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CORPORATE-LEVEL RISK ANALYSIS FOR INDUSTRIAL PROJECTS

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Abstract: The planning and execution of design, procurement and construction (EPC) of capital projects is a lengthy and complex endeavor due to various technical and non-technical factors. Uncertainty and risk events further add to this complexity and as a result many projects suffer from significant cost overruns and schedule delays. One way to account for such overruns is to accurately establish and assess a project's risk (threat and opportunity) profile, including the confidence in achieving cost, schedule, and/or other project objectives (e.g., quality) projections. An accurate assessment of risk and uncertainty leads to a reasonable estimate of contingency. It also results in prioritizing the mitigation of risks with the greatest impact on the project outcomes. Furthermore, it enables decision-makers and stakeholders to have an enhanced understanding of project drivers, increased certainty in project-based decisions, and improved ability to successfully achieve desired outcomes. This paper highlights the main steps required to conduct a practical risk and uncertainty analysis at a corporate level using operational experience provided by an industry partner.

1 INTRODUCTION

1.1 Background

Management of risks and uncertainty begins during the project development stage (i.e., go/no-go phase) and continues until the project is completed (close-out phase). It is important to note that as the project matures the number of risks to be assessed and monitored will fluctuate. The purpose of this paper is to provide EPC based organizations with recommended practices and processes to more efficiently identify and analyze risks (both opportunities and threats) and uncertainty over the project lifecycle. Furthermore, the effective analysis of risk and uncertainty can result in the following benefits:

- Maximize the probability of positive events (opportunities)
- Minimize the probability and consequences of negative events (threats)
- Enable better management of project costs and schedule and other possible objectives (e.g., quality)
- Enable better management of risks
- Enable risk managers to make risks explicit
- Increase confidence in project decision making
- Improve internal collaboration and discussion with project team and organization

Appropriate analysis of risk and uncertainty (which fall under the umbrella of Risk Management) are crucial in developing sufficient contingency for large scale projects (i.e., $500M and above). Risk Management further focuses on reducing the possibility of "unexpected" events which can result in "unexpected" cost overruns and schedule slippages to occur in various phases of a project.

This paper provides a framework for the identification and analysis of uncertainty and risk throughout the life cycle of industrial based project (e.g., Power Plant, Gas Compression, Nuclear Rehabilitation, Pipeline) based on operational experience provided by an industry partner.

The risk analysis section in this paper is divided into three channels, namely: risk identification, qualitative assessment of risks, and quantitative assessment of risks. The third channel is further divided into two sections which are: deterministic and probabilistic assessments which depending on the criticality level of the risk will be applied. Once risks are quantified, risk response will be set and the finalized risk register (i.e., a list of identified risks, and for each risk the following information is available: risk description, probability of occurrence, consequences, owner, etc.) will be monitored and updated throughout the project lifecycle. An example of a risk register with a deterministic impact value is shown in Table 1. Note that the risk register is a live document throughout this lifecycle. On the other hand, uncertainty analysis occurs once the project is awarded, and it assist in providing a realistic contingency by incorporating ranges for the duration and cost of critical and near critical activities in the schedule. The transformation of single point value to a range of values enables a set of outcomes (instead of a single outcome) and the confidence of achieving each of those outcomes (Shahtaheri et al. 2017). The level of confidence to accomplish certain outcomes is also known as the Confidence Index Threshold.

Table 1: Risk Register Sample

Risk Title	Probability	Schedule Impact (days)	Mitigation Plan	Owner	Deadline
Thunderstorms cause a material delay	0.05	20	Schedule deliveries prior to storm season	Robert Jackson	3/21/16

The detailed steps required for initiating and completing each level of risk and uncertainty assessment is provided in Figure 1.

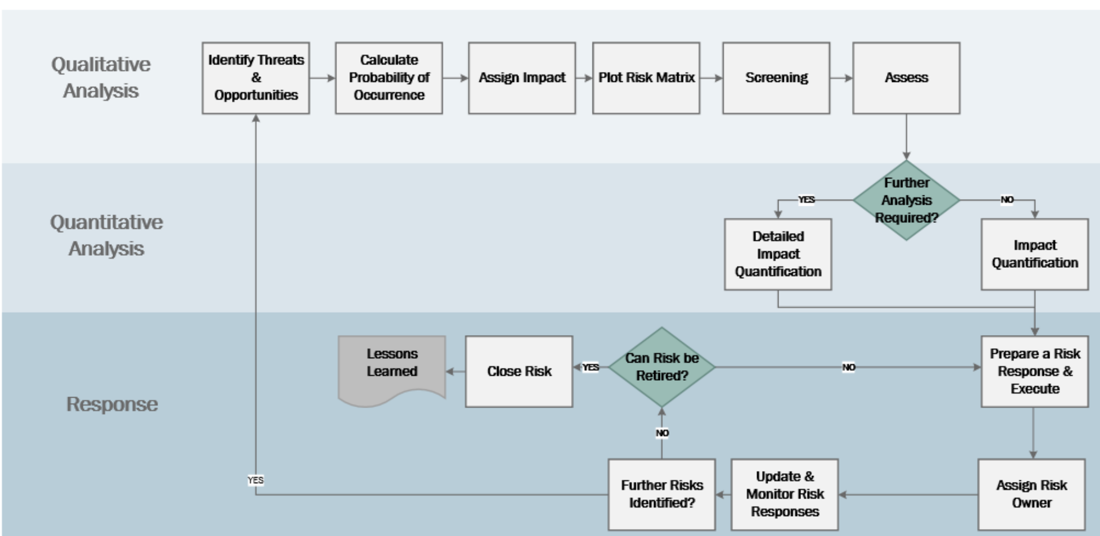

Figure 1: Risk Analysis Flowchart

1.2 Risk Modelling and Assessment

Risk is typically defined as: $Risk = \text{Probability} \times \text{Impact}$ (P-I), reflecting the common view that risk has two elements: (1) probability and (2) impact (Shahtaheri et al. 2016). Unfortunately, compared to other industries such as finance and insurance, the construction industry has a poor reputation for risk analysis (Laryea, 2008) because of the significant gap between the theory and practice of risk modelling and assessment. The probability-impact (P-I) risk model has been the most common risk assessment technique applied (Taroun, 2014). However, over time, many revisions have been made in an effort to improve this model (Jannadi & Almishari, 2003; Cervone, 2006; Han et al. 2008; Vidal & Marle, 2012).

Similar to risk modelling approaches, risk assessment techniques progressed overtime. Before the 1980s, probability theory and later Monte Carlo simulation were introduced to deal with cost and duration risks (Hertz, 1964; Taroun, 2014). At that time, risk was perceived as an estimation deviation. During the 80s, a philosophical shift began to reflect on risk as a project attribute instead of an estimation variance. This reflection is observed in techniques developed at the end of that decade, such as: Fuzzy Sets Theory (FST). FST was introduced as a tangible approach for handling subjectivity (e.g., human factors) in the risk assessment process (Paek et al., 1993; Kangari and Riggs, 1989). In the 90s, another issue that faced risk assessment was the concept of complexity. Complexity is defined as the relationship between project complexity and the risk assessment techniques. To quantify this relationship, the Analytical Hierarchy Process (AHP) was introduced (Mustafa & Al-Bahar, 1991). AHP provided a reasonable approach for assessing risk impact and allocating importance weighting to link project complexity to assessment. Since 2000, as the central processing units became more powerful, decision support systems (DSSs) were used to facilitate the risk assessment process (Taroun, 2014). Mentioned approaches hold a great value, however due to time and resource limitations throughout the lifecycle of an actual project, it is often challenging to regularly implement such techniques on real-world ventures.

Based on literature, development of an accurate risk assessment method leads to a realistic determination of the project risk level. To estimate the project risk level, first risks need to be accurately identified, categorized, and structured via methods such as: influence diagrams, Bayesian networks, decision trees, and the hierarchical risk breakdown structure, and second the individually structured risks need to be aggregated, via methods such as: fuzzy averaging rule and Utility Theory to generate the project risk level. The main limitation associated with these methods are the failings to consider the realistic interdependence among risks (Dikmen et al., 2007b). Solutions to this challenge include the judgement of Subject Matter Experts (SMEs) based on previous exposure to similar risks and the use of proper simulation platforms such as @Risk™ (Shahtaheri, 2016).

1.3 Uncertainty Modelling and Assessment

In the construction industry, uncertainty is often described as the variability embedded in the base cost and schedule estimates. This variability depends on the maturity of input available to the planning process (AACE International, 2010), which depends on the level of project definition. Sources of uncertainty include: (1) cost and schedule estimating assumptions, (2) productivity variability, (3) material cost variability, and (4) mobilization issues (Shahtaheri et al., 2015). These variations transform the deterministic project objective values into distributions. Three main approaches are employed for uncertainty analysis: analytical, probabilistic, and fuzzy (Zonouz & Miremadi, 2006; Sadeghi et al. 2010; Arunraj & Maiti, 2013). Once the output has been obtained using any of the mentioned approaches, project decision makers are primarily interested in two statistics: an arbitrary quantile and the probability of exceeding a specific threshold (Sadeghi et al., 2010).

One practical way to capturing uncertainty is using Monte Carlo simulation which is based on the probabilistic technique. Next, the framework used for Monte Carlo simulation is described.

1.4 Monte Carlo simulation-based Scheduling

As mentioned earlier, uncertainty is the variations inherited in the base duration and cost of an activity. To address uncertainly, the deterministic cost and duration of each activity need to be transformed into a probabilistic range of possible values. To effectively reflect the impact of uncertainty associated with time and cost on project objectives, Monte Carlo simulation (MCS) can be used. An MCS-based scheduling method generates two random values for cost and duration based on their associated uncertainty profiles. A typical procedure for MCS-based scheduling is as follow:

- A random number between 0 and 1 is generated from a seed value using pseudorandom number generators.
- The random number is then used to generate a duration and cost value from the predefined probability distributions. Triangle distributions are mainly used to address uncertainty as a common distribution used in the construction industry (Hendrickson, 2009).
- A typical triangle distribution is developed via three values, namely: minimum (a), most likely (c), and maximum (b). The cumulative distribution function of a random variable X that follows a triangle distribution can be given by Equation 1.

[1] $$P(X < x) = \begin{cases} 0 & x < a \\ \frac{(x - \ldots)^2}{(b-a)(\ldots} & \\ 1 - \frac{(b \ldots}{(b-a \ldots} & \\ 1 & \end{cases}$$

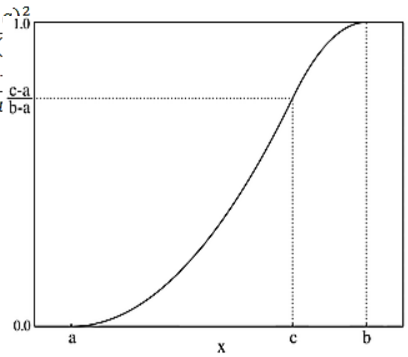

Figure 2: Triangle Cumulative Distribution Function (CDF)

If u is used as a parameter to denote the cumulative probability $P(X < x)$, which lies between 0 and 1, one can have:

[2] $$\begin{cases} x = a + \sqrt{u(b-a)(c-a)} & for\ 0 < u < \frac{c-a}{b-a} \\ x = b - \sqrt{(1-u)(b-a)(b-c)} & for\ \frac{c-a}{b-a} < u < 1 \end{cases}$$

Equation 2 allows for sampling from a triangular distribution with support [a, b] utilizing the inverse CDF transformation technique (Vose, 1996).

The randomly generated value by Monte Carlo process is then used to replace the baseline duration and cost values to simulate the corresponding project schedule. This process allows the determination of the “criticality index” which is used to determine the probability that an activity falls on the critical path. It also enables the criticality calculations of parallel paths. Figure 3 summarizes the steps required to complete on simulation run using MCS procedure.

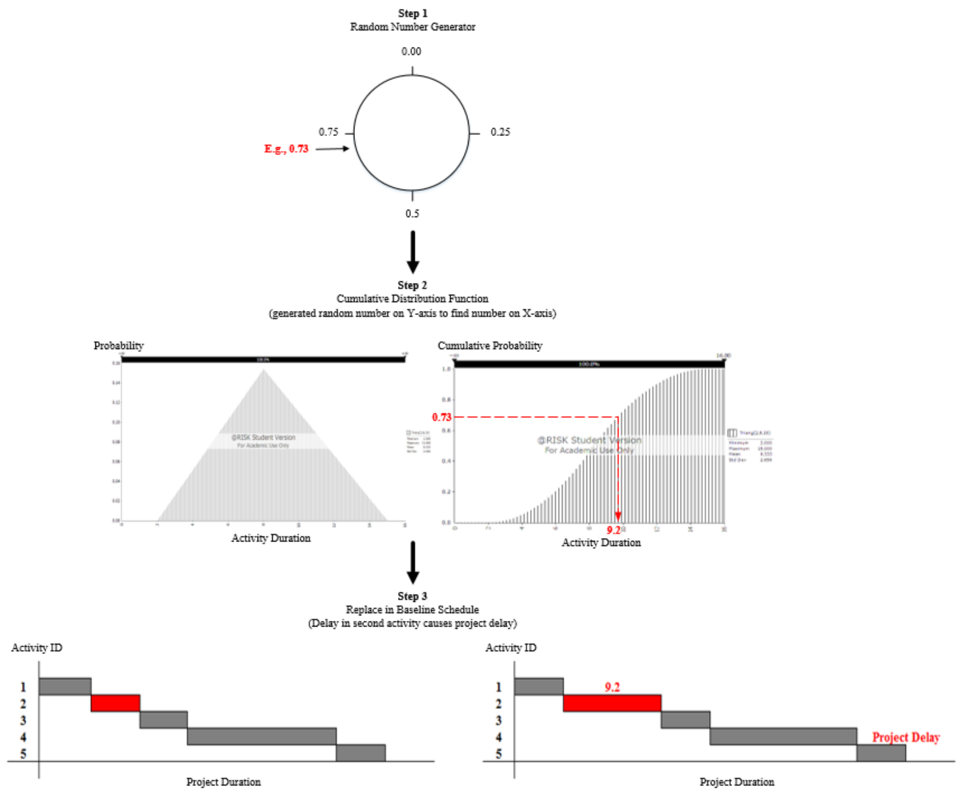

Figure 3: The Monte Carlo simulation approach in project scheduling (for Duration)

Another factor that leads to variations in duration and cost values of activities is the occurrence of a materialized risk events. A risk event may affect many activities, each with a different level of impact. Similar to quantifying uncertainty, Monte Carlo Simulation is used to measure the potential impact of risks on the project objectives (cost and time). Probability and impact are considered as random variables within probability density functions. The calculation of the estimated risk involves a large number of iterations in order to obtain a set of sample values rather than a single value, which means that the results can be treated statistically. Note that, it is crucial for the stakeholders and decision makers to comprehend the mechanistic nature of risk and uncertainty assessment approach used in order to provide more efficient feedback during the identification and evaluation process of risks.

1.5 Project Lifecycle and Risk Analysis

Since industrial projects are commonly long, complex, expensive, and highly dependent on technology, the planning stage is often long completed before the execution phase begins (Asrilhant et al., 2006). The purpose of planning is to identify the main activities that satisfy the project objectives (e.g., duration, cost, and quality) (Gomez-Mejia et al., 2012). As the planning window for a project increases, the probability of inaccurate estimations increases as well. Therefore, the greater the project's duration and complexity, the more likely the estimated baseline will vary along the progression of the project. As mentioned by Prieto (2015), Olaniran et al. (2015), and Cooke-Davies et al. (2007) the classical project management approaches are not sufficient for planning and monitoring industrial projects, as an error in the initial estimation phase (e.g., unknowable error during the estimation, unpredictability of project team behaviour, unanticipated changes in the climatic conditions, political conflicts, geographical conditions, exchange rate fluctuations, changes in legislation, and unexpected less in productivity) (Olaniran et al., 2015) can lead to a chain reaction that can create a series of errors which result in the executed objective values substantially varying from the planned ones (Prieto, 2015; Olaniran et al., 2015; Cooke-Davies et al., 2007). Figure 4 shows the relationship between the project lifecycle and exposure to risk impacts.

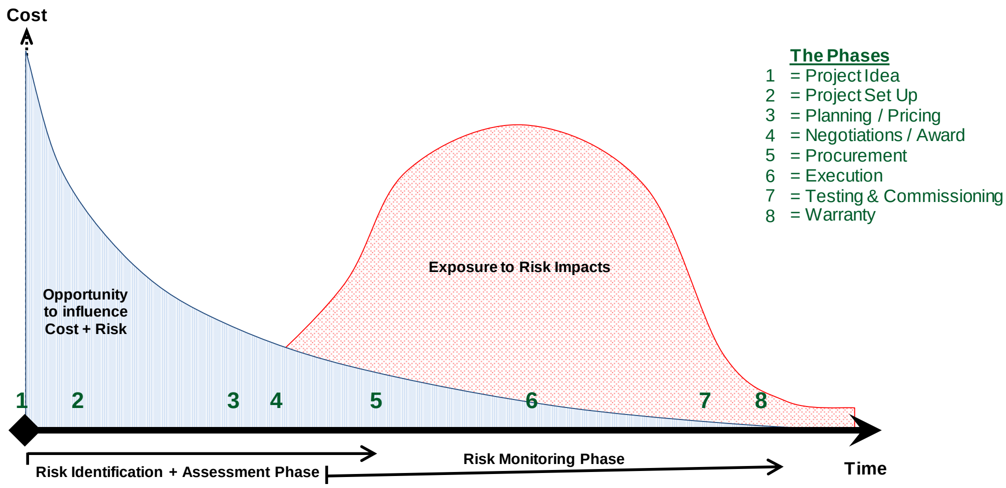

Figure 4: Project Lifecycle & Risk Analysis

2 RISK IDENTIFICATION & ANALYSIS

The process of risk identification within an industrial setting typically starts by conducting a risk workshop during the bidding stage. The risk manager/person in-charge of the risk register needs to assist the proposal manager to stimulate thinking and discussion in to order to identify risks. For such workshops, experience with similar types is typically a good starting point. During this meeting, the risk manager provides prompt lists to help stimulate or start this dialogue. Part of a generic risk list provided by the industry partner for the category of execution/performance and subcategory of construction is shown in Table 2.

Table 2: Construction Initial Risk List

Subcategories	Risk Items	Considerations
Procurement Risk	Long lead items, small number of providers	
Site Risk	Site access, neighbourhood, local Conditions, First Nation, staging area.	
Pre-existing conditions	Archaeological artifacts, Subsurface conditions, soil conditions, ground water level	unlimited soil risks?
Labour	Number/Experience/Availability/Trade Union jurisdictions	
Equipment	Quality/Quantity/Availability	Including transportation/shipment limitations
Material	Quality/Quantity/Availability	Including transportation/shipment limitations
Subcontractors	Experience, staff, internal administration	Pre-qualification recommended. Any nominated subcontractors?
Consultants	Quality/Quantity/Availability	Includes for surveyors
Partners	Experience, staff, internal administration	
Required Standards/ Quality	One of a kind job, extraordinary high standards, unusual foreign standards, nuclear standards	New untried technologies
Required construction methods	Noise, vibrations, emission restrictions.	

Performance Guarantees	Time/output guarantees/quality guarantees	Do we guarantee future performance of the project including for elements beyond our control?
Time Limits	Short durations, planned work interruptions, reaction periods, time limits on notices, predetermined durations / work sequences	Basically all work schedule related issues.
Existing Structures	Demolition risks, unknown conditions (covered)	This includes for structural weakness, undisclosed deficiencies and others.
Owner/Third Party participations	Third Party Works (e.g. Tenants), Owner's own forces, Owner delivered supply items/materials/equipment.	

First step to risk analysis is the subjective approach to assessing each risk for its likelihood of occurrence and impact on the project, which is also known as quantitative risk analysis. The primary objective of qualitative analysis is to provide the project team with a prioritization of risks to be addressed and analyzed further by the project team. A risk register is suitable to capture the quantitative assessment of risks attained in the workshop mentioned in the previous step. One common way to do so is using a risk heat map. A risk heat map represents a qualitative measure of all possible probable effects associated with all possible risk types. Letters “V”, “H”, “M”, and “L” respectively represent very, high, medium, and low. The qualitative assessment will further be translated into a quantitative assessment of risk events, by assigning numerical values to each ranking category (e.g., VL and L). A typical risk heat map is shown in the Figures 5 (Molenaar et al., 2013).

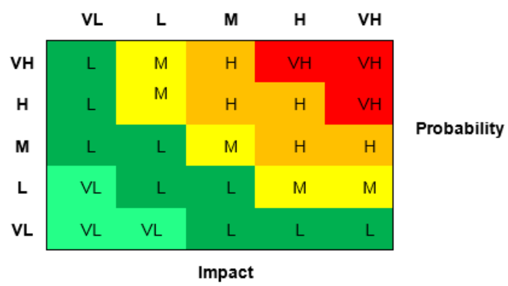

Figure 5: Risk Heat Map

After the qualitative analysis is complete, the risks are rated and ranked into one of the three categories: (1) Minor risks, which do not require further management attention are low impact and low frequency, (2) Medium to moderate risks, that may require quantitative analysis are either low likelihood/low impact or low likelihood/high impact (deterministic risk analysis), and significant risks, that require management attention and quantitative analysis are high impact and high frequency (probabilistic risk analysis).

Tables 3 and 4 are used to transform the risk heat map into a quantitative assessment of risk probability and impact, respectively. If the quantitative probability of occurrence related to a threat exceeds 80% (i.e., very high impact) the risk is no longer considered a risk event and is defined as an activity to be included in the schedule (if accepted).

Table 3: Numerical Ranges for Probability of Threat Occurrence

Description	Label	Probability
Will probably occur in most circumstances	Very High	70% to 80%
Might occur under most circumstances	High	50% to 70%
Might occur at some time	Medium	30% to 50%
Could occur at some time	Low	10% to 30%
May occur in exceptional circumstances	Very Low	≤10%

Table 4: Numerical Ranges for Impact of Risk Occurrence

Label	Impact (% of Managed Value)
Very High	1.00%
High	0.75% to 1.00%
Medium	0.50% to 0.75%
Low	0.25% to 0.50%
Very Low	≤0.25%

Impact assignments are based on the qualitative assessment (risk heat map) of the impact as a percentage of the managed (contract) value (i.e., total value of work in terms of cost, duration, and quality measures). For example, if a threat identified for a large-scale project with an estimated budget of $800,000,000 falls under an impact level of medium, the impact value for this risk is in the range of $4,000,000 (0.005×$800,000,000) to $6,000,000 (0.0075×$800,000,000). Also, if the impact level of a threat occurrence falls within the very high category, a maximum impact value should be assigned to that specific threat. Note that, either values of $4,000,000 or $6,000,000 is the final outcome/stage of the deterministic level of the risk analysis for that specific threat.

There also exists a list of activities associated with the risk events. This item is a list of all possible activities and durations, along with the additional associated dollar value that may be applied during the occurrence of risk events. It is important that each risk be mapped to its possible list of manipulated items (i.e., activities) in order to provide further assistance with the identification of the resources required and the definition of appropriate response strategies. The process of a feasible risk response plan includes the identification, evaluation, and selection of appropriate response strategies and actions. Risk response must be intended to eliminate or lower the probable impact of a threat to an acceptable level considering project objectives and constraints, or alternatively to increase the benefits of an opportunity. Commonly used risk response plans include: acceptance, avoidance, transference, mitigation, and contingency planning. Note that, the final outcome of a quantitative risk analysis is the post-mitigated probable consequence (aka revised risk magnitude based on the selected response plan).

For probabilistic risk analysis, it is important to the define the input and output sets. Example of input set include: activity distribution, probability of risks occurrences, impact of risks on budget and schedule, activities starting time. Example of output sets include: finish date based on threshold of probability, estimated number of days added to the schedule due to risk occurrences, estimated additional costs added to the budget for handling certain risk events that may occur during project execution (contingency). The input ranges/distributions need to be defined using SMEs previous exposure to similar risks and data available for similarly executed projects in the past during the risk workshop meetings. Once required information is available, section 1.4 is used to provide outcome for a probabilistic risk analysis.

3 UNCERTAINTY ANALYSIS

In order to produce a more transparent and traceable set of outputs, it is crucial to assess uncertainty which is inherited in the duration of each planned activity. Uncertainty primarily refers to the variability in duration of the schedule activities and the values of the base cost estimates, with the amount of variability dependent on the degree of ambiguity and accuracy in the schedule and cost estimate data utilized. Uncertainty is embedded in the duration/cost values and transforms deterministic values into distributions. Examples of sources of uncertainty include: cost and schedule estimating assumptions, variable productivity rates, variable material costs, and mobilization problems.

Factors such as variable skill sets and levels of experience, inconsistencies between individual workers at different times, lack of knowledge of/or failure to understand the scope definition of project specifications, and inaccurate assumptions made about “unknown unknowns” are considered and incorporated in the determination of ranges once the project is awarded. Assuming AACEi estimate classification system is used during the estimation phase of a project, the range defined for an activity in a Class 2 estimate can be in a range between -15% to +20% with respect to its deterministic value, resulting in a triangle distribution (0.75×most-likely, most-likely, 1.2×most-likely). Note that, this classification system consists of 5 estimate classes which are defined based on the level of project definition. Class 5 represents the lowest level of project definition (with a low range of -20% to -50% and a high range of +30% to +100%) and the Class 1 estimate (with a low range of -3% to -10% and a high range of +3% to +15%) represents the closest to complete project definition. Now, there may be other sources of uncertainty/ranges which need to be added or deducted to/from this range to produce the final range that represents the uncertainty for this certain activity. Section 1.4 can be used to attain results for this section.

4 CONCLUDING REMARKS

Industrial type project are inherently complex endeavors that requires interaction between a great number of interface points to coordinated the production of deliverables. The successful execution of such project is inherently dependent on the project team’s ability to proactively identify and analyze risks that potential can impact the project negatively from a cost and schedule perspective. The framework presented in this paper provides a comprehensive and intuitive approach for the use of Monte Carlo Simulation in quantifying risk. The success of any simulation model is dependent on the quality of information, it has been observed that the use of prompt lists, such as the one presented, provides project team members with a structured approach and a logical roadmap to identify risk.

The framework presented is scalable and can be easily implemented into any project based on the overall organizational risk tolerance levels. The principals of MCS do not change, only the definitions of probability and impact will need to be updated accordingly.

Today, most organizations have an internal Confidence Index Threshold that must be met by the proposal team prior to bid submission. This allows executives to analyze potential exposure and liability of an organization as it relates to any given project being executed.

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