RISK.06

A Recommended Total Project Cost Risk Model Approach

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ABSTRACT—In the current world of project cost risk analysis, models to determine a probabilistic total project cost can vary considerably. Two common approaches are to put probabilistic cost distributions directly on the cost items, and to apply impact costs to the qualitative assessment of identified risks. However, both approaches have shortcomings that decrease the value of the assessment. This paper recommends a cost modeling approach that uses separate cost elements and discrete cost variables for scope, price, productivity, and duration, which represent the identified risks, but avoids the shortcomings from using the risk register directly. This approach, which can be used by both owners and contractors, helps provide a realistic assessment of the probabilistic total project cost by linking the identified risks to the cost estimate, recognizing compounding impacts on costs, avoiding overlapping risks, and considering the schedule variability impact on the cost. The end result provides the project team with a higher confidence in the results and a workable set of priorities for areas of high risk.

Keywords: Cost, estimates, modeling, projects, and risk analysis

Quantitative risk analysis for project costs is becoming more and more common with large capital projects throughout the world, particularly in the US. Both owners and contractors are interested in understanding the potential variability in a project cost and their exposure to these variances. Risk, for the purpose of this paper, is defined as any impact that results in a variance from the planned outcome, including both threats and opportunities. A cost risk analysis is the quantitative process used to determine how the project cost may vary because of systemic and project specific risks, positive or negative. The analysis uses a model reflecting the estimated project cost and potential variations in that cost. However, the approaches used to model these cost variances can significantly differ from one practitioner to another.

Regretfully, most cost risk analyses are performed by consultants or contractors that are interested in protecting their means and methods from others. While this practice of using third parties is good since they are not biased, recommended practices are difficult to establish. As a result, the evaluation of different approaches to cost risk analysis is hampered by a lack of data. Other variables also make comparisons extremely difficult. Every project is unique, making comparisons of risk analyses difficult at best. The skill and experience of the analyst and the quality of the underlying cost estimate are probably the two most important determinants in the quality of the assessment, regardless of the method used to model the cost variability. As a result, a particular model method may yield a high quality assessment in the hands of a skilled analyst and a low quality assessment in the hands of someone without the proper experience.

This paper compares two common cost risk model approaches against a recommended third approach based on the author's experience with the different approaches. This recommended approach, which will be called the "cost variable approach" for the purposes of this paper, builds on the work of others regarding the use of influence factors in performing cost risk analysis. [1, 4, 6] This approach can be more time intensive, but helps avoid issues that may occur with the other two approaches. The cost variable approach is not appropriate for assessing the risk on a Class 5 (screening or feasibility) estimate and may not be appropriate for a Class 4 (conceptual) estimate, depending on the format.

Current Common Modeling Approaches to Cost Risk Analysis
Cost risk models often take one of two forms, either assigning variability ranges directly to cost items or assigning probability and potential impacts to a list of risks that have been identified. [3, 5].

Cost Item Ranging: This approach, sometimes called "range estimating", is the most common model, which distills the cost estimate into discrete cost items and assigns a range of variability to each cost item. Typically the analyst will meet with the project team to discuss the cost items, including how well the work has been defined, the preparation of the estimate, and risks associated with those cost items. Figure 1 shows a very simple example of this type of model.

Cost Item	Base Cost (US$M)	Low Range	High Range	Mean Expected Cost (US$M)
Concrete	$ 32.00	-5%	10%	$ 32.68
Steel	$ 28.00	-8%	10%	$ 28.24
Drywall	$ 10.00	-10%	15%	$ 10.21
Finishes	$ 15.00	-15%	20%	$ 15.32
Totals	**$ 85.00**			**$ 86.45**

Figure 1—Simple Model Example for Cost Item Ranging

Advantages of Approach

- This type of model is easy to create and administer. It does not require a significant amount of knowledge regarding modeling and statistics.
- This approach is very time effective. The entire exercise, in most cases, can be completed in a day or less. And,

- The team can quickly identify which cost items have the most risk and require the most contingency.

Disadvantages of Approach

- This approach may "over simplify" risks on a project. Quite often the discussion on the possible ranges focus on the direct risks to that cost item and fail to incorporate some broader risks that may impact the entire project.
- This approach does not address the compounding impact of risks well. If the scope grows and the productivity is worse, the two risks are compounded together. And,
- The model typically does not address the fact that a number of risks may impact multiple cost items. Labor productivity issues may impact all the direct cost items at the same time. The possible correlation of risks between cost items is typically left out of the model.

Risk Register Ranging: This approach for analyzing cost risk is commonly done as a part of a risk workshop, where key project team members and stakeholders meet together with the analyst to identify the risks and assess the probability that each identified risk will occur and the potential impact if it does occur. Figure 2 provides a very simple example of this type of model.

#	Risk Description	Probability of Occurrence	Low Range of Impact (US$M)	Most Likely Impact (US$M)	High Range of Impact (US$M)	Mean Expected Impact (US$M)
1	Market escalation of material prices beyond expected rate of 5% per year	50%	$ 20.00	$ 25.00	$ 30.00	$ 12.50
2	Inability to find sufficient skilled craft labor to perform work, impacting labor cost and schedule	25%	$ 5.00	$ 10.00	$ 15.00	$ 2.50
3	Definition of technology package for building may change, impacting the IT and electrical requirements	75%	$ 6.00	$ 8.00	$ 15.00	$ 7.62
4	Site security may have to be increased due to threats, impacting laydown and site access	50%	$ 4.00	$ 5.00	$ 7.00	$ 2.72
					Total	$ 25.34

Figure 2—Simple Model Example for Risk Register Ranging

Advantages of Approach

- This approach quickly identifies which risks are considered the highest threats and opportunities to the project cost. And,
- Often this approach is performed in a group setting, which creates group awareness of the project risks as well as determining potential responses to them.

Disadvantages of Approach

- Most risk identification exercises and resulting risk registers typically focus on the threats to a project and often discount potential opportunities that might improve the project cost.
- This approach does not recognize the overlapping effect of certain risks, resulting in a "double-dip" of the impact in the results. For instance, two risks may impact labor productivity. But if both risks occur, the resulting impact may not be the same as the impact of each risk combined. And,

- The potential impact assessments are typically not based directly on the cost items that would be impacted by those risks. The ranges are more often based on an intuitive approach for the potential impact rather than based on a quantitative analysis of examining exactly which costs would be impacted.

Hybrid Models: The author has also seen hybrid models that combined the above approaches, placing ranges around the various cost items to recognize general estimating uncertainty and then ranging the project specific risks that were identified in a workshop. The hybrid approach does provide the best of each of these approaches but does not completely eliminate any of the disadvantages associated with them.

Key Modeling Considerations for Cost Risk Analysis

Any cost risk model needs to be capable of dealing with a number of different factors to ensure the integrity of the model and avoid any unintended negative effects from a poorly constructed model. Such factors include the source of project risks, the estimate basis, and basic development of the model.

Sources of Uncertainty, Threats, and Opportunities

- Level of definition supporting the estimate – how well has the scope been defined and how advanced is the underlying design basis. An estimate based on a conceptual design has more uncertainty than one based on schematic design or detailed design.
- Type of estimate – factored estimate, parametric estimate, or detailed estimate
- Unknown or latent conditions at the site or in the market place. And,
- Project specific risks, such as use of new technology, project team experience, project location, etc.

Estimate Basis

- The execution plan for the project, including the contracting strategy for performing the work and risk allocation.
- The project schedule, which may be aggressive or conservative, may require a significant amount of overtime or high worker levels.
- The methodology used to prepare the estimate, including:
    - If labor and material costs separate or combined; and,
    - If costs factored from other costs or independently estimated, such as engineering and design being factored from construction cost.
- The assumptions used for the procurement of bulk materials or process equipment, including if a local purchase or world open market, level of competition, single source suppliers or proprietary systems. And,
- The assumptions on construction techniques and labor performance, such as the extent of pre-assembly, off-site fabrication and modularization; how much labor is local as opposed to travelers.
- Consistency between the estimate and the schedule and execution plan basis?

Cost Model Development

- The cost model needs to divide the risks into discrete, i.e. non-overlapping, variables.
- The model needs to be able to address how certain risks may impact multiple project cost items at the same time and in the same manner.
- The model needs to consider and be consistent with the schedule risks that could occur. And,
- The model should be consistent with the class of estimate.

A Recommended Cost Model Approach

A perfect cost risk model approach does not exist since we do not have perfect information about a project and any model can only approximate real world interactions between the various risks and the project costs. However, the cost variable approach avoids many of the disadvantages of the previously-described approaches and better addresses some of the real world interactions between elements on a project.

The cost variable approach establishes cost items and cost variables from the base estimate. By using this modeling approach, a cost item can have several cost variables assigned to it – which helps to simulate the interplay of several project risks to the cost model.

The project cost estimate is summarized and sub-divided into specific cost items (or cost elements) that relate to areas of interest as well as areas of risk vulnerability. Complementary to the cost items are cost variables which help to simulate the effects of project cost uncertainties and identified risks. These variables relate to scope, price (material or labor), productivity, and duration for cost items. Each variable may be assigned to one or multiple cost items. For example, the variability in labor productivity for the electrical work may also be applied to instrumentation work, if the work will be performed by the same contractor and is subject to the same major risks. This model approach can be fairly simple or very intricate, depending on the stage, size, and complexity of the project.

Definition of Cost Items

The thought process to break down (or sub-divide) the base cost estimate into several cost items is very important. The division of costs into separate cost items needs to be detailed enough to ensure that items with different discrete risks are not combined, but summary level enough to not get lost in the details and to avoid problems with "dampening" during the simulation process. "Dampening" occurs when so many cost items are defined that the variability between all the elements effectively cancels each other out during the simulations. This issue can also be avoided through correlating the cost variables, which will be discussed further in this paper. [2, 3] The key to defining the cost items is to group items subject to the same risks and separate items subject to different risks.

Considerations for Defining Cost Items

- Where possible, material and labor costs should be separated in to different cost items.

- Costs for different trades may be combined or kept separate as necessary. For a building, all the finishes may be combined into two cost items, one for material and one for labor. Mechanical and plumbing may be similarly combined.
- Major engineered equipment should be separated from bulk materials. Changes in the equipment scope will typically have a low impact on the worker hours required to install it, whereas a change in the bulk material scope will typically have a direct impact on the worker hours required to install it.
- For construction indirects or field overheads, it is helpful to divide the costs into three categories to segregate such costs that are (a) time-dependent, (b) dependent on the direct work being performed and (c) one-time costs. Each of those indirect cost items are often subject to different risks.
- Engineering may be broken into project management support, which is more time-dependent, and production engineering and design work, which is often more dependent on risks associated with the project's scope and complexity.
- All project costs should be included in the model so that the total of all cost items in the model equals the total cost of the base estimate.
- For situations where some costs in an estimate are already expended, a separate cost item should be created and treated as an historical cost with no variability.
- In general, no cost item should be less than 1 percent of the total project cost to keep from getting overly detailed.
- Most models should have between 20 and 40 cost items.

Definition of Cost Variables

Most project threats, opportunities, and general uncertainty can be easily grouped into scope, price, productivity, and duration variables [3].

- **Scope**: How well is the scope defined? What scope issues still need to be resolved? How might the quantities vary as the design is developed? What risks will impact the scope of the project?
- **Price (Material)**: What changes in the local, regional, and global market may impact the cost of the materials? Changes in the material selection may impact the price. Are there technology issues that might impact the price? What potential escalation is included and may it change?
- **Price (Labor)**: What changes in the local and regional labor market may impact the labor rates? How will a different crew mix impact the average rate? Will the amount of overtime vary and impact the total labor cost? What potential escalation is included and may it change?
- **Productivity**: How may the experience and skill levels of the craft impact productivity rates? How accessible is the laydown area and other support facilities? Is there a potential of stacking of trades? What other project risks will impact the productivity of the craft? What risks will impact the productivity of the engineering labor?
- **Duration**: What is the variability in the duration of the different phases of the project and what time-dependent costs will be impacted?

This type of breakdown closely aligns with how an estimate is typically prepared, as demonstrated in figures 3 and 4.

	Cost	Scope		Price		Productivity		Duration
Material	$ 3,000	100 lf	x	$30/lf				
Installation	$ 5,000	100 lf	x	$25/mh	x	2 mh/lf		
Design	$ 1,000	2 dwgs	x	$50/mh	x	10 mh/dwg		
Management	$ 480			$60/mh	x	8 mhs / day	x	1 day

Figure 3—Cost Estimate Formulation

	Cost	Scope		Price		Productivity		Duration
Material	$ 3,000	(90% - 115%)	x	(98% - 105%)				
Installation	$ 5,000	(90% - 115%)	x	(95% - 108%)	x	(90% - 120%)		
Design	$ 1,000	(99% - 105%)	x	(98% - 108%)	x	(90% - 110%)		
Management	$ 480			(99% - 105%)		(95% - 110%)	x	(80% - 130%)

Figure 4—Cost Variables Formulation

Considerations for Defining Cost Variables

- In some cases these variables may be combined, depending on how the costs were developed and the associated risks. Examples:
  - **Mechanical** equipment scope and price variables may be combined, since the price of a piece of equipment is often directly tied to the equipment technology, materials, and accessories.
  - **Pricing**, both labor and material, and labor productivity, variables may be combined if the estimate does not separate these costs and they cannot be easily derived.
- The cost variables will typically follow the general breakdown guidelines of the cost items, but could be combined with the variables for other cost items.
- If the mechanical and plumbing costs were combined into two cost items, one for material and one for labor, then the model would include one scope variable for the combined mechanical and plumbing work, one price variable for the mechanical and plumbing material, one price variable for the mechanical and plumbing labor, and one productivity variable for the mechanical and plumbing labor.
- Concrete and steel costs may have been defined as separate cost items, resulting in four separate cost items: material and labor costs for concrete and separately for steel. However, the labor for the concrete and steel may be subject to the same risks (availability of labor, weather, site access, etc.). In that instance one labor productivity variable may be assigned for both the concrete labor and for the steel labor cost.

- The typical ratio of cost variables to cost items is 1.5-2.5. So a cost model with 30 cost items may have 45-75 cost variables. This ratio is driven primarily by the class of estimate and identification of risks. The more detail that is available, the higher the ratio.

Cost Variable Ranging and Distribution

Prior to the development of the cost risk analysis or as a part of this process, a risk register should be developed to identify all the project specific risks. Typically as a part of risk identification workshop, the identified risks are given a qualitative assessment, where the group assigns the likelihood that the risk will occur and the potential impact if it does occur. This process is occasionally turned into a quantitative assessment as described earlier in this paper. However, this risk register is not intended to be used as cost variables.

When evaluating the risk ranges for the different cost variables, this register should be referred to determine which risks would contribute to that variability range. When establishing the variability range, all of the applicable risks should be considered. Since most risk registers typically only list project specific risks, systemic risks also need to be considered in the ranging, taking into account such issues as:

- **Stage of Project Development** – the earlier the stage, the broader the range should be.
- **General Market Price Variability** – not all variability is because of inflation or escalation, there are also effects due to market microeconomic (supply and demand) conditions and willingness to offer bids as evidenced by the range of prices received when bids are solicited.
- **General Weather Variability** – the weather by season is rarely the calculated "average," but either better or worse, resulting in variability in productivity or other factors. And,
- **Quality of the Estimate** – just like tax forms, it is unlikely two estimators would arrive at the same exact estimate. Every estimate is based on assumptions and experience that will vary from one person to another and likely to be different from that actually experienced when the project is constructed.

The variable ranges need to take all of these risks and their potential impacts into account, while taking a dose of reality. The ranges should avoid using either a fairy tale low range or a Hollywood disaster movie high range. While it is certainly possible that a project may experience one or the other, the probability is so small that the analysis would be unduly biased by including it in consideration. One approach is to define ranges based on something less than the absolute best case scenario or the absolute worst case scenario, such as using a 10 – 90 percent range. The low end can be defined as having a 10 percent chance of being as good or better as that number. The high end can be defined as having a 90 percent chance of being as good or better as that number. Most software packages will have distributions that can be selected that allow setting those parameters, as opposed to the absolute best and worst numbers.

The distribution profile to select for the cost variables should be based on the type of risk being addressed. However, most practitioners default to either a triangular or beta type distribution profile. Past experience indicates that either distribution will provide similar results, at least within the 10%-90% range. The beta distribution will result in a broader 0%-100% range than the triangular distribution. However, these distribution profiles are certainly not applicable for all risks. Log normal, uniform, discrete, or other distributions are also used as appropriate. The analyst will need to select the appropriate distribution type to match the potential variability profile.

Correlations

The cost risk model needs to also include correlations between cost variables as appropriate. Correlation between variables means that they have a tendency to move in the same direction at the same time. While the model may have different variables for the scope of the concrete and the scope of the steel, if the scope of the steel grows, the scope of the concrete may grow also. If both variables will always be better or worse to the same degree, then the two variables would have a 1-to-1 correlation. If they have no interdependence, then the correlation would be 0. Many variables of the same type will have some correlation to each other. Labor pricing variables will typically have a high correlation to each other. Scope growth in certain disciplines will typically have some correlation for growth in other areas, such as between drywall and finishes.

Figure 5 is a simple example of model using the cost variable model approach for a process type project.

			Cost Variables																												
	Cost Items	Cost (US$k)	1 Scope of Civil/Concrete Work	2 Price of Civil/Concrete Mat'l	3 Productivity of Civil/Concr. Labor	4 Price of Civil/Concrete Labor	5 Scope of Steel Work	6 Price of Steel Mat'l	7 Productivity of Steel Labor	8 Price of Steel Labor	9 Scope & Price of Mech. Equip.	10 Productivity of Mech. Labor	11 Price of Mech. & Piping Labor	12 Scope of Piping Work	13 Price of Piping Mat'l	14 Productivity of Piping Labor	15 Scope of Elec./Instr. Work	16 Price of Elec./Instr. Mat'l	17 Productivity of Elec./Instr. Labor	18 Price of Elec./Instr. Labor	19 Price & Productivity of Paint/Insul.	20 Productivity of Indirect Labor	21 Price of Indirect Labor	22 Scope & Price of Temp. Facilities	23 Scope & Productivity of CM	24 Price of CM Labor	25 Scope & Productivity of Engin.	26 Price of Engin. Labor	27 Scope & Productivity of PM	28 Price of PM	29 Duration of Construction
1	Civil Material	$ 41	□	□																												
2	Civil Labor	$ 124	□		□	□																										
3	Concrete Material	$ 207	□	□																												
4	Concrete Labor	$ 309	□		□	□																										
5	Steel Material	$ 347					□	□																								
6	Steel Labor	$ 154					□		□	□																						
7	Mechanical Equipment	$ 842									□																					
8	Mechanical Labor	$ 172										□	□																			
9	Piping Material	$ 422												□	□																	
10	Piping Labor	$ 799											□	□		□																
11	Elec. & Instr. Material	$ 518															□	□														
12	Elec. & Instr. Labor	$ 340															□		□	□												
13	Paint/Insul. Mat'l & Labor	$ 89												□							□											
14	Indirect Labor	$ 110												□								□	□									
15	Temporary Facilities	$ 45																						□								□
16	Constr. Management	$ 120																							□	□						□
17	Engineering	$ 620																									□	□				
18	Project Management	$ 320																											□	□		□
		Correlations:		A	B	C		A	B	C		B	C		A	B		A	B	C			C			D		D		D	

Cost Variable Ranges and Correlation %'s not included in example.

Figure 5 – Cost Risk Model Example

Advantages and Disadvantages of Approach

Like every cost risk model method, this approach also has advantages and disadvantages. This approach may be "overkill" for certain projects, particularly smaller projects with low complexity. However, the approach does provide a fair amount of latitude in defining the cost items and variables to address straight forward projects and highly complex projects.

Advantages of Approach

- By grouping risks into common categories, such as scope, price, productivity, or duration, it is easier to avoid duplication of impacts and provide a realistic range due to risks.
- The cost variable approach recognizes the variability in underlying components of each cost item and reflects the resulting compounding impact that may occur. This is accomplished by the ability to assign multiple cost items to each variable as well as the designation and application of correlation into the model.
- This approach incorporates duration risks, helping to ensure a consistency between the cost risk model approach and the schedule risk model. Even if a schedule risk model is not developed, this approach provides for addressing variability due to schedule, which requires some assessment of the project schedule.
- The variables consider the project specific risks that have identified and listed in a risk register.
- By grouping risks into common categories, the results can help summarize key areas of risk, such as scope definition in a particular area or overall, or labor productivity in a particular discipline or all labor.
- The output from this model will provide more details on the risk drivers, which can be summarized in multiple fashions, including by Cost Item, Cost Variables, and variable types.

Disadvantages of Approach

- Because of its higher level of sophistication, this approach may take more time than other approaches, particularly in the time required to build the actual cost risk model.
- This approach requires an analyst with a high level of skill and experience to properly assemble the model and build in all the necessary interactions of risks among the sub-divisions of the cost estimate.

As stated in the introduction, the quality of any cost risk analysis is driven more by the skills of the analyst than anything else, even the method used to prepare the model. However, this approach can help avoid certain inherent issues with other typical cost risk models. A skilled practitioner can take this approach and develop an intricate model that helps represent the real life interactions between elements of a project and the impact of risks on the project.

This approach helps recognize the compounding impacts between different risks while avoiding overlapping risks. At the same time, this approach provides more detailed feedback on the cost risk drivers for the project, pointing to scope, price, productivity, and duration risks for the various components of the project.

Developing appropriate simulation models for cost estimates is part science and part art. The modeling presented in this paper is an elegant approach which recognizes many of the key issues from a cost and risk management perspective: basis of the estimate, sensible sub-division or categorization of costs, identification of risks, and association of risks to the right elements of the cost estimate. From the experience of the author, this method has provided sensible simulation results and plausible explanation of the effects of various project risks to the cost estimate. The author recommends other practitioners or cost risk analysts to follow this methodology.

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