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SIEPR Discussion Paper No. 04-05

**Cost Contingency
as the Standard Deviation of the
Cost Estimate for Cost Engineering**

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February 9, 2004

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for

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ABSTRACT

Traditional cost contingency estimation relies heavily on expert judgment based on various cost-engineering standards. This paper compares project stages, accuracy ranges, and cost contingencies recommended by the Association for the Advancement of Cost Engineering International and the Electric Power Research Institute. It shows that current guidelines are consistent with contingencies equal to the standard deviation of the cost estimate. It suggests how this standard deviation can be derived from a confidence level (e.g., 80%) for a given accuracy (e.g., $\pm 10\%$) for normal and lognormal probability distributions.

Keywords: contingency, cost estimating, risk assessment, project management

Acknowledgments: This work was done in association with the Economics Modeling Working Group of the Generation IV International Forum (GIF) with support from the US Department of Energy under contract DE-FC07-03ID14448. I thank members of the committee and GIF, particularly E. Bertel, E. Onopko, B. Rasin, and K. Williams; K. Arrow, C. Braun, and D. Korn for comments and encouragement; and M. Gelhausen and anonymous referees for their comments.

Traditionally, cost contingency estimation relies heavily on expert judgment based on various cost-engineering standards. Table 1 compares Project Stages and expected Accuracy Ranges recommended by the Association for the Advancement of Cost Engineering International (1997) and contingencies recommended in Electric Power Research Institute (1993).[1] (The association of AACEI definitions with EPRI definitions is approximate.) See Parsons (1999) for similar comparisons with American National Standards Institute, the UK Association of Cost Engineers, and the US Department of Energy, Office of Environmental Management.

Table 1: Comparison of AACEI and EPRI Cost Estimate Stages

AACEI Project Stage	AACEI Expected Accuracy Range L=Low, H=High	AACEI Suggested Contingency	EPRI Project Stage	EPRI Suggested Contingency
Concept Screening	L: -20% to -50% H: +30% to +100%	50%	NA	NA
Feasibility Study	L: -15% to -30% H: +20% to +50%	30%	Simplified Estimate	30-50%
Authorization or Control	L: -10% to -20% H: +10% to +30%	20%	Preliminary Estimate	15-30%
Control or Bid/Tender	L: -5% to -15% H: +5% to +20%	15%	Detailed Estimate	10-20%
Check Estimate or Bid/Tender	L: -3% to -10% H: +3% to +15%	5%	Finalized Estimate	5-10%

Sources: American Associate of Cost Engineers International (1997) and EPRI (1993)

Lorance and Wendling (1999, p. 7) discuss expected accuracy ranges reproduced in Table 1: “The estimate meets the specified quality requirements if the expected accuracy ranges are achieved. This can be determined by selecting the values at the 10% and 90% points of the distribution.” This infers that 80% of the probability is contained between the outer bounds of the

accuracy ranges, $\pm X\%$. The cost estimator can determine an 80% confidence level by answering the following three questions: (1) What is the most likely final cost? (This is MODE.) (2) The final cost of the project will be *above* what value 90% of the time? (This is LOW.) (3) The final cost of the project will be *below* what value 90% of the time? (This is HIGH). Then $-X\%$ equals $[(\text{LOW}-\text{MODE})/\text{MODE}]$ and $+X\%$ equals $[(\text{HIGH}-\text{MODE})/\text{MODE}]$. For example, let $\text{LOW} = \$90$, $\text{MODE} = \$100$, and $\text{HIGH} = \$110$, then $\pm X\% = \pm 10\%$.

To better understand confidence intervals and accuracy ranges, consider the normal (“bell-shaped”) probability distribution.[2] This distribution can be completely described by its mean (the expected cost) and its standard deviation (a measure of the cost estimate uncertainty). The normal distribution is symmetric (i.e., it is equally likely that the final cost will be above or below the expected cost), so the mean equals the median (half the probability is above the median and half is below) and equals the mode (the most likely cost). (Section 2 considers the lognormal distribution in which the mean, median, and mode are not equal, and the expected accuracy ranges are not symmetric, as in Table 1.) The standard deviation, σ , is the square root of the variance. The variance equals the average squared deviation of each observation from the mean. About 68% of the probability of a normal distribution is between plus and minus one standard deviation ($\pm \sigma$) of the mode.

1 Contingency with a Normally-Distributed Cost Estimate

If the cost estimate is normally distributed, the standard deviation is $\sigma = X/Z$, where X is the level of accuracy and Z depends on the confidence level. For example, the level of accuracy for a “Preliminary Estimate” is about $\pm 30\%$. If the cost estimator has an 80% confidence in this range of accuracy, $Z = 1.28$, i.e., 80% of the standard normal distribution is between mode $\pm 1.28 \cdot \sigma$. (For a given accuracy range, with a 90% confidence level, Z equals 1.65, and with a 50%

confidence level, Z equals 0.67.) Therefore, $\sigma = (X / Z) = (30\% / 1.28) = 23.4\%$. If the cost estimator had a 90% level of confidence in the $\pm 30\%$ accuracy range, then $\sigma = (30\% / 1.65) = 18.2\%$, i.e., about two-thirds of the time the expected final cost would be $\pm 18.2\%$ of the estimate of the most likely cost. As an example, consider the cost estimate in the following figure.

Figure 1: A Cost Estimate with a Normal Distribution

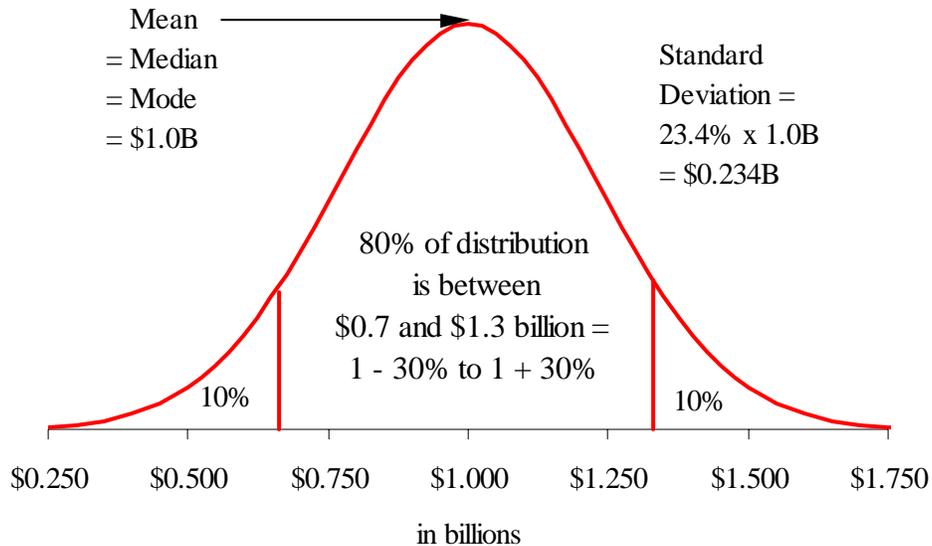


Figure 1 shows a normally distributed cost estimate with a mean, median, and mode of \$1 billion and a standard deviation of \$0.234 billion, or 23.4% of the expected cost. In this example, 10% of the distribution is below \$0.700 (LOW) and 10% is above \$1.300 billion (HIGH), yielding an 80% confidence level for an accuracy range of $\pm 30\%$.

To approximate the underlying standard deviation of the cost estimate, the estimator can identify the upper and lower bounds (i.e., $\pm X\%$) that define an 80% confidence interval. How does this relate to the contingency estimate? In the AACEI and EPRI guidelines (see Table 1):

- Under the normal distribution, for a “Finalized Estimate” with $X = \pm 10\%$ and an 80% confidence, $\sigma = (X / Z) = (10\% / 1.28) = 7.8\%$. Compare this with the AACEI-suggested contingency of 5% and the EPRI-suggested contingency of 5 to 10%.

- An accuracy range of $\pm 20\%$ for a “Detailed Estimate” yields $\sigma = (20\%/1.28) = 15.6\%$, compared with a suggested contingency by AACEI of 15% and by EPRI of 10 to 20%.
- An accuracy range of $\pm 30\%$ for a “Preliminary Estimate” yields $\sigma = (30\%/1.28) = 23.4\%$, compared with a suggested contingency by AACEI of 20% and by EPRI of 15 to 30%.

Therefore, the standard deviation of the cost estimate is approximately equal to the contingencies suggested by AACEI and EPRI.[3]

2 Contingency with a Lognormal Cost Estimate

Many cost estimate accuracy ranges are non-symmetric, as shown in Table 1, where the low range is less (in absolute value) than the high range. This is because (1) final costs are usually higher than those estimated and (2) there is no probability that the final cost will ever be less than zero (which is a possibility with the normal distribution, however small the probability). Therefore, a non-symmetric distribution is more realistic for many cost estimates. One such probability distribution is the lognormal.[4] Figure 2 presents three lognormal densities. Figure 3 presents the corresponding lognormal cumulative distributions.

Figure 2: Lognormal Densities for Three Project Stage Estimates

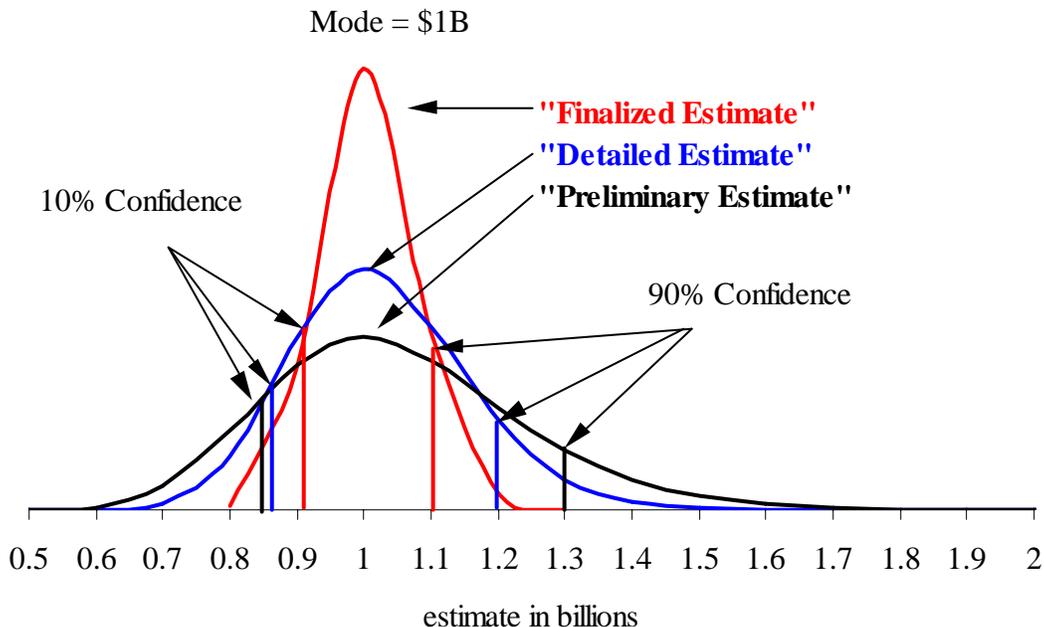
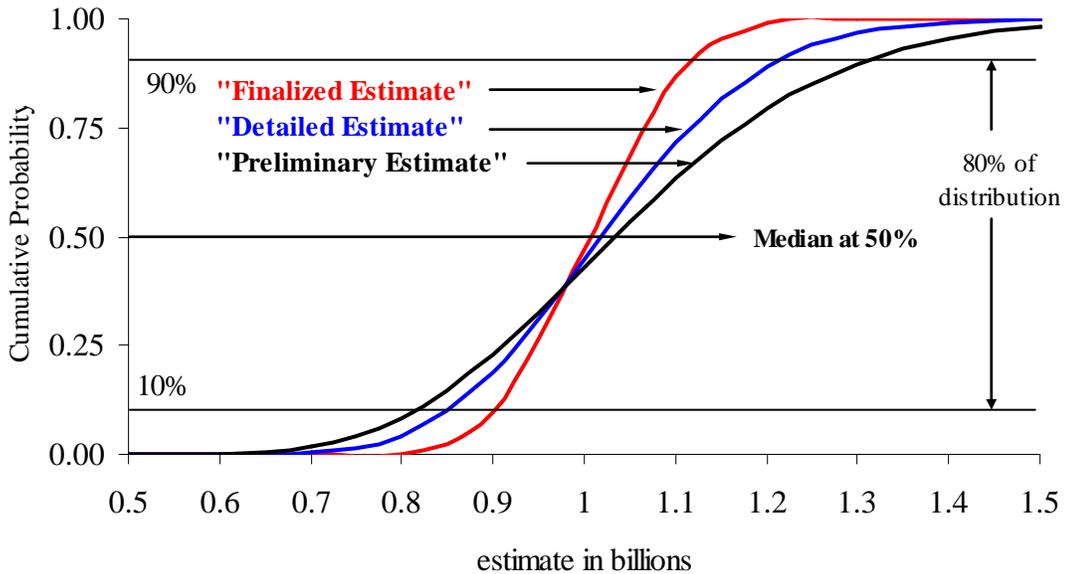


Figure 3: Lognormal Cumulative Distributions for Three Project Stage Estimates



In Figures 2 and 3 all three estimates have the same mode, but have different medians, means, variances, and standard deviations, as shown in Table 2. As with all standard lognormal distributions, the mean is greater than the median, which is greater than the mode. Here, with the mode equal to 1.0 (billion dollars), variance equals $[\text{median} \cdot (\text{median} - 1)] \cdot [5]$ (The mode can be set to 1.0 by dividing the cost distribution by the mode.)

Table 2: Medians, Means, and Standard Deviations for Lognormal Estimates

	Mode	Median	Mean	Variance	Standard Deviation	80% Confidence
Preliminary Estimate	1.000	1.033	1.049	3.4%	18.3%	-18% to +31%
Detailed Estimate	1.000	1.017	1.025	1.7%	13.1%	-14% to +20%
Finalized Estimate	1.000	1.005	1.008	0.5%	7.0%	-8% to +10%

Setting the contingency equal to the standard deviation, the contingency for a “Preliminary Estimate” with an 80% confidence interval between -18% and +31% would be 18.3%, which is less than the 20% contingency recommended by the ACEI, but within the range suggested by EPRI (i.e., 15 to 30%). The contingency for a “Detailed Estimate” is 13.1%, which is again less than the 15% suggested by the ACEI, but within the range suggested by EPRI (i.e., 10 to 20%).

The contingency for a “Finalized Estimate” is 7%, which is greater than suggested by AACEI, but within the range suggested by EPRI (i.e., 5 to 10%). Therefore, cost estimates with lognormal distributions can also be assigned a contingency equal to their standard deviation. Further, as lognormal cost estimates become more precise, the distribution becomes more symmetric and the contingency approaches the values found for the symmetric normal distribution.

Finally, the accuracy ranges in Table 2 can be adjusted to the cost estimator’s confidence interval for a specific cost estimate following the parameters of the lognormal distribution. To determine these, the cost estimator needs to answer another question: The final cost of the project will be *above* (or *below*) what value 50% of the time? (This is the MEDIAN.) The standard deviation for the lognormal distribution is the square root of $\{(MEDIAN/MODE) \cdot [(MEDIAN/MODE) - 1]\}$. Following the example above, let MODE = \$100 and MEDIAN = \$104, then contingency is $\{(\$104/\$100) \cdot [(\$104/\$100) - 1]\}^{1/2} = 20.4\%$, i.e., a contingency associated with a “Preliminary Estimate,” but with a non-symmetric 80% confidence interval of -20% to +35%. Cost estimators can calculate the standard deviation from the 80% confidence interval using a cumulative lognormal distribution, such as LOGNORMDIST in EXCEL; see Figure 4. Table 3 presents an abbreviated spreadsheet used to graph Figure 4.[6] The median and standard deviation can be adjusted to the cost estimator’s 80% confidence interval and the accuracy range can be determined from the 10% and 90% cumulative probability.

Figure 4: Lognormal Cumulative Distribution for EXCEL example

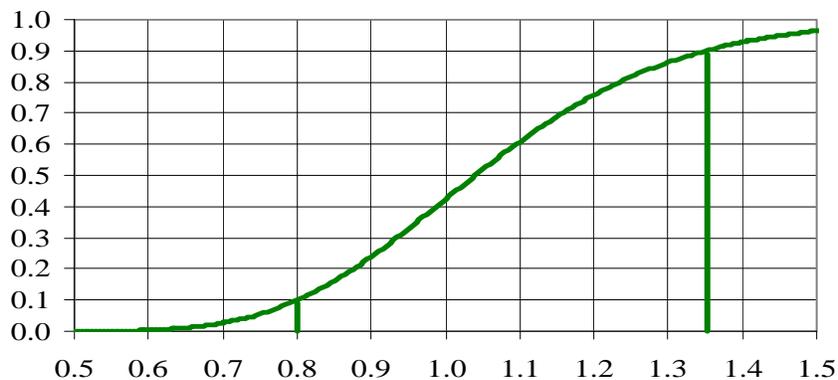


Table 3: Abbreviated Spreadsheet to Graph Figure 4

	A	B	C	D
1		Median		Std_dev
2		1.040		0.204
3		0.039	< =LN(B2)	
4			=LOGNORMDIST(B6,\$B\$3,\$D\$2)	=(B6-B5)
5		X =	v	v
6		0.500	0.000	0.000
7		0.600	0.004	0.000
8		0.700	0.026	0.002
9		0.750	0.055	0.004
10	10% Confidence	0.800	0.099	0.005
11		0.850	0.161	0.007
12		0.900	0.239	0.008
13		0.950	0.329	0.009
14		0.995	0.414	0.010
15	mode ->	1.000	0.424	0.010
16	median (50%) ->	1.040	0.500	0.009
17		1.050	0.519	0.009
18	mean ->	1.060	0.537	0.009
19		1.100	0.608	0.009
20		1.150	0.689	0.008
21		1.200	0.758	0.006
22		1.250	0.816	0.005
23		1.300	0.863	0.004
24	90% Confidence	1.350	0.900	0.003
25		1.400	0.927	0.002
26		1.500	0.964	0.001
27		"X-axis"	Cumulative Probability	Density

3 Estimating Cost Contingency

As discussed in Rothwell (2004), under the appropriate assumptions the cost contingency can be approximated by the standard deviation of the cost estimate. The standard deviation of the cost estimate can be determined either (1) by considering the accuracy and confidence in the cost estimate based on expert judgement, or (2) by using statistical or Monte-Carlo techniques (as discussed in Nasser, 2003) or those available in @RISK (an EXCEL add-in, see Lorange and Wendling, 1999, p. 4-6.)

This technique provides the cost estimator with a method for comparing values for contingency with (1) expectations regarding accuracy and confidence in the cost estimate and (2)

traditional definitions of cost estimate project completion. This allows an easy comparison of cost contingency percentages with the probability distribution of the cost estimate *and vice versa*.

4 Endnotes

1. EPRI (1993) is the last publicly available version of the *Technology Assessment Guide*. Later versions are proprietary, but use the same definitions and Suggested Contingencies as in Table 1.

2. The normal density is $N(x) = (2\pi\sigma^2)^{-1/2} \exp\{-(1/2)(x-\mu)^2/\sigma^2\}$, μ is the mean and σ is the standard deviation. See Palisade (1996, p. 235).

3. Lorance and Wendling (1999, p. 7) state, “We are most familiar with and strongly support assigning contingency such that the base estimate plus contingency equals the 50/50 point (median) of the cumulative distribution.” In their Monte Carlo example, “note that at the 50/50 point is a 16.2% contingency.” (p. 6). The standard deviation of their cost estimate is 16.6% = (14,170.46 / 85,156.10), i.e., their example is consistent with the conclusion reached here.

4. The lognormal density is $LN(x) = x^{-1} (2\pi\sigma^2)^{-1/2} \exp\{-(1/2)(\ln x - \mu)^2/\sigma^2\}$, where μ equals the natural log of the median and σ^2 equals the natural log of the median minus the natural log of the mode. The mean is $\exp\{\mu + (\sigma^2/2)\}$. The variance is $\exp\{2\mu - \sigma^2\}[\exp\{\sigma^2\} - 1]$. See Palisade (1996, p. 233) and Johnson, Kotz, and Balkrishnan (1995). The LOGNORMDIST function in EXCEL (e.g., in OFFICE97, equal to LOGNORM in Palisade, 1996, p. 232) can be used to calculate the lognormal probability cumulative distribution, as in Figures 3 and 4. However, in LOGNORMDIST the “mean” is the natural logarithm of the median in Table 2 and the “standard deviation” is as in Table 2.

5. With the mode equal to 1.0, both μ and σ^2 are equal to the natural log of the median and the variance equals $\exp\{2\ln(\text{median}) - \ln(\text{median})\}[\exp\{\ln(\text{median})\} - 1] = [\text{median} \cdot (\text{median} - 1)]$.

6. In the actual spreadsheet X varies by 0.005, so that column D is the difference in column C for every $X + 0.005$, e.g., $\text{LOGNORMDIST}(0.995, 0.039, 0.204) - \text{LOGNORMDIST}(1.000, 0.039, 0.204) = 0.414 - 0.424 = 0.010$. Also, the mean equals $\exp\{0.039 + (0.204^2/2)\} = 1.062$.

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