



Designation: ~~E1946-07~~ Designation: E1946 – 12

Standard Practice for ~~Measuring Cost Risk of Buildings and Building Systems~~ Measuring Cost Risk of Buildings and Building Systems and Other Constructed Projects¹

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.

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

E2103 [Classification for Bridge Elements](#) UNIFORMAT II

E2168 [Classification for Allowance, Contingency, and Reserve Sums in Building Construction Estimating](#)

3. Terminology

3.1 *Definitions*—For definitions of general terms used in this guide, refer to ~~Terminologies~~ [Terminology E631](#) and; 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. [standards/sist/69345c66-2ed9-48f4-bb39-66c26f059210/astm-e1946-12](https://standards.sist/69345c66-2ed9-48f4-bb39-66c26f059210/astm-e1946-12)

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 ~~Building cost risk analysis (BCRA) provides a tool for building owners, architects, engineers, and contractors to measure and evaluate the cost risk exposures of their building construction projects.~~

5.1 Measuring cost risk enables owners of buildings and other constructed projects, architects, engineers, and contractors to

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.

Current edition approved Apr. 1, 2007-2012. Published April 2007-2012. Originally approved in 1998. Last previous edition approved in 2002-2007 as E1946 – 027. DOI: 10.1520/E1946-07.10.1520/E1946-12.

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.

measure and evaluate the cost risk exposures of their construction projects.³ Specifically, BCRA helps answer the following questions: 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 building's project's cost risk exposure?

5.2 BCRA 5.2 CRA can be applied to a building 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 "building project cost."

6. Procedure

6.1 Identify Critical Cost Elements:

6.1.1 A building project cost estimate consists of many variables. Even though each variable contributes to the total building 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 building project cost to vary by an amount greater than the total building 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:

$$IF V_y > V_{CRIT} \quad (1)$$

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where:

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

6.1.3 A typical value for the total building 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 makes the analysis more detailed and difficult to interpret. A BCRA with about 20 critical elements provides an appropriate level of detail. Review the critical variation used and the number of critical elements for a BCRA 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 for Bridges). 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, 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.

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

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

TABLE 1 Sample UniformatNIFORMAT II Cost Model

ITEM	GROUP ELEMENT	INDIVIDUAL ELEMENT	GROUP ELEMENT COST	INDIVIDUAL ELEMENT COST	EST MAX/ VARIATION
A10	FOUNDATIONS		\$150,000		\$45,000
A10	FOUNDATIONS		\$150 000		\$45 000
A1010		Standard Foundations		\$100,000	
A1010		Standard Foundations		\$100 000	
A1030		Slab on Grade		\$50,000	
A1030		Slab on Grade		\$50 000	
A20	BASEMENT CONSTRUCTION		\$70,000		\$30,000
A20	BASEMENT CONSTRUCTION		\$70 000		\$30 000
A2010		Basement Excavation		\$20,000	
A2010		Basement Excavation		\$20 000	
A2020		Basement Walls		\$50,000	
A2020		Basement Walls		\$50 000	
B10	SUPERSTRUCTURE		\$915,000		\$275,000
B10	SUPERSTRUCTURE		\$915 000		\$275 000
B1010		Floor Construction		\$815,000	\$244,500 ±
B1010		Floor Construction		\$815 000	\$244 500 *
B1020		Roof Construction		\$100,000	40,000
B1020		Roof Construction		\$100 000	40 000
B20	EXTERIOR ENCLOSURE		\$800,000		\$250,000
B20	EXTERIOR ENCLOSURE		\$800 000		\$250 000
B2010		Exterior Walls		\$576,000	\$172,800 ±
B2010		Exterior Walls		\$576 000	\$172 800 *
B2020		Exterior Windows		\$204,000	\$102,000 ±
B2020		Exterior Windows		\$204 000	\$102 000 *
B2030		Exterior Doors		\$20,000	\$8,000
B2030		Exterior Doors		\$20 000	\$8 000
B30	ROOFING		\$54,000		\$20,000
B30	ROOFING		\$54 000		\$20 000
B3010		Roof Coverings		\$54,000	
B3010		Roof Coverings		\$54 000	
C10	INTERIOR CONSTRUCTION		\$240,000		\$72,000 ±
C10	INTERIOR CONSTRUCTION		\$240 000		\$72 000 *
C1010		Partitions		\$132,000	\$45,000
C1010		Partitions		\$132 000	\$45 000
C1020		Interior Doors		\$108,000	\$30,000
C1020		Interior Doors		\$108 000	\$30 000
C20	STAIRS		\$95,000		\$40,000
C20	STAIRS		\$95 000		\$40 000
C2010		Stair Construction		\$75,000	
C2010		Stair Construction		\$75 000	
C2020		Stair Finishes		\$20,000	
C2020		Stair Finishes		\$20 000	
C30	INTERIOR FINISHES		\$916,000		\$300,000
C30	INTERIOR FINISHES		\$916 000		\$300 000
C3010		Wall Finishes		\$148,000	\$45,000
C3010		Wall Finishes		\$148 000	\$45 000
C3020		Floor Finishes		\$445,000	\$178,000 ±
C3020		Floor Finishes		\$445 000	\$178 000 *
C3030		Ceiling Finishes		\$323,000	\$129,200 ±
C3030		Ceiling Finishes		\$323 000	\$129 200 *
D10	CONVEYING		\$380,000		\$228,000 ±
D10	CONVEYING		\$380 000		\$228 000 *
D1010		Elevators & Lifts		\$380,000	\$228,000 ±
D1010		Elevators & Lifts		\$380 000	\$228 000 *
D20	PLUMBING		\$142,000		\$45,000
D20	PLUMBING		\$142 000		\$45 000
D2010		Plumbing Fxtures		\$70,000	
D2010		Plumbing Fxtures		\$70 000	
D2020		Domestic Water Distribution		\$30,000	
D2020		Domestic Water Distribution		\$30 000	
D2030		Sanitary Waste		\$22,000	
D2030		Sanitary Waste		\$22 000	
D2040		Rain Water Drainage		\$20,000	
D2040		Rain Water Drainage		\$20 000	
D30	HVAC		\$1,057,000		\$550,000
D30	HVAC		\$1 057 000		\$550 000
D3010		Energy Supply		\$20,000	\$8,000
D3010		Energy Supply		\$20 000	\$8 000
D3020		Heat Generating Systems		\$80,000	\$30,000
D3020		Heat Generating Systems		\$80 000	\$30 000
D3030		Cooling Generating Systems		\$275,000	\$137,500 ±
D3030		Cooling Generating Systems		\$275 000	\$137 500 *
D3040		Distribution Systems		\$500,000	\$300,000 ±
D3040		Distribution Systems		\$500 000	\$300 000 *
D3050		Terminal & Package Units		\$60,000	\$30,000
D3050		Terminal & Package Units		\$60 000	\$30 000
D3060		Controls and Instrumentation		\$217,000	\$130,200 ±
D3060		Controls and Instrumentation		\$217 000	\$130 200 *
D3070		System Testing & Balancing		\$20,000	\$10,000
D3070		System Testing & Balancing		\$20 000	\$10 000

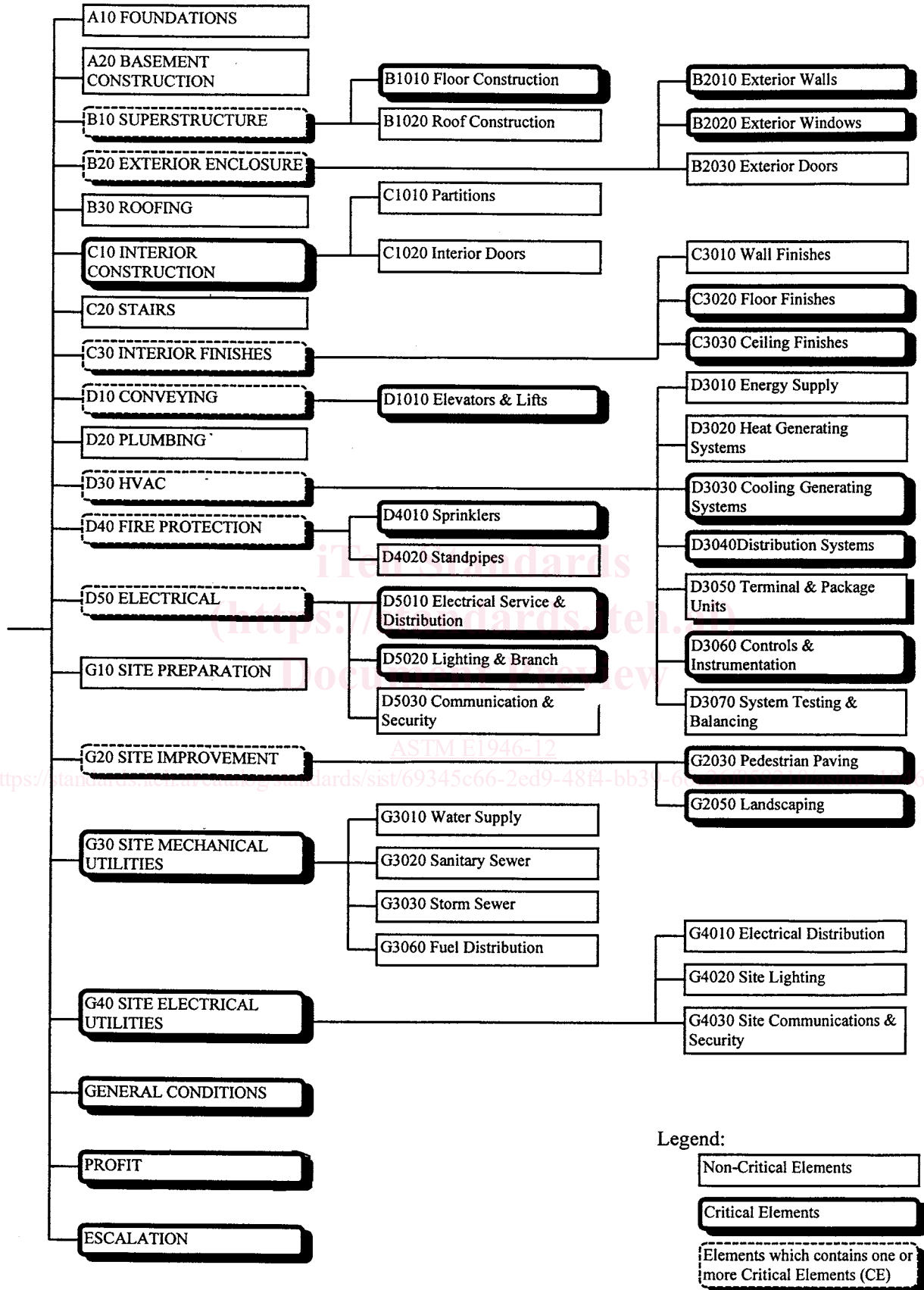


FIG. 1 Identification of Critical Elements in the Sample Project

6.1.8 Allowance and contingency, as commonly used in the building 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 ~~BCRA~~, ~~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 ~~BCRA~~~~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, 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 ~~BCRA~~~~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 building 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.

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⁵ Biery, Fred, Hudak, David, Gupta, Shishu, “Improving Cost Risk Analysis,” *Journal of Cost Analysis*

⁵ Biery, F., Hudak, D., and Gupta, S., “Improving Cost Risk Analysis,” *Journal of Cost Analysis*, Spring 1994.

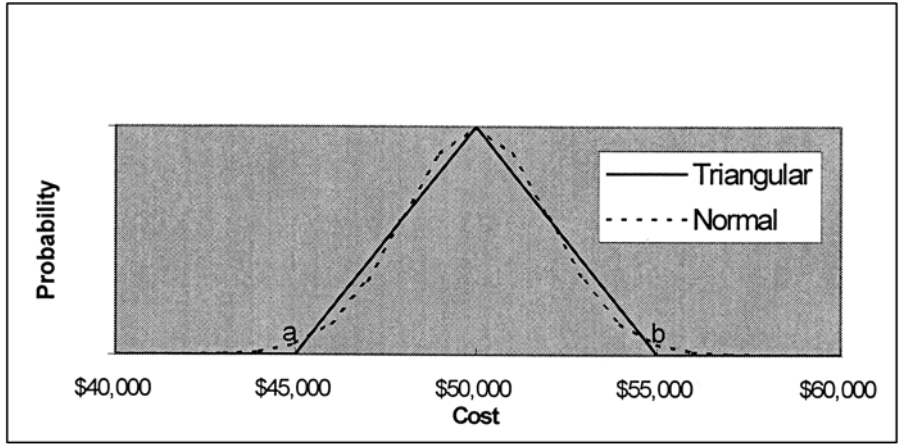


FIG. 2 Comparison of Triangular PDF to Normal Distribution Function

TABLE 2 Sample Critical Element Input List

	CRITICAL ELEMENT	LOW	MOST LIKELY	HIGH
B1010	Floor Construction	\$652,000	\$815,000	\$1,059,500
B1010	Floor Construction	\$652,000	\$815,000	\$1,059,500
B2010	Exterior Walls	\$460,800	\$576,000	\$748,800
B2010	Exterior Walls	\$460,800	\$576,000	\$748,800
B2020	Exterior Windows	\$142,800	\$204,000	\$306,000
B2020	Exterior Windows	\$142,800	\$204,000	\$306,000
C10	Interior Construction	\$192,000	\$240,000	\$312,000
C10	Interior Construction	\$192,000	\$240,000	\$312,000
C3020	Floor Finishes	\$333,750	\$445,000	\$623,000
C3020	Floor Finishes	\$333,750	\$445,000	\$623,000
C3030	Ceiling Finishes	\$226,100	\$323,000	\$452,200
C3030	Ceiling Finishes	\$226,100	\$323,000	\$452,200
D1010	Elevators & Lifts	\$228,000	\$380,000	\$608,000
D1010	Elevators & Lifts	\$228,000	\$380,000	\$608,000
D3030	Cooling Generating Systems	\$192,500	\$275,000	\$412,500
D3030	Cooling Generating Systems	\$192,500	\$275,000	\$412,500
D3040	Distribution Systems	\$300,000	\$500,000	\$800,000
D3040	Distribution Systems	\$300,000	\$500,000	\$800,000
D3060	Controls & Instrumentation	\$108,500	\$217,000	\$347,200
D3060	Controls & Instrumentation	\$108,500	\$217,000	\$347,200
D4010	Sprinklers	\$154,000	\$220,000	\$308,000
D4010	Sprinklers	\$154,000	\$220,000	\$308,000
D5010	Electrical Service & Distribution	\$108,000	\$180,000	\$228,000
D5010	Electrical Service & Distribution	\$108,000	\$180,000	\$228,000
G5020	Lighting & Branch Wiring	\$411,000	\$685,000	\$1,096,000
G5020	Lighting & Branch Wiring	\$411,000	\$685,000	\$1,096,000
G2030	Pedestrian Paving	\$210,000	\$420,000	\$672,000
G2030	Pedestrian Paving	\$210,000	\$420,000	\$672,000
G2050	Landscaping	\$228,000	\$380,000	\$608,000
G2050	Landscaping	\$228,000	\$380,000	\$608,000
G30	Site Mechanical Utilities	\$336,000	\$420,000	\$546,000
G30	Site Mechanical Utilities	\$336,000	\$420,000	\$546,000
G40	Site Electrical Utilities	\$140,000	\$200,000	\$300,000
G40	Site Electrical Utilities	\$140,000	\$200,000	\$300,000
	General Conditions	\$493,800	\$823,000	\$1,234,500
	General Conditions	\$493,800	\$823,000	\$1,234,500
	Profit	4 %	10 %	15 %
	Escalation	3 %	5 %	7 %