Risk Analysis of Bridge Construction Projects in Pakistan

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Abstract:

Construction process is inherently prone to risks. The remedy to manage these risks effectively is in adopting a comprehensive risk management framework. Risk analysis, as the core part of the risk management process enables professionals to quantify and analyze risks which can pose a potential threat to performance of project in terms of cost, quality, safety and time. This research work attempts to identify and analyze the risks associated to bridge construction projects in Pakistan during their construction phase. A structured questionnaire was developed and administered. Risks affecting the performance of bridge projects were identified through interviews with engineers and managers working on various bridge projects. The impact of these risks on cost and schedule is analyzed using a case study which included analysis, results and discussion. The paper also shows insights of Monte Carlo simulation for project risk analysis. Through this research, risk analysis guidelines are provided that can be used for bridge construction projects in future.

Keywords: Risk Analysis; Monte Carlo Simulation; Bridge Construction; Pakistan

1. Introduction

Risk is the quality of a system that relates to the possibility of different outcomes. Schuyler (2001) defines risk as the contingency event, which either happen or does not. Subsequently, he argued that risk is a constituent of a threat and opportunity. Risk affects productivity, performance, quality and budget of a construction project (Akintoye and Macleod, 1997). Risk management is defined as a systematic controlling procedure for predicted risks to be faced in an investment or a project (Dikemen et al, 2004). In project risk management, strategy is to reduce the probability and impact of a threat and increase the probability and impact of an opportunity (Schuyler, 2001). Evidence has defined risk management as a stepwise procedure consisting of risk identification, risk classification, risk analysis, and risk response tasks (Flagnan and Norman, 1993). Risk analysis is defined by (Loosemore et al. 2006): the process of evaluating identified risks and opportunities to discover their magnitude, whether they merit a response, and how responses should be prioritized in the light of limited resources.

To cater for the needs of analyzing risks various techniques and models have been developed by researchers. Program evaluation and review technique (PERT) was devised by Dept. Of the Navy 1958, it can be considered as a schedule risk analysis tool. Advanced Programmatic Risk Analysis and Management Model (APRAM) is an example of a decision support framework that can be useful for the management of the risk of project failures *(*Dillon and Pate-Cornell, 2001*)*. Evaluating Risk in Construction – Schedule Model (ERIC-S): a comprehensive schedule risk model to estimate the pessimistic and optimistic values of an activity duration based on project characteristics (Nasir et al., 2003) . Construction schedule risk analysis model (CSRAM): is used to evaluate construction activity networks under uncertainty when activity durations and risk factors are both correlated in between *(*Ökmen and Öztas, 2008*)*. These techniques either address the schedule risks, budget risks or both. Also, some models like APRAM have been developed which analyze these risks along with technical risks such as quality.

Management of risk on a formal level is a practice scarce in Pakistan (Ahmed et al., 2009). A recent study undertaken to investigate the current state of adoption of risk management practices in the construction industry of Pakistan showed that the contractors in Pakistani construction industry are generally not practicing formal risk management and majority of projects suffer from risk causes resulting in low productivity, poor quality and cost overruns (Farooqui et al. 2007). Pakistan has faced the trauma of bridge failures and loss of life as a consequence in the Earthquake of 2005 and the recent Floods of 2010. The literature gives the idea that a pioneering research presenting risk analysis guidelines for Pakistani bridge construction projects is the need of this developing construction industry. Thus, the main objectives of this research are:

- To identify critical risks affecting the performance of bridge projects.
- To quantify and analyze these risks using Monte Carlo (MC) Simulation and to prioritize risks according to their impact on project performance (Cost & Schedule).
- To present risk analysis guidelines for bridge construction projects

2. Methodology

This research focusing on the intrinsic area of risk analysis was carried out in a systematic manner. Extensive literature was reviewed in the form of academic journals, books and published content. The following sequence was then decided by the researchers. a) Develop questionnaire to identify critical risk factors b) Identify survey participants c) Pilot survey d) Questionnaire survey & Interviews of selected participants e) Data analysis of survey by SPSS Statistics 17 f) Case study of a bridge project g) Quantify impact of risk on project schedule and cost by Pertmaster V8 h) Formulate the risk analysis guidelines for bridge construction projects.

The questionnaire was developed keeping in view the important research work done by (Masood and Choudhry 2010), (Ahmed et al., 2009) and (Farooqui et al., 2007) to extract risk factors more applicable to Pakistani Construction Industry. The questionnaire was divided into two parts, first part included questions about respondent's name, name of the company, and years of experience (Table 1). Second part consisted of a total of 37 risk factors divided into seven categories (Table 2). Before the questionnaire survey began, a pilot test was carried out, which included a panel of three professionals with more than 20 years of work experience in the construction industry. The respondents were requested to rate each risk factor based on its importance of impact on bridge project performance. The respondents were advised to rate the risk on a likert scale from 1 to 5. The respondents of the questionnaire were identified with the intent of obtaining accurate information related to bridge projects. This included the engineers and managers working on various bridge projects throughout Pakistan. The respondents were contacted through e-mail, fax and by personal interaction. A total of 100 questionnaires were distributed, an appreciable (77% response rate) 77 questionnaires were returned out of which 69 were usable for data analysis. The sample included 35% participants from public sector owners, 10% from private owners, 43% from consultants and 12% from contractors. It is pertinent to mention here that the majority of bridge construction projects are owned by public sector because of their complex nature and jargon of finances are required, which the private sector is hesitant to invest. The low response of contractors is an alarm, depicting their lack of awareness and interest towards research and development. To ensure survey validation, each participant involved in the survey had an experience of working on bridge construction projects. The participants of the survey ranged from project directors, general managers, project managers and specialist engineers. Majority of the participants had acquired a bachelor's degree in civil engineering. The average experience of surveyed participants in number of years is approximately 16.

3. Risk Factors and Categories

The risk factors were divided into seven categories namely financial risks, contractual risks, design risks, health & safety risks, construction risks, management risks, external risks. The risk factors of the seven categories are as follows:

Financial Risks

Comprising of a) unavailability of funds, b) inflation, c) hike in material prices, d) financial delays e) financial failure of contractor and, f) economic disaster.

Contractual Risks

a) change in project scope/ change orders, b) contractual anomalies, c) disputes & claims and, d) unrealistic cost estimates & schedules.

Design Risks

a) Design changes, b) incomplete design and, c) inadequate site investigation.

Health & Safety Risks

a) Accidents, b) equipment and property damage and, c) fatality

Management Risks

a) Inadequate project planning, b) insufficient engineers & specialist, c) lack of coordination, d) poor site management & supervision, e) strikes & theft and, f) subcontractor failure.

Construction Risks

a) Construction delays, b) defective work / quality issues, c) insufficient technology, d) labor productivity, e) material shortage, f) over-inspections/audits, g) scope of work not clear, h) unexpected site conditions (dewatering/rock), i) Unexpected weather (rain/windstorm) and, j) work interruptions / lack of space.

External Risks

a) Delay in approval from regulatory bodies, b) political instability, c) third party delays, d) Unstable government policies and, e) unavailability of land / right of way (ROW) not clear.

4. Data Analysis

The collected data from the questionnaires was analyzed using Microsoft Excel and the statistical software, SPSS Statistics 17. The type of Analysis performed on the data was to find a) Risk Importance Index (RII) as devised by Ghosh and Jintanapakanont (2004). b) Correlation of risk factors. The RII was calculated as shown in equation 1.

Relative Importance Index = $\sum (aX) * 100/5$ (Equation 1)

Where *a* is the constant that expresses the weighting given to each response, ranging from 1 (least important) to 5 (most important); and X = *n*/N, where *n* is the frequency of the responses; and N is the total number of responses.

Table 1: Part one of Questionnaire (Information of respondents)

Questionnaire on RISK ANALYSIS	
Name of Respondent	
Name of Organization	
Designation	
Years of Experience	
Please rate the risks mentioned below depending upon their impact on cost and time, on bridge construction projects. The scale indicates 1 being the least important, 2 somewhat important, 3 significant, 4 very important and 5 being the most important.	

Table 2: Part two of Questionnaire (Rating of risk factors according to their importance)

Category	**Scale**				
	1	2	3	4	5
Health & Safety Risks					
Accidents					
Equipment and Property Damage					
Fatality					

The relative importance index ranks each category in the descending order as financial risks, external risks, design risks, management risks, construction risks, contractual risks, and health & safety risks. The results from Table 3 also imply that the professionals are not categorizing health & safety as an important aspect of the bridge construction project.

The health & safety risks being rated so low could either mean a) there is a lack of awareness of importance of occupation health & safety amongst the participants b) lack of regulatory framework, which allows professionals not to be concerned about the physical hazards during the project.

Table 3: RII of risk factor categories in descending order

Risk Category	**Relative Importance Index**
Financial Risks	69.95
External Risks	66.67

Design Risks	66.28
Management Risks	65.17
Construction Risks	62.72
Contractual Risks	59.42
Health & Safety Risks	53.82

Table 4: Correlation among the seven risk factor categories

Correlations

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

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level

The Pearson's correlation amongst the risk factor categories is displayed in Table 4. This was computed using SPSS Statistics 17. The highest correlation is among the construction and management risks 0.756 at significance level 0.01. It shows that many of the construction and management risks are correlated to each other and need to be catered by good construction project management. Another important correlation is 0.605 at significance level 0.01 among construction and external risks. External risks tend to impact cost and time more than the construction risks as shown in Table 3; they are in fact the second most important risk factor category. A positive correlation amongst health & safety risks and construction 0.459 at significance level 0.01 is a proof that how important health & safety is for a bridge project, during the construction process. As the construction risks increase, so does the physical hazards. The health & safety risks are positively correlated to contractual risks 0.428 at significance level 0.01, depicting the involvement of health & safety into the construction contracts might reduce contractual as well as health & safety risks.

The results of this study are comparatively consistent with that of previous research carried out in Pakistan (Ahmed et al, 2009). Table 5 shows the top 15 risk factors of this study in descending order of their importance. These risk factors are important for consideration of owners, consultants and contractors. The need of an effective risk management system and awareness programs amongst the stakeholders of Pakistani construction industry is required. Out of the 37 factors used in the survey, surprising results were that health & safety related risks were ranked the lowest by participants. This depicts that neither owners nor consultants lay emphasis on a contractor to have an appropriate health & safety management system. Management risks have also been rated important. One reason for this is lack of construction management experts in the country. Further to that, only few institutes offer a degree in construction engineering and management. There is also a least requirement of a contractor to higher qualified engineers and managers unless stressed by the owner or consultant. This picture urges the industry to have a behavioral shift towards construction project management education, research and practices. The external risks remain important after financial risks because of bureaucratic and political problems in the country.

Table 5: Comparison of this study with previous research in Pakistan

Risk Factor	**Relative Importance Index**	**Risk Rank**	**Risk Factors, Previous research** **(Ahmed et al., 2009)**	**Risk Value**	Risk Rank
Unavailability of funds	85.80	1	Differing site conditions	16.93	1
Financial failure of contractor	76.52	2	Inadequacy of project financing	16.36	2
Poor site management & supervision	74.20	3	Poor cost estimation (underestimation)	16.13	3
Inadequate site investigation	73.91	4	Inadequate/Inappropriate specification	15.72	4
Inadequate project planning	73.91	4	Incorrect/Inadequate site information	15.44	5
Construction	73.62	6	Internal cash flow issues	15.35	6

delays					
Unavailability of land ROW not clear	72.17	7	Construction change order/ directives	15.32	7
Defective work/ Quality issue	71.88	8	Lack of qualified craftsmen	14.61	8
Financial delays	71.01	9	Inadequate project planning	14.36	9
Insufficient technology	69.86	10	One-side contracts, Inappropriate contract terms	14.17	10
Insufficient engineers & specialists	69.28	11	Over-Inspection / audits	14.16	11
Delay in approvals from regulatory bodies	69.28	11	Poor site management & supervision	14.08	12
Political instability	69.28	11	Disputes / Claims and related issues	14.06	13
Unstable government policies	66.96	14	Defective work / quality issues	13.80	14
Unrealistic cost estimates & schedules	66.67	15	Labor productivity issues	13.78	15

5. Case Study of a Bridge Project.

The selected bridge project is constructed to facilitate an expressway connecting a highway with a housing society. The project is located in Islamabad, the capital of Pakistan. The bridge has the following salient features: a) To be constructed over a river with an annual peak discharge of 11170 cusecs, b) total length of bridge 544.67 ft, c) 4 spans, d) 56 piles of diameter 2.5 ft and depth of abutment piles 50 feet, depth of pier piles 30 feet, e) 12 pile caps, f) 2 abutments, g) 4 abutment walls, h) 12 piers, six each of 36 feet, and 44 feet respectively, i) 6 transoms, j) 24 precast girders 12 each of lengths 127.66 and 144.66 ft respectively, k) 47 feet width of each deck slab, l) 12 feet length of approach slab on each side and, m) length of asphalt 545 ft and guard rails on both sides. The bridge is designed for 6 lanes of traffic.

For the purpose of this research, a work schedule of the project was developed and saved as a baseline. Similarly, a base cost-estimate of the project was prepared. The estimate was prepared in a manner that each activity could be assigned a cost. To remove the bias of missing the project over-head costs, the estimate of each activity included the sum of material costs, manpower costs, equipment costs and overhead costs.

The risks identified through the questionnaire survey were then loaded into the schedule to quantify the impact of these risks on project schedule and cost. For the purpose of risk analysis, Primavera Pertmaster V8 was used. The inputs of Pertmaster for risk register are a) risk ID number, b) threat or opportunity (T/O), c) risk description, d) probability of occurrence, e) effect of this risk on activity, f) type of risk i.e. cost, time or performance, g) distribution type i.e. triangular, uniform, etc., h) correlation with other risk factors. The sample risk register shown below was created for the complete project. Inputs required by software, like probability, impact of risk on activity, risk correlation, etc, were entered with consultation of the same panel involved in pilot survey of the questionnaire (Figure 1 and Figure 2).

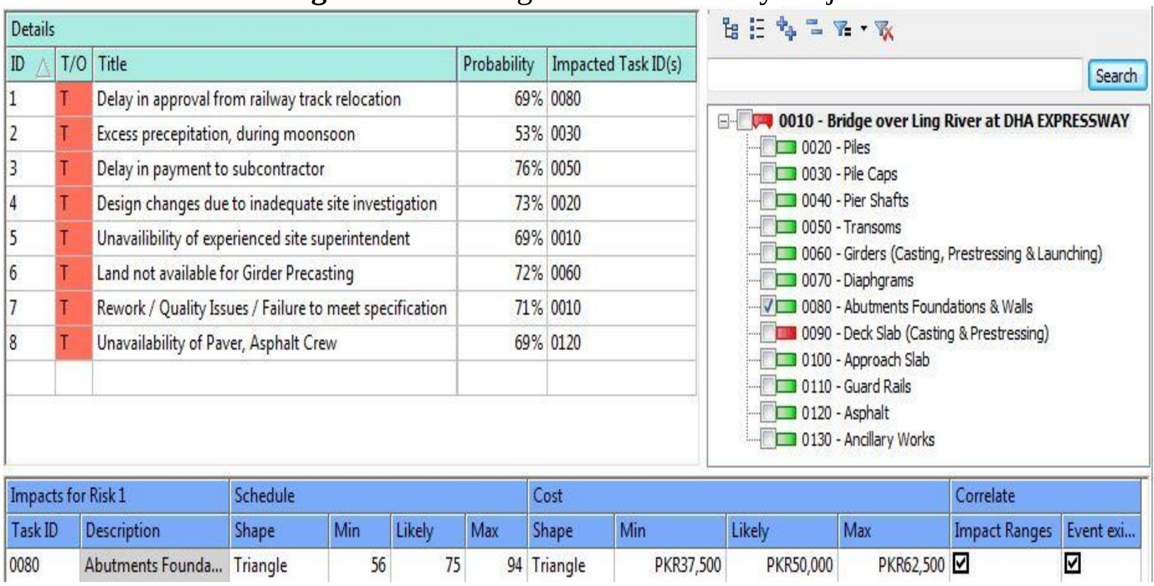
The work schedule which is loaded with costs and risks is subjected to risk analysis. The risk analysis function performed by the Pertmaster V8 is based on MC simulation. MC simulation is perhaps the most popular of the various management science techniques. The simple, elegant method provides a means to solve equations with probability distributions (Schuyler, 2001). MC simulation is a technique that uses random samples of the independent variables to obtain solutions of problems. Simple random number sampling and Latin hypercube sampling are among the possible many sampling techniques that can be used with Monte Carlo simulations (Lian and Yen, 2003). Further to embellish the study project it was decided that 1000 iterations are to be performed by the software (Figure 3 and Figure 4).

The cumulative probability distribution of project cost, finish date and duration were computed through MC simulations. Extract of project cost is shown in Figure 5. The cumulative probability distribution of project cost and duration is shown in Figure 6. Table 6 gives a summary of the risk impact on project cost and duration. The probability to finish project within cost is less than 1% and within time is 4%. Terms P80 and P100 represent the probability, 80% and 100% respectively. The arrows in Figure 6 are representing the project completion with 80% and 100% probability.

Table 7, 8 and 9 are drawing the comparison of simulation results with actual data of the case study project. The time of observation for the project was from November 2009 to March 2011; therefore, the comparison was drawn with the actually completed activities.

From the results it can easily be depicted that the risk estimation carried out for this study performed very well, the risks identified were actually effective and faced in the real time construction of the project. Nonetheless, due to a non-existent risk management framework none of the risks were managed or treated effectively. The case study project is built by self-performance project delivery method wherein the owner played the leading role in the construction of the project; similar studies can be carried out for other types of project delivery methods.

Figure 1: Risk Register of Case Study Project



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 2: Risk Correlation of Case Study Project

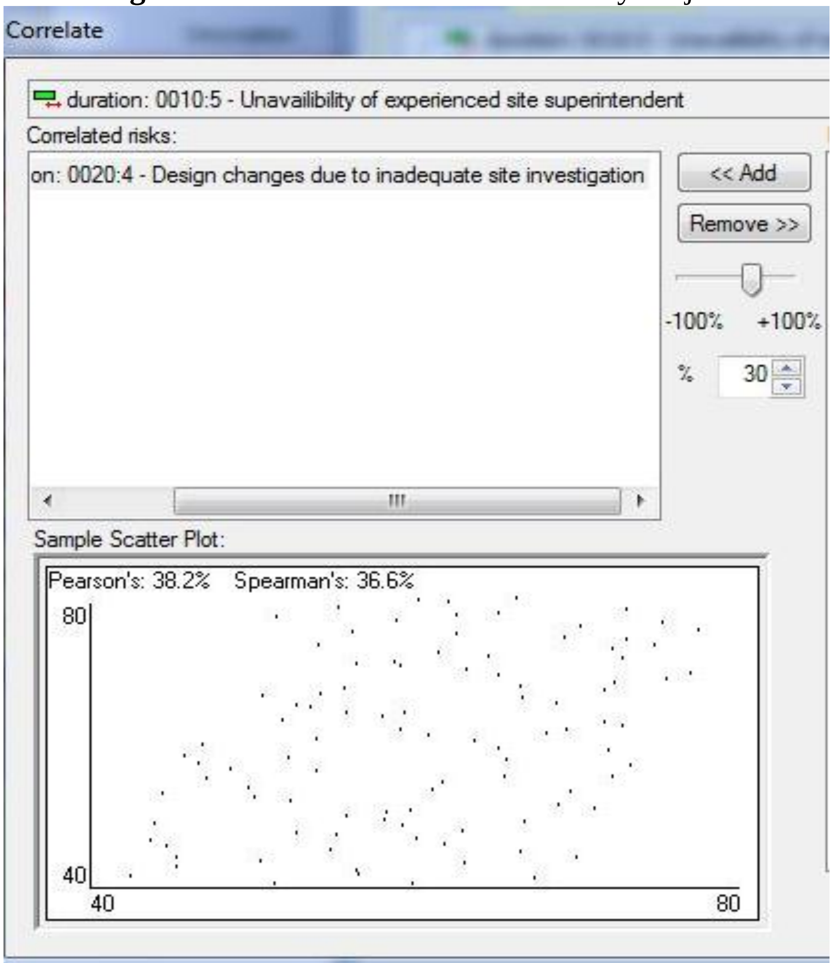


Figure 3: Risk Analysis in Pertmaster

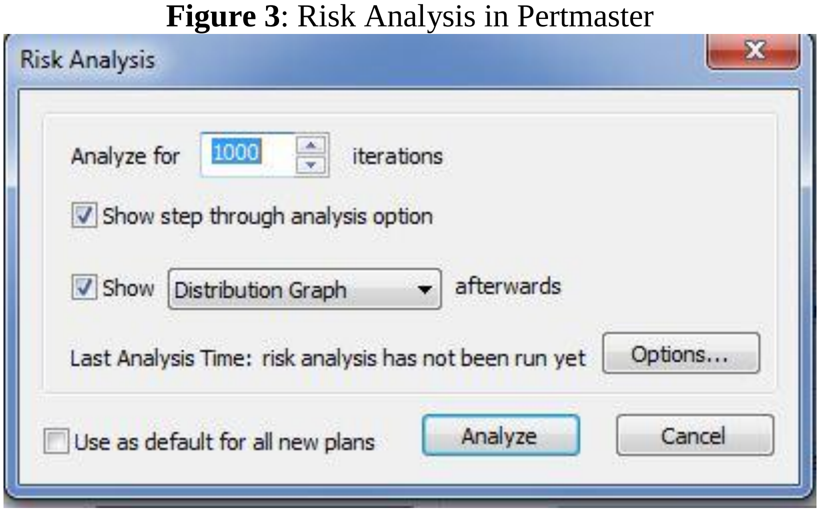


Figure 4: Iterations

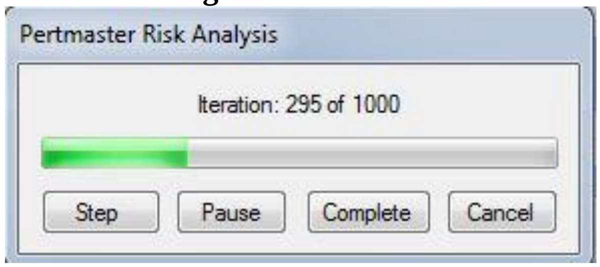


Figure 5: MC Simulation results and Impact of risks on project schedule

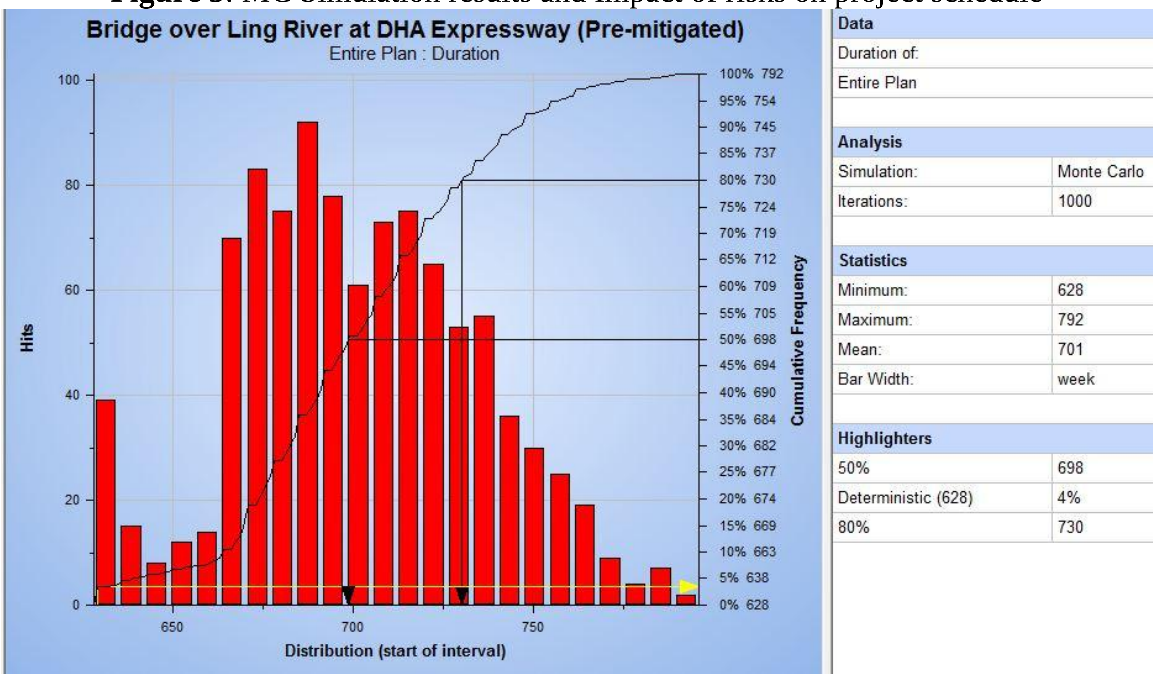


Figure 6: Impact of risk on Project time and cost.

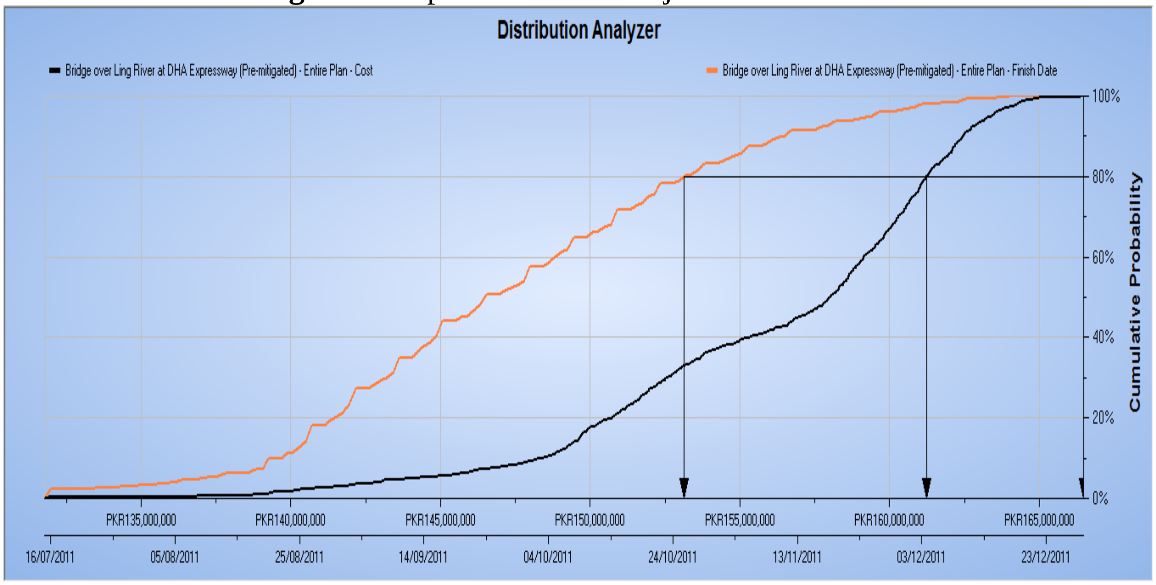


Table 6: MC Simulation Results of the Case Study Project

Description	Deterministic Value	Deterministic probability	Mean	P80	P100
Cost (PKR)	129,221,836	<1%	156,006,383	161,234,806	166,478,535
Duration (Days)	628	4%	701	730	792
Finish Date	15/07/2011	4%	25/09/2011	25/10/2011	26/12/2011

Table 7: Comparison of MC Simulation Results with Actual Situation (Start Date)

Activity	P80 Start	P100 Start	Actual Start
Piles	26/10/2009	26/10/2009	26/10/2009
Pile Cap	7/4/2010	18/4/2010	4/6/2010
Pier Shaft	4/7/2010	3/8/2010	10/6/2010
Transoms	23/8/2010	21/9/2010	1/1/2011
Girders	21/5/2010	3/7/2010	
Diaphragm	26/12/2010	27/2/2011	
Abutments	14/4/2010	25/4/2010	
Deck Slab	15/1/2011	19/3/2011	
Guard Rail	16/3/2011	18/5/2011	
Electrical Works	31/3/2011	2/6/2011	
Asphalt	4/10/2011	6/12/2011	

Table 8: Comparison of MC Simulation Results with Actual Situation (Finish Date)

Activity	P80 Finish	P100 Finish	Actual Finish
Piles	6/4/2010	17/04/2010	14/4/2010
Pile Cap	3/9/2010	2/10/2010	13/9/2010
Pier Shaft	18/11/2010	27/12/2010	27/10/2010
Transoms	28/01/2011	12/3/2011	31/3/2011
Girders	21/02/2011	25/04/2011	
Diaphragm	28/03/2011	25/05/2011	
Abutments	17/01/2011	8/2/2011	
Deck Slab	28/05/2011	17/09/2011	
Guard Rail	3/10/2011	5/12/2011	
Electrical Works	22/09/2011	24/11/2011	
Asphalt	25/10/2011	26/12/2011	

Table 9: Comparison of Costs

Activity	P80 Cost	P100 Cost	Actual Cost
Project	161,149,586	165,945,109	72,840,547
Piles	23,610,037	24,903,230	23,519,573
Pile Cap	17,950,572	19,539,369	18,868,638
Pier Shaft	19,673,635	21,374,974	20,326,544
Transoms	8,553,384	10,230,338	10,125,792
Girders	48,672,759	49,247,929	
Diaphragm	2,309,237	3,010,231	
Abutments	5,473,253	5,790,028	
Deck Slab	20,934,974	21,911,994	
Guard Rail	5,666,186	5,764,904	
Electrical Works	8,820,857	9,776,048	
Asphalt	3,045,760	4,008,724	

6. Risk Analysis Guidelines

Through this research it is intended to present the guidelines necessary for a successful risk analysis of bridge projects. A stepwise guideline is provided below, which shall help the professionals working on bridge projects. Guidelines are prepared by keeping in view the evidence of (Schuyler, 2001) and (Loosemore et al., 2006).

a) Develop the context (specify scope, stakeholder analysis, etc.)
b) Identify risks (checklists, brainstorming, historical data, etc.)
c) Quantify risks (likelihood, impact, correlation, distribution type, effect on activity)
d) Formulate the project cost-loaded schedule.
e) Load the schedule with risks.
f) Run MC simulations.

g) Understand the output and develop strategy to respond for the risks.

7. Conclusions

Amid the failure of various bridges globally and in Pakistan, this research is targeted to ensure the awareness of project stakeholders about the threats affecting the performance in the construction process of a bridge project, they are likely to face. This research is unique in a way that a project case study is used to develop a better understanding using the realistic data compared with computational simulation of risks. The potential risks related to bridge construction projects were identified, which included in descending order of importance financial risks, external risks, design risks, management risks, construction risks, contractual risks and health & safety risks. The guidelines are developed in a manner easy to adopt and implement. A step wise case study is elaborated in the light of these guidelines. From the results of the case study it showed that the forecasted results were approximately accurate and similar to those actually experienced in terms of project cost and time.

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