Chapter

Risk Analysis Related to Cost and Schedule for a Bridge Construction Project

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Abstract

The construction sector is subject to more risk than many other sectors. Managing risk is the hottest topic of discussion for engineers within the construction sector. It is difficult to imagine managing of projects without risk management in construction. Risk management is concerned with risk management planning, identification, analysis, responses, monitoring and controlling project risk. Risk analysis is an evaluative process that establishes the magnitude of risks on projects. This work is planned to identify and analyze risks in the construction of a bridge project. The data are collected through a survey approach by administering a questionnaire. Professionals involved in the construction of bridges identify the project risks. A case study is utilized to determine the impact of cost and schedule risks. The analysis is carried out using the Monte Carlo simulation. The findings of the Monte Carlo simulation are compared with the actual times and costs of the case-study project. The results show the actual times and costs fell within the expected distribution of the simulation. The results indicate that risk analysis is helpful in managing costs and schedule risks. Additionally, this work documents guidelines for risk analysis.

Keywords: bridge project, cost risk, schedule risk, risk analysis, risk management, Monte Carlo simulation, risk guidelines

1. Introduction

Risk is the chance of something happening that has an impact upon objectives. It is measured in terms of consequences and likelihood. Probability, likelihood, and chance are used synonymously, as also are consequences and impact. Everyone struggles to understand and deal with many risk situations—from a domestic to corporate level, personal to national level, activity to project level. Management of projects can be improved by raising awareness about risks, and then implementing formal processes to deal with them. Construction projects are fundamentally susceptible to risks. Projects can be successful if managers plan for risks—planning, identifying, analyzing, and providing response for undesirable events that can occur. Choudhry and Iqbal [1] reveal that risk management is a new area in the construction sector and is attaining importance in the construction industry. The application of systematic risk management system is necessary for managing project risks [1]. Risk management can be applied successfully by identifying the risk sources connected with activities of the project. These risks are quantified in terms of likelihood and impact. Akintoye and Macleod [2] revealed that risk affects the performance, quality, budget and productivity of projects in construction. The strategy is to decrease the probability and impact of a risk [3]. Dikemen et al. [4] defined risk management as a systematic procedure of controlling risk. Choudhry and Iqbal [1] defined risk management as a stepwise process comprising on identification, analysis and risk response. Other researchers defined risk analysis as the procedure of evaluating identified risk and opportunities for their magnitude to proceed for a matching response in the light of limited funds.

Projects related to construction are complicated because they contain a range of human and non-human factors. These projects are started in complicated and vibrant environment resulting in high uncertainty, which are multifaceted by challenging time restraints [5]. Identifying and analyzing prospective risks can increase effective completion of the project. Risk management offers an opportunity for project stakeholders to review the project through a collective dialog, to recognize better and evaluate the prospective problems and then formulate a suitable response [6].

Various methods and models are developed by investigators to analyze risks. A decision support framework called as Advanced Programmatic Risk Analysis and Management Model (APRAM) is useful for risk management [7, 8]. Nasir et al. [9] devised a schedule risk model called as Evaluating Risk in Construction—Schedule Model (ERIC-S) that estimates the pessimistic and optimistic duration of activities. Ökmen and Öztas [10] proposed the Construction Schedule Risk Analysis Model (CSRAM) that evaluates schedule networks under uncertainty when duration of activities and risk factors are correlated. All these models evaluate either the time schedule risks, cost risks or both.

Risk management is vital in construction to minimize losses and improving profitability [2]. Williams et al. [11] proposed a method of risk management. Complicated projects, such as metro rail contains risks from the feasibility stage, construction to commissioning. Risks in heavy construction have a direct impact on the cost, schedule and performance. Reilly and Brown [12] reveal that infrastructure underground metro is inherently complex project having uncertain and variable ground situations. For these kinds of projects, it is vital to identify risk as early as possible in the project [12]. A risk management plan, if developed would ensure smooth attainment of project goals within given time, cost and quality. Moreover, it can safeguard better safety throughout the construction process and operative stage of the project.

Uncertainties in on-site and off-site project activities often result in the risk of delays and schedule overruns in construction projects. A risk analysis approach that assesses the integrating impact of uncertainties [13] show that growth in project size and work quantities intensifies pair and group interconnection of tasks within and between groups of on-site and off-site activities, resulting in lengthened completion times and deviations from project plans. Vu et al. [14] revealed that prolonged schedule delays have an extremely detrimental impact on a project's efficiency, cost and investment reputation.

Experienced experts are involved in analysis of risks qualitatively. Analyst needs to systematic and experienced to identify effectively internal or external risks. Mulholland and Christian [5] reveal that the decision maker makes the best use of experience and information in identifying risks. Akintoye and Macleod [2] reveal that an individual's attitudes, beliefs, and judgment can influence risk perception. Many professionals find that risk identification and risk analysis require involvement of experts and advanced techniques [1].

Choudhry and Iqbal [1] reveal that formal risk management is a rare in the construction industry of Pakistan. The authors explained that contractors are not practicing risk management formally. Major barriers to risk management are non-adaptation of formal risk management system [1]. Projects in the construction industry suffer in terms of low productivity, cost overruns and poor quality due not conducting risks management [1, 2]. The country is confronting the trauma of bridge failures and loss of lives every year due to floods. There is a need to develop risk analysis guidelines to avoid bridge failures. This chapter is to identify risks and critically rank them that affect the performance of project time and cost. Monte Carlo (MC) simulation on a case study project determines that risk analysis is helpful in managing schedule and costs risks. Identifying and analyzing schedule and costs risks on bridge project, this work makes a unique contribution and provides an insight into the risk management concepts.

2. Method

This work focuses on risk analysis by including a case study bridge project. The research investigates the impact of risks on costs, schedule and suggest guideline for bridge projects. To collect, data, a questionnaire is designed based on the previous studies [1, 15]. The questionnaire includes questions related to respondent identification, years of experience and 37 risk factors. Among the 37 risk factors, 7 are adopted from Choudhry and Iqbal [1], 8 are from Masood and Choudhry [15], 11 from the pilot survey, and 11 are developed by the researcher. These 37 risk factors are divided into 7 categories: design risks, contractual risks, construction risks, management risks, financial risks, health and safety risks, and external risks.

A pilot study is performed with a panel comprising five professionals having over 20 years of experience in construction. The questionnaire is modified based upon the pilot study. Based on importance of impact on the bridge project performance, respondents ranked each risk factor on a 5-point Likert scale (5 = extra ordinary, 4 = major, 3 = moderate, 2 = minor, 1 = insignificant). The respondents comprised on managers and engineers involved with numerous bridge projects. The targeted population for this work included private and public sector clients, consultants, and contractors. These include around 7000 enterprises that are involved in bridge construction projects and are registered with the Pakistan Engineering Council.

According to Dillman et al. [16], a sample size of 61 is fine with ±10% sampling error and a 95% confidence level. The respondents are approached through e-mails and personal visits to construction sites. Overall, 100 surveys forms are distributed on 25 construction sites. The response rate for this survey is 77%, but only 69 are analyzed. Eight surveys forms are not filled properly and thus discarded. Black et al. [17] stated that a 30% response rate is satisfactory in construction. The composition of the respondents is 35% public clients, 10% private clients, 12% contractors and 43% consultants. Public clients own most of the bridge projects. A majority of respondents are civil engineers holding a bachelor's degree with over 16 years of experience. In addition, 25 interviews are conducted; one at each project. These interviews delivered valuable information about risk management and risk analysis guidelines.

The collected data are analyzed by using a software called as Statistical Package for the Social Sciences (SPSS). Statistical techniques such as preliminary analysis, internal consistency analysis, relative importance index, Pearson's product–moment correlation are used in the analysis.

In addition, a case study of a bridge project is documented to establish costs and time risk analysis. The researcher obtained assistance from the five-member expert panel (comprising on scheduling manager, project manager, resident engineer, construction manager, an academia) and Monte Carlo simulation to analyze risks on of the case study project. The panel members are having more than 20 years of experience in industry and academics. This panel identifies the risks relevant to the case study project and assigned probability to the risk factors. This panel assigned the probabilistic (optimistic, most likely, pessimistic) durations and costs in Pakistan Rupees (PKR). These probabilistic durations and costs permitted us to practice triangular distribution in Primavera Pertmaster. A 3 days' workshop is held with the attendance of all panel members. Their involvements for the risk analysis are documented.

3. Results and analysis

3.1 Tests for factor analysis

Kaiser-Mayer-Olkin (KMO) test and Bartlett's test of sphericity are carried out to check the suitability for factor analysis. The suitability of a sample in relations to the distribution of the data is checked by KMO test. Pallant [18] stated that KMO value should be more than 0.5. The researchers [18, 19] revealed that factor analysis is meaningless with an identity matrix. The tests showed that KMO value is 0.689 that is more than 0.5 and Bartlett's test of sphericity is large (chi-square value = 1626.4890 with small significance (p value < 0.001).

3.2 Analysis for internal consistency

Cronbach's alpha (α) is used to check the internal consistency in the items involved in each factor [20] and the minimum recommended value is $\alpha = 0.7$ [19]. Cronbach's α [19] also measures the reliability of all factors. Factor analysis shows that all 7 themes of the 37 factors had Cronbach's α ranging from 0.921 to 0.912, which means that all the variables are reliable [19]. For all 37 variables, the overall α is 0.917.

3.3 Relative importance index

Chan and Kumaraswamy [21] reveal that the mean and standard deviation of individual factor are not appropriate to decide the total ranking as they do not indicate any association among the factors. As a substitute, we calculate the weighted average for every factor and formerly divide them with the highest scale of the dimension. The researchers [19, 21, 22] indicate that this results in a relative importance index. Respondents provide their responses on a Likert scale about the standing of the 37 risks affecting the cost and schedule aims of the project. Shash [22] provided the formula for relative importance index as:

$$\text{Relative importance index (RII)} = \sum (a\text{X}) \times 100/5 \tag{1}$$

where 'n' is the frequency of the responses; and 'N' is the total number of responses that gives $\text{X} = n/\text{N}$. Where 'a' is the constant that express weight specified to each response, ranging from 1 (insignificant) to 5 (extra ordinary).

The relative importance index categorized the seven risk factors in descending order as: financial risks (RII = 69.95), external risks (RII = 66.67), design risks

Risk category	Relative importance index (RII)
Financial risk	69.95
External risk	66.67
Design risk	66.28
Management risk	65.17
Construction risk	62.72
Contractual risk	59.42
Health and safety risk	53.82

Table 1.
RII of risk categories.

(RII = 66.28), management risks (RII = 65.17), construction risks (RII = 62.72), contractual risks (RII = 59.42), and health and safety risks (RII = 53.82). According to the results, financial risks are vital in affecting the cost and schedule aims of projects (see **Table 1**). The 2nd and 3rd most important risks are external risks and design risks.

Among the 37 factors, the highest 10 risk factors in order of importance are: unavailability of funds (RII = 85.80), financial failure of contractor (RII = 76.52), poor site management and supervision (RII = 74.20), inadequate site investigation (RII = 73.91), inadequate project planning (RII = 73.91), construction delays (RII = 73.62), unavailability of land and/or right of way for site access (RII = 72.17), defective work and or quality issue (RII = 71.88), financial delays (RII = 71.01), insufficient technology (RII = 69.86). These risk factors are important for clients, consultants and contractors. There is a need for an effective risk management system on construction projects. Health and safety risks are ranked at the bottom in the 37 factors. This indicates that clients and consultants do not demand from contractors to implement a proper health and safety management system. Management risks are rated with high importance. There is lack of construction management experts and only few institutions offer program in construction management. Small contractors generally do not hire qualified engineers unless it is mandatory by the client. There is a need for construction management and risk management education as well as research in the industry.

3.4 Pearson's product-moment correlation

The Pearson product-moment correlation ('r' Rho) is a measure of the degree of linear relationship among the variables. The correlation coefficient ('r' Rho) is any value between plus and minus and the sign (±) explains the direction of the relationship, either positive or negative. A positive coefficient means that the value of the variable increases with the increase in value of the other variable; or if one goes down, the other also reduces. A negative coefficient indicates that as one variable increases, the other decreases, and vice-versa. The absolute value of the coefficient indicates the strength of the correlation. A coefficient of r = 0.50 shows a robust degree of linear relationship than that of r = 0.30. A coefficient of zero (r = 0.0) shows the lack of a linear relationship and coefficients of r = +1.0 and r = −1.0 show a perfect linear relationship [19].

Table 2 shows the Pearson's correlations for the risk factor categories. The maximum coefficient (0.756) is between the construction and management risks, which is significant at the p value = 0.01. This indicates that numerous construction and management risks are correlated to each other and they are to be jointly addressed

Risk factor category	Financial	Contractual	Design	Safety	Management	Construction	External
Financial	1						
Contractual	.442**	1					
Design	.306*	.374**	1				
Safety	.098	.428**	.341**	1			
Management	.174	.445**	.374**	.366**	1		
Construction	.113	.380**	.250*	.459**	.756**	1	
External	.162	.290*	.399**	.373**	.430**	.605**	1

*Correlation is significant at 0.05 level.
**Correlation is significant at 0.01 level.

Table 2.
Pearson's product-moment correlation of risk factor categories.

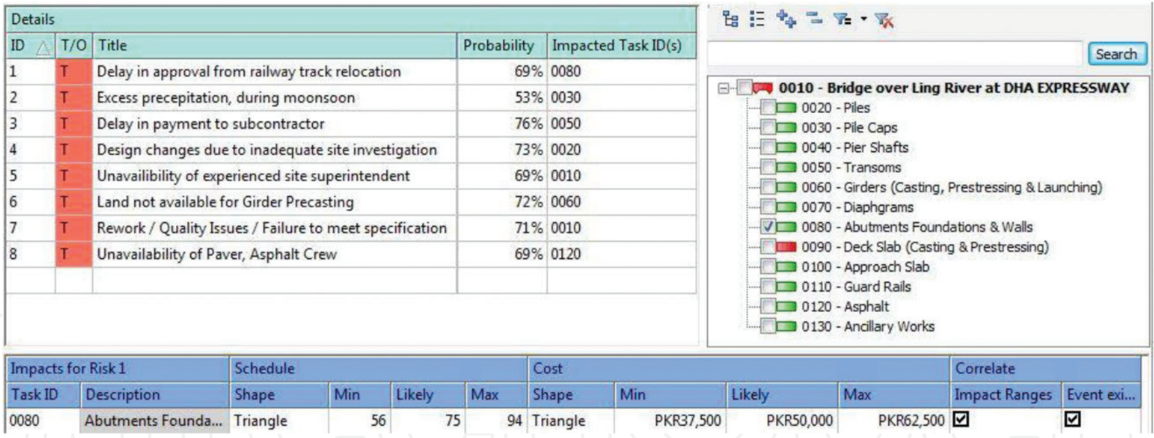
with good risk management practices. There is another essential coefficient of 0.605 at significance p value = 0.01 between construction and external risks. External risks impact on project costs and schedule more than the construction risks (see **Table 1**). They are in fact the second most important risk factor category. A positive correlation of health and safety risks with construction (0.459) at a significance p value = 0.01 confirms the importance of health and safety on bridge projects. Higher rate of risks in construction indicate an increase in physical vulnerabilities. The health and safety risks are correlated positively with contractual risks (0.428) at a significance p value = 0.01, indicating improvement in health and safety in construction may reduce contractual and health and safety risks.

3.5 Bridge project: a case study

The case study project is a bridge construction in Islamabad that links the Islamabad highway with a residential community. The project is located in the capital city of Pakistan. It has the following features: (a) bridge total length 166 m (544.8 ft), (b) constructed over a river with an annual peak discharge of 11,170 cusecs, (c) 56 piles of diameter 762 mm (2.5 ft) and abutment piles 15.24 m (50 feet) deep, (d) 4 spans, (e) pier piles 9.14 m (30 feet) deep, (f) 12 pile caps, (g) 4 abutment walls, (h) 2 abutments, (i) 12 piers, (j) 6 transoms or cross-beams, (k) 24 precast girders of 44.09 m (144.66 ft), (l) 14.32 m (47 feet) width of deck slab on one side, (m) 3.66 m (12 feet) length of approach slab on each side and, (n) asphalt 166.12 m (545 ft) long and the bridge is designed for 3 + 3 lanes of traffic.

A baseline work schedule is prepared for the project. The project has a base cost-estimate. Each activity in the schedule had its cost allocated. The allocation includes cost estimate for materials, equipment, labor, and overhead costs for each activity. The risks that are identified in the project are presented to the experts. The expert panel identifies specific risks to the case study project. These risks are loaded into the schedule to determine the impact on project schedule and cost. Primavera Pertmaster is used for risk analysis. The inputs to Pertmaster for the risk register are: (a) risk description, (b) risk ID number, (c) threat or opportunity, (d) effect of this risk on activity, (e) probability of occurrence, (f) type of risk e.g. schedule or cost, (g) distribution e.g. triangular, (h) correlation with other risk factors. The risk register (see **Figure 1**) is developed for the whole project.

Pertmaster uses Monte Carlo simulation for risk analysis. Monte Carlo simulation uses random independent variables to obtain solutions of problems. Lian


Details

ID	T/O	Title	Probability	Impacted Task ID(s)
1	T	Delay in approval from railway track relocation	69%	0080
2	T	Excess precepitation, during moonsoon	53%	0030
3	T	Delay in payment to subcontractor	76%	0050
4	T	Design changes due to inadequate site investigation	73%	0020
5	T	Unavailibility of experienced site superintendent	69%	0010
6	T	Land not available for Girder Precasting	72%	0060
7	T	Rework / Quality Issues / Failure to meet specification	71%	0010
8	T	Unavailability of Paver, Asphalt Crew	69%	0120

Impacts for Risk 1		Schedule				Cost				Correlate	
Task ID	Description	Shape	Min	Likely	Max	Shape	Min	Likely	Max	Impact Ranges	Event exi...
0080	Abutments Founda...	Triangle	56	75	94	Triangle	PKR37,500	PKR50,000	PKR62,500	☑	☑

Figure 1.
Risk register of the project.

and Yen [23] reveal that Latin hypercube sampling and simple random number sampling are among the sampling techniques that are used with Monte Carlo simulations. This simple and elegant method delivered a means to solve equations with triangular probability distributions [24, 25]. Critical path is found and further calculations are documented with activities that are on the critical path. The time schedule loaded with costs and risks is analyzed. Real versus simulation outcomes are compared. A total of 1000 iterations are conducted for risk analysis.

The cumulative distribution for project cost, finish date, and duration are calculated with Monte Carlo simulations. The project duration (maximum = 792 days, minimum = 628 days, mean = 701 days) is displayed in **Figure 2**. The cumulative distribution for project duration and cost is determined. The results showed that the probability of finishing the project within the allotted time (628 days) is 4% and within the budget (PKR 129 million) is less than 1%. Terms P100 and P80 indicate the probabilities of 100 and 80% respectively. For instance, P80 shows that the project could be completed in 730 days with an amount of PKR 161 Million. There shall be 100% sure that the project would be completes in 792 days or even less with a cost amounting to PKR 166.5 Million or less.

The observations are performed for 5 months for the case study project. We have compared Pertmaster results with the actual completed activities. The researchers spent full time on-site to ensure extreme communication with the project implementation team. Documents are cautiously reviewed and are assimilated in analysis. On-site real data are equated with the simulation outcomes. The evaluation associated with schedule start dates is noted. For piling activity, actual start dates matched with the base line as well as with P80 and P100. For pier-shaft, actual start dates are between P80 and P100.

Finish dates are also compared for the case study project. Piles activity finishes between the forecasted dates of P80 and P100. Pile-cap activity finishes between the expected dates of P80 and P100. The 'pier-shaft' activity also accomplished 22 days before the P80 finish date. Transom activity finishes 19 days after the P100 completion. This indicates that the simulation results are precise as the activities are actually completing either within the predicted dates or within ±20 days.

For the case study, costs are compared that are important to the contract partners. The project cost is at all times important to the management team. Probabilistic cost calculation with the model is very precise as all the genuine costs fell within the P80 and P100. The project cost incurred up to the completion of transoms is PKR 72.8 Million, while that forecasted by simulation with 80% probability is PKR 69.8 Million. The evaluation is PKR 76.0 Million with 100% probability, indicating that the expected cost using Monte Carlo simulation is precise

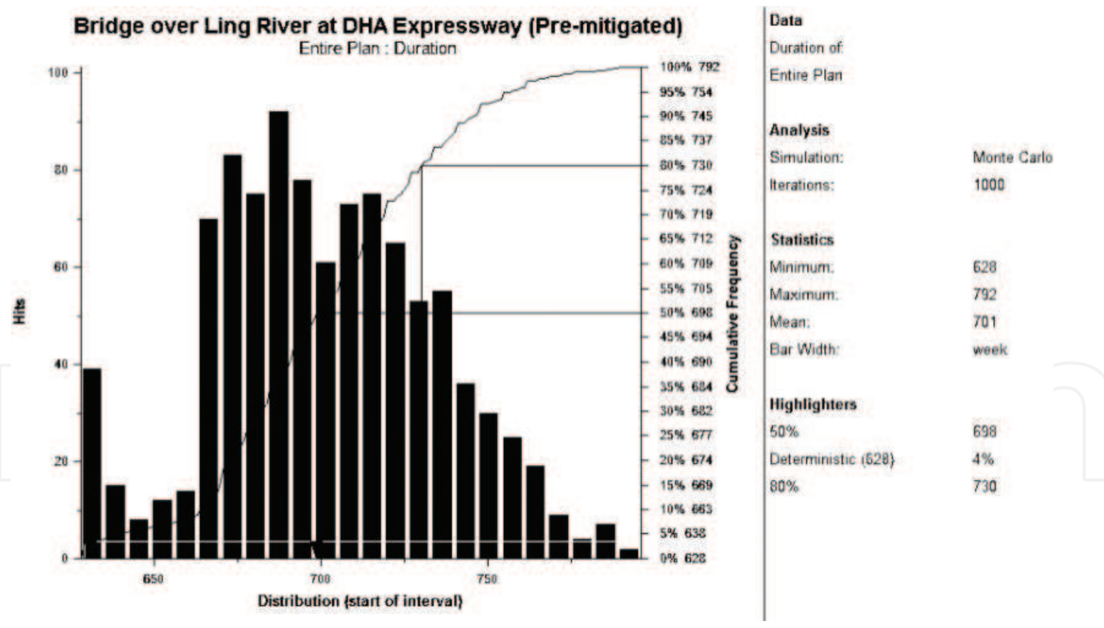


Figure 2.
Monte Carlo simulation results.

(P80 costs = 69.8 Million, Actual = 72.8 Million, P100 costs = 76.0 Million). The baseline cost of the project is only PKR 37.2 Million up to 'Transoms' construction that shows a cost overrun of 96%, portraying the absenteeism of monitoring and control of cost practices. This shows a clear requirement of risk management on bridge construction projects.

For the case study project, risk analysis shows that project management can obtain a fair idea of schedule and cost changes and variations. For the case study project, risks (see **Figure 1**) that affected the schedule and cost objectives are: (a) delay in approval from the regulatory authority i.e. delay in sanctioning relocation of the railway track, (b) unexpected weather i.e. excess rainfall during monsoon, (c) design variations i.e. design changes due to insufficient site investigation, (d) insufficient work space i.e. land not available for pre-casting of girders, (e) lack of technology i.e. breakdown in asphalt paving equipment, (f) unavailability of funds i.e. delay in payment to subcontractor, (g) unavailability of material i.e. quality issues and material failure to meet specifications.

3.6 Guidelines for risk analysis

The study advocates the succeeding guidelines for an effective risk analysis of any bridge project:

1. *Context development*: Developing the context for risk analysis is exceptionally vital as indicated in the 25 interviews documented. The expert panel emphasized the requirement for precise definition of the scope of the construction project; develop the project method statement, and conduct stakeholder analysis systematically. These points set the boundary for risk analysis as stressed by researchers [26]. Factors and variables contributing to project risks are required to be recognized.

2. *Identification of risks*: Tools and techniques such as checklists, historical data, brainstorming, and idea stimulating techniques may be employed [25, 26]. Nonetheless, risks are required to be identified and defined as is carried out

in the design of questionnaire. Help from expert panel should be sought in identifying risks. Choudhry and Iqbal [1] have documented the risks identification techniques and they may be adopted. Especially, risk related to time and cost is to be evaluated as it plays a major role in affecting the project performance.

3. *Quantifying risks*: The risk quantification is the most important process that requires skills, extensive experience and good judgment. In this process, one has to assess the probability of each risk [24, 25]. Next is to evaluate the impact of time or cost, or both. Generally, expert panels play a major role in calculating the probability of risks and their impact. The correlation of risks either positive or negative is addressed in this study. Lastly, the risk quantification decides, whether they have an effect on cost or duration, or both.

4. *Prepare cost-loaded schedule for the project*: Mubarak [27] revealed that the project baseline schedule needed to be prepared at the initial stage the project to measure the project's progress against it. Probabilistic or deterministic durations of time and costs of activities are to be estimated. The critical path needs to be determined based on the probabilistic durations. Project cost is determined based on the probabilistic costs of the activities' information. The comparison of actual duration and actual cost of activities is carried out with computed results and with the baseline.

5. *Schedule loading with risks*: When cost-loaded schedule is complete, the next step is to allocate risks as they are quantified with each of the project activities. These risks are generally documented in a risk register. The risk register contains all particulars of each risk for the project. From the risk register, relevant risks are assigned with the cost-loaded schedule.

6. *Running of Monte Carlo simulations*: The schedule loaded with risk is run by Monte Carlo simulations to calculate the impact. One needs to perform the Monte Carlo simulations by using software, for example, @Risk. Pertmaster is employed in this this research.

7. *Understand the output*: The results that are produced by Monte Carlo simulations are easy to comprehend. Outputs reflects the probability of meeting the time and costs. The P80 and P100 values represent 80 and 100% probability. They specify the values of time and cost with 80 and 100% confidence level. The results shows how much an activity is behind from its initial time and how much cost can overrun (see **Figure 2**).

This work reveals a systematic process to identify and quantify major risks related to construction and predominantly to bridge construction affecting cost and schedule of the project. All projects have their own special conditions; nonetheless, experts can acquire valuable evidence from the results as all projects have risks that need to be managed. Risks related to schedule create cost risk. The case study demonstrates with the help of Monte Carlo simulation that how schedule and cost risk can be analyzed and managed. The case study shows that understanding the probabilistic cost is vital to forecast long-term budgets. The risk management guidelines are documented from surveys, interviews and analysis. One can determine the probabilistic cost of project by adopting these guidelines.

4. Conclusions

This work has identified and ranked the critical risks threatening the performance of bridge construction projects and evaluated the consequence of risks on project time and cost. This work is planned to developed consciousness of project stakeholders in relation to risk analysis in the construction industry. The major risks concerning a bridge construction project are identified. After carrying out risk analysis, the major results of this work are examination of critical risks affecting project costs and schedule. Relative importance index of important risk factors is calculated. This exercise categorized risk that include 'financial risks', 'design risks', 'external risks', 'management risks', 'contractual risks', 'health & safety risks' and 'construction risks'. Financial risks are categorized at the top. The five highest ranked risk factors are 'financial failure of contractor', 'unavailability of funds', 'poor site management & supervision', 'inadequate project planning' and 'inadequate site investigation' among the 37 factors. Many risks are correlated and they need to be managed by applying management practices.

Schedule and costs risks are investigated in a case study project of a bridge construction. Real data of the bridge construction project is compared with simulation results after the risk analysis. Simulation findings are precisely correct and comparable to those really performed in relations to project duration and cost. In addition, guidelines for risk analysis are developed that can assist management in ascertaining possible risks on construction project of bridges. The research stresses that management is required to perform risks analysis after identifying prospective risks at the initial stage of bridge projects. Predicting risks can enable policymakers to detect areas of anxiety for project managers to take preemptive actions.

Although, each project in construction has its particular circumstances, project managers can acquire positive information from this study for their projects as the risks recognized for the construction are alike to risks in all sorts of projects across the world. The evidence delivered through this investigation can empower engineering professionals to safeguard that their projects advance efficiently without making unnecessary errors. This would be supportive to improve the execution of their projects. Even though there is some body of awareness in relation to management of risks, the formation of guidelines for risk management persisted to be vague. This research provided guidelines for risks management accompanying with heavy engineering construction in the construction sector. The research is important for project managers, academicians and professionals who are linked with heavy engineering construction and the construction sector in common.

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