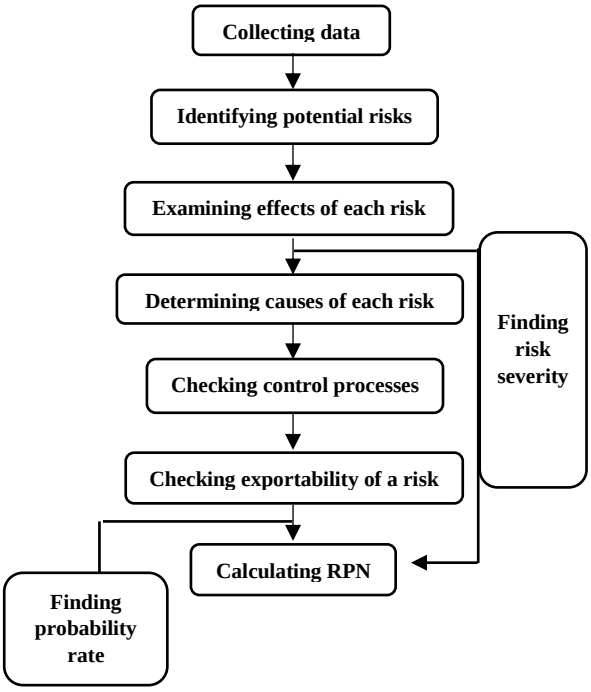

Figure 1. Hierarchy in FMEA method (AIAG, 2008)

RPN (risk priority number) is a product of S (severity), O (occurrence probability) and D (detection probability).

$$RPN = S \times O \times D \quad (1)$$

Now, risks are ranked based on their priority numbers limited by the FMEA system (AIAG, 2008). Severity, occurrence probability and detection probability of risks are determined as follows:

3.1. Risk Severity

Risk severity means its "effect" and its quantitative indices are scaled from 1 to 10 (Table 1).

[1] Failure mode Effect Analysis

Table 1. Risk severity

Rank	Severity
10	No alarming
9	Alarming
8	Very high
7	High
6	Average
5	Low
4	Very low
3	Low
2	Almost none
1	None

3.2. Occurrence Probability

Occurrence probability determines the frequency of the cause/mechanism of a potential risk and Table 2 helps specify this probability on a 1-10 scale. Reviewing past records/documents, control processes, standards, work rules/requirements and how they are used can help reach this number (AIAG, 2008).

Table 2. Risk occurrence probability

Rank	Occurrence probability
10 9	Quite high – almost unavoidable
8 7	High - repetitive risks
6 5 4	Average
3 2	Low
1	Improbable - unlikely

3.3. Detection Probability

Risk detection probability rate (Table 3) helps detect risks before they occur and examining the standards control, processes requirements / rules and how they are applied can highly help reach this number (AIAG, 2008).

Table 3. Risk detection probability

Rank	Detectability
10	Absolutely none
9	Very low
8	Low
7	Very low
6	Low
5	Average
4	Relatively high
3	High
2	very high
1	Almost certain

This research has addressed the risk identification and qualitative analysis based on related frameworks, and used the fuzzy FMEA method and designed/prepared questionnaires for prioritization purposes.

4. Data and Analysis

It is worth noting that since the risks identified in road projects should relate and adapt to the project site, and each country faces its own risks, this study has collected them by reviewing the related literature and experts' opinions in Iran and summarized them in 4 categories: 1) employer, 2) consultant, 3) contractor and 4) other (Table 4).

Table 4. All risks identified in road projects

No	Category	Title
1	**Employer**	Relations govern instead of rules (in the tendering system)
2		Ambiguity in agreements and contracts
3		Improper contractor selection (due to their proposed prices)
4		Insufficient budget for initial studies
5		Ignoring complementary studies (in the study and planning phase)
6		Employer's technical weakness in controlling/reviewing consultant studies
7		Lack of quality control units fitting to the volume of the project execution operations
8		Not providing funds required by the project
9		Not providing sufficient funds at the right time, which elongates execution time
10		Not determining proper duration for project execution based on scientific studies
11		Delayed land delivery
12		Not resolving opponents on time

No	Category	Title
13		Not delivering land to the contractor on time
14		Delay in issuing remittance of materials that need the employer's sales approval
15		Employer's not fulfilling his obligations on time (e.g., delay in issuing bitumen remittance
16		Delay in providing materials/items guaranteed by the employer
17		Employer's changing managers during project implementation
18		Delay in paying contractor's statements and financial documents
19		Not paying consultant's claims on time
20		Technical weakness of employer agent in consultant-contractor coordination and failing to solve technical/operational problems on time
21		Not controlling the contractor schedule
22		Hastened project opening due to political/social reasons (with negative results)
23		Weak technical knowledge of employer's related personnel/managers and delayed procurement of materials/items guaranteed by the employer
24		Employer experts' lack of enough knowledge about project planning/controlling
25		Changes in the orders and in the scope of the contractor's contract services
26		Prioritizing financial over technical issues
27		Lack of coordination with relevant organizations/organs and delay in getting permits
28	**Consultant**	Consultant weakness in economic justification of plans
29		Incomplete project surveying, inaccurate site surveys and insufficient/incorrect geotechnical tests
30		Not preparing a list of major items (materials and their quantities, equipment, machines, tools, etc.) used in different parts of the project
31		Designers' improper map design due to lacking executive/workshop vision
32		Consulting engineer's not being familiar with the project conditions
33		Consulting engineer's weak designs/executive maps
34		Defective documents/maps
35		Mistakes/ambiguities in executive maps
36		Improper supervision on work execution
37		Delayed inspection/supervision on work execution
38		Weakness in identifying project opponents
39		Weakness in on-time schedule controlling
40		Undesirable, inflexible project scheduling
41		Ignoring day-to-day controlling of the project operations
42		Consulting engineer's unnecessary strictness during the project execution
43		Not observing road construction design standards
44		Not delivering on-time reports to the employer
45		Consulting engineer's lack of experienced, knowledgeable design/supervision personnel
46		Delayed timely decision-making in sensitive, necessary cases
47		Delay in communicating agreements, introduction letters, approvals, warnings and agendas to the contractor
48		Head supervisor's weak technical/managerial ability in coordinating the residing and higher supervisors to solve the project's technical/operational problems
49		Consulting engineer's delay in checking the contractor statements or other related documents
50		Delay in preparing and communicating maps needed by the contractor during the work execution

No	Category	Title
51		Delay in checking tests and announcing results to the contractor
52		Incorrect estimation of time, costs and resources in accordance with the WBS
53		Changes in maps/specifications 25% more than those specified in the general conditions of the contract due to the employer's incorrect project studies and estimations
54		Lacking decision-making power
55		Ignoring proper precision in price offering
56		Contractors' offering unconventional, low prices aiming at winning the tender
57		Contractors' lacking suitable, sufficient financial resources/power
58		Lack of expert, experienced personnel
59		Manpower supply risk
60		Employer's untimely land delivery
61		Contractor's untimely workshop equipping
62		Delayed procurement of necessary material/equipment
63		Inadequate workshop facilities
64		Untimely schedule submission
65		Contractor's improper, unrealistic planning/scheduling
66		Not considering proper methods and suitable machines to execute the work
67		Insufficient required equipment/machinery
68		Project machinery defects/breakdown
69		Delayed personnel-salary payments
70		Reworking due to improper planning/work methods
71		Contractor's untimely statement delivery
72		Ignoring safety and environmental issues, and points and procedures in the site leading to life and financial losses
73	**Contractor**	Excavation/demolition during road construction operations
74		Inaccessibility of construction materials the contractor needs to execute the work
75		Not performing work based on the schedule
76		Contractor's weak executive management, site planning and site administration
77		Contractor's late notifying the consultant and employer to solve the problem
78		Contractor's failure to make timely, quick decisions, especially in execution stages
79		Contractors' unwillingness to cooperate with consultants
80		Disagreements and lack of coordination among the consultant, employer, subcontractors and suppliers
81		Increased labor/machinery costs due to project delays
82		Long time-intervals between preliminary and detailed engineering until the execution time, which cause changes to occur in primary resources
83		Execution delays due to assigning work to subcontractors
84		Problems caused by assigning work to inappropriate subcontractors
85		Main contractor's erroneous contract estimates with subcontractors
86		Improper equipment maintenance until installation/launching
87		Problems due to the preservation and maintenance of the implemented routes; their repair and re-implementation
88		Not finishing different parts simultaneously for launching
89		Contractor's not checking the site before starting the work
90		Cultural situation of the region
91	Other	Economic inflation and increased price of necessary materials
92		Scarcity of some materials/equipment in the market

No	Category	Title
93		Varied customs duties
94		Tax risks
95		Currency price fluctuations and its non-convertibility
96		International sanctions
97		Geotechnical problems (landslides, underground waters, etc.)
98		Bad weather conditions
99		Geographical location of the region
100		Unfavorable regional weather conditions
101		Seasonality of some executive activities
102		Environmental restrictions/permits
103		Natural disasters (floods, earthquakes, fires, etc.)
104		Too many public holidays in the country calendar
105		Untimely communicating of required directives based on society conditions
106		Ambiguity of rules/regulations that cause the employer and contractor to have different interpretations
107		Weak contractor recognition/project allocation rules/regulations that cause his technical-executive mismatch with the project-contract price and, hence, lengthening of the contract period and increased contract price

4.1. Questionnaire Design

Since prioritizing the risks identified in road projects required a questionnaire to ask the experts' opinions, its initial form was prepared by the Delphi method in the FMEA framework. And since the most important ones overlapped, time and cost risks were categorized with the help of road project managers, 23 risks were identified, which were, finally, placed under 16 groups. In the final questionnaire, some risks were omitted due to their low importance in the project schedule; for instance, in road schedules, as time and cost are not considered in relation to opponents, the related risk was removed from the final questionnaire. A number of risks were also placed in the same category due to similarity, and other risks remained as they were. Table 5 lists the finalized risks identified. It has to be noticed that the purpose of this research is to identify all the risks of road projects in Iran. With the help of their identification, this questionnaire is prepared in order to prioritize them, so that as a result of this article, the risks will be applied to the schedule of real road projects and the effect of these risks will be determined. Risks such as land acquisition, considering that they are outside the schedule of road projects, have not been used in the design of the questionnaire.

Table 5. Cost and time risks finalized in road projects to prepare the questionnaire

No	Combined risks (finalized for the questionnaire)
1	Not providing funds on time required by the project
2	Employer’s delay in workshop delivery for equipment installation
3	Maps and specification changes of more than 25% with respect to the values specified in the general conditions of contract due to the employer’s incorrect studies/estimation of the project
4	Lack of coordination with relevant organizations/organs and delay in getting permits
5	Consulting engineer’s delay in checking the contractor statements or other related documents
6	Consulting engineer’s lack of experienced, knowledgeable design/supervision personnel
7	Materials destruction due to improper maintenance
8	Delayed procurement of necessary material/equipment
9	Project machinery deficit/defect/breakdown
10	Contractor’s weak executive management, site planning and site administration

No	Combined risks (finalized for the questionnaire)
11	Long time-intervals between preliminary and detailed engineering until the execution time, which cause changes to occur in primary resources
12	Ignoring safety and environmental issues, and points and procedures in the site leading to life and financial losses
13	Currency price fluctuations and its non-convertibility
14	Economic inflation and increased price of necessary materials
15	Importance of some seasons for different executive activities
16	Geographical location of the region and geotechnical problems (landslides, underground waters, etc.)

To analyze cost and time risks qualitatively, a questionnaire was designed using the fuzzy FMEA prioritization approach, and experts were asked about: 1) risk severity effect, 2) risk occurrence probability and 3) risk detectability. This questionnaire contained 16 road construction risks, 6 of which had both time and cost effects on the projects; hence, they were asked separately because their severity had different effects from time/cost point of view. The questionnaire of this research, sent to the related managers via email in the form of an Excel file, was completed by asking 20 experts familiar with related projects.

In table 6 that lists the Cronbach's alpha test results, the alpha rate for time/cost risk-related questions is 88% (> 70%), which means the questionnaire has good reliability.

Table 6. Cronbach's alpha of the FMEA questionnaire

Case Processing Summary			
		N	%
Cases	Valid	20	100.0
	Excluded[a]	0	0
	Total	20	100.0
Reliability Statistics			
Cronbach's Alpha (Fuzzy FMEA)		N of Items	
.882		22	

5. Results and Discussion

MATLAB Software was used as an analysis tool to prioritize the risks in the fuzzy FMEA questionnaire. Risk severity, occurrence probability and detectability were inputs and prioritization were the output - both in the form of fuzzy numbers; the former varied in the 0 – 10 range and the latter in the 0 – 100 range (very low, low, medium, high and very high).

It is worth mentioning that "detectability" questions the risk non-detectability; in fact, the higher is the number of this parameter, the lower is the risk detectability. To infer information, use was made of Mamdani inference system that uses the center of gravity for defuzzification. Figure 2 shows the FMEA fuzzy model in the MATLAB Software environment.

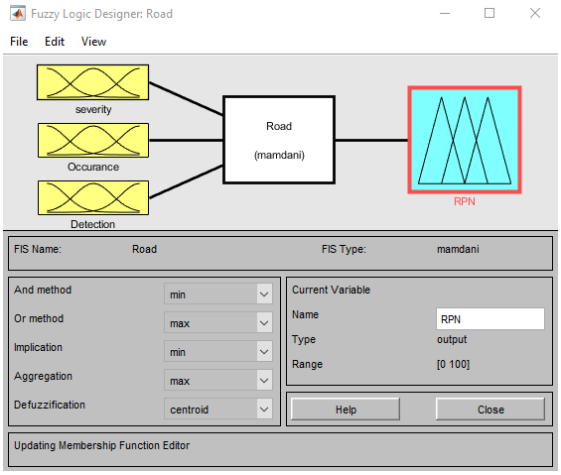

Figure 2. Define Fuzzy FMEA in MATLAB

To infer the risk priority fuzzy number, use was made of the “if, then” rules, and to calculate it, all the cases - 125 rules - were defined in MATLAB.

Rules defined for input variables (effect severity, occurrence probability and detectability of risk) and also for the output variable (risk priority number and membership functions) can help obtain the answer corresponding to the defuzzied risk priority number for each input variable.

After creating the defuzzification steps in MATLAB, the RPN was obtained and fuzzy prioritization was done based on the experts' opinions regarding the effect severity, occurrence probability and detectability of risks. Table 7 shows the FMEA prioritization of the most critical risks of road projects according to RPN. Since the experts were at the same level of expertise, the prioritization of the indicators in Table 7 is based on the average response of the experts.

Table 7. Fuzzy prioritization of critical time/cost risks of road projects

No	Risk	Type	RPN
1	Economic inflation and increased price of necessary materials	Cost	90
2	Not providing funds required by the project on time	Time	90
3	Not providing funds required by the project on time	Cost	70
4	Project machinery deficit/defect/breakdown	Time	70
5	Maps and specification changes of more than 25% with respect to the values specified in the general conditions of contract due to the employer's incorrect studies/estimation of the project	Time	70
6	Maps and specification changes of more than 25% with respect to the values specified in the general conditions of contract due to the employer's incorrect studies/estimation of the project	Cost	70

As shown, 3-time risks and 3-cost risks are the very serious ones; among all those in the questionnaire, 6 risks have both time and cost effects on the project - these were asked separately due to their probable different severity effects on time and cost. The most serious risk identified in road projects is the "economic inflation and increased price of required materials", which is a cost risk. "Not providing funds required by the project on time" is the second most serious in terms of time; it is the third most serious risk in terms of cost meaning that is a very serious risks in terms of both time and cost. "Project machinery deficit/defect/breakdown" and " Maps and specification changes of more than 25% with respect to the values specified in the general conditions of contract due to the employer's incorrect studies/estimation of the project " are, respectively, the next most serious time/cost risks. It should be noted that in order to validate the output of fuzzy FMEA analysis, traditional FMEA analysis was also performed in a separate study. The results were obtained almost the same with the present study (Rezaee Arjoody et al., 2022).

In this paper, all the risks of road projects in Iran were investigated through literature review. The output of the results of this article, which are based on the risks that are effective in the schedule of road projects, can help the managers of road projects to be aware of the amount of delay and possible cost increase before the project starts, by applying them to the project schedule and in this regard, they can remove these risks or provide an appropriate response aware of the amount of delay and possible cost increase before the project starts, by applying them to the project schedule.

6. Conclusions

Road projects are multi-activity infrastructural projects that always face different risks during their execution and, hence, require much time and cost; however, identifying these risks can prevent this problem. This study has done so and found that "not providing funds required by the project on time" is the most serious time risk and "Economic inflation and increased price of necessary materials", "Project machinery deficit/defect/breakdown" and "Maps and specification changes of more than 25% with respect to the values specified in the general conditions of contract due to the employer's incorrect studies/estimation of the project" are, respectively, the most serious time/cost risks. It is suggested, for future studies, that reactive

measures be considered to reduce risks effects. As this research has prioritized risks and determined the prioritization number of the most serious ones based on their severity, occurrence probability and detectability, its results can be used for quantitative analysis so that a more accurate estimate of time and cost can be provided for the project manager, and especially for the employer, before the project starts.

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