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Measuring the Impact of Risk Events and Uncertainty in Activity Durations on Project Schedule

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Abstract: Construction projects are usually over budget and beyond their planned schedule. One possible reason for these situations is that proper risk management techniques are not applied during the planning and execution of projects. This paper introduces a method which uses the impacts of risk in project scheduling. A simple infrastructure project is considered for analysis. Uncertainty in activity durations is assigned using various statistical distributions. Further, certain risk events are added to the project using risk register. The impact of these uncertainties in activity durations and risk events are modeled and simulated in @Risk software. The software uses Monte Carlo simulations for risk analysis. The results show that the model can predict the impact of uncertainty in activity durations on the project completion time. The additional days added to the planned schedule because of occurrence of risk events can also be predicted with confidence. The results provide confirmation that risks associated with project schedules can be managed if properly accounted for.

Keywords: Risk, uncertainty, project schedule, Monte Carlo simulation, construction projects.

1. INTRODUCTION

Construction industry is a major source of a country's economy. It is one of the largest sources of providing job opportunities in both the developing and developed countries. However, most of the construction projects take considerably longer time for completion than the planned and estimated durations. This happens in both the developed and developing countries. As a result productivity in construction industry has seen a decline or remained stagnant (Harrison 2007; Nasir *et al.,* 2014). One significant reason for these delays in project schedules is that proper risk management is not followed during the life cycle of the project, particularly in the planning, design, and execution phases (Serpell *et al.,* 2017).

Risk management techniques have not been applied vigorously on construction projects. Little attention has been paid to the risk management using qualitative risk analysis techniques. The qualitative risk analysis techniques can help the project stakeholders in identifying and prioritizing the potential risks which can have a negative impact on a project schedule (Akintoye and MacLeod1997; Boateng *et al.,* 2015).

However, these qualitative risk analyses do not provide information on delays related to project schedule. In order to measure the impact of risks in terms of actual project completion times and additional days added to the project plan, quantitative risk analyses are required. Monte Carlo simulation technique is widely regarded as a best approach to assess the risks impact (Kwak and Ingall 2007).This technique was used for assigning uncertainties in the project schedule in the research presented in this article.

This research considers a small infrastructure construction project involving 24 activities. The project duration was initially assessed using a single point deterministic duration. Then uncertainty in project activities durations was estimated using PERT and Triangular distributions, two widely used distributions for determining activity distributions in construction projects based on probabilistic scheduling. Further, the impacts of certain risk events were integrated with the project schedule using Risk Register. A commercially available software known as @Risk (Palisade 2016) was used to model and simulate the risk impacts on project schedule. The results confirm that uncertainties associated with activities durations and the likelihood of certain risk events occurring and their impacts can be estimated with certain degree of confidence. These analyses will help in determining realistic project schedules considering risks, which are unavoidable.

Background

The topic of risk management in construction projects is gaining more and more attention these days because most of the projects go beyond their planned schedule and cost. One possible reason is that proper risk identification, assessment, and control techniques are not applied on construction projects. As a result of

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improper risk management the projects tend to go beyond cost and schedule.

When we speak about risk, we mean deviation of system results from the expected outcomes. In terms of construction projects, risk deals with uncertainties that can influence a project's budget, schedule, quality, scope and other dimensions.

Risk management is generally considered the process of identification, assessment and prioritization of risks, followed by the necessary actions to monitor, control and reduce the negative aspects of risks (Boehm 1991; Fairley 1994). The Project Management Body of Knowledge (PMBOK) defines Project Risk management as "the systematic process of identifying, analyzing, and responding to project risk." (PMI 2013).

Generally, the following six processes are implemented for project risk management (PMI 2013): (1) Risk Management Planning; (2) Risk Identification; (3)Qualitative Risk Analysis; (4)Quantitative Risk Analysis; (5) Risk Response Planning; and (6) Risk Monitoring and Control.

The project schedule is traditionally calculated using the Critical Path Method (CPM). This method is a very useful for planning purposes as it gives necessary information about the estimated project completion time, start and finishes time of activities, critical activities and floats available for each activity (Hegazy 2002). The CPM method is based on the assumption that all resources required for carrying out tasks are available at all times. Further, the CPM schedule is based on the deterministic approach, meaning the activity duration is fixed using a single point estimate or sometimes three point estimates. It doesn't consider the probabilities of some risk events happening, which can cause delays and eventually delaying project completion. Risk management has been recommended to answer some of these discrepancies (Zhi 1995; Zavadskas *et al.,* 2010; Shahtaheri *et al.,* 2015).

Monte Carlo Simulation

The uncertainties in projects' activities durations can be assigned and modeled using Monte Carlo simulation method (Kwak and Ingall 2007; PMI 2013).Monte Carlo simulation is a computerized mathematical technique that allows people to account for risk in quantitative analysis and decision making. It has been used by professionals in fields such as finance, project management, energy, manufacturing, engineering, research and development, insurance, oil and gas, transportation, and the environment.

Monte Carlo simulation gives the decision-maker a range of possible outcomes and the probabilities they will occur for any choice of action.It performs risk analysis by building models of possible results by substituting a range of values a probability distribution for any factor that has inherent uncertainty. It then calculates results over and over, each time using a different set of random values from the probability functions (Hegazy 2002; Kwak and Ingall 2007). Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands or tens of thousands of recalculations before it is complete. Monte Carlo simulation produces distributions of possible outcome values.

In this way, it provides a much more comprehensive view of what may happen. It tells us not only what could happen, but how likely it is to happen. In terms of construction project scheduling, the method basically uses randomly generated numbers to determine possible activity durations. The technique essentially generates various scenarios associated with the project; each involves a random set of durations for the project activities. Each of these scenarios is then used to produce a CPM-type deterministic schedule. At the end, we can analyze the results of all these scenarios to understand the resulting range of variability in project duration (Hegazy 2002).To generate the random project scenarios, the Monte Carlo simulation technique requires information about the duration of activities and their distributions. The outcome of the technique is basically an estimate of expected time and variance of project completion time. Accordingly, the probability of meeting a particular completion date is determined and also the probability that a particular activity could become critical.

2. RESEARCH METHODOLOGY

The research studied the impact of uncertainties in activities duration and risk events considering a small infrastructure construction project. There are a total of 24 activities in the project. The following steps explain the methodology used in this research:

1. The initial project duration was estimated using a single point deterministic duration for each activity. The project network was drawn using these deterministic durations in MS Project software and the critical path is determined.

2. Then uncertainties in activities durations were added. PERT and Triangular, two commonly used distributions were used for this purpose. @Risk (Palisade 2016) was used for this purpose. Each activity duration was estimated using these two distributions. Based on these probabilistic activities durations, project completion time was determined.

3. Risk events were integrated with the project schedule using Risk Register. Probabilities of risks events happening were estimated and their impacts were determined using three point estimates (Minimum, Most Likely, Maximum) using @Risk.

4.A model was developed with inputs from steps 2 and 3 above. The model outputs were project completion times and days added to the original plan because of risks events.

5.Simulations were carried out in @Risk. Sensitivity analyses were performed and the results were analyzed.

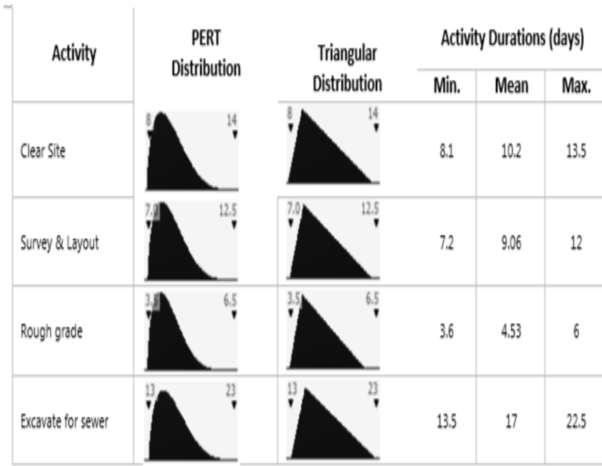
Model Development

Models were developed in @RISK and analyses were performed as explained in the research methodology. Table 1 provides the information about activities of the construction project. The initial project network was calculated in MS Project using these deterministic activities' durations. The project activities, durations, relationships, start dates and finish date are shown in **(Table 1).** It gives initial project completion duration of 88 days and a project completion date of 03/27/2018. This 88 days completion is the critical path duration considering the deterministic activity durations and without occurrence of any risk events.

Table 1: Project information with activities' durations, relationships, start and finish times.

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Project Completion Duration**	**88 days**	**11/24/2017**	**3/27/2018**	
2	Clear Site	9 days	11/24/2017	12/6/2017	
3	Survey and Layout	8 days	12/7/2017	12/18/2017	2
4	Rough grade	4 days	12/19/2017	12/22/2017	3
5	Excavate for sewer	15 days	1/4/2018	1/24/2018	25
6	Excavate elec. Manholes	5 days	12/25/2017	12/29/2017	4
7	Drill well	20 days	1/4/2018	1/31/2018	25
8	Water tank foundations	4 days	1/4/2018	1/9/2018	25
9	Tank fabrication and erection	14 days	1/10/2018	1/29/2018	8
10	Install manholes	6 days	1/1/2018	1/8/2018	6
11	Install electric duct	8 days	1/9/2018	1/18/2018	10
12	Erect overhead poles	6 days	12/25/2017	1/1/2018	4
13	Overhead poles wiring	8 days	1/2/2018	1/11/2018	12
14	Duct wiring work	10 days	1/19/2018	2/1/2018	15,11,16
15	Transformer erection	3 days	1/9/2018	1/11/2018	10
16	Bus bar erection	4 days	1/9/2018	1/12/2018	10
17	Electric safety inspection	3 days	2/2/2018	2/6/2018	13,14
18	Connect piping	10 days	3/8/2018	3/21/2018	19,21
19	Tank piping and valves	4 days	1/30/2018	2/2/2018	9
20	Install well pump	15 days	2/1/2018	2/21/2018	7
21	Under ground water piping	10 days	2/22/2018	3/7/2018	20
22	Install sewer and back fill	10 days	1/25/2018	2/7/2018	5
23	Sewer inspection, test	2 days	2/8/2018	2/9/2018	22
24	Sanitary inspection, test	4 days	3/22/2018	3/27/2018	18
25	Obtain permit	8 days	12/25/2017	1/3/2018	4

In the second step, uncertainties in activities' durations were added using @Risk. Two commonly used techniques, PERT and Triangular distributions were used for this purpose. Each activity duration was estimated using these two distributions. Based on these probabilistic activities durations, project completion time was determined. **(Fig 1)** shows some examples of activity durations using PERT distribution and Triangular distribution.



Activity	PERT Distribution	Triangular Distribution	Activity Durations (days)		
			Min.	Mean	Max.
Clear Site			8.1	10.2	13.5
Survey & Layout			7.2	9.06	12
Rough grade			3.6	4.53	6
Excavate for sewer			13.5	17	22.5

Fig. 1: Examples of activity duration using PERT and Triangular distribution

The parameters for PERT distributions were assigned based on minimum, mean, and maximum duration. The minimum and maximum values were assigned as -10% and 50% below and above the normal duration. The parameters for Triangular distribution were considered as minimum, most likely, and maximum. The minimum and maximum values were again assigned as -10% and 50% below and above the normal duration.

Using these values of min. /max, the distributions are skewed to the right as can be seen in Figure 1, giving more likelihood of activity being completed in longer duration than the mean duration. This is considered better for assigning uncertainties. All the activities' durations were calculated using these distributions in the software.

2. RESULTS AND DISCUSSION

Using the two distributions mentioned above, models were built in @RISK. The inputs to the models were activity duration distributions using PERT and Triangular distributions. The models output were Project Completion Duration/Finish Date. Simulations were performed on the models for both the distributions using 5,000 iterations. In addition, a model was built with an output for additional days added to the plan if certain risk events occurred using their impacts and probabilities. The results are presented below.

Project Finish Time

The original project duration using a single point deterministic duration for activities was 88 days and the project finish date was 3/27/2018.Figure 2 shows the simulation results for project using PERT distribution. It shows that the mean finish date is 4/4/2018. Further, the earliest completion date is 3/20/2018 and the maximum completion date is 4/26/2018. However, there are only less than 1% chances that the project will finish on these minimum and maximum dates. The probability of the project to finish on the mean completion date of 4/4/2018 is 50%.

Summary Statistics for Project Completion Duration / Finish			
Statistics		**Percentile**	
Minimum	3/20/2018	**1.0%**	3/26/2018
Maximum	4/26/2018	**2.5%**	3/27/2018
Mean	4/4/2018	**5.0%**	3/28/2018
Std Dev	4.911030339	**10.0%**	3/29/2018
Variance	24.11821899	**20.0%**	3/30/2018
Skewness	0.213450992	**25.0%**	4/2/2018
Kurtosis	3.000997147	**50.0%**	4/4/2018
Median	4/4/2018	**75.0%**	4/9/2018
Mode	4/3/2018	**80.0%**	4/9/2018
Left X	3/28/2018	**90.0%**	4/11/2018
Left P	5%	**95.0%**	4/12/2018
Right X	4/12/2018	**97.5%**	4/13/2018
Right P	95%	**99.0%**	4/17/2018
#Errors	0		

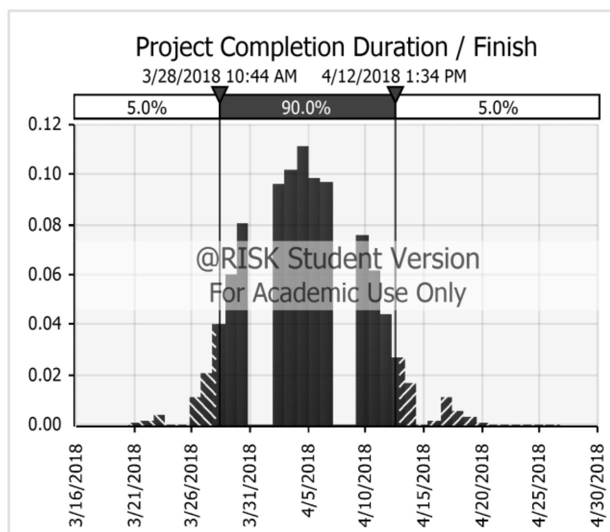
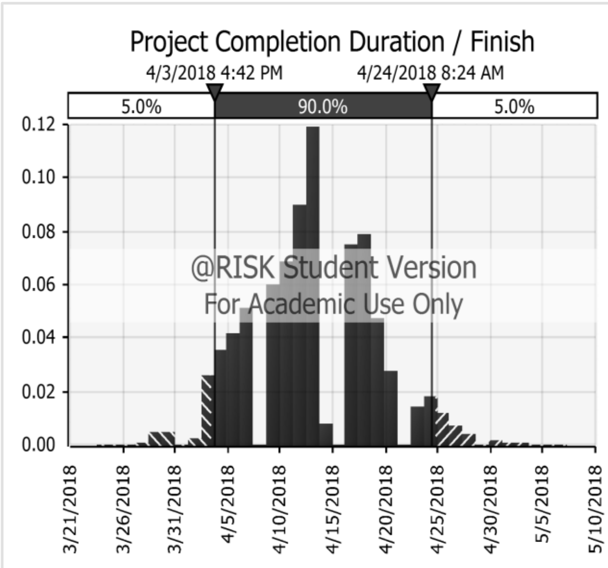


Fig. 2: Simulation results for project completion date using PERT distribution

Fig. 3 shows the simulation results for project using Triangular distribution. It shows that the mean finish date is 4/13/2018. Further, the earliest completion date is 3/23/2018 and the maximum completion date is 5/7/2018. However, there are only less than 1% chances that the project will finish on these minimum and maximum dates. The probability of the project to finish on the mean completion date of 4/13/2018 is 50%



Summary Statistics for Project Completion Duration / Finish			
Statistics		**Percentile**	
Minimum	3/23/2018	**1.0%**	3/30/2018
Maximum	5/7/2018	**2.5%**	4/2/2018
Mean	4/13/2018	**5.0%**	4/3/2018
Std Dev	6.015777913	**10.0%**	4/5/2018
Variance	36.1895839	**20.0%**	4/6/2018
Skewness	0.215387539	**25.0%**	4/9/2018
Kurtosis	2.879488484	**50.0%**	4/12/2018
Median	4/12/2018	**75.0%**	4/17/2018
Mode	4/10/2018	**80.0%**	4/18/2018
Left X	4/3/2018	**90.0%**	4/20/2018
Left P	5%	**95.0%**	4/24/2018
Right X	4/24/2018	**97.5%**	4/25/2018
Right P	95%	**99.0%**	4/26/2018
#Errors	0		

Fig. 3: Simulation results for project completion date using Trinagular distribution

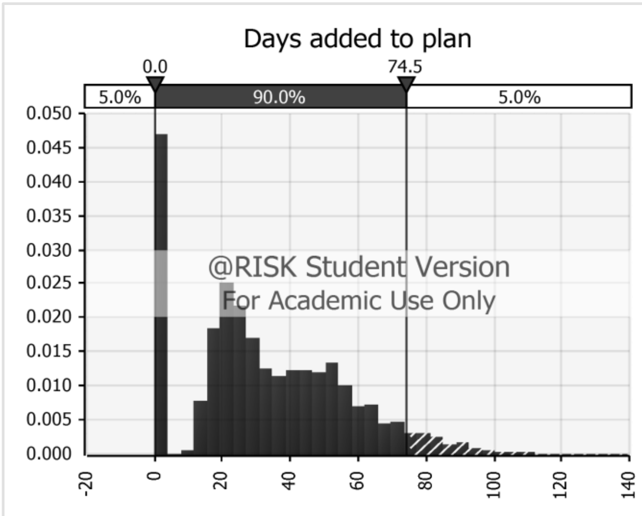
Risk Events' Impacts on Project Schedule

In order to assess the impact of risk events on the project schedule, certain risks were added to the project using risk register. Table 2 provides information about the risks events added to the risk register, including their probabilities of occurring and their impact on project schedule in terms of days added to the plan. The probabilities are assigned to risk events based on their likelihood of happening or historical information. A three point estimate of minimum, most likely, and maximum was used to calculate the impact in terms of days if risk evert occurs. A simulated schedule impact was calculated from these three estimates.

Table 2: Risk register showing risk events and their probabilities and impacts

					Schedule Impacts (days)					
Risk ID	Risk	Probability	Simulated Occurrence	Occurs?	Min	Most Likely	Max	Mean	Simulated Schedule Impact	Days added to plan
R1	Material Delay	50%	0	No	10	20	40	10.83	21.67	0
R2	Labour Delays	40%	0	No	15	25	50	11	27.50	0
R3	Weather	25%	0	No	10	25	50	6.66	26.67	0
R4	Natural Calamity	2%	0	No	20	30	60	0.666	33.33	0
R5	Government Permissions	15%	0	No	10	20	40	3.25	21.67	0

The risk events considered for this research were material delay, labour delay, weather problems, natural calamity, and government permissions. These risks most commonly have a negative impact on projects, especially infrastructure projects. The RiskDiscrete function was used to simulate the impact of risk occurrence or not. @RISK calculates the days added to the original plan if risk event occurs based on the simulated schedule impact. 5000 iterations were performed and the results are provided below in Fig. 4.



Summary Statistics for Days added to plan			
Statistics		**Percentile**	
Minimum	0	**1.0%**	0
Maximum	139.2037154	**2.5%**	0
Mean	32.51091547	**5.0%**	0
Std Dev	23.41929172	**10.0%**	0
Variance	548.4632247	**20.0%**	14.22543957
Skewness	0.474284526	**25.0%**	17.6518039
Kurtosis	2.855155312	**50.0%**	28.90032856
Median	28.90032856	**75.0%**	49.12047013
Mode	0	**80.0%**	52.78665299
Left X	0	**90.0%**	64.08620221
Left P	5%	**95.0%**	74.51804914
Right X	74.51804914	**97.5%**	82.35514057
Right P	95%	**99.0%**	91.4034904
#Errors	0		

Fig. 4: Simulation results for risk events showing days added to the plan

The minimum days added to the plan are zero, meaning that no risk event occurs and therefore, no days added to the original schedule. The mean of the days added to the plan are 32 and the maximum days added are 139. This shows that if the risk events occur there could be a possible delay if mitigation measures are not put in place. The mean/average days that could be added to the plan are 32, whereas in worst-case scenario, up to 132 days can be added.

A sensitivity analysis was also performed to find which risk event has the highest impact. Figure 5 below provides the results of sensitivity analysis. It shows the impact of the risk events arranged by rank or from high impact to low impact on the days added to the original schedule. Labour delays have the highest contribution to the days added and natural calamity has the lowest impact. Weather and material related risks have contributed moderately to the schedule delays.

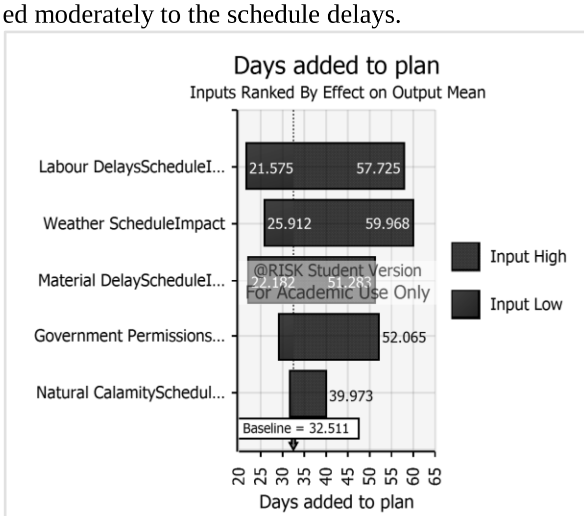


Fig.: 5: Sensitivity analysis showing ranking of risk events

3. CONCLUSION

This research introduced a method to manage risks by measuring their impact on activities' durations and risk events. Models were built in @RISK to perform quantitative risk analyses and determine the impact of uncertainties using Monte Carlo simulations. Two type of distributions were used for assigning uncertainty in activities' durations, PERT and Triangular. Without assigning the uncertainties in activity durations, the project finish date was 3/27/2018. With PERT distribution, the mean finish date is 4/4/2018 with a 50% probability of finishing project on this date. Using Triangular distribution, the mean finish date is 4/13/2018 with a probability of 50%. The Triangular distribution gives a delayed project finish time than the PERT distribution. Therefore, we can conclude that Triangular distribution is better suited for situations where high degrees of uncertainty are involved. Further, analyses were performed for risk events using their probabilities and impacts. It was found that the mean of the days added to the plan are 32 and the maximum days added are 139. This shows that if the risk events occur there could be a possible delay if mitigation measures are not put in place. This research provides the project managers a tool to perform quantitative risk analyses and determine the project schedules based on uncertainties. It can be concluded that risks associated with project schedules can be managed if properly accounted for.

REFERENCES:

Akintoye, A. S., and M. J MacLeod,. (1997). "Risk analysis and management in construction". *International Journal of Project Management*, 15(1), 31-38. DOI 10.1016/S0263-7863(96)00035-X.

Boateng, P., Z. O. Chen, S. Ogunlana (2015). An Analytical Network Process model for risks prioritization in megaprojects. International Journal of Project Management 33 (2015) 1795–1811.

Boehm B. W.(1991) Software risk management: principles and practices. IEEE Software Vol. 8:32-41.

Fairley R. (1994) Risk Management for Software Projects. IEEE Soft-ware; 57-67

Harrison, P. (2007). Can measurement error explain the weakness of productivity growth in the Canadian construction industry? Centre for the Study of Living Standards (CSLS), Research Report No. 2007-01

Hegazy, T. (2002).“ Computer-Based Construction Project Management”, Published by Prentice Hal,.

Kwak, Y. H. and L. Ingall, (2007).“Exploring Monte Carlo Simulation Applications for Project Management,” Risk Management, Vol. 9, 44-57. doi:10.1057/palgrave.rm.8250017

Nasir, H., H. Ahmed, C. Haas, and P. Goodrum (2014) “An Analysis of Construction Productivity Differences between Canada and the United States.” *Journal of Construction Management and Economics*, Vol 32 (6), 595- 607.
doi: 10.1080/01446193-2013-848995.

PMI (2013) “A Guide to the Project Management Body of Knowledge” PMBOK Guide Fifth Edition, Published By Project Management Institute (PMI), Inc., Pennsylvania, USA.

Palisade Corporation (2016). @Risk, Risk Analysis Add-in for Microsoft Excel, Version 7.5.1: Industrial Edition, by Palisade Corporation, 2016 .

Serpell, A. X. Ferrada, and , N. L. Norma Larissa Rubio (2017). Fostering the effective usage of risk management in construction. Journal of Civil Engineering and Management, Pages 858-867, Published online: 13 July 2017. doi.org/10.3846/13923730.2017.1321578

Shahtaheri, M., H., Nasir, C. Haasand T. Salimi (2015). “A time-cost-quality trade-off model for nuclear-type projects.” In proceedings of 5th International/11th Construction Speciality Conference (ICSC), Canadian Society for Civil Engineering (CSCE), Vancouver, British Columbia, June 8-10, 2015.

Zavadskas, E. K., Z. Turskis, and, J. Tamošaitiene (2010) Risk assessment of construction projects, Journal of Civil Engineering and Management, 16:1, 33-46 doi.org/10.3846/jcem.2010.03

Zhi, H. (1995) Risk management for overseas construction projects. International Journal of Project Management Vol.13(4). 231-237
doi 10.1016/0263-7863(95)00015-I