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Research Paper

Analyzing the Effects of Critical Risk Occurrence Probability on Time and Cost of Road Construction Projects Using a Schedule Plan

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Abstract

Many projects fail to achieve their expected benefit, cost, scope, and time objectives because their related risks and uncertainties reduce the accuracy in properly estimating the objectives and, thus, reduce the project efficiency. Since risks are accompanied with uncertainties and lack of reliability, many of them are irremovable in construction projects and their proper management is the only way to prevent damage. Hence, before a project starts, it is quite necessary that its risks should be identified, quantified, and evaluated to prevent them to occur using proper strategies and prioritization methods. As road construction projects involve numerous activities, and unexpected factors affect their final time and cost, the present study has identified their related risks by reviewing the literature and asking the experts' opinions, prioritized them by the traditional Failure Mode and Effect Analysis (FMEA), selected the critical ones, and used the Monte Carlo simulation technique to quantitatively analyze their effects on the project time/cost scheduling. Also, sensitivity analysis was done by varying the percent occurrence probability of risks to evaluate determine the relationship between the percentage of probability of occurrence of risks and time and cost of road projects. Finally, responses to identified risk provided in order to reduce their effects on the time and cost of road construction projects.

Keywords: Risk analysis, Road Project, Quantitative, Qualitative, Response

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1. Introduction

The need for accurate estimation of the project time/cost and the required resources that directly affect the proper implementation/exploitation of infrastructure projects are quite obvious today. As a dynamic and efficient transportation network is an important index of a country's development, the effective role of proper related infrastructures is also noteworthy in strengthening the passive defense and management of various crises. Currently, a significant budget is allocated to infrastructure road construction projects that are seldom finished with the estimated cost and time; studies show that many projects faced remarkable delays and increased major costs [Habibi and Kermanshachi and Safapour, 2018].

Risk management is a comprehensive process used to minimize the effects and consequences of potential events. It is meant to reduce the operational risks of certain activities/processes to an acceptable level and gain the senior management approval because all infrastructure projects face risks during their operation that cannot be eliminated, but can be managed [Creemers and Demeulemeester and Van de Vonder, 2018].

To this end, the present study has tried to identify the risks related to road construction projects and analyze their effects on the time/cost scheduling both quantitatively and qualitatively.

2. Literature Review

Islam and Nepal (2017) reviewed on risk analysis methods and showed that the fuzzy analytical network process was often used for various complex projects. They revealed that since FANP involved tedious and lengthy calculations for binary comparisons and could not apply new information in the risk structure, a fuzzy Bayesian-based network (FBBN) risk-assessment method was increasingly used to overcome this limitation. They then recommended specific FBBN-based project studies to better justify the FBBN's wider applications. Islam and Nepal (2017) showed that besides the FBBN, Credal, which was a developed form of it, could assess risks under potential uncertainties [Islam and Nepal, 2017]. One study has shown that risk analysis techniques used most in developing countries include the Risk Matrix [Mahamid, 2013], Monte Carlo simulation [Choudhry et al., 2014], AHP [Zayed and Amer and Pan, 2008], Fuzzy Logic Analysis [Bahamid and Doh, 2017], Failure Modes and Effects Analysis (FMEA) [Ahmadi et al., 1995] and Financial Value Analysis and Expert Judgment [El-Sayegh, 2014].

In a case study meant to identify the contracting parties' responsibilities to improve their risk management strategies related to Sri Lankan road construction projects, Perera (2009) used semi-structured interviews to collect baseline data, and stated that since risk was an unavoidable phenomenon, its identification and consideration in related contracts was a good solution because its proper management had obvious effects on resource allocation decisions achieved only if the parties understood the risk responsibilities, circumstances and management capabilities. They showed that road construction projects in Sri Lanka were exposed to many risks and the most serious was when the employer did not supply the contractor with enough budgets [Perera,2009].

Using opinions of interviewed experts, applying hierarchical analytical processes, ranking risks with the Expert Choice software and APH technique, and utilizing Ishikawa's cause-and-effect diagrams, Borje Ghaleh et al. (2009) identified, evaluated and prioritized the implementation-phase delays of Garmsar-Simin Dasht road construction project and showed that financial, management, land ownership and technical problems along with natural disasters have had the highest risks among all the main criteria [Borje Ghaleh et al., 2009].

In a comprehensive study, Diab (2017) analyzed various risk factors affecting highway construction projects in the US, identified 31 significant ones in previous studies, categorized them into 5 groups (project site, road vicinity, inconsistencies, architecture and engineering), and evaluated them for the effects and correlation of each by asking the experts' opinions in questionnaires [Diab, 2017].

In a high-traffic-volume road-construction-project risk-analysis study, Okate and Kakade (2019) grouped risks under employer, consultant and contractor categories, prioritized them using questionnaires and the relative importance index (RII), identified more important ones, and showed that payment delays, employer bankruptcy, vague project site definition, project manager's weak-quality management and contractor's poor site management/monitoring were 5 main factors in road construction projects [Okate and Kakade, 2019].

Sarkar and Sing (2020) used experts' opinions and FEVM and FMEA techniques to identify, analyze and prioritize risks in railway projects [Sarkar and Sing, 2020]. Alvand et al. (2021) too used the FMEA, SWARA and WASPAS methods in a fuzzy framework to analyze and prioritize road construction projects [Alvand et al., 2020].

Alvand et al. (2020, 2021) analyzed infrastructure/hyper projects quantitatively and showed that the Monte Carlo simulation and sensitivity analyses were effective techniques that helped managers analyze projects' cost/time deviations [Alvand et al.,2020] [Alvand et al., 2021].

3. Research Methodology

PMBOK, an authoritative reference in the field of management, presents very efficient standards. It is worth noting that the FMEA technique can replace the PMBOK-defined process in such analyses, and although it is meant to identify potential errors in a process/product, it can be developed to identify and rank risks likely to occur in a project. As its advantage over the standard PMBOK process is that it takes much less time to do qualitative analysis and is more accurate in identifying critical risks, its use can highly increase the analyses effectiveness [Van Leeuwen et al., 2009].

The present study is aimed to determine the effects of risks on the time and cost of road construction projects; risks are prioritized by the FMEA method, analyzed quantitatively by the Monte Carlo method and analyzed for sensitivity by the linear regression model and the SPSS software.

FMEA is an analytical assessment method that identifies and ranks risks [Van Leeuwen et al., 2009]. Parameters needed to obtain the risk priority number are the effect severity, occurrence probability and identifiability. Severity is considered only in terms of "effect" and is reducible only by varying the work process and how activities are performed. Occurrence probability determines how often a potential risk mechanism/cause will occur; number of occurrences can reduce only by eliminating/reducing the causes/mechanism of each risk. The ability to discover the identifiability of the cause/mechanism of a risk means the probability of discovering the ability to perceive risk before it occurs [AIAG, 2008].

Quantitative risk analyses are usually performed by the Monte Carlo method which involves a set of computational algorithms that yield results through repeated random sampling. Monte Carlo simulation is useful especially [Islam and Nepal, 2017].

Risk-response management techniques are: 1) risk retention, which is accepting its presence and taking conscious steps to accept its level without any special effort to control it, 2) risk reduction, which is reducing its occurrence probability and effects below an acceptable threshold, 3) risk sharing, which is achieved mainly through a contractual mechanism to create a sense of collective responsibility among the project stakeholders, 4) risk control, which does not seek to totally stop the source, but seeks to reduce the existing risk, 5) risk avoidance, which is refusing to accept the risk or measures taken to ensure that the risk will not continue and 6) risk transfer, which is change and transfer of ownership from one party to a third person without changing the total risk or reducing the importance of the risk sources [PMI, 2017] [Smith and Merna and Jobling, 2009] [Goh and Abdul-Rahman, 2013]. In response to risks, effort has been made in this research to reduce their effects as much as possible.

This study has used a linear regression model and the SPSS to perform sensitivity analyses and has then defined the resulting model to determine the risk-time-cost relationship of road construction projects. As variable selection is done differently in developing regression models, the present study has used a simultaneous modeling method where variables enter simultaneously and, then, their effects are considered in the desired equation.

4. Data and Analyses

This research has used a road construction project schedule to analyze the related critical risks. The specifications of the mentioned project are listed in Table 1. It is worth mentioning that the prices are based on Iranian Rials

Table 1. Technical specifications of the road construction project used in this research

Road length	20.5 km
Type of road	Main
No. of lanes	2
Project start time	June 28, 2014
Project-completion time in the schedule	June 26, 2016
No. of activity days in the schedule	729 days
Real project-completion time	April 18, 2017
No. of actual project-completion days	1020 days
Project cost in the schedule	272510942834 rials
Actual cost at the project-completion time	38 0000000000 rials

To investigate the effects of critical cost and time risks in a case study through their quantitative analyses, use has been made of a road construction project the data of which are listed in a schedule file.

4.1. Qualitative Analysis

Risks identified in the PMBOK framework are collected within the scope of road construction projects and the cost and time risks are identified and extracted according to Table 2 and Table 3. As some of them have both time and cost effects, they are titled in both lists, and since some are unimportant in the schedule framework, they are eliminated in the final questionnaire. For instance, as opponent-related time and cost are not considered in road construction project schedules, its risk was omitted in the final questionnaire; some risks were grouped in one category due to similarity, and others remained the same. Among the identified risks, 13 are cost-related and 9 are time-related. Using the final risks and the FMEA method, a questionnaire was set for qualitative risk analyses. Identified risks are shown in Tables 2 and 3.

Table 2. Identified time risks related to road construction projects

No	Agent	Risk
1	Consultan t	Untimely checking of contractor statements and documents
2	Consultan t	Lack of experienced, knowledgeable design/supervision personnel
3	Contractor	Deficit, breakdown or defect of required equipment/machinery
4	Contractor	Weak executive management and site planning/supervision
5	Contractor	Long preliminary-detailed engineering time-interval until execution causing changes in primary resources
6	Contractor	Ignoring safety/environmental issues,

No	Agent	Risk
		tips and instructions in the site causing human/financial losses
7	Contractor	Delays in providing necessary materials/equipment
8	Employer	Untimely project funding
9	Employer	Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations
10	Employer	Delays in site delivery for the contractor to install equipment/machinery
11	Employer	Non- coordination with relevant organizations/organs causing delays in obtaining licenses
12	Other	Geography of site location creating geotechnical problems (e.g., landslides, groundwater seepage, etc.)
13	Other	Seasonality of some executive activities

Table 3. Identified cost risks related to road construction projects

No	Agent	Risk
1	Consultant	Lack of experienced, knowledgeable design/supervision personnel
2	Contractor	Material decay due to improper maintenance
3	Contractor	Ignoring safety/environmental issues, tips and instructions in the site causing human/financial losses
4	Contractor	Long preliminary-detailed engineering time-interval until execution causing changes in primary resources
5	Employer	Untimely project funding
6	Employer	Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations
7	Other	Increased material price due to economic inflation
8	Other	Currency fluctuations and exchange problems
9	Other	Geography of site location creating geotechnical problems (e.g., landslides, groundwater seepage, etc.)

In the FMEA risk analysis and prioritization, the severity, occurrence probability and identifiability variables asked in the questionnaire for identified risks ranged from 0 to 10. The risk score was the product of the severity and occurrence probability and then the RPN (risk priority number), which is the product of the risk score and its identifiability (unidentifiability), was calculated for prioritization purposes. Table 4 shows the results of the qualitative analyses and prioritization of risks. It is worth noting that since some risks had different-rate high-severity concurrency and cost-similarity natures, they were questioned separately in the time and cost questionnaires. Next, time/cost questionnaires were compiled with 13 and 9 questions, respectively and road construction project experts were asked to reply them; results are shown in Tables 4 and 5.

Table 4. FMEA time-risk analyses results of the road construction project

No	Risk	Severity	Occurrence probability	Risk No	Identifiability	RPN
1	Untimely project funding	9	8	72	6	432
2	Deficit, breakdown or defect of required equipment/machinery	8	8	64	5	320

No	Risk	Severity	Occurrence probability	Risk No	Identifiability	RPN
3	Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations	9	6	54	5	270
4	Untimely checking of contractor statements and documents	5	5	25	5	125
5	Delays in site delivery for the contractor to install equipment/machinery	9	3	27	3	81
6	Lack of experienced, knowledgeable design/supervision personnel	6	4	24	4	96
7	Weak executive management and site planning/supervision	8	2	16	4	64
8	Geography of site location creating geotechnical problems (e.g., landslides, groundwater seepage, etc.)	8	4	32	2	64
9	Long preliminary-detailed engineering time-interval until execution causing changes in primary resources	4	2	8	4	32
10	Non- coordination with relevant organizations/organs causing delays in obtaining licenses	6	2	12	2	24
11	Ignoring safety/environmental issues, tips and instructions in the site causing human/financial losses	5	2	10	2	20
12	Delays in providing necessary materials/equipment	2	3	6	3	18
13	Seasonality of some executive activities	3	2	6	2	12

Table 5. FMEA cost-risk analyses results of the road construction project

No	Risk	Severity	Occurrence probability	Risk No	Identifiability	RPN
1	Increased material price due to economic inflation	9	9	81	6	486
2	Untimely project funding	8	8	64	6	384
3	Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations	9	6	54	5	270
4	Currency fluctuations and exchange problems	5	5	25	5	125
5	Lack of experienced, knowledgeable design/supervision personnel	6	4	24	4	96
6	Geography of site location creating geotechnical problems (e.g.,	8	4	32	2	64

No	Risk	Severity	Occurrence probability	Risk No	Identifiability	RPN
	landslides, groundwater seepage, etc.)					
7	Material decay due to improper maintenance	6	4	24	2	48
8	Ignoring safety/environmental issues, tips and instructions in the site causing human/financial losses	7	2	14	2	28
9	Long preliminary-detailed engineering time-interval until execution causing changes in primary resources	2	2	4	3	12

As shown, higher-effect risks were 3 in the time field and 3 in the cost field which were placed under 4 titles and questioned separately due to their different severities. The highest-severity cost-risk was the "Increased material price due to economic inflation" with a severity of 9, occurrence probability of 9, identifiability of 6 and RPN of 486. "Untimely project funding" was the second highest (as regards time) with a severity of 9, occurrence probability of 8, identifiability of 6 and RPN of 384. Among the most important risks, this one stand third which, as regards cost, it has a severity of 8, occurrence probability of 9, identifiability of 6 and RPN of 384 concluding that it is a very important risk in terms of both time and cost, but more important in terms of time. The time-risk "Deficit, breakdown or defect of required equipment/machinery" stands next with a severity of 8, occurrence probability of 8, identifiability of 5 and RPN of 320. The risk entitled "Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations" stands next (in terms of both time and cost) with a severity of 9, occurrence probability of 6, identifiability of 5 and RPN of 270. Tables show the ranks and importance of other risks and Figure 1 shows the qualitative risk assessment matrix of the road construction project.

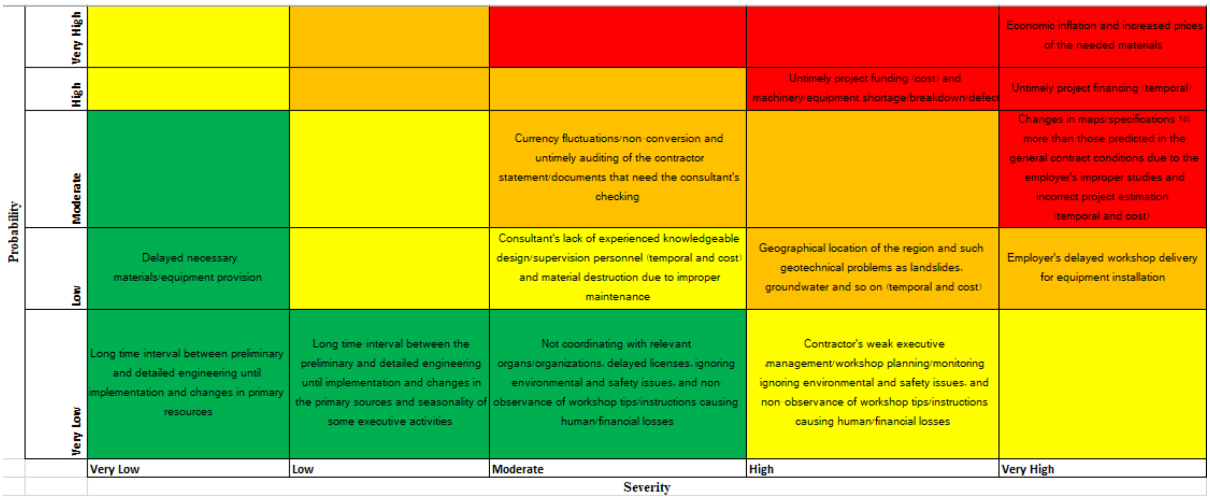

Figure 1. Qualitative risk assessment matrix of the road construction project

4.2. Quantitative Analysis

As quantitative risk analyses first require critical risks to be identified, a risk-RPN chart was drawn and those above the permissible range were identified. In Fig. 2, 5 critical risks are shown with red dots which are actually 6, two risks placed on top of one another because of equal RPNs.

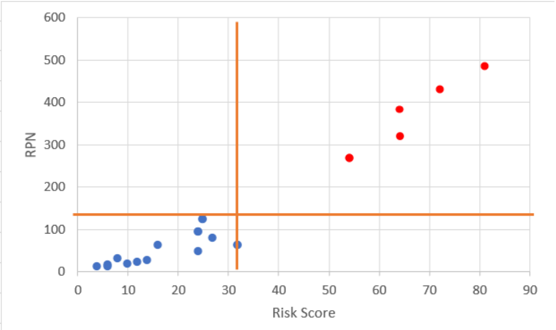

Figure 2. Identification of critical risk

After critical risks were identified, those of time and cost were extracted (Table 6) and coded for quantitative analyses

Table 6. Critical risks of the road construction project

No	Risk	Type	Severity	Occurrence probability	Code
1	Increased material price due to economic inflation	Cost	9	9	RC1
2	Untimely project funding	Time	9	8	RC2
3	Untimely project funding	Cost	8	8	RC3
4	Deficit, breakdown or defect of required equipment/machinery	Time	8	8	RS1
5	Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations	Time	9	6	RS2
6	Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations	Cost	9	6	RS3

To study the effects of critical time/cost risks, a road project schedule including site equipment, demolition, excavation/filling operations, construction of technical structures (i.e., foundation, scaffolding, in-situ/advanced concreting, reinforcement, masonry works, insulation, sub-base/base layer, etc.), implementation of asphalt layers (i.e., the first and second binder layers and Topeka), light steel works and installing transportation safety signs/equipment. It is worth noting that since the project site delivery is a no-time-cost issue in the schedule, it has been omitted in the questionnaire. Figure 3 shows the general project schedule in the Primavera software environment.

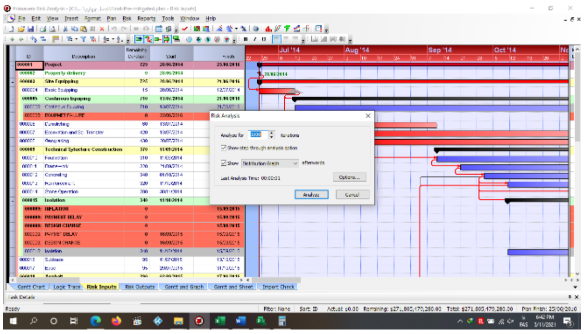

Figure 3. Road project schedule and simulation in the Primavera software environment

To study the effects of critical risks on the project and obtain the costs of each project activity, besides its time frame, the detailed cost/time schedule of the project activities was implemented in the Primavera software by introducing RC1, RC2, RC3 and RS1, RS2, RS3 Codes for cost and time risks, respectively, and then the details of the severity and occurrence probability of each were defined in the program.

The BetaPert distribution was used to apply the probable cost/time values to effective project scheduling activities. These values were defined in the software under “pessimistic”, “optimistic” and “most likely” titles and the project time/cost values were obtained after applying the risks under 1000 times simulations.

The total estimated project cost in the schedule (with no critical risks) was 271,805,479,280 rials turning out to be 358,512,566,522 rials - 32% increase - considering critical risks with 80% occurrence probability. Based on the same cost in the schedule (without any risks), the minimum calculated project completion cost is 271,805,479,280 rials concluding that the probability that project will finish with the intended amount is less than 4%. As the project is completed with 380,000,000,000 rials (an increase of about 38% compared to that in the schedule), it is quite close to that estimated with critical risks, and the simulation-estimated value is about 6% less than the final project value due, maybe, to low-impact risks and other factors; simulation and cost results are shown in Figure 4.

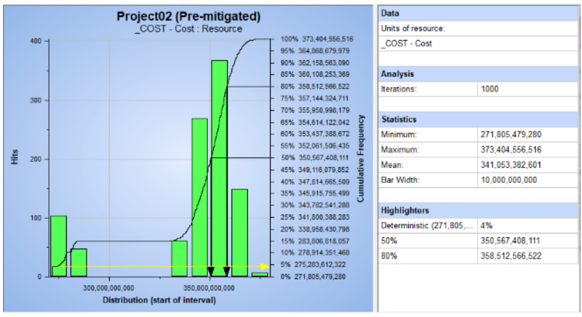

Figure 4. Min and max probable project costs considering critical risks and completion costs

According to temporal studies, the scheduled without-risk project completion time is 729 days while that of the with-risk simulation with 80% probability is 976 days showing an increase of 247 days (about 34% over the scheduled time). In Figure 5 that shows the time-effect results of the with-risk project simulation, the with-risk MCS simulation-estimated project completion time is about 5% less than the actual scheduled 1020 days.

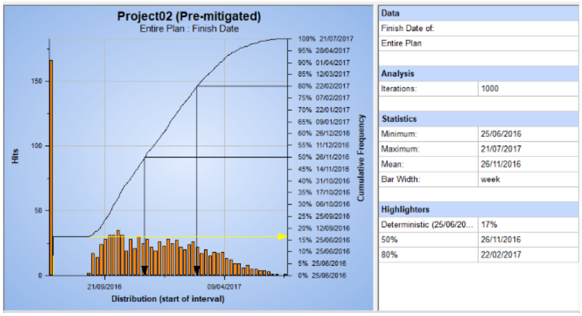

Figure 5. Probable, with-critical risk total project completion time

4.3. Sensitivity Analysis

After examining critical risk effects on the completion time/cost of road construction projects, varied occurrence probabilities were used in sensitivity analyses to check their effects. Simulations, in different risk-occurrence-probability modes, were done by the Primavera software and the project completion time and cost were extracted with 80% reliability; simulation results are listed in Table 7.

Table 7. Time/cost simulation of the road construction project with varied critical-risk occurrence probabilities

Nu.	Time Risks			Cost Risks			Road Project schedule (728 days, 271,805,479,280.00 Rial)			
	P(RC1) %	P(RC2) %	P(RC3) %	P(RS1) %	P(RS2) %	P(RS3) %	Sim Cost (Rial)	Cost Diff %	Sim. Time (Days)	Time Diff %
1	85	60	40	85	60	40	$358,597,070,299	31.93	914	25.55
2	85	40	40	85	40	40	$357,241,017,753	31.43	914	25.55
3	85	20	40	85	20	40	$355,454,128,536	30.78	914	25.55
4	85	0	40	85	0	40	$354,013,791,682	30.25	914	25.55
5	85	85	40	85	85	40	$359,947,461,514	32.43	914	25.55
6	85	60	20	85	60	20	$357,900,802,513	31.68	866	18.96
7	85	40	20	85	40	20	$356,316,535,972	31.09	866	18.96
8	85	20	20	85	20	20	$354,844,115,470	30.55	866	18.96
9	85	0	20	85	0	20	$353,221,240,833	29.95	866	18.96
10	85	85	0	85	85	0	$358,182,582,811	31.78	841	15.52
11	85	60	0	85	60	0	$356,994,435,644	31.34	842	15.66
12	85	40	0	85	40	0	$355,365,293,752	30.74	842	15.66
13	85	20	0	85	20	0	$354,206,776,862	30.32	841	15.52
14	85	85	60	85	85	60	$360,720,350,657	32.71	966	32.69
15	85	60	60	85	60	60	$359,400,504,386	32.23	966	32.69
16	85	40	60	85	40	60	$357,970,383,040	31.70	966	32.69
17	85	20	60	85	20	60	$356,683,065,178	31.23	966	32.69
18	85	0	60	85	0	60	$354,797,760,193	30.53	966	32.69
19	85	0	85	85	0	85	$355,793,810,512	30.90	989	35.85
20	85	20	85	85	20	85	$357,582,752,852	31.56	989	35.85
21	85	40	85	85	40	85	$358,771,511,203	32.00	989	35.85
22	85	60	85	85	60	85	$360,240,023,603	32.54	989	35.85
23	85	85	85	85	85	85	$361,453,331,260	32.98	989	35.85
24	60	0	0	60	0	0	$350,450,056,963	28.93	834	14.56

Nu.	Time Risks			Cost Risks			Road Project schedule (728 days, 271,805,479,280.00 Rial)			
	P(RC1) %	P(RC2) %	P(RC3) %	P(RS1) %	P(RS2) %	P(RS3) %	Sim Cost (Rial)	Cost Diff %	Sim. Time (Days)	Time Diff %
25	60	20	0	60	20	0	$351,776,343,722	29.42	834	14.56
26	60	40	0	60	40	0	$353,245,474,187	29.96	834	14.56
27	60	60	0	60	60	0	$354,511,972,711	30.43	834	14.56
28	60	85	0	60	85	0	$356,253,308,196	31.07	825	13.32
29	60	0	20	60	0	20	$351,009,739,822	29.14	865	18.82
30	60	20	20	60	20	20	$352,344,427,412	29.63	864	18.68
31	60	40	20	60	40	20	$354,039,430,080	30.25	864	18.68
32	60	60	20	60	60	20	$355,741,784,487	30.88	864	18.68
33	60	85	20	60	85	20	$357,246,447,160	31.43	865	18.82
34	40	0	40	40	0	40	$348,442,723,741	28.20	940	29.12
35	40	20	40	40	20	40	$349,681,232,283	28.65	940	29.12
36	40	60	40	40	60	40	$352,556,381,571	29.71	940	29.12
37	40	85	40	40	85	40	$353,708,270,958	30.13	914	25.55
38	40	0	0	40	0	0	$346,544,015,164	27.50	823	13.05
39	20	0	0	20	0	0	$271,805,479,280	0.00	728	0.00
40	20	20	20	20	20	20	$283,684,742,808	4.37	859	17.99
41	40	40	40	40	40	40	$350,869,913,046	29.09	940	29.12
42	60	60	60	60	60	60	$357,241,333,707	31.43	945	29.81
43	0	40	0	0	40	0	$278,271,715,172	2.38	728	0.00
44	0	0	40	0	0	40	$275,719,453,763	1.44	914	25.55
45	0	0	85	0	0	85	$276,274,306,534	1.64	989	35.85
46	0	85	85	0	85	85	$362,619,236,756	33.41	993	36.40

To perform sensitivity analyses, occurrence probabilities of critical risks were varied and the 80% ones were used as the simulation criteria; percent occurrence probabilities were considered as independent variables and differences between the simulated and scheduled values were, separately, the dependent variables. According to the results of the sensitivity analyses performed by the IBM SPSS Statistics software and the regression model, there is a meaningful relationship between the occurrence probability of critical risks and the percent difference between simulated and scheduled time and cost. In the cost sensitivity analyses, there is a meaningful relationship between independent variables: 1) Increased material price due to economic inflation, 2) Untimely project funding and 3) Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations and the difference between the simulated and scheduled cost known to be the dependent variable. Results obtained for this model by entering variables and using R^2 = 0.826 are shown in the following Tables.

Table 8. Variable in the cost sensitivity analyses of the road construction project

Model	Variables Entered	Variables Removed	Method
1	RC3, RC2, RC1[b]		Enter
a. Dependent Variable: Cost Diff % 1			
b. All requested variables entered.			

Table 9. Model summary, in the cost sensitivity analyses of the road construction project

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.891[a]	.826	.800	5.799329872285856
a. Predictors: (Constant), RC3, RC2, RC1				

Table 10. Anova Table in the cost sensitivity analyses of the road construction project

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2366.573	3	788.858	23.455	.000[b]
	Residual	1412.554	42	33.632		
	Total	3779.126	45			

Table 11. Coefficients of variables in the cost sensitivity analyses of the road construction project

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig
		B	Std. Error	Beta		
1	(Constant)	9.324	2.438		3.824	.000
	RC1	.230	.032	.688	7.184	.000
	RC2	.085	.029	.281	2.935	.005
	RC3	.017	.030	.056	.587	.005
a. Dependent Variable: Cost Diff % 1						

The relationship between the occurrence probability of cost critical risks and percent simulated- scheduled cost difference in the road construction project is:

$$Cos\,t_{Project1}\,(Diff\%) = 0.23P(RC1\%) + 0.85P(RC2\%) + 0.17P(RC3\%) + 9.324 \quad (1)$$

In the time sensitivity analysis of the road construction project, there is a meaningful relationship between independent variables: 1) Untimely project funding, 2) Deficit, breakdown or defect of required equipment/machinery and 3) Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations and the difference between the simulated and scheduled cost known to be the dependent variable. Results obtained for this model by entering variables and using R2 = 0.884 are shown in the following Tables. As shown, the critical time risks with coefficients of, respectively, +0.043, +0.005 +0.289, constant number of 10.428 and 95% reliability, have a really meaningful relationship with the percent simulated-scheduled time difference.

Table 12. Variable entry in the time sensitivity analyses of the road construction project

Model	Variables Entered	Variables Removed	Method
1	RS3, RS2, RS1[b]	.	Enter
a. Dependent Variable: Time Diff % 1			
b. All requested variables entered.			

Table 13. Model summary in the time sensitivity analyses of the road construction project

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.940[a]	.884	.876	3.238634830520019

Table 14. Anova Table in the time sensitivity analyses of the road construction project

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3372.018	3	1124.006	107.163	.000[b]
	Residual	440.528	42	10.489		
	Total	3812.545	45			

Table 15. Coefficients of variables in the time sensitivity analyses of the road construction project

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	10.428	1.362		7.658	.000
	RS1	.043	.018	.129	2.413	.002
	RS2	.005	.016	.016	.304	.003
	RS3	.289	.017	.919	17.433	.000

The relationship between the occurrence probability of time critical risks and percent simulated- scheduled time difference in the road construction project is:

$$Time_{Project1}(Diff\%) = 0.043P(RS1\%) + 0.005P(RS2\%) + 0.289P(RS3\%) + 10.428 \quad (2)$$

4.4. Risk Response Measures

As risks are generally reduced by mitigation plans, it is necessary to take response measures to fight those identified in road construction projects. Measures proposed, based on the experts' opinions, to reduce effects of risks are listed in Table 16.

Table 16. Road project risks' response measures

No	Risk	PMBOK Fields	Response measure
1	Increased material price due to economic inflation	Cost	• Signing fixed price contracts and timely provision of materials that are more likely to rise in price.
2	Untimely project funding	Time/cost	• Establishing appropriate relationships with the employer and consulting to receive payments before they are due • Timely cost forecasts before they are due
3	Deficit, breakdown or defect of required equipment/machinery	Time	• Periodic machinery services • Predicting required machinery when preparing the schedule

No	Risk	PMBOK Fields	Response measure
4	Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations	Time/cost	• Full contract/project site location review before signing the contract
5	Currency fluctuations and exchange problems	Cost	• Using foreign financiers • Using foreign investors • Signing foreign-currency contracts
6	Untimely checking of contractor statements and documents	Time	• Improving statement review processes • Setting due time for related reviewers and reproaching them if delayed
7	Delays in site delivery for the contractor to install equipment/machinery	Time	• Checking appropriate site location/required equipment before signing the contract
8	Lack of experienced, knowledgeable design/supervision personnel	Time/cost	• Appointing the right interviewer when hiring people and avoiding the use of low-knowledge people in key positions
9	Weak executive management and site planning/supervision	Time	• Using sufficiently experienced knowledgeable people in such positions as the project manager or site supervisor
10	Geography of site location creating geotechnical problems (e.g., landslides, groundwater seepage, etc.)	Time/cost	• Studying the site geotechnical location and estimating the exact cost and time of activities according to the conditions precisely before signing the contract
11	Material decay due to improper maintenance	Time/cost	• Checking the warehouse location and selecting a suitable one in terms of ventilation, light, temperature and area • Using the right person for the warehouse management
12	Delays in providing necessary materials/equipment	Time	• Forecasting required materials properly before starting executive operations • Supplying materials through timely financing
13	Ignoring safety/environmental issues, tips and instructions in the site causing human/financial losses	Time/cost	• Considering a person in charge of HSE • Checking working conditions and safety equipment required for each operation by the person in charge • Banning work if HSE permit is lacking
14	Long preliminary-detailed engineering time-interval until execution causing changes in primary resources	Time	• Considering a sufficient-number engineering team • Registering/checking produced maps and preventing their production/approval delays
15	Non- coordination with relevant organizations/organs causing delays in obtaining licenses	Time	• Checking required permits before starting work • Taking timely measures to obtain required permits
16	Seasonality of some executive activities	Time	• Planning to finish activities at the right time/season • Considering weather conditions/seasons of each activity when preparing the schedule

5. Summary (Conclusions)

All the risks related to the time/cost of road construction projects were identified asked in FMEA questionnaire to investigate their effects on such projects. To study the effects of critical risks on the road project time and cost, use was made of the schedule program of a real main road and those that affected the project activities were introduced with their specific occurrence probabilities. The most serious risk identified in the cost category was the "Increased material price due to economic inflation". Next was the "Untimely project funding" in the time category. The third was this same risk in the cost category. Other risks identified and prioritized as critical in road construction projects were "Deficit, breakdown or defect of required equipment/machinery" in the time category and "Changes in maps/specifications 25% more than those predicted in the contract general conditions due to incorrect estimations" in the time and cost category.

In the road construction project of this research, the total, without-critical risk, scheduled (criterion) cost was 271,805,479,280 rials, which changed to 358,512,566,522 rials - 32% increase - considering critical risks with 80% reliability. As the project is completed with 380,000,000,000 rials (an increase of about 38% compared to that in the schedule), it is quite close to that estimated with critical risks, and the simulation-estimated value is about 6% less than the final project value due, maybe, to low-impact risks and other factors

According to temporal studies, the scheduled without-risk project completion time is 729 days while that of the with-risk simulation with 80% probability is 976 days showing an increase of 247 days (about 34% over the scheduled time). The Result shows the time-effect results of the with-risk project simulation, the with-risk simulation-estimated project completion time is about 5% less than the actual scheduled 1020 days. Next, to perform sensitivity analyses, the simulation time and cost were extracted by changing the occurrence probability of critical risks and those with 80% probability were used as the simulation criteria; percent occurrence probabilities were considered as independent variables and simulated-scheduled time/cost difference were taken separately as dependent variables. The regression model sensitivity analyses results showed that the occurrence probabilities of critical risks and percent simulated-scheduled time/cost difference were meaningfully related. Finally, to respond to the identified risks, road construction experts were interviewed and their opinions were used to propose measures to reduce the effects of the critical risks.

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