CONSTRUCTION—YOU NEED RISK-BASED COST ESTIMATING

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ABSTRACT

Every cost estimate is uncertain. Underestimating construction costs by owners in the planning or design phase or by contractors in the bidding phase, and the possibility of low probability/high impact "black swan" events, can lead to disputes, claims, and litigation. A better understanding of potential costs can help owners budget and secure authorization for projects, with a reduced chance of cost overruns. A better understanding of potential costs can help contractors in determining an appropriate base cost and margin for bidding, strategies to secure the work in a low-bid environment, and construction management strategies to maximize profit, to avoid loss, and to better manage and recover costs of construction changes and claims.

This paper will address cost estimating methods focused on construction. It will address the uncertainty inherent in predicting the value of any future project element or process as well as identifying risk (threats or opportunities) that can impact outcomes. It will address risk-based methods that can improve our understanding of the cost of uncertainty and potential risk events.

INTRODUCTION

Estimating and managing the costs of complex infrastructure projects—in the planning/design and construction phases, for both owners and contractors—has been a challenge for decades. The more complex and technologically advanced the project, the greater the uncertainty, including potential risks, that are important to owners and contractors, such as:

- Cost risks to owners—meeting budget and schedule, maintaining public credibility
- Cost risks to contractors—profit, consequences of loss, impacts to reputation/future work

This concern has been addressed in various ways by the underground construction industry for some time (Reilly 2001). In particular, while significant advances have been made in cost estimating for the planning and design phases (Reilly et al., 2004) which are important to agencies and political decision-makers, it is not apparent that these advances have been widely adopted for construction cost estimates. The reasons for this may relate to "low-bid" considerations—any method that tends to increase the contractor's cost estimate, by including risk or likely costs, could lead to an erosion of the contractor's competitive position—if others are not similarly required to include such costs.

Different cost estimating methods produce different levels of information. Specifically, there is a large difference in the character and depth of information if a deterministic (quantities times price plus a contingency) and risk-based cost methods

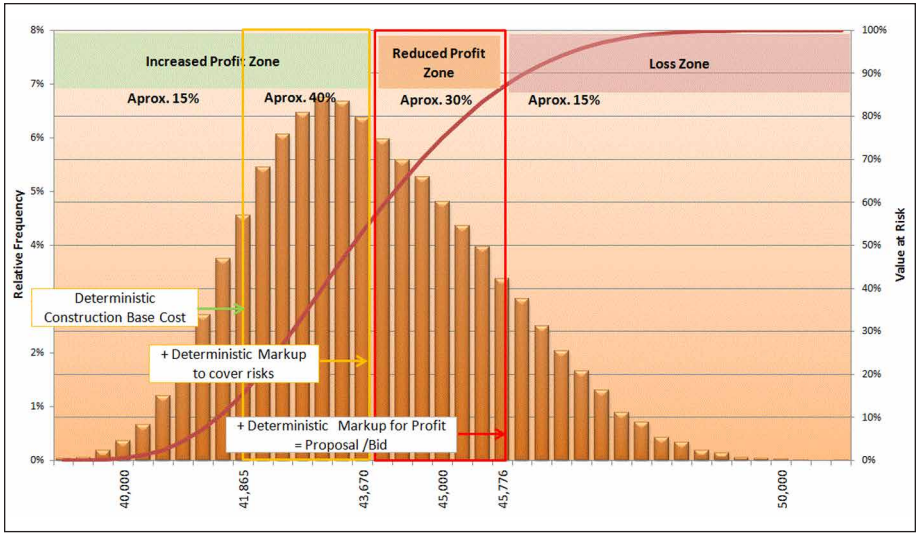

Figure 1. Deterministic cost plus profit–loss curve (Sander 2014)

are used. It is this difference in character and depth of information that is the reason that risk-based cost estimating has potential value for owners and contractors. Figure 1, following, presents hypothetical cost results from deterministic and risk-based methods, illustrates some of these differences.

In Figure 1, the results for deterministic and risk-based cost estimates are given related to the potential profit or loss for a typical project. As is evident in this example, there is significant potential for costs to be realized that are higher than the proposal/bid value estimated using a deterministic approach, with a 15% probability of a loss. There is a 30% probability that the project will have a reduced profit. There is a 55% probability that the project will return a good profit. Using a risk-based approach, it is possible to better recognize this potential outcome in the bid phase and, as a consequence, develop a strategy to:

1. Change the proposal/bid amount—if this is consistent with a strategic approach to win the bid, compared to the competition, in order to realize a profit a the end of the job, or
2. To withdraw from the project if a strategy to win the bid but not realize a profit is likely.

COST ESTIMATING—OVERVIEW

Cost Estimating Must Deal Adequately with Uncertainty

Cost estimating must deal adequately with uncertainty, especially in the very early stages of projects where:

- Quantities and prices are not well known
- Quantities and prices can only be addressed by reference to basic elements plus a large contingency
- A detailed analysis is not yet available due to a lack of sufficiently precise information

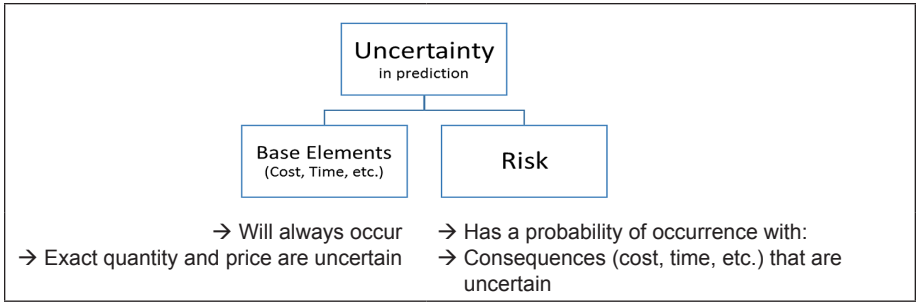

Figure 2. Uncertainty in base costs and risks (Sander 2014)

With a deterministic approach, information about uncertainties and their characteristics—such as higher or lower values, ranges of quantities, and potential costs—cannot be easily taken into consideration for cost estimating. A risk-based approach can more reasonably deal with this type of uncertainty.

Types of Cost Estimates

There are several different methods of cost estimating, depending on the purpose, level of planning, and/or design as well as project type, size, complexity, circumstances, schedule, and location. These methods can fall into categories such as: parametric, historical bid-based, unit cost/quantity based, range, and risk-based estimates. For a detailed discussion of cost estimating, see Reilly 2010. References for best cost estimating practices include "Project Management Body of Knowledge" Chapter 7, "Project Cost Management" (PMI 2004), State Agency guideline documents such as WSDOT's "Cost Estimating Manual for WSDOT Projects" (WSDOT 2009) and the AACEI Guidelines (AACEI 2003 et seq.).

Components of Cost Estimates—Base Cost, Risks, and Other Uncertainties

The components of cost that need to be correctly addressed in the estimate include:

- Base cost—the cost that will result if "all goes according to plan" (Reilly 2004)
- Risk costs—the result of threat and opportunity events, if they should occur
- Escalation costs—costs resulting from normally expected inflation with variability
- Other uncertain costs—costs that result from other events, normally external to the project team's control, which may include unanticipated events, politically related changes, and "black swan" events (Talib 2007)

In order to identify and address risk factors, an individual uncertainty factor should be associated with each cost category. In particular, for larger projects, individual budgets should be created for all cost components to enable tracking of deviations and management of changes as the estimate and the project evolves.

The method by which these cost components are evaluated, quantified, modeled, and combined is critical to a valid result. Different methods treat each component differently—which can lead to differences in the reliability and usefulness of the results. Additionally, uncertainty always plays a major role in estimates—for example, while basic cost elements may be reasonably well known, the quantities and prices associated with them are uncertain leading to variability in these base costs.

$$R_{total} = \sum p_i * I_i$$

Figure 3. Equation for deterministic aggregation of risks

Representative Cost Estimating Methods Addressed in This Paper

1. *Deterministic:* Aggregated unit quantities multiplied by unit prices—usually with some degree of conservatism built in—plus an added reserve or contingency
2. *Risk-Based:* A range approach which combines base costs, with some variability, plus risk and opportunity costs, combined probabilistically to produce a "range of probable cost"

The Deterministic Cost Estimating Method

The deterministic base cost approach process is commonly used by contractors to create a bid price. This involves estimating known quantities (from bid plans) and unit prices (from the contractor or suppliers) to get "line item costs" and adding an overall contingency to the base costs to account for the incomplete nature of the design, project uncertainties, and the consequence of future events.

A risk-based deterministic approach adds line-item risk to the deterministic base cost elements and assigns a probability of occurrence and impact to each line item. The result is the expected value of risk impacts. If multiple risks are to be accounted for, the total risk is often computed as the mathematical sum of all single risks.

However, such a simple summation of risks delivers no information about any probability and best and worst case scenarios. It is also necessary to add an overall contingency to account for other unknowns. An overall contingency is subject to bias since there may be no rational basis for how unknowns are aggregated or estimated.

Contingency

The uncertainty (and associated contingency) at various project phases can be classified by such techniques as "Estimate Class Levels" (AACEI 2003), used in deterministic cost estimates, in which the inherent uncertainty is reduced as the project advances through the phases of planning, design, bidding, and into construction. The uncertainty is represented by "contingency factors" that are related to these phases. Contingency in the AACEI table can range from 5–75% depending on phase and circumstance. Alternatively, cost-risk estimating recognizes that base costs and risk events have uncertainty in both probability and impact (positive or negative). This method is more detailed and analytically more complete.

Contingency is a very broad approach, not very useful for identifying and developing a strategic management of risk or achieving a profit in construction. The contingency applied in the deterministic standard method is often based solely on the cost estimator's judgment or experience with a history of similar projects, if available—but this is problematic for at least the following reasons:

- Estimators and project staff are generally optimistic in their approach to cost.
- The "history of similar projects" varies with each contractor's experience.
- The "history of similar projects" is likely to be inadequate to apply to the current project.

The contingency approach does not give useful information on the probability and impact of uncertain events. This means that strategies such as risk avoidance, risk

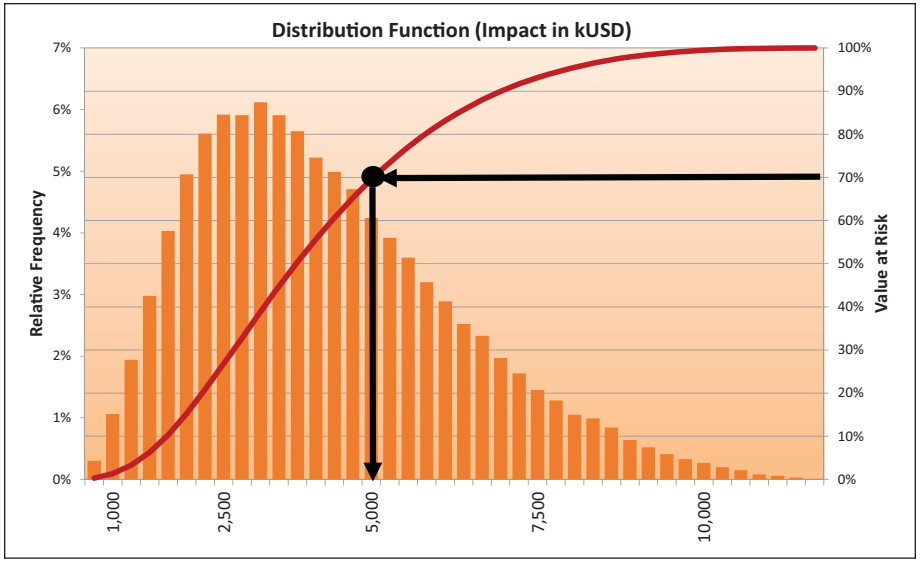

Figure 4. Probability density distribution function showing probable project cost with Value at Risk information

mitigation, or risk transfer cannot be sufficiently evaluated in the bidding phase—which is very important for the contractor in order to:

1. Determine a competitive bid price, while understanding relevant risks, and then
2. Implement strategies to maintain a profit margin in the construction phase

The Risk-Based Cost Estimating Method

In the risk-based method, the total cost is made up of base costs (quantities times unit prices, both with some variability) plus risk events including risks of delay with associated liquidated damages, risks of escalation, and the cost impact of other higher-level (e.g., political) risks. Risk impacts are determined by estimating the probability of occurrence and the impact of specific risk events (normally in a workshop with project staff and subject matter experts). Dependencies and correlations between specific risks are also elicited and used in modeling.

Since empirical/historical data as input to the risk analysis is often not available, the risk probabilities can be difficult or complex to estimate. The risk-based method characterizes each risk, with individual and specific distributions, such as a large range for large uncertainties or a narrower range for smaller uncertainties. Using this approach, the uncertainty contributing to a particular cost estimate can be modeled more specifically and in greater detail than by use of a single-point deterministic estimate (Sander et al., 2009).

Single risks can be evaluated using distributions, and those distributions can be aggregated using simulation methods (e.g., Monte Carlo Simulation or Latin Hypercube Sampling) to determine a probability distribution that represents the overall risk environment.

Value at Risk (VaR) defines a value (e.g., USD) which will not be exceeded at the corresponding probability (risk). In the example above, VaR 70 means that a $5M cost would not be exceeded in 70% of all simulated scenarios. However, even with such

Table 1. Comparison of deterministic versus risk-based probabilistic cost estimation methods

Element	Deterministic Base + Risk Cost	Risk-Based (Probabilistic)
Input	A single value for probability and a single value for impact of each risk.	One figure for the probability of occurrence and several values for the impact (e.g., minimum, most likely, and maximum) to define "fuzzy" risk.
Result	A single value from a mathematical addition of base cost and the expected cost of risks (probability multiplied by impact).	A "range of probable cost" with all project risks shown as a probability density function based on thousands of coincidental but realistic scenarios.
Qualification	Results are displayed as a single, sharp figure, which, in itself, does not have a probability.	Results are displayed using distribution densities.
Treatment of risk	Risk and uncertainty are added as a lumped "contingency" based on the estimator's historical experience and industry guidelines (e.g., AACEI 2003).	Risk and uncertainty are explicitly and quantitatively identified, characterized, modeled, and aggregated probabilistically. Risks are added probabilistically.
Risk management/ response	Risk management is usually based on a separate risk register, using historical experience.	Risk management can be focused on the higher level risks that are identified and quantified by this method.
Other high level risks	Financial, schedule, and other risks are identified, characterized, and quantified "approximately." Significant high-level risks may not be included or addressed.	Financial, schedule, and other risks can be explicitly identified, quantified, and prioritized for risk response

coverage, there remains a 30% probability that the $5M cost will be exceeded (Sander 2012).

COMPARISON OF COST ESTIMATION METHODS

Key Considerations—Deterministic Versus Risk-Based Cost Estimates

Cost estimating using the deterministic process can significantly misestimate potential costs by:

- Misapplication of "contingency factors"
- Neglect of variability in prices and quantities
- Lack of appreciation of the impacts and probabilities of potential risk events
- Including additional (non-explicit) contingency in base cost and the overall contingency
- Overestimating the total cost of upper levels of ranges in the range-estimating approach

A risk-based cost estimating process inherently identifies more detail regarding risks and opportunities and can generate more useful information of the characteristics of uncertain events. Risk-based methods can better quantify the range of potential costs by more detailed characterization of risk and opportunity and the inclusion of conditional, dependent, and inter-related risk cost results. This can lead to better

strategies in the bidding phase (to secure the project) and in the construction phase (to preserve profit).

Risk-based methods are more sophisticated than deterministic methods, which are often based on a normal spreadsheet approach. The main reasons why a risk-based approach is recommended can be summarized as follows (Tecklenburg 2003):

- A deterministic method can give equal weight to risks that have a low probability of occurrence and high impact and risks that have a high probability of occurrence and low impact if using a simple multiplication of probability and impact. This approach is incorrect.
- By multiplying the two elements of probability and impact, these values are no longer independent. Therefore, this method is not adequate for aggregation of risks where probability and impact information need to remain available. Due to multiplication the only information that remains is the mean value.
- The actual impact will definitely deviate from the deterministic value (i.e., the mean).
- Without the Value at Risk information, there is no way to determine how reliable the mean value is and how likely it is to be exceeded.

Bier summarizes the opportunities for probabilistic risk assessment as follows (Bier 1997):

- Probabilistic risk analysis allows reasonable modeling of deviations from normal (expected) values for complex projects and systems.
- Probabilistic risk analysis can characterize any element or system performance, including the performance of subsystems and their interactions.
- As a consequence, specific impacts from different interacting systems can be identified and differentiated.
- Probabilistic risk analysis delivers a quantitative risk estimation, which can lead to better decision-making and risk response/mitigation.
- Probabilistic risk analysis takes uncertainties into consideration. This is especially valuable if statistical data about potential impacts are sparsely available and large uncertainties dominate.

COMPARING COST ESTIMATING METHODS—EXAMPLE

In order to compare these estimating methods, the same input parameters are used in Table 2 following which shows inputs used for estimating the base cost of a simplified tunnel excavation and support element in order to compare the above estimating methods by means of a practical example. Quantities are used with a triangle distribution using a “minimum (min), most likely (ml), and maximum (max)” expectable value for each cost item.

Deterministic Approach

The deterministic approach delivers a single figure (USD 307) as the sum of all products of most likely quantity multiplied by the most likely price.

Risk-Based Probabilistic Approach

The probabilistic approach combines base cost plus risk costs in a simulation. The result is a “probability density function,” showing the probability that the out-turn cost will be a particular value (or between a range of values).

Table 2. Deterministic base cost of an excavation and support category with triangle distributions

Cost Item	Quantity				Unit Price (USD)			Deterministic Cost/Meter of Tunnel (ml)
	min	ml	max	unit	min	ml	max	
Shotcrete 10 cm, Top Heading	13.8	15.4	17.7	m^2	9.7	12.1	15.8	186.3
Steel Mesh AQ50	13.8	15.4	16.9	m^2	1.0	1.2	1.6	18.8
Swellex 3.0 m, Top Heading	1.7	1.8	2.0	pc	20.7	25.9	33.7	47.1
Shotcrete 5 cm—Bench	5.2	5.8	6.6	m^2	6.0	7.5	9.7	43.1
Swellex 3.0 m—Bench	0.4	0.5	0.5	pc	20.7	25.9	33.7	11.7
ml = “Most Likely Value”								307.0

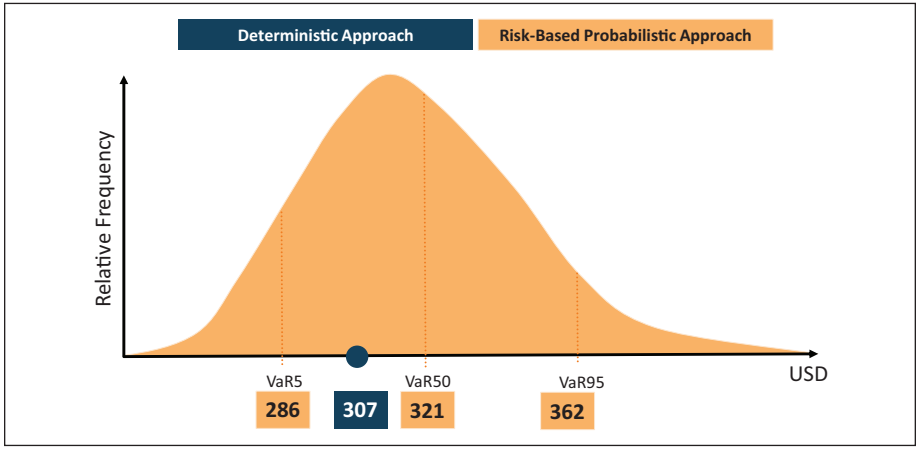

Figure 5. Visualized result—comparison of estimating methods

Figure 5 shows results of the above methods for the example given. It is apparent that the risk-based method gives much more useful information about the potential cost.

Assessment of the Estimating Methods

Table 3 compares “pros” and “cons” for the Deterministic and Probabilistic methods.

Recommendation

Contractors and owners can benefit strategically and operationally from sufficiently complete risk-based information, including potential cost ranges and risk characterization. The more complex and “risky” a project is, the more information is needed, and this information is critical to success. If a contractor does not identify and characterize risks early, they will not be able to manage their project sufficiently or to protect against adverse events and loss of profit. Risk management procedures have been sufficiently defined, and sufficient Information Technology (IT) is available in a variety of software products that are not difficult to understand and use.

Table 3. Assessment of estimating methods from an owner's or contractor's perspective

Estimating Method	Pros	Cons
Deterministic	One single figure Well-known & accepted Quick Can be performed "manually"	No probability information of single value No VaR information More often than not on the unsafe side (high, unknown probability of cost overruns)
Risk-Based (probabilistic)	Full probability information	Needs probabilistic thinking & understanding Needs software support

ADVANTAGES OF USING A RISK-BASED (PROBABILISTIC) METHOD

How a Better Cost-Risk Assessment Helps in a "Low-Bid" Environment

Previous papers (Reilly 2008) have noted that, in a "low-bid" environment, each party enters a contract at their own risk and the contractual environment is characterized by the ability of each party to treat the other party as an adversary—for their gain, at the potential expense of the other. To be the "low bidder," the contractor must do at least two things:

1. Determine the lowest cost to deliver the work specified at an acceptable quality level
2. Determine a strategy to bid that cost—or lower—to secure the work, with the expectation that any deficiencies in price can be made up in changes caused by new agency requirements, changed site or environmental conditions, defects in the design documents, or other strategies that will accrue to their advantage.

The risk assessment used in the probabilistic method results in an improved understanding of who "owns" each potential risk according to the requirements of the contract documents, industry, and legal precedent. The contractor can therefore better prepare a bidding and construction strategy to achieve a profit even in a very competitive bidding environment. The better risk assessment also allows better construction change management since the strategy related to those changes can be better understood and quantified early in the bidding and construction process.

Contractor's Advantage Using Risk-Based Estimating

Risk-based estimating produces information that allows a better understanding of the risks that might occur, as well as their characteristics and probabilities. Several benefits flow from this:

- The deterministic contingency approach, adding a percentage on top of the base cost, may give an estimate that is greater than that obtained using risk-based cost (because not all risks will occur). This could mean that, if using a cost-risk process, a reduced bid price is possible, leading to a competitive edge for that contractor.
- The potential contractor will have a more realistic understanding of base cost, risk cost, and the level of risk that they are willing to undertake in order to bid the job.
- Because the risks are defined (characterized) in detail, it is possible to understand who should own those risks—i.e., which risks are clearly the responsibility of the contractor, which are clearly the responsibility of the owner, and which risks are clearly the responsibility of other (external) third parties.

In particular, if the owner has included a sufficiently comprehensive risk register in the bid documents, and the potential contractor prepares their own detailed risk register, they will better understand the risk environment and can also judge if the owner's risk register is accurate. There are several possibilities in this regard:

- If the potential contractor thinks that the owner has estimated the consequence or probability of some risks too high, they may see a bidding advantage compared to other bidders.
- If the owner has estimated the consequence or probability of some risks too low, it may mean that the potential contractor, using a reasonable assessment of risk, is likely to submit too high a bid and may not win the project compared to other bidders who have a lower appreciation of risk.

A concern has been expressed that if an improved risk identification process is used the contractor's estimate will include higher potential costs, which will mean that their bid will be higher and they are likely not to be successful in so many bids. This is a valid concern—however, we would argue that more detailed and realistic information about potential risk events is an advantage if an appropriate bidding and construction management strategy is used by the owner and contractor and these strategies are compatible and consistent. See also the "contractor's advantage" section above.

Owner's Strategy for Budgeting and Bidding

The owner is interested in fostering conditions for a reasonable and responsible low-bid. Better (more complete, detailed, specific) information can inform all bidders about issues and risks that may be realized. This means that all bidders will have more complete information as they prepare their bids. If the owner uses a more detailed probabilistic cost-risk estimating process in the planning and design phases, and includes a reasonably complete risk register in the specifications, two benefits are possible:

- The owner's budget for the project will be more likely to reflect a more realistic project cost, leading to a more realistic establishment of an appropriate budget (Figure 4). This permits sufficient resources to be committed to deal with issues in construction. If an inadequate budget is the case, a lack of public trust can develop if major problems and cost increases occur in the construction phase, requiring additional funding.
- All bidders will have a consistent basis for their cost estimate and to establish their bid price. This will help to reduce the probability of the low-bidder submitting an unrealistically low bid, which can lead to issues in construction and an increased probability of disputes, claims, and litigation.

Owner's Strategy in the Construction Phase

Using the more detailed cost-risk estimating process, the associated risk register can show which risks are the responsibility of the owner, the contractor, and third parties. This means that those risks which are the responsibility of the contractor or the owner can be made explicit and their respective risk management plans can reflect this. Additionally, the probability of unforeseen risks—those which the contractor may claim as "unforeseeable"—is reduced if such risks are explicit in the owner's risk register.

Contractor's Strategy in the Construction Phase

Likewise, the contractor can better analyze the risks that may occur and determine, during the bidding phase, which risks are theirs and which belong to the owner or third parties. A strong rationale for risks that are not the contractor's will help defend the contractor in the construction phase, if they occur. A correspondingly robust

risk-management plan will help to reduce exposure to such risks in construction (Grayson et al., 2015).

SUMMARY

Traditional deterministic cost-estimating methods, while well accepted, can overestimate or underestimate costs and provide very limited information regarding risks that may occur. Risk-based cost-estimating methods build on a deterministic cost base and add consideration of variability and potential risk events to give information that is relevant to risk identification, characterization, and management. They also give more information to manage to budget (owners) and to secure a project in a competitive bidding environment (contractors), as well as inform strategies to manage disputes and claims in construction (owners and contractors).

More relevant information gives more options to manage risk. The earlier such information is available, the sooner that strategies and management actions can be implemented to avoid problems and achieve good results.

In particular, such information helps owners by highlighting budget issues early, allowing good decisions to be made regarding expected bid results, and helps contractors to decide if they can be competitive given the owner's budget and in competition with other contractors. Subsequent to winning a bid, strategies for cost and claims management are informed by better cost and risk information.

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