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Standard Practice for
Measuring Cost Risk of Buildings and Building Systems and Other Constructed Projects[1]

This standard is issued under the fixed designation E1946; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers a procedure for measuring cost risk for buildings and building systems and other constructed projects, using the Monte Carlo simulation technique as described in Guide E1369.

1.2 A computer program is required for the Monte Carlo simulation. This can be one of the commercially available software programs for cost risk analysis, or one constructed by the user.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E631 Terminology of Building Constructions
E833 Terminology of Building Economics
E1369 Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems
E1557 Classification for Building Elements and Related Sitework—UNIFORMAT II
E2083 Classification for Building Construction Field Requirements, and Office Overhead & Profit
E2103/E2103M Classification for Bridge Elements—UNIFORMAT II
E2168 Classification for Allowance, Contingency, and Reserve Sums in Building Construction Estimating
E2514 Practice for Presentation Format of Elemental Cost Estimates, Summaries, and Analyses

3. Terminology

3.1 *Definitions*—For definitions of general terms related to building construction used in this guide, refer to Terminology E631; and for general terms related to building economics, refer to Terminology E833.

4. Summary of Practice

4.1 The procedure for calculating building cost risk consists of the following steps:

4.1.1 Identify critical cost elements.

4.1.2 Eliminate interdependencies between critical elements.

4.1.3 Select Probability Density Function.

4.1.4 Quantify risk in critical elements.

4.1.5 Create a cost model.

4.1.6 Conduct a Monte Carlo simulation.

4.1.7 Interpret the results.

4.1.8 Conduct a sensitivity analysis.

5. Significance and Use

5.1 Measuring cost risk enables owners of buildings and other constructed projects, architects, engineers, and contractors to measure and evaluate the cost risk exposures of their construction projects.[3] Specifically, cost risk analysis (CRA) helps answer the following questions:

5.1.1 What are the probabilities for the construction contract to be bid above or below the estimated value?

5.1.2 How low or high can the total project cost be?

5.1.3 What is the appropriate amount of contingency to use?

5.1.4 What cost elements have the greatest impact on the project's cost risk exposure?

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[1] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.81 on Building Economics.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] This practice is based, in part, on the article, "Measuring Cost Risk of Building Projects," by D. N. Mitten and B. Kwong, Project Management Services, Inc., Rockville, MD, 1996.

5.2 CRA can be applied to a project's contract cost, construction cost (contract cost plus construction change orders), and project cost (construction cost plus owner's cost), depending on the users' perspectives and needs. This practice shall refer to these different terms generally as "project cost."

6. Procedure

6.1 *Identify Critical Cost Elements:*

6.1.1 A project cost estimate consists of many variables. Even though each variable contributes to the total project cost risk, not every variable makes a significant enough contribution to warrant inclusion in the cost model. Identify the critical elements in order to simplify the cost risk model.

6.1.2 A critical element is one which varies up or down enough to cause the total project cost to vary by an amount greater than the total project cost's critical variation, and one which is not composed of any other element which qualifies as a critical element. This criterion is expressed as:

$$IF\ V_Y > V_{CRIT} \tag{1}$$

$$\text{AND Y contains no other element X where } V_X > V_{CRIT}$$

$$\text{THEN Y is a critical element}$$

where:

$$V_Y = \tag{2}$$

$$\frac{(\text{Max. percentage variation of the element Y})*(\text{Y's anticipated cost})}{\text{Total Project Cost}}$$

V_{CRIT} = Critical Variation of the Project Cost.

6.1.3 A typical value for the total project cost's critical variation is 0.5 %.[4] By experience this limits the number of critical elements to about 20. A larger V_{CRIT} will lead to fewer critical elements and a smaller V_{CRIT} will yield more. A risk analysis with too few elements is over-simplistic. Too many elements make the analysis more detailed and difficult to interpret. A CRA with about 20 critical elements provides an appropriate level of detail. Review the critical variation used and the number of critical elements for a CRA against the unique requirements for each project and the design stage. A higher critical variance resulting in fewer critical elements is more appropriate at the earlier stages of design.

6.1.4 Arrange the cost estimate in a hierarchical structure such as UNIFORMAT II (Classification E1557 for Buildings or Classification E2103/E2103M for Bridges; Practice E2514 provides a presentation format for elemental costs). Table 1 shows a sample project cost model based on a UNIFORMAT II Levels 2 and 3 cost breakdown for a building. The UNIFORMAT II structure of the cost estimate facilitates the search of critical elements for the risk analysis. One does not need to examine every element in the cost estimate in order to identify those which are critical.

6.1.5 Starting at the top of the cost estimate hierarchy (that is, the Group Element level), identify critical elements in a downward search through the branches of the hierarchy. Conduct this search by repeatedly asking the question: Is it possible that this element could vary enough to cause the total building cost to vary, up or down, by more than its critical variation? Terminate the search at the branch when a negative answer is encountered. Examine the next branch until all branches are exhausted and the list of critical elements established (denoted by asterisks in the last column of Table 1). Table 1 and Fig. 1 show the identification of critical elements in the sample project using the hierarchical search technique.

6.1.6 In the sample project, Group Element B10 Superstructure has an estimated cost of $915 000 with an estimated maximum variation of $275 000, which is more than $50 000, or 0.5 % of the estimated total building cost. It is therefore a candidate for a critical element. However, when we examine the Individual Elements that make up Superstructure, we discover that Floor Construction has a estimated maximum variation of $244 500, qualifying as a critical element; whereas Roof Construction could only vary as much as $40 000, and does not qualify. Since Floor Construction is now a critical element, we would eliminate Superstructure, its parent, as a critical element.

6.1.7 Include overhead cost elements in the cost model, such as general conditions, profits, and escalation (see Classification E2083), and check for criticality as with the other cost elements. Consider time risk factors, such as long lead time or dock strikes for imported material, when evaluating escalation cost.

6.1.8 Allowance and contingency, as commonly used in the construction cost estimates, include both the change element and the risk element. The change element in allowance covers the additional cost due to incomplete design (design allowance). The change element in contingency covers the additional cost due to construction change orders (construction contingency). The risk element in contingency covers the additional cost required to reduce the risk that the actual cost would be higher than the estimated cost. However, the risk element in allowance and contingency is rarely identified separately and usually included in either design allowance or construction contingency. When conducting CRA, do not include the risk element in allowance or contingency cost since that will be an output of the risk analysis. Include design allowance only to the extent that the design documents are incomplete. Include construction contingency, which represents the anticipated increase in the project cost for change orders beyond the signed contract value, if total construction cost, instead of contract cost, is used. See Classification E2168 for information on which costs are properly included under allowance and contingency.

6.1.9 The sample project represents a CRA conducted from the owner's perspective to estimate the construction contract value at final design. General conditions, profits, and escalation are identified as critical elements. Since the design documents are 100 % complete, there is no design allowance. The contingency in the cost element represents the risk element and is therefore eliminated from the cost model. There is no construction contingency in the model since this model estimates construction contract cost only. If total project cost is desired,

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[4] Curran, M. W., "Range Estimating—Measuring Uncertainty and Reasoning With Risk," *Cost Engineering*, Vol 31, No. 3, March 1989.

TABLE 1 Sample UNIFORMAT II Cost Model

ITEM	GROUP ELEMENT	INDIVIDUAL ELEMENT	GROUP ELEMENT COST	INDIVIDUAL ELEMENT COST	EST MAX/ VARIATION	
A10	FOUNDATIONS		$150 000		$45 000	
A1010		Standard Foundations		$100 000		
A1030		Slab on Grade		$50 000		
A20	BASEMENT CONSTRUCTION		$70 000		$30 000	
A2010		Basement Excavation		$20 000		
A2020		Basement Walls		$50 000		
B10	SUPERSTRUCTURE		$915 000		$275 000	
B1010		Floor Construction		$815 000	$244 500	*
B1020		Roof Construction		$100 000	40 000	
B20	EXTERIOR ENCLOSURE		$800 000		$250 000	
B2010		Exterior Walls		$576 000	$172 800	*
B2020		Exterior Windows		$204 000	$102 000	*
B2030		Exterior Doors		$20 000	$8 000	
B30	ROOFING		$54 000		$20 000	
B3010		Roof Coverings		$54 000		
C10	INTERIOR CONSTRUCTION		$240 000		$72 000	*
C1010		Partitions		$132 000	$45 000	
C1020		Interior Doors		$108 000	$30 000	
C20	STAIRS		$95 000		$40 000	
C2010		Stair Construction		$75 000		
C2020		Stair Finishes		$20 000		
C30	INTERIOR FINISHES		$916 000		$300 000	
C3010		Wall Finshes		$148 000	$45 000	
C3020		Floor Finishes		$445 000	$178 000	*
C3030		Ceiling Finishes		$323 000	$129 200	*
D10	CONVEYING		$380 000			
D1010		Elevators & Lifts		$380 000	$228 000	*
D20	PLUMBING		$142 000		$45 000	
D2010		Plumbing Fxtures		$70 000		
D2020		Domestic Water Distribution		$30 000		
D2030		Sanitary Waste		$22 000		
D2040		Rain Water Drainage		$20 000		
D30	HVAC		$1 057 000		$550 000	
D3010		Energy Supply		$20 000	$8 000	
D3020		Heat Generating Systems		$80 000	$30 000	
D3030		Cooling Generating Systems		$275 000	$137 500	*
D3040		Distribution Systems		$500 000	$300 000	*
D3050		Terminal & Package Units		$60 000	$30 000	
D3060		Controls and Instrumentation		$217 000	$130 200	*
D3070		System Testing & Balancing		$20 000	$10 000	
D40	FIRE PROTECTION		$270 000		$100 000	
D4010		Sprinklers		$220 000	$88 000	*
D4020		Standpipes		$50 000	$15 000	
D50	ELECTRICAL		$985 000		$500 000	
D5010		Electrical Service & Distribution		$180 000	$108 000	*
D5020		Lighting & Branch Wiring		$685 000	$411 000	*
D5030		Communication & Security		$120 000	$45 000	
G10	SITE PREPARATION		$120 000		$45 000	
G1030		Site Earthwork		$120 000		
G20	SITE IMPROVEMENT		$800 000		$450 000	
G2030		Pedestrian Paving		$420 000	$252 000	*
G2050		Landscaping		$380 000	$228 000	*
G30	SITE MECHANICAL UTILITIES		$420 000		$126 000	*
G3010		Water Supply		$120 000	$40 000	
G3020		Sanitary Sewer		$120 000	$42 000	
G3030		Storm Sewer		$140 000	$46 000	
G3060		Fuel Distribution		$40 000	$20 000	
G40	SITE ELECTRICAL UTILITIES		$200 000		$100 000	*
G4010		Electrical Distribution		$100 000	$45 000	
G4020		Site Lighting		$25 000	$15 000	
G4030		Site Communications & Security		$75 000	$42 000	
	SUBTOTAL			$7 729 000		
		GENERAL CONDITIONS		$823 000	$411 500	*
	SUBTOTAL			$8 552 000		
		PROFIT (10 %)		$855 200	$427 600	*
	SUBTOTAL			$9 407 200		
		ESCALATION (5 %)		$470 360	$188 144	*
	SUBTOTAL			$9 877 560		
		CONTINGENCY (5 %)		$493 878		
				$10 371 438		
	TOTAL CONSTRUCTION CONTRACT COST					
		* Meets criteria for critical elements				

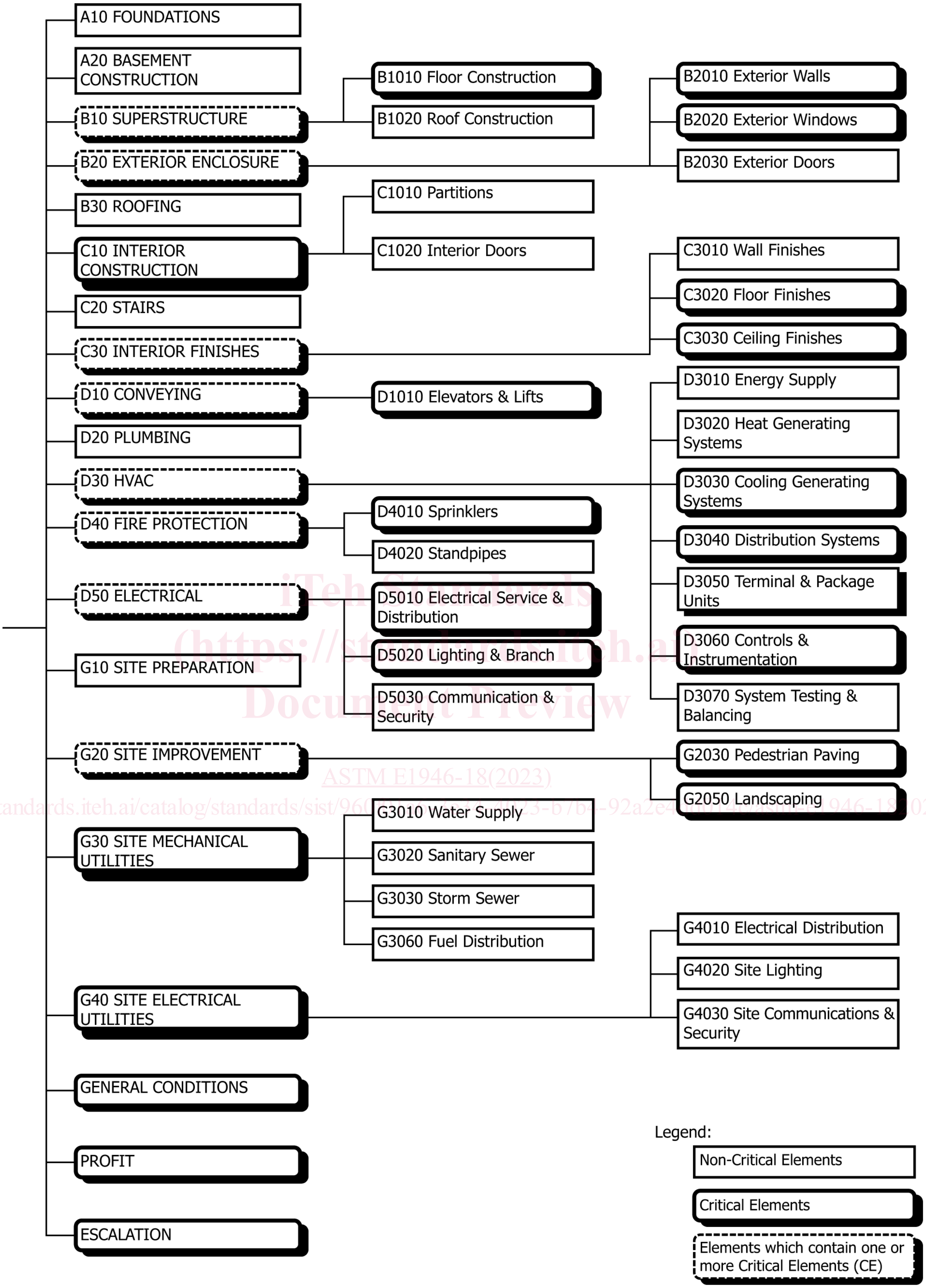

FIG. 1 Identification of Critical Elements in the Sample Project

add other project cost items to the cost model, such as construction contingency, design fees, and project management fees.

6.2 *Eliminate Interdependencies Between Critical Elements:*

6.2.1 The CRA tool works best when there are no strong interdependencies between the critical elements identified. Highly interdependent variables used separately will exaggerate the risk in the total construction cost. Combine the highly dependent elements or extract the common component as a separate variable. For example, the cost for ductwork and the cost of duct insulation are interdependent since both depend on the quantity of ducts, which is a highly uncertain variable in most estimates. Combine these two elements as one critical element even though they both might qualify as individual critical elements. As another example, if a major source of risk is labor rate variance, then identify labor rate as a separate critical element and remove the cost variation associated with labor rates from all other cost elements.

6.2.2 In the sample project, a percentage escalation is treated as a separate cost element, instead of having the escalation embedded in each cost element. The escalations for all cost elements are highly correlated because they all depend on the general escalation rate in material and labor. Therefore the model is more accurate when taking escalation as a separate cost element. Treat escalation as a critical element if it causes the total cost to vary by more than 0.5 %.

6.3 *Select Probability Density Function (PDF):*

6.3.1 Assign a PDF to each critical element to describe the variability of the element. Select the types of PDFs that best describe the data. These include, but are not restricted to, the normal, lognormal, beta, and triangular distributions. In the construction industry, one does not always have sufficient data to specify a particular distribution. In such a case a triangular distribution function has some advantages.[5] It is the simplest to construct and easiest to conceptualize by the team of design and cost experts. The triangular PDF assumes zero probability below the low estimate and above the high estimate, and the highest probability at the most likely estimate. Straight lines connect these three points in a probability density function, forming a triangle, thus giving the name triangular distribution.

6.3.2 Because the triangular distribution function is only an approximation, the low and high estimates do not represent the absolute lowest and highest probable value. As compared to the more realistic "normal distribution," these values represent about the first and 99th percentiles, respectively. In other words, there is a 1 % chance that the value will be lower than the low estimate (point "a" on Fig. 2) and another 1 % chance that it will be higher than the high estimate (point "b" on Fig. 2). The triangular distribution is a reasonably good approximation of the normal distribution except at the extreme high or low ends. However, for construction estimates, there is rarely a requirement for values below the 5th and above the 95th percentile. Therefore, there is no significant loss of model accuracy in using the triangular distribution.

6.4 *Quantify Risks in Critical Elements:*

6.4.1 Quantify the risk for each element by a most likely estimate, a low estimate, and a high estimate. Table 2 shows the list of critical elements identified in the sample project, with the associated three point estimates. As discussed in the previous section, the high and low estimates should capture the middle 98 % of the probable outcome for the element. The most likely estimate, on the other hand, represents value with highest probability of occurrence, and is the peak of the triangular distribution. This may not coincide with the single value cost estimate since the single value is most often interpreted as the mean or median, rather than the mode. On a skewed triangular distribution, the mean (average), median, and mode (most likely) values are all different (Fig. 3).

6.4.2 There may be a tendency to select low estimates that are not low enough, and high estimates that are not high enough. In part this is a result of not being able to envision lowest and highest possible outcomes. It may be helpful to quantify the high and low estimates in a narrower band (for example, 10th and 90th percentiles). Then adjust these estimates to get the two extreme points on the triangular distribution.

$$HE = MLE + (HE' - MLE) * r \tag{3}$$

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[5] Biery, F., Hudak, D., and Gupta, S., "Improving Cost Risk Analysis," *Journal of Cost Analysis*, Spring 1994.

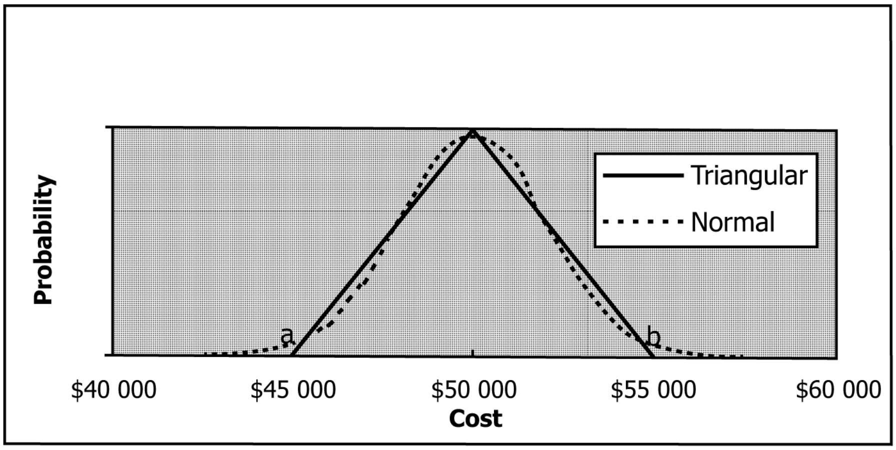

FIG. 2 Comparison of Triangular PDF to Normal Distribution Function