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Quantifying the Monetary Impact of Schedule and Cost Risks in Construction Projects

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Abstract **–** The competitive nature of construction projects coupled with the tight budgets and limited resources make them good candidates for failure if not managed properly. This is in addition to the complex, fragmented, and multidisciplinary nature of projects involving thousands of tasks and details and many participants. These immanent facts promote the emergence of risks in every single construction project. These risks should be effectively managed to mitigate their impact and avoid or reduce delays and cost overruns. While risk management is a difficult and challenging task and requires careful considerations throughout the life cycle of a project, it is important to be proactive and have a risk management plan to tackle this crucial issue by regularly monitoring risk events with an effective communication mechanism among the various project stakeholders, despite the high cost associated with the risk managing process. The majority of research efforts focused on the identification and assessment of risk events with limited efforts addressing the issue of quantifying the effect of these risk events and suggesting effective responses to them. This paper focusses on the use of the program evaluation and review technique (PERT) and the earned value analysis to quantify the impact of the severity of risk events and estimate the expected cost at completion. The study also suggests practical responses to mitigate the impact of risk events. A spreadsheet is developed to help project managers manage risk events and estimate their monetary impact on the project's duration and cost. The developed spreadsheet is expected to help construction contractors mitigate risks in construction projects and be more competitive.

Keywords**:** Construction Projects, Cost and Schedule Risks, Earned Value, Risk Management

1. Introduction

Construction projects are complex, multidisciplinary, and involve many participants and details. As a result, a large number of risk events is naturally expected, and these risk events normally result in rework in design and construction. The uncertainty associated with rework in construction projects has been largely overlooked due to the lack of data regarding its occurrence, reasons, and mitigation mechanisms. For example, errors, discrepancies, mismatches that necessitate rework often remain unnoticed and always lead to delays and cost overruns [1]. The construction industry is well known for its poor reputation history in risk management. Early research efforts have proposed different approaches for assessing construction project risks. Dey, 2001 [2], for example, proposed a risk management system during the early stages of a construction project using the Analytic Hierarchy Process (AHP) and decision trees to manage construction project risks. The approach recommends risk response scenarios rather than quantifying the impact of these risks. Clark and Besterfield-Sacre, 2009 [3] developed a Bayesian Belief Network (BBN) model for risk assessment using a probability and statistics-based approach and historical data. Qiao et al., 2009 [4] developed a model for estimating accident frequency based on empirical databases and fuzzy logic. Kim et al., 2009 [5] developed a BBN model to quantify the probability of construction project risks related to delays. Linthicum and Lambert, 2010 [6] utilized expert elicitation and geographic data to mitigate cost risks associated with infrastructure performance. Li et al., 2013 [7] addressed the management of risks by identifying risk factors and assessing the impacts of the identified risk factors on project cost and duration. Creemers et al., 2014 [8] ranked project risks based on their impact on project objectives. Mouraviev and Kakabadse, 2014 [9] identified the main risks associated with public-private partnership type of contracts. Hossen et al., 2015 [10] proposed a method that uses the AHP for assessing construction risks in nuclear power plants. Gunduz et al., 2015 [11] proposed a fuzzy logic method to quantify the probability of delay risks in construction projects while Muneeswaran et al., 2018 [12] used fuzzy logic to assess schedule risks. Similarly, Budayan et al., 2018 [13] developed a fuzzy logic method to assess construction risks using experts' judgement.

More recently, El-Kholy, 2019 [14] used artificial neural networks (ANN) to predict schedule risks and cost overrun in highway projects. Muizz et al., 2020 [15] developed a model for assessing schedule risks in construction projects using ANN. El-Rasas and Marzouk, 2020 [16] investigated the risks associated with the delays in residential construction projects and developed a fuzzy logic model to predict project delays. Sami Ur Rehman et al., 2020 [17] used building information modeling to identify and manage schedule risks. El Khatib et al., 2022 [18] investigated the significance of business information management as an approach to mitigate project risks during the various stages of projects. Mohamed et al., 2022 [19] presented an interesting approach to assess risks in mega housing construction projects and their impact on time and cost from contractors' perspective. Alfadil et al., 2022 [20] reviewed thousands of articles and concluded that there has been a continuous increase in research related to the handling force majeure and environmental risks in construction and risks associated with the coronavirus pandemic. Wang et al., 2023 [21] used a hybrid multi-criteria decision-making framework to quantify the relative importance of artificial intelligence in managing construction risks, whereas the fuzzy methodology is used to rank and select the most appropriate AI technologies for the construction industry.

Despite the importance of previous research efforts related to risk assessment and management of construction projects, the construction industry is still lagging behind in adopting smart technologies for risk management and quantifying the monetary impact of risk events [22]. This is in addition to the fact that there is a need to overcome the main barriers to risk management implementation in the construction industry, including the use of appropriate risk management techniques. Construction practitioners remain concerned over the task of effective methodologies to assess and manage risks associated with the project's schedule and cost. To address this crucial issue, this study presents a methodology to assess schedule and cost risks associated with construction projects and quantify the the monetary impact of these risks. The study also developed a user-friendly spreadsheet to achieve this objective.

2. Research Methodology

The main objective of this study is to develop a practical mechanism for assessing and managing risks related to the schedule and cost of construction projects using expert opinions and the earned value technique. This study was conducted following the following 6-step methodology: 1) review previous research efforts and identify possible risk events that may affect projects' schedule and cost; 2) conduct a questionnaire survey to obtain the feedback of construction experts in identifying risk events and prioritizing them. The survey was distributed to construction practitioners from municipalities, contractors, and design offices in the United Arab Emirates (UAE) construction industry; 3) the data received from the survey respondents was then analyzed and most important risk events related to construction projects' schedule and cost were identified and the probability of occurrence of the risks was calculated. Identified risks were then ranked by calculating the relative importance index of the probability of occurrence and impact; 4) the severity of each identified risk event was then calculated based on their probability of occurrence and impact. The level of severity of each risk event will be determined based on the severity of these risk events resulting from the calculated probability of occurrence and level of impact of the risk events; 5) the PERT and EV techniques were used for the analysis of the impact and severity of risk events and to measure the schedule and cost progress at any point of time; and 6) a spreadsheet was then developed to determine the relative important index of the probability of occurrence and impact of identified risks and their levels of severity. The spreadsheet also quantifies the monetary impact of these risk events and suggest responses to them.

3. Feedback of Construction Experts

More than 43 risk events related to projects' schedule and cost were identified from the literature. A questionnaire survey was conducted among 68 practitioners in the UAE construction industry, representing a wide range of geographical locations in the country. The purpose of the survey is to provide the feedback of construction experts regarding the most important schedule and cost risk events to be considered for further assessment and analysis. The feedback was received from 52 respondents, representing around 76% response rate. The majority of the respondents selected 15 risk events (shown in Table 1) considering them the most important ones. The construction experts were then asked to provide their feedback on the probability of occurrence and impact of each of the most important 15 risk events on a Likert scale range from "1 to 5" for each risk event, where (1) indicates a "very low" probability of occurrence or impact while (5) represents a "very high" probability of occurrence or impact.

Table 1: The Most Important Risk Events in the View of Construction Experts.

Risk Event
Scope change (additions/deletion)
Late delivery of materials
Errors in the estimation of quantities & costs
Efficiency, late arrival, and downtime of equipment
Rework due to design errors & conflicts in contract documents
Delay in the approval of materials & shop drawings
Limited funds
Quality problems (poor quality & failure to meet specifications)
Unavailability of skilled resources
Complex design
Weather conditions
Different site conditions
Poorly defined scope & inadequate design details
Delays resulting from poor coordination during design & construction
Errors in the estimation of task durations

The data received was analyzed and relative importance index (*RII*) for the likelihood of occurrence and impact were then calculated for each risk event to provide an indication on the importance of each risk event relative to other risk events. The *RII* was calculated as follows:

$$RII_i^k\,(\%) = \frac{(n_1 + 2n_2 + 3n_3 + 4n_4 + 5n_5)}{(n_1 + n_2 + n_3 + n_4 + n_5)} \text{ X } (\frac{100}{5})$$

Where, RII_i^k is the relative importance index of each risk event, "i" to "k" is the batch of respondents, and "n" is the number of responses received. The *RII* is used to rank the risk events in terms of their probability of occurrence and impact. The *RII* for the likelihood of occurrence of the "Scope change (additions/deletion)" risk event, for example = [(1X3 + 2X5 + 3X11 + 4X18 + 5X15)/52] X (100/5) = 74%. Similarly, The *RII* for the impact of the "errors in the estimation of quantities and costs" risk event = [(1X2 + 2X10 + 3X14 + 4X14 + 5X12)/52] X (100/5) = 69%. The *RII* percentages for the probability of occurrence and impact of all risk events are listed in Table 2. As shown in Table 2, the likelihood of occurrence of the "errors in the estimation of task durations" risk event is the most probable event with an *RII* of 75%, ranking it first. The "scope change (additions/deletion)" is ranked second with an *RII* of 74%, while the "weather conditions" risk event is ranked last with an *RII* of 47%. On the other hand, the impact of the "poorly defined scope and inadequate design details" risk event is ranked first with an *RII* of 73%. The impact of the "complex design" risk event is ranked second with an *RII* of 72% while the impact of the "weather conditions" risk event is ranked last with an *RII* of 49%. The severity of each risk event was then calculated using the following equation: severity (*S*) = frequency of occurrence (*F*) X impact (*I*). As shown in Table 2, the "poorly defined scope and inadequate design details" risk event has the highest severity with a severity = 74% X 69% = 52%. The severity of the "scope change (additions/deletion)" risk event is ranked second with a severity value of 51% while the "weather conditions" risk event was ranked last with a severity value of 23%. The severity of risk events is classified into four levels: negligible (NEG) if the severity value is below 4%, low (LOW) if the severity is ≥ 4% and less than 16%, medium (MED) if the severity is ≥ 16% and less than 40%, high (HIG) if the severity is ≥ 40% and less than 60%, and extreme (EXT) if the severity is ≥ 60%.

Table 2: RII of the Likelihood of Occurrence and Impact of Risk Events.

Risk Event	Likelihood *RII*	Impact *RII*	Severity	
Scope change (additions/deletion)	74%	69%	51%	EXT
Late delivery of materials	70%	69%	48%	HIG
Errors in the estimation of quantities & costs	69%	70%	49%	HIG
Efficiency, late arrival, and downtime of equipment	54%	71%	38%	MED
Rework due to design errors & conflicts in contract documents	58%	67%	39%	MED
Delay in the approval of materials & shop drawings	72%	64%	46%	HIG
Limited funds	49%	65%	32%	LOW
Quality problems (poor quality & failure to meet specifications)	63%	62%	39%	MED
Unavailability of skilled resources	59%	69%	41%	HIG
Complex design	53%	72%	38%	MED
Weather conditions	47%	49%	23%	NEG
Different site conditions	48%	53%	26%	LOW
Poorly defined scope & inadequate design details	71%	73%	52%	EXT
Delays resulting from poor coordination during design & construction	70%	61%	43%	HIG
Errors in the estimation of task durations	75%	66%	50%	HIG

In a generic representation, Table 3 suggests a risk matrix to identify the level of risk depending on the likelihood of occurrence and impact of the risk event, assuming a likelihood of occurrence range of rare (RAR), unlikely (UNL), possible (POS), likely (LIK), and almost certain (ALC), while the impact range is assumed to be insignificant (INS), minimum (MIN), moderate (MOD), major (MAJ), and catastrophic (CAT).

Table 3: Risk Severity Matrix.

Likelihood	**ALC**	MED	MED	HIG	EXT	EXT
	LIK	LOW	MED	HIG	EXT	EXT
	POS	LOW	MED	MED	HIG	HIG
	UNL	LOW	LOW	MED	MED	MED
	RAR	NEG	LOW	LOW	LOW	MED
		INS	**MIN**	**MOD**	**MAJ**	**CAT**
		Impact				

4. The Developed Spreadsheet

A spreadsheet was developed to help project managers assess and manage schedule and cost risk events of their projects. The spreadsheet is developed to perform four main functions:

Risk severity matrix generation: as explained in the previous section, severity levels of the risk events are determined from the calculated *RII* values of the likelihood of occurrence and impact. Project managers, however, have the option to use the calculated risk severity values, use the suggested severity risk matrix (Table 3), or generate their own risk severity matrix by adding new risk events, deleting existing risk events, or suggesting different values for the likelihood of occurrence and impact of risk events.

Project scheduling: considering the optimistic (o), most likely (m), and pessimistic (p) times of all tasks in a project, the spreadsheet calculates the expected time ($t_e = \frac{o + 4m + p}{6}$), standard deviation ($\sigma = \frac{(p-o)}{6}$), and variance ($v = \sigma^2$) for each task and sends the expected times (t_e) of tasks to Microsoft Project scheduling software to schedule the project and identify critical activities. Excel then reads the project's expected time (T_E) from Microsoft Project and calculates the project's standard deviation (σ_{TE}) using the critical activities identified by Microsoft Project.

Quantitative risk assessment and analysis: using the project's calculated T_E and σ_{TE}, the probability (P_T) of finishing the project in its planned duration (T_S) is calculated. The probability of risk (PR_T) for finishing the project in its "T_S" duration is then calculated as follows: $PR_T = 1 - P_T$. A delay in finishing a project in its scheduled time (T_S) normally results in a delay penalty paid by the contractor for each day of delay. The monetary impact resulting from the delay = the overall delay (in days) X the amount of the delay penalty per day. The severity of the risk associated with the project's schedule (SR_T) is then calculated, where SR_T = monetary impact resulting from the delay X PR_T. The risk associated with the bid price is also determined in a similar manner. The *PERT* technique is used to calculate the expected project's cost (C_E) and the standard deviation of the expected project's cost (σ_{CE}). The probability (P_C) of meeting the planned bid price of the project (C_S) is then calculated and the probability of risk (PR_C) of meeting the project's bid price is determined, where $PR_C = 1 - P_C$. The *EV* technique is then used to measure the project's schedule and cost progress using the schedule performance index (*SPI*) and the cost performance index (*CPI*). The calculated *CPI* value is then used to estimate the project's cost at completion (*EAC*) at any time during construction, where *EAC* = (*budgeted cost of work scheduled)*$_{\text{(at completion)}}$/*CPI*$_{\text{(at present)}}$. The monetary impact resulting from the effect of the current *CPI* on the *EAC* = *EAC* X (the project's pessimistic price - C_S). The severity of the risk associated with the project's bid price (SR_C) is then calculated, where SR_C = the impact of the *EAC* X PR_C.

Risk response: the developed spreadsheet suggests a set of responses to risks associated with the project's schedule and cost, depending on the risk event that may result in a delay or a cost overrun. Project managers will have the option to suggest responses to the current risk events and the newly added ones.

5. Mitigation Strategies

A plan to mitigate the effect of identified risks on the project's schedule and cost is necessary to bring them to an acceptable level. Several actions are necessary to mitigate risk and minimize their impact. Some of the important actions include the preparation of a detailed risk management plan and implementing it, obtaining a commitment from the organization for funding and staff, replanning the work to remove some serious risks, avoiding complex design and using standard design methods, documenting all project deliverables, minimizing changes, considering the impact of external and environmental problems, keeping contract documents current, using experienced and reputable suppliers, asking for materials to be shipped early to avoid shipment delays, managing outsourcing and controlling the work done by others, tracking project resource use, break large projects with large staff into smaller parallel ones, breaking long projects into phases that produce measurable outputs, reducing the number of critical paths to a minimum, modifying the work to have fewer activity dependencies, scheduling high-risk activities as early as possible. Other mitigation strategies include tracking progress with and reporting status frequently, decomposing lengthy activities further, using proper and effective project organizational structure, modifying plans to reduce the load on excessively committed staff, delegating risky work to experienced and successful problem solvers and use the best people available for the most critical activities, training team members to use more efficient or faster methods, upgrading or replacing older equipment to make work more efficient, automating manual work when possible, minimize dependence on a single individual for project work, establishing contract terms with all suppliers and subcontractors, establishing a risk work breakdown structure and a risk register to track risks, providing enough time to correctly estimate activities' durations and quantities, paying attention to areas where costs may increase and include contingencies in the project's budget, monitoring the project's schedule and cost and measuring the project's performance, having a well-defined scope and avoid changing it, making sure that materials are delivered on time and track material and shop drawings submittals, assigning a coordinator during the design and construction stages, and transferring risks where the impact is primely financial.

6. Conclusion

This paper uses the feedback of construction experts to prioritize risk events and estimate their impact. A total of 15 risk events have been identified as the most important schedule and cost risks. A spreadsheet is then developed to analyze identified risks events, determine their severity, and quantify their monetary impact. Survey responses were analyzed and the relative importance index values for the likelihood of occurrence, impact, and severity of each risk event were determined. Analysis results revealed that the "errors in the estimation of task durations" is considered the most probable risk event to happen followed by the "scope change (additions/deletion)" risk event. The "weather conditions" risk event is the least probable risk event. The results also revealed that the impact of the "poorly defined scope and inadequate design details" risk event is maximum followed by "complex design" risk event, while the "weather conditions" risk event has the minimum impact. The severity of the "Poorly defined scope & inadequate design details" risk event is ranked first with an *RII* of 52% while the "scope change (additions/deletion)" risk event is ranked second with an *RII* of 51%. The "weather conditions" risk event was the least severe with an *RII* of 23%. The proposed spreadsheet also estimates the monetary impact of schedule and cost risks using the *PERT* and *EV* techniques by estimating the severity of risks associated with the project's schedule and bid price. The spreadsheet provides project managers with several suggested responses to each risk event and presents a list of guidelines to mitigate risks. The developed spreadsheet is expected to help project managers effectively manage risks associated with task durations and costs of projects, estimate their monetary effect, and mitigate their impact.

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