# RISK-BASED, PROBABILISTIC COST ESTIMATING METHODS

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# 1. Summary

Every cost estimate is uncertain. Underestimating construction costs, by owners in the planning or design phases or by contractors in the bidding phase, and with respect to 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 get 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 risk-based probabilistic cost estimating methods that can improve our appreciation of the cost of uncertainty and potential risk events. It will address the uncertainty inherent in predicting the value of any future project element or process and the identification and characterization of potential risk (threats or opportunities) that can impact outcomes.

# 2. Introduction

Estimating and managing the costs of complex infrastructure projects – in the planning, design, and construction phases, has been a challenge for decades for both owners and contractors. The more complex and technologically advanced the project, the greater the uncertainty and related challenges – 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 et seq.). 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 included in construction phase cost estimates. The reasons for this seem to relate to “low-bid” considerations – any method that tends to increase the contractor’s cost estimate by including risk costs may lead to an erosion of the contractor’s competitive position if others are not similarly required to include such costs.

## 2.1 Cost Estimating Methods - Deterministic and Probabilistic

The probabilistic approach, compared to the simpler deterministic approach, fundamentally gives more useful information with respect to the range of probable cost and cost drivers (risks, opportunities, variability, potential for loss or gain) as shown in Figure 1 following.

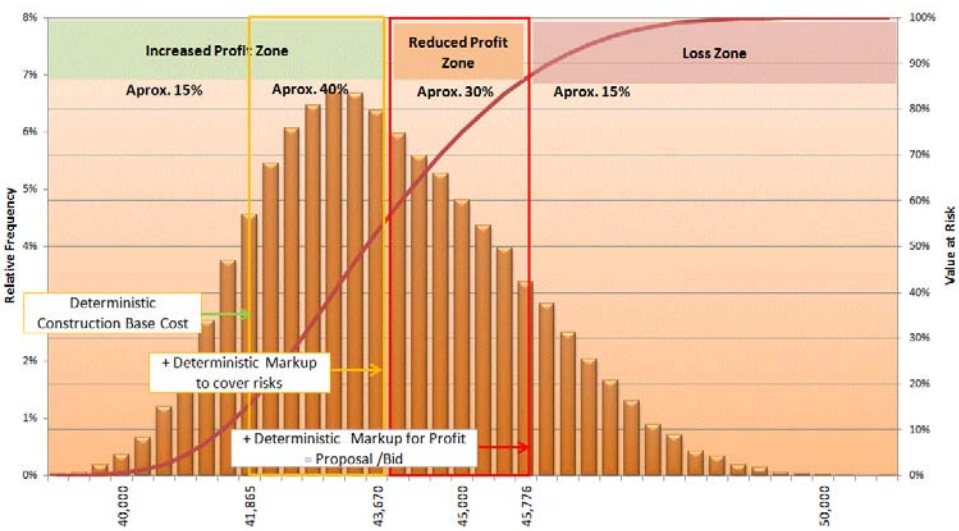



***Fig. 1*** *Deterministic Cost Compared to Probabilistic Profit–Loss Curve (Sander 2014)*

In Figure 1, the results for deterministic and probabilistic cost estimates are shown 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. Using a probabilistic approach, it is possible to better recognize this potential outcome in the bid phase and, as a consequence, to:

1. Change the budget (as an owner) or proposal-bid value (as a contractor) – if this is consistent with a strategic approach to win project funding (as an owner) or the bid (as a contractor), in order to realize a project within budget (as an owner) or a profit a the end of the job (as a contractor), or
2. To stop the project (as an owner) or withdraw from the project (as a contractor) if a strategy to win the bid and still realize a profit is not feasible.

# 3. Cost Estimating - Overview

### 3.1 Cost Estimating Must Adequately Consider Inherent Uncertainty

Cost estimating must deal adequately with uncertainty, especially in the very early stages of projects where neither the exact quantities nor the exact costs or prices are known, and quantities can only be addressed by reference to basic elements and a detailed analysis is not yet available due to a lack of precise information. 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 although this information is generally available or could be estimated. A probabilistic approach can more reasonably address this type of uncertainty.

### 3.2 Types of Cost Estimate Methods

There are several different methods of preparing a cost estimate 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 probabilistic 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), and State Agency guidelines documents such as WSDOT's "Cost Estimating Manual for WSDOT Projects" (WSDOT 2009) and the AACEI Guidelines (AACEI 2003 et seq.).

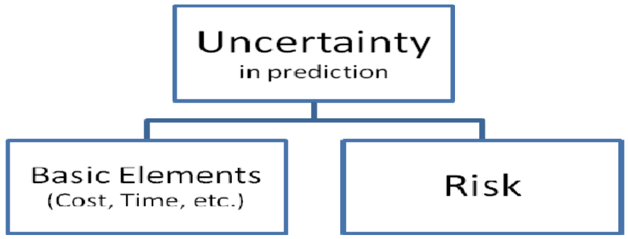
### 3.3 Components of Cost Estimates – Base Cost, Risks, and Other Uncertainties

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

1. Base cost – the cost that will result if "all goes according to plan" (Reilly 2004)
2. Risk cost – the cost result of threat and opportunity events, if they should occur
3. Escalation cost – cost resulting from normally expected inflation
4. Other uncertain cost – cost that results 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 cost, all cost components should be considered. Each cost component will have an individual uncertainty that should be considered using adequate evaluation methods. In particular, for larger projects, individual line-item budgets should be created for every cost component to enable tracking of deviations and management of changes throughout project development, design, and construction.

The method by which these components are evaluated, quantified (estimated), modelled, 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.




→ Will always occur
→ Exact price, quantity, or time uncertain

→ Has a probability of occurrence
→ Consequences (cost, time, etc.) are uncertain

***Fig. 2*** *Uncertainty in Base Cost and Risks*

## 3.4 Representative Cost Estimating Methods

1. Deterministic: Aggregated unit quantities multiplied by unit prices – usually with some degree of conservatism built in – plus an added reserve or contingency
2. Probabilistic: Range approach which characterizes cost information with probability distributions
3. Bandwidth: Range approach where costs of each line element are characterized with parameters of minimum, most likely, and maximum cost. The total cost is obtained by simply adding these parameters for all line items
4. Square Root: The Square Root approach delivers one single figure which is the sum of all base costs plus the square root of the sum of the squares of the risk contingencies.

## 3.5 The Deterministic Method

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

A more sophisticated deterministic approach adds line-item risk elements to the deterministic base cost, using a risk-register and assigning a probability of occurrence and impact to each risk register 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.

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

***Fig. 3*** *Equation for Deterministic Aggregation of Risks*

However, such a simple summation for risks (or for ranges) should not be done by simple mathematical addition because it is statistically not valid. It is also necessary to add an overall contingency to account for other unknowns. That overall contingency is subject to bias since there may be no rational basis for how the unknowns are aggregated or how they are estimated.

### 3.5.1 Contingency Factors

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, probabilistic 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.

Applying contingency factors 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 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:

1. Estimators and project staff are generally optimistic in their approach to estimating costs.
2. The "history of similar projects" varies with each contractor's experience.
3. The "history of similar projects" may be inadequate if applied to the current project.

The contingency approach does not give useful information on the impact (probability and magnitude) of uncertain events. This means that strategies such as risk avoidance, risk mitigation, or risk transfer cannot be sufficiently evaluated.

### 3.6 The Probabilistic Method

In the probabilistic 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 modelling.

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

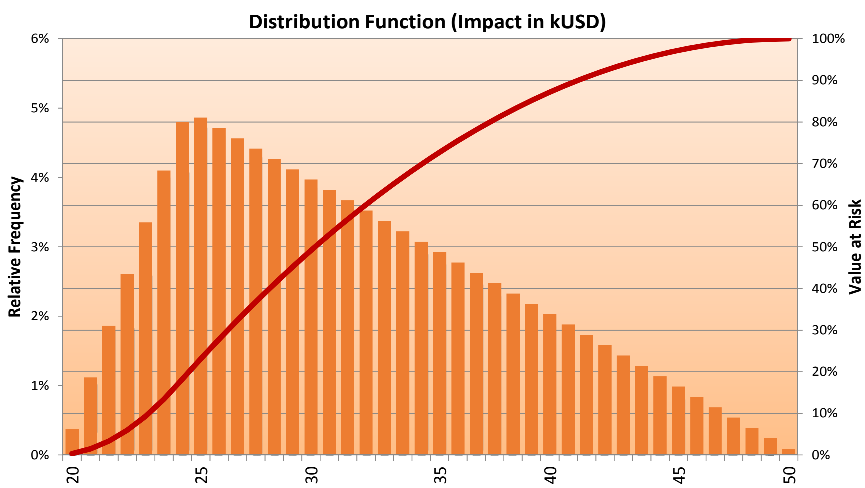



***Fig. 4*** *Probability Distribution for an Individual Risk Using a Triangle Function (Sander 2014)*

Single, individual risks can be evaluated using probability distributions, one of which is shown in the figure above. These individual distributions can be aggregated using simulation methods (Monte Carlo Simulation or Latin Hypercube Sampling) to determine a probability distribution that depicts the total risk potential.

Value at Risk (VaR) defines, within a distribution, a certain amount (e.g., USD) that will not be exceeded according to the corresponding probability. In the example below, VaR 70 means that a $5M budget would not be exceeded in 70% of all simulated scenarios. However, even with such coverage, there remains a 30% probability that the $5M budget will be exceeded.

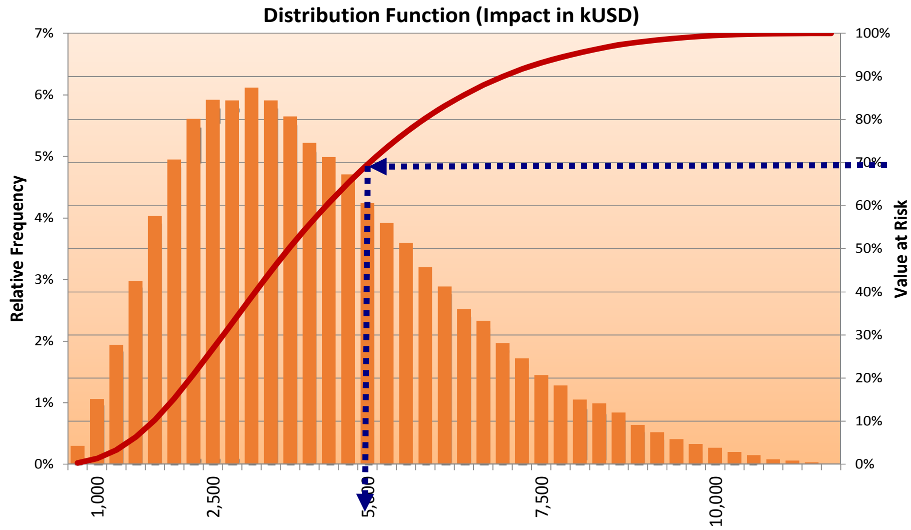



***Fig. 5*** *Probability Distribution Showing Probable Cost with Value at Risk Data (Sander 2014)*

3.6.1 Comparison of Deterministic and Probabilistic Cost Estimation Methods

***Table 1*** *Comparison of Deterministic versus Probabilistic Cost Estimation Methods*

| Element | Deterministic | 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), therefore including uncertainty. |
| Result | A single value from a mathematical addition of the impacts of all risks (probability multiplied by impact). | A "range of probable cost" with all project risks included, 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 as probability distributions. |
| 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. |

### 3.6.2 Key Considerations of Deterministic Versus Probabilistic Cost Estimates

Cost estimating using a deterministic process could significantly underestimate potential costs by:

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

A risk-based, probabilistic cost-estimating process inherently identifies more detail regarding risks and opportunities and can generate more useful information about 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, probabilistic methods can be more complex and time-consuming than deterministic methods, which are often based on a simple spreadsheet approach. The main reasons why a probabilistic approach is recommended can be summarized as follows (Tecklenburg 2003).

1. A deterministic method can produce the same value for risks that have a low probability of occurrence and high impact as those risks which have a high probability of occurrence and low impact by using a simple multiplication of probability and impact. This approach is probabilistically incorrect and can have a large impact on the accuracy of results and an appreciation of potential consequence.
2. 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 the characteristics of the elements need to be available. The only information that remains is the mean value of the combination.
3. 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 that it might be exceeded.

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

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

### 3.7 The Bandwidth Approach

The bandwidth approach is one form of a range approach to address uncertainty. This method deals with uncertainty, but it is still an approximate method. In addition to "normal variability" in base costs, specific elements of the cost estimate can be characterized by ranges (plus and/or minus), expressed as percentages or values. The ranges are summed to indicate a range of probable cost. However, it is not accurate to do this arithmetically as this will lead to aggregated maximum and minimum values that have an extremely low probability of occurrence and are therefore not realistic. This is because only the upper and lower bounds of each element are summed. Both these bounds are of extremely low probability when aggregated.

The bandwidth approach is an approximate method. It can include all scenarios, however each will have the same probability of occurrence. All probability information is missing. There are methods to address this concern, however they will only yield approximate results and rely on a sufficiently accurate determination of the interrelationships between the cost elements – something that probabilistic methods do explicitly, not approximately.

### 3.8 The Square Root Approach to Aggregate Risk Value

The Square Root approach is another form of range approach that results in one single figure – characterized the sum of all base costs plus the square root of the sum of the squares of the risk contingencies – as shown in the following figure.

**Standard Cost Estimation Items**

| Subsection | Base Cost | Risk Surcharge | Risk Contingency |
|---|---|---|---|
| Painter | $ 10,000.00 | 10% | $ 1,000.00 |
| Roofer | $ 30,000.00 | 12% | $ 3,600.00 |
| Floor tiler | $ 15,000.00 | 8% | $ 1,200.00 |
| | $ 55,000.00 | | $ 5,800.00 |

**Square root method is used to adapt the risk contingency in order to consider that all risks won't occur at the same time.**

$$\sqrt{\sum Risk^2}$$

**→ New overall risk contingency**

$$\sqrt{1{,}000^2+3{,}600^2+1{,}200^2}=3{,}924$$

Comment
- → No probabilistic approach
- → Simple deterministic surcharge
- → Information on the individual item is lost (not valid in comparison to the overall result)
- → No evidence for decreased budget
- → No probability information
- → No VaR information, e.g. risk covered by budget

***Fig. 6*** *Approximate Treatment of Aggregated Risk Contngency (Sander 2014)*

# 4. Cost Estimating for Construction

## 4.1 The Traditional Way – A Deterministic Approach

As noted above, in the deterministic method, it is usual for cost estimators work up the cost for a defined project (based on plans and specifications) using aggregated quantities multiplied by unit prices obtained from historical projects using bid tab data, crew/activity analysis, and pricing data from current estimates or quotes. Usually there is a degree of conservatism (both implicit and explicit) built in to the quantities and prices, which can skew the result. To the aggregated units (summed quantities and prices) an overall contingency is added to arrive at an "estimated construction cost" – a cost at a point in time with specific assumptions (often not explicitly or sufficiently stated or documented).

# 5. Comparing Cost Estimating Methods

The same input parameters from the following table are used, 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.

## 5.1 Comparing Cost Estimating Methods – Examples

***Table 2*** *Deterministic Base Cost of an Excavation & Support Category Using Triangle Uncertainty Distributions (Sander 2014)*

| **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 | m² | 9.7 | **12.1** | 15.8 | 186.3 |
| Steel Mesh AQ50 | 13.8 | **15.4** | 16.9 | m² | 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 | m² | 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** |

### 5.1.1 Deterministic Approach

The deterministic approach delivers a single figure (USD/$307) that is the sum of the products of the most likely quantity multiplied by the most likely price.

### 5.1.2 Bandwidth Approach

The Bandwidth Approach delivers three results as the sums of the following elements:

1. Sum of all minimum quantities multiplied by all minimum prices (USD/$223.36)
2. Sum of all most likely quantities multiplied by all most likely prices (USD/$307.00)
3. Sum of all maximum quantities multiplied by all maximum prices (USD/$453.86)

### 5.1.3 Square Root Approach

The Square Root approach delivers one single figure which is the sum of all base costs plus the square root of the sum of the squares of the risk contingencies. Its value in this case is USD/$376.

### 5.1.4 Probabilistic Approach

The probabilistic approach combines base cost plus risk costs in a simulation. The result is a probability distribution showing relative probability of a particular cost over a range.

The following diagram, Figure 7, compares results of the above methods for the example given.

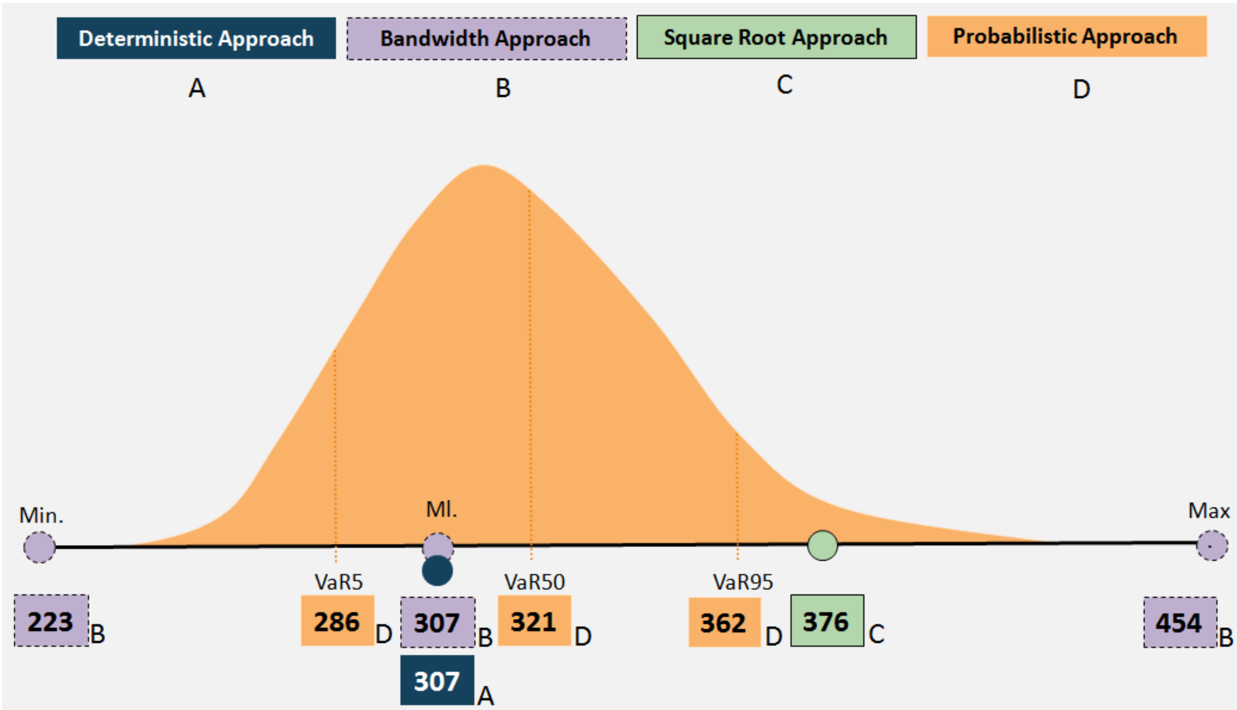



***Fig. 7*** *Visualized Result, Comparison of Discussed Estimating Methods (Sander 2014)*

## 5.2 Assessment of Estimating Methods

***Table 3*** *Assessment of Cost Estimating Methods*

| Estimating Method | Pro | Con |
|---|---|---|
| Deterministic | One single figure<br>Well-known & accepted<br>Quick<br>Can be performed “manually” | No probability information for single value<br>No VaR information<br>More often than not on the unsafe side (high, unknown probability of cost overruns) |
| Bandwidth | Three values (minimum, most likely, and maximum) in a range<br>Quick<br>Can be performed “manually” | No probability information for range values<br>No VaR information<br>More often than not on the unsafe side (high, unknown probability of cost overruns)<br>Range maximum and minimum very unlikely |
| Square Root | One single value<br>Quick<br>Can be performed “manually” | No probability information for single value<br>Bandwidth information is lost<br>No VaR information<br>Range limits are extreme values and very unlikely |
| Probabilistic | Full probability information | Needs probabilistic thinking & understanding<br>Needs (a little bit) more time<br>Needs software support |

# 6. Advantages of Using Risk-Based, Probabilistic Cost-Estimating

## 6.1 How a Better Cost-Risk Assessment Helps Even 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," a 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 as well as 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.

## 6.2 Contractor's Advantage Using Risk-Based, Probabilistic Estimating

Risk-based, probabilistic 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:

1. The deterministic approach results in – more often than not – a value below the Var50. Therefore, the probability of exceeding that single value is likely to be more than 50%.
2. The deterministic contingency approach, adding a percentage on top of the base cost, may give an estimate that is greater than that obtained using a risk-based cost method (because not all risks will occur). This could mean that by using a cost-risk process a reduced bid price is possible, leading to a competitive edge for that contractor.
3. 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.
4. Because 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 risks are clearly the responsibility of the owner, and which risks are clearly the responsibility of other (external) third parties.

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 that 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.

## 6.3 Benefits of More Complete Risk Information

With a better understanding and definition of risks that might occur, including their characteristics, probabilities, and consequences, several additional benefits are possible. Specifically, if the owner has included a sufficiently comprehensive risk register in the bid documents, and the potential contractor prepares his own detailed risk register, he 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:

1. If the potential contractor thinks that the owner has estimated the consequence or probability of some risks too high, he may see a bidding advantage compared to other bidders and the possibility of a greater reserve by the owner to cover changes in construction.
2. If the owner has estimated the consequence or probability of some risks too low, it may mean that the potential contractor, using his (assumed better) assessment of risk, is likely to submit too high a bid and may not win the contract compared to other bidders who have a lower appreciation of risk. Realizing this early might support better-informed decision-making and the decision to submit a bid or not.

Traditionally, contractors start with a deterministic estimate of the cost they expect if everything goes according to plan. Different contractors use different estimating methods and software support. More often than not the estimate is only deterministic, multiplying one quantity value (either pre-determined by the owner or estimated by contractors themselves based on design, specifications, and plans) with cost elements, ending up with one price for each Bill of Quantity element.

However, by adding a risk-based, probabilistic cost estimate, the contractor can include the influence of variations both in quantities and prices as well as potential risks. This is much more valuable than an estimate based on plans and specifications only, since it includes a rich source of information (such as the Tornado Diagram following) that can inform strategies to avoid loss and to make a profit. An example of such information follows.

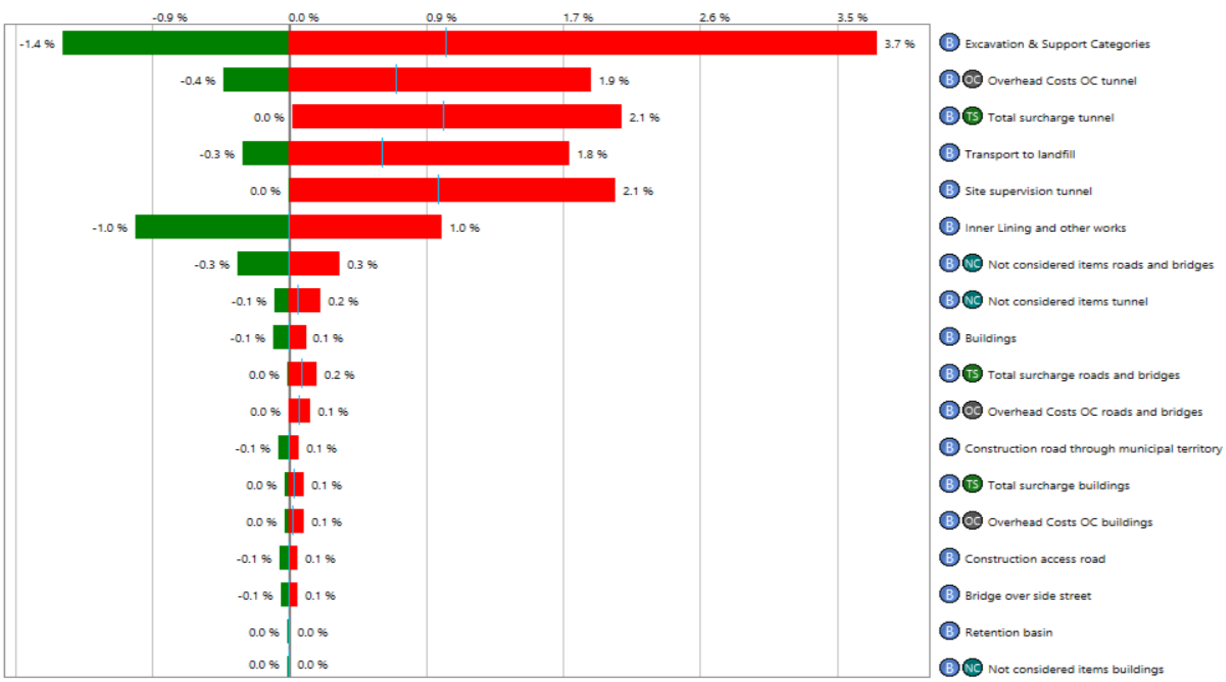



***Fig. 8** Example - Visualization of Base Costs Variability in a Tornado Diagram (Sander 2014)*

If the contractor's estimating team adds risks (e.g., all the risks they cannot reject or transfer back to the owner) based on their specific risk register and aggregates those risks by probabilistic simulations, they will be able to have a much better picture of their potential out-turn cost.

This means that the contractor's management can see – visualized and quantified – the range of potential costs (sum of base cost plus risk costs) to be expected. Management's decision to submit a specific price can then be evaluated, explained, and defended using the full cost and probability information. The Value at Risk (VaR) information can support a comparison of their bid price against the probability of an out-turn cost that may exceed their bid price. This can inform their strategy for bidding and management of the construction and potential claims.

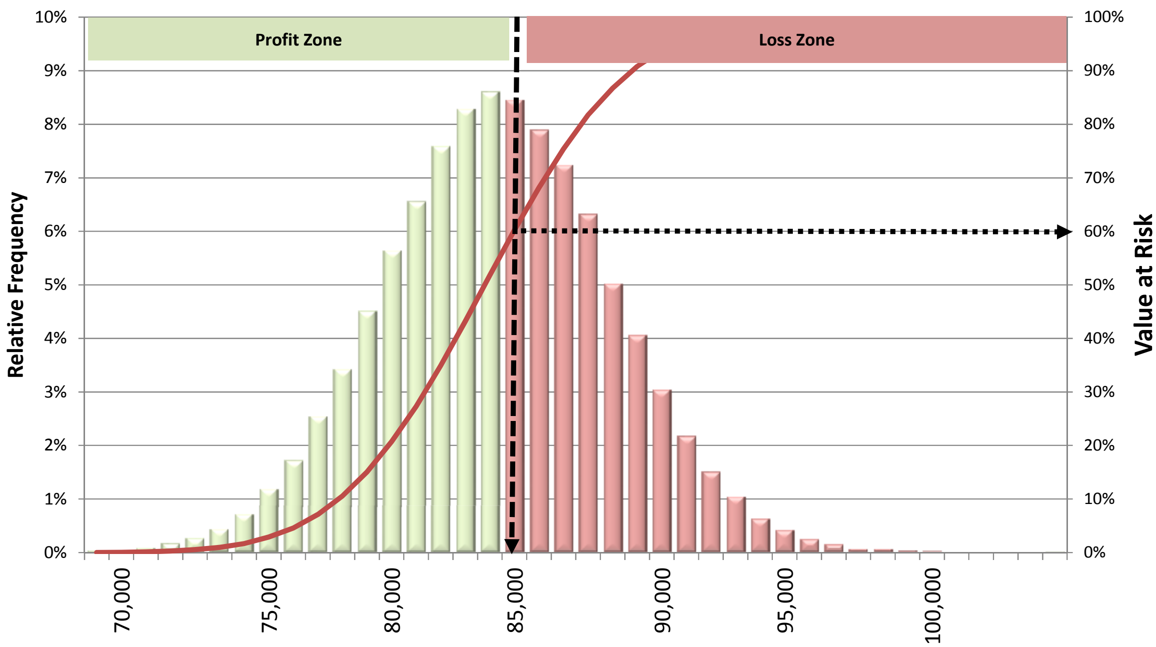



***Fig. 9*** *Probability Distribution for Total Construction Cost (Sander 2014)*

The example in the figure above illustrates that there will be a 60% chance of the out-turn cost being below the bid if the contractor decides to submit a bid for USD/$85,000. However, a 40% probability that the bid value will be exceeded by the out-turn cost will also remain. If that should occur, the contractor will face a financial loss unless he can recover costs through changes or claims.

### 6.4 Contractors Focus on Making a Profit During Construction

For contract management and construction change negotiations, an updated estimate is recommended that incorporates all previous versions (e.g., including bid-oriented interpretations) and includes an updated risk assessment based on current circumstances and conditions. The new (baseline) estimate will allow the contractor (and the owner) to continuously update their construction cost management based on the planned and actual cost information (base cost plus updated costs, realized and potential risks) and compare that status to the plan.

By including associated costs from Change Order Management (with accepted quantity changes or Change Orders, Notice of Potential Claims, either in negotiations or rejected) the contractor's project management will be able to better forecast total cost at completion, using the already established model and cost management system.

In particular, for very long-term, complex projects that inherently undergo numerous changes, it is necessary to practice continuous cost management with the ability to compare current and projected costs to the assumptions and strategies from earlier project status reports. To support this, structuring costs into elements (cost components) at the beginning of the project is an essential step in the establishment of continual cost management (Sander 2014).

### 6.5 Owner's Advantages Using a Risk-Based, Probabilistic Cost Estimating Method

The following advantages and considerations are of interest to the owner.

#### 6.5.1 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:

1. The owner's budget for the project will most likely reflect a more realistic project cost, leading to a more realistic and appropriate budget. This permits sufficient resources to be committed to account for issues that may arise in construction. If there is an inadequate budget, a lack of public trust can develop if major problems and cost increases occur in the construction phase, requiring additional funding.
2. All bidders will have a consistent basis for their cost estimate 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.

#### 6.5.2 Owner's Strategy in the Construction Phase

Using a more detailed cost-risk estimating process, the associated risk register can show which risks are the responsibility of the owner, contractor, and third parties. This means that those risks that 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 that the contractor may claim as "unforeseeable" – is reduced if such risks are explicit in the owner's risk register.

Additionally, the owner must also practice continuous cost management with the ability to compare current and projected costs to the status from earlier project reports and ensure that the contractor is meeting the requirements of the contract and applicable standards. This will also aid in progress reporting and an understanding of costs and risks (realized and potential) and will provide a management strategy and defence regarding the contractor's claims for additional cost due to changed conditions and realized risk events.

## 7. Examples of Probabilistic Cost Estimating Methods

### 7.1 Cost Estimate Validation Process (CEVP®)

The Washington State Cost Estimate Validation Process (Reilly 2004) develops a probabilistic cost and schedule estimate to comprehensively and consistently define probable ranges of cost and schedule required to complete a project. The basic approach requires a peer-level review, or "due diligence" analysis, of the scope, schedule, and cost estimate for a project (cost validation) and then the inclusion of uncertainty (risks) to estimate a range of probable cost and schedule.

Specific objectives of the method are to evaluate the quality and completeness of base costs together with the inherent uncertainty in a project estimate. The results of the assessment are expressed as a probability distribution of cost and schedule values for the project (such as shown above in Figures 1 and 10). In summary, the CEVP® process:

1. Critically examines the project's cost estimate to validate all cost and quantity components using independent, external professionals/subject matter experts
2. Removes all contingency and allowances for unknowns and uncertainties
3. Replaces contingency and other approximating allowances with individually identified and explicitly quantified risk events plus an allowance for other undefined risks
4. Addresses variability of base costs – quantities and prices
5. Builds a model of the project including design, permitting, and construction activities. Included are the quantification of costs and critical path schedules. The model assigns the identified risks to activities with associated probabilities and impacts (consequences)
6. Runs a simulation to produce the projected "range of probable cost and schedule"
7. Reports the results for consideration by the owner and project team

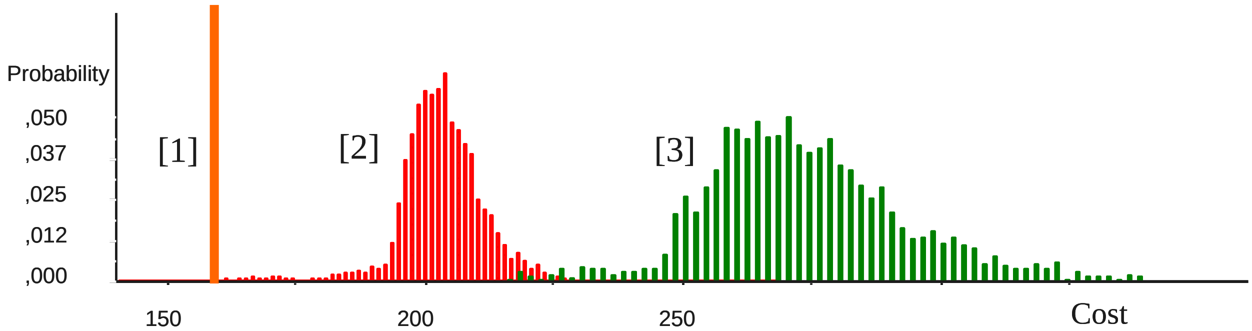



***Fig. 10*** *Base Cost [1] + Risk Costs [2] Gives the "Range of Probable Cost" [3]*

## 7.2 RIAAT (Risk Administration and Analysis Tool)

RiskConsult (Sander 2014) has developed the risk analysis software RIAAT (http://riaat.riskcon.at), which is designed and used specifically to evaluate cost and schedule risks for infrastructure projects, particularly in transportation. RIAAT is an all-in-one integrated risk and cost analysis and management software, fully supporting probabilistic methods. Based on experience from using it on many major infrastructure projects, this software provides transparency to the risk analyst through its comprehensive reporting features. RIAAT's features include:

1. A structured and hierarchical risk register (including base costs, a base schedule, risk events with probabilities and impacts using appropriate profiles, escalation, risk mitigation, and residual effects)
2. Quantified mitigation costs for use in assessing risk mitigation measures and the acceptability of residual risk
3. Internal tools for event tree analysis and fault tree analysis to supplement standard correlation estimates
4. Tracking and trending of risk management actions with updating as needed
5. Risk management reports with flexible tabular and graphical contents for examining results in different ways
6. Fully supported MS-Excel export and import for all data
7. The ability to integrate change orders (including materialized risks) and update the risk assessment to obtain an updated probabilistic cost and schedule
8. Powerful visualization tools to present the risk model and results in ways that are meaningful to decision makers

Risk elements, probabilities and impacts, and graphs can be output to an Excel spreadsheet so that any specific input can be varied to examine its effects on the calculated results (sensitivity analysis). Members of the project team can perform their own sensitivity analyses of specific risk elements in order to obtain a better understanding of the possible impact of that element on project cost and schedule. This will also allow the project's team to update the risk assessment over time as more information on probabilities and impacts becomes available. This capability is particularly useful to monitor what should be decreasing uncertainty in projected project cost and schedule as construction advances. This significantly benefits the project team by providing a tool to monitor and evaluate risk as the project progresses. It also avoids the pitfall of being presented with a "blackbox of results" that is not understood by the owner or contractor mangers.

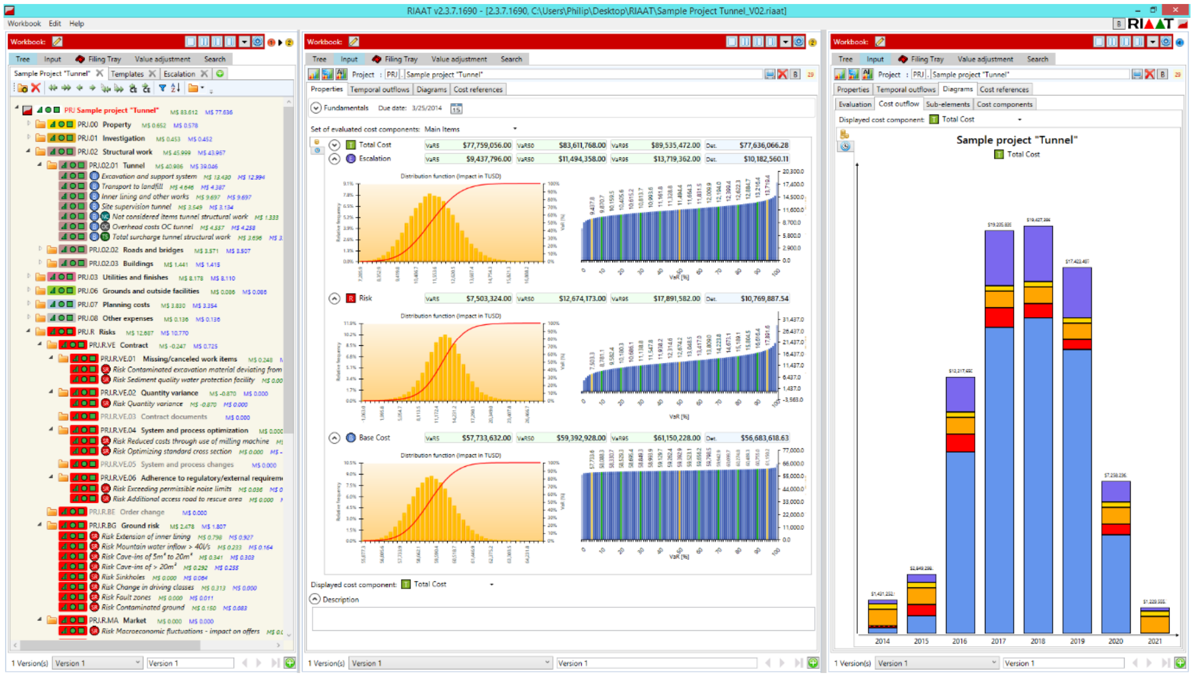



***Fig. 11*** *Example of RIAAT Display of Analysis Information*

The above figure provides a summary of the hierarchical risk listing (left panel), the probabilistic aggregation of base cost plus risk costs in two types of probability distributions (center section), and the forecast project cash flow (right panel).

## 8. Interdependent and Correlated Risks

A significant issue in risk assessments for infrastructure projects is the treatment of interdependent, correlated risks. These types of risks are much more difficult and complex to evaluate and model. Some analysts wrongly assume that all risks are independent and uncorrelated. This simplification can result in significant errors in the results and lead to poor decisions. The CEVP® and RIAAT methods have the capability to model interdependent and correlated risks correctly. This topic is currently being addressed and will be published in a subsequent paper.

## 9. Key Points

1. Traditional deterministic cost-estimating methods, while well accepted, can overestimate or underestimate costs and provide very limited information regarding risks that may occur.
2. Risk-based, probabilistic cost-estimating methods can 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.
3. Risk-based, probabilistic cost-estimating methods also give more information to manage budgets (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).
4. 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 get better results.
5. In particular, such information helps owners by highlighting budget issues early, allowing better 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.
6. Subsequent to winning a bid, the contractor's strategies for cost and claims management are informed by better cost and risk information.

## 10. Considerations

1. The more information you have, the more options you have to manage your risks.
2. The earlier you have this information, the greater the opportunities to anticipate and manage risks.
3. No cost estimation method will ever deliver the “right” value. All methods are a more or less sophisticated form of prognosis. Therefore, the more complete and accurate your information is, and the earlier it is understood, the better you can make decisions on a sound basis. However, it is, and will always remain, your final decision to:
   a. Walk away and leave the chances (for loss of money and/or public trust) to others, or
   b. Reduce or increase your profit (or loss) by adding transparently estimated contingencies for risks to your budget or bid.
4. Everyone can benefit strategically and operationally from sufficiently complete risk-based, probabilistic information, including potential cost ranges and risk characterization.
5. The more complex and “risky” a project is, the more information is needed, and this information is critical to success. If a risk is not identified and characterized early, the project cannot be managed fully or reasonably protected against adverse events and cost overruns.
6. Risk management procedures to control these potential outcomes have been defined sufficiently, and sufficient Information Technology (IT) is available in a variety of software products that are not difficult to understand and use.

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See also “Publications” in the websites **[www.JohnReilly.us](http://www.JohnReilly.us)** **[www.moergeli.com](http://www.moergeli.com)** **[www.riskcon.at](http://www.riskcon.at)**