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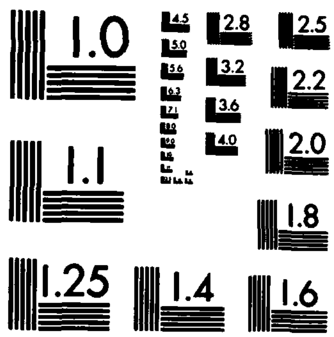

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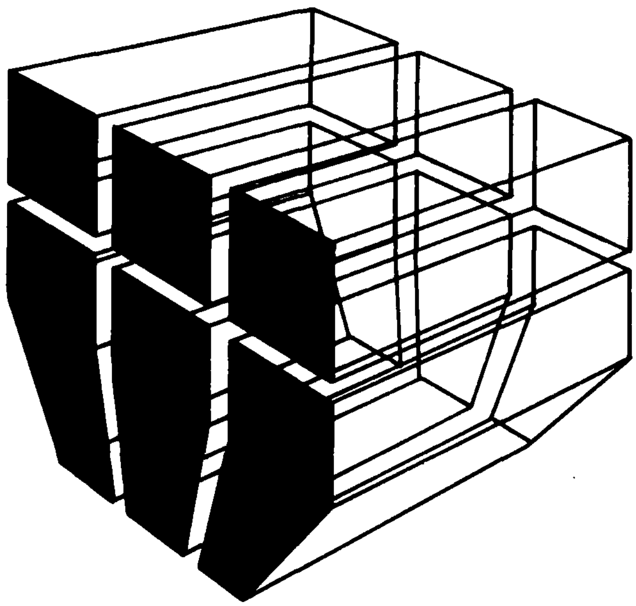
May 1985

Uncertainty Assessment in Life Cycle Cost Analysis

by
Arup K. Mallik



Several of the leading probabilistic methods for measuring uncertainties in construction project life cycle costs were evaluated for their applicability to military construction projects. The confidence index and statistical testing approaches are discussed in detail; other approaches revealed in a search of available literature are discussed briefly. The confidence index approach is recommended as a simple, cost-effective method suitable for military construction design.

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Several of the leading probabilistic methods for measuring uncertainties in construction project life cycle costs were studied to evaluate their applicability for military construction projects. The confidence index and statistical testing approaches are discussed in detail; other methods are discussed briefly. The confidence index approach is recommended as a simple, cost-effective method suitable for use in military construction design.

FOREWORD

This research was conducted by the U.S. Army Construction Engineering Research Laboratory (USA-CERL), Facility Systems (FS) Division, for the Directorate of Engineering and Construction, Office of the Chief of Engineers (OCE), under FAD 2-4905 dated 14 Sep 83. Robert D. Neathammer was the CERL Principal Investigator and Dr. Larry Schindler, DAEN-ECE-G was the OCE Technical Monitor. Administrative support was provided by E. A. Lotz, Chief of CERL-FS.

The author is an industrial engineering faculty member at North Carolina A&T State University in Greensboro. This report was prepared while he was at USA-CERL under the Intergovernmental Personnel Act during July 1983 and July 1984.

COL Paul J. Theuer is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

UNCERTAINTY ASSESSMENT IN LIFE CYCLE COST ANALYSIS

1 INTRODUCTION

Background

Life cycle cost analyses (LCCA) are required in the military construction design process to ensure that the lowest cost design alternative is selected. Engineer Technical Letter 1110-3-332[1] gives rationale and guidance for these analyses.

The input information for an LCCA is based primarily on estimated quantities and costs of materials and labor, and the time of occurrence. The effect of uncertainties in the estimates on the results of an LCCA can significantly influence design decisions. One alternative may appear to be lowest in net LCC under one set of assumptions but may not be the lowest under another set of assumptions. The need for clear understanding of uncertainties and their associated impact should be considered an important part of every LCCA.

In general, an analysis of the uncertainty is needed unless (1) the relative economic rankings of the (apparently) top-ranked alternative and its nearest competitors cannot be affected by the results of the assessment, or (2) the LCCA results appear to be either clearly conclusive or clearly inconclusive.

Exact uncertainty analyses using probabilistic techniques can be very complex and require the use of computers. A simple, cost-effective approximation usable by Corps of Engineers (CE) designers is needed.

One such method, the confidence index (CI) has been proposed in a draft Army technical manual on life cycle costing. An assessment of this and other such methods is needed before selecting a method for use in the CE design process.

Objective

The objective of this investigation was to review some of the leading probabilistic approaches to uncertainty assessment of LCCA in order to determine their applicability for military construction design, and to

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[1]Engineer Technical Letter 1110-3-332, Engineering and Design, Economic Studies (Office, Chief of Engineers, 22 March 1982).

recommend an approach for use in an Army technical manual on life cycle costing.

Approach

A literature search was conducted and promising articles reviewed. The statistical technique of test of hypotheses was used to evaluate the CI method.

Mode of Technology Transfer

The selected method will be used in a new Technical Manual on Life Cycle Costing to be published in the 5-802 series.

2 CONCEPT OF UNCERTAINTY IN CONSTRUCTION LCCA

Consider the following example in which two projects, M and N, are to be compared on the basis of LCC or present worth (PW). Figure 1 shows four cases in which the PW_M and PW_N are expressed as probability distributions reflecting actual uncertainty surrounding each LCC computation. In all cases, PW_M and PW_N are computed as "best estimates" and therefore represent the central value of the PW distribution. In case A, the decision problem is clearcut since all possible values of PW_M are lower than all possible values of PW_N.

The situation in case B is slightly different in that there is some nontrivial probability that PW_M will be higher than PW_N. If this probability is not large, the decisionmaker would still select project M. However, when the overlap is large, the point estimates may not provide valid criteria for selection.

In case C, both expected costs are the same, but the distribution of PW_N has a larger variance. Here the decisionmaker's disposition toward uncertainty and risk dominates the selection process. Case D illustrates a more complicated situation in which the expected PW of N is lower but much less certain than for project M. With a quantitative measure of uncertainty, decisionmakers should be able to make better decisions according to their attitudes toward risk and the availability of initial capital.

For proper comparison of two alternatives using LCCA, decisionmakers must have quantitative measures of uncertainty. As a measure of variability of a random number, the range (difference between the high and low estimates) may be a reasonable estimate of variability. When two estimating procedures are compared statistically, method A is considered more reliable than method B if method A yields a smaller variance of the estimate.

For assessing uncertainty of each cost element, some knowledge of the element's probability distribution is desirable. This helps the analyst to be as specific as possible and to allow assigning specific probability values.

There is no established probability distribution for any cost element. "Standard" procedures tend to bias the results toward normality; that is, there is an equal chance of the actual values being either greater or less than the most likely one. In actuality, the probability distribution could be skewed one way or the other. Beta, Lognormal, and Weibull distributions also have been used with no proof that these distributions are better than other available nonsymmetric distributions.

Once the individual distributions are established, the next task is to generate the distribution of an overall system LCC. Unless all cost elements and their subsystems are normally distributed, the Monte Carlo simulation approach may be the only approach for generating probability distributions of overall systems.

For each critical cost component, the estimator can gauge the uncertainty in several ways. However, the most important and effective measure may consist of four components--best estimate, low estimate, high estimate, and the confidence level for the low and high estimates.

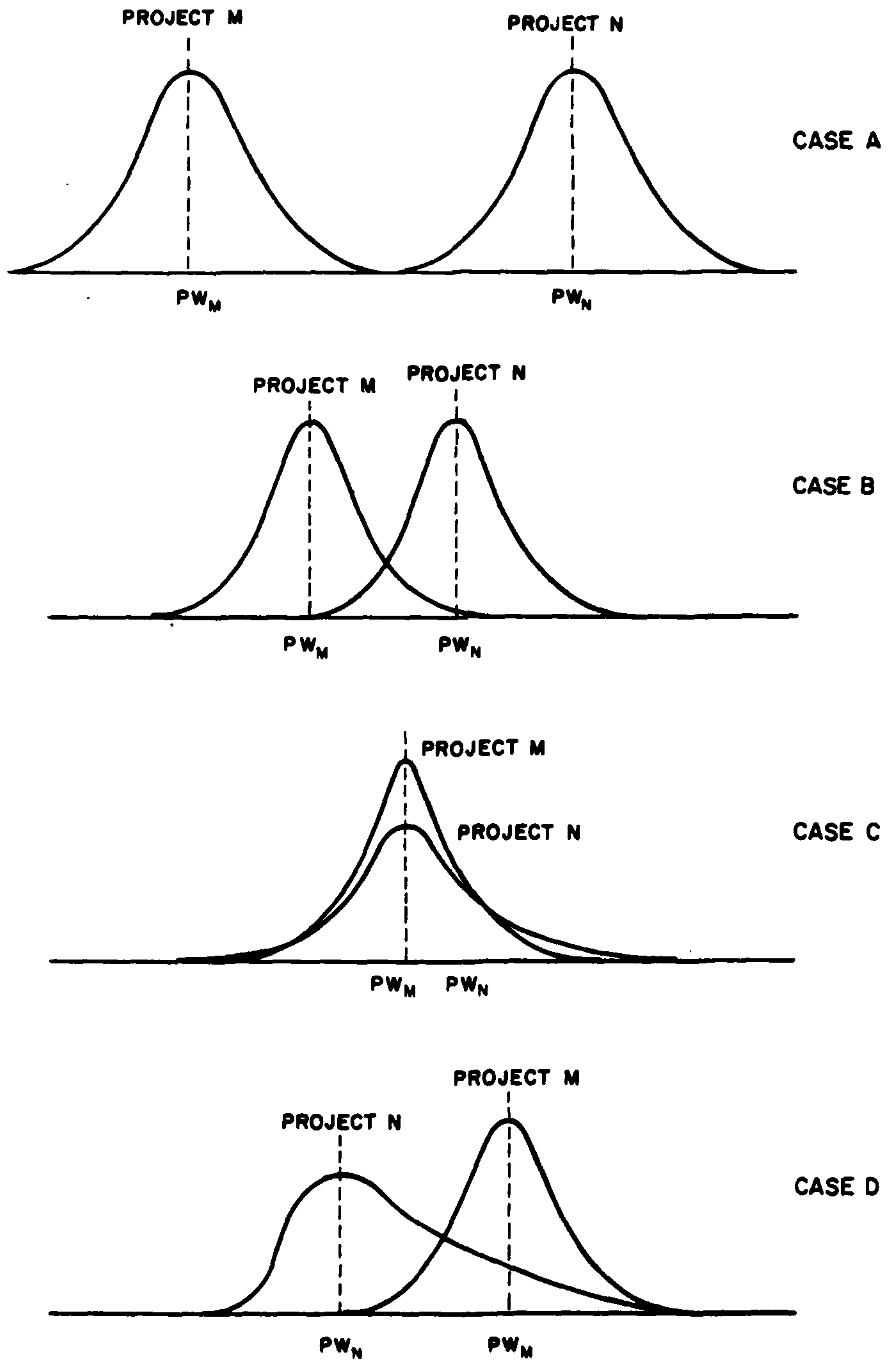

Figure 1. Four cases of economic decisions.

3 REVIEW OF LITERATURE

This chapter discusses several of the publications reviewed to see if there is a good existing approximation method and to document some of the more complex methods.

1. Risk and Uncertainty: Non-Deterministic Decision Making in Engineering Economy, edited by Gerald A. Fleischer, Engineering Economy Monograph Series No. 2, AIIE-EE-75-1, 1975.

This booklet reprints 20 related articles published previously in technical journals. It lists over 194 references, some of which might be useful in developing a meaningful model for a quick risk assessment of various military construction design projects. The following articles were reviewed:

- "Risk Analysis in Capital Investment," by David Hertz, pp 141-152.

This article introduces the concept of uncertainties and probabilities in capital investment analysis. The author emphasizes more accurate forecasts of cash flows, empirical adjustments of construction cost estimates, three-level estimates and use of probabilities for specific factors in the calculations. The article provides a good conceptual foundation of risk analysis but provides no applicable guidelines for use in military construction design projects.

- "Investment Policies That Pay Off," by David Hertz, pp 153-165.

This article suggests that computer simulation offers corporate management, for the first time, a tool that will enable it to examine the risk consequences of various investment policies. Conceptually, this article provides a good basis of modeling high, moderate, and low risk assessment of capital investment. This simulation approach may be too complicated for military construction design project applications.

- "A Simplified Model for Portfolio Analysis," by William F. Sharpe, pp 184-192.

This paper describes the advantages of using a particular model of the relationships among securities for practical application of Markowitz portfolio analysis technique. A computer program has been developed (not fully described or coded) using quadratic programming codes to take full advantage of the model: 2000 securities can be analyzed. No apparent use is observed for military construction design project analysis.

2. "Risk Analysis of Construction Cost Estimates," Hans C. Bjornsson, Member AACE, D-3, American Association of Cost Engineers Transactions, 1977, pp 182-188.

This paper briefly discusses the basics for risk simulation and presents a computerized model for cost estimating. Bjornsson includes several distributions for simulating estimation, such as uniform distribution, triangular distribution, normal distribution, beta distribution, and lognormal distribution. The paper provides a solid basis for simulating construction cost estimates and risk analysis. The approach discussed in this paper can be used if one is willing to develop computer software applicable to military construction projects.

3. A Monte Carlo Simulation Approach to Cost-Uncertainty Analysis, Donald F. Schaefer, Frank J. Husic, Michael F. Gutowski, Research Analysis Corporation (RAC), McLean, Virginia.

This report describes a technique for quantifying uncertainty in cost analysis. The model allows the user to specify probability distributions for the cost model input variables rather than the usual single-point estimates, and the outputs are confidence intervals. The report is resourceful but provides limited application to military construction design projects because of the complexity of input variables and their availability.

4. Probabilistic Estimating in the Building Process, Technical Report No. 72, Federal Construction Council Consulting Committee on Cost Engineering, National Academy Press, 1983.

This report introduces the concept of probabilities in cost estimating and the Monte Carlo simulation method. Basically, it suggests generating three values for all cost elements.

5. Cost Uncertainty Analysis: Predicting the Reliability of Construction Cost Estimates, prepared by Frederic R. Harris, Inc., Consulting Engineers. Report on Task 5.3/5.4 of contract number SGC-02-1397, Amendment 1, Royal Commission for Jubail and Yanbu, Saudi Arabia, March 1979.

In this report, to measure uncertainties of each cost element, three values (high, low and best) are estimated. However, a valid concern is expressed regarding selection of high and low values: the sincerity of estimators is overly relied upon in estimating these values. Selecting the expected value as the mid-point between high and low value is also questioned as it expresses the implicit assumption of the mid-point of the cost distribution where the probability of a cost overrun or cost underrun is the same.

To measure cost uncertainties, the beta distribution is chosen for several reasons: it is continuous, unimodal, has finite minimum and maximum values, and can be skewed or symmetric. However, for assessing uncertainties, subjective judgment is used to specify variances of various cost elements.

Specifically, high, medium, and low confidence values for cost estimates are quantified by computing expected values and variances as follows:

Expected Values	Confidence Level
$E = 0.1L + 0.8M + 0.1H$	High
$E = 0.15L + 0.7M + 0.15H$	Medium
$E = 0.2L + 0.6M + 0.2H$	Low
Variances	
$V = 0.05\ (H-L)^2$	High
$V = 0.09\ (H-L)^2$	Medium
$V = 0.19\ (H-L)^2$	Low

where H, M, and L represent high, medium, and low estimates, respectively.

A proof is provided that if the distribution is normal and H and L represent 90 percent of the range, then the variance is $0.09\ (H-L)^2$.

This report also includes a procedure to compute the expected value and variance of each resource item. The total resource cost is assumed normally distributed and the uncertainty is quantified by computing low (L) and high (H) values for a 90 percent confidence range about the most likely value (E) as

$$L = E - 1.67\sqrt{V} \text{ and } H = E + 1.67\sqrt{V}$$

where V represents an estimate of total resource cost variance.

Also included is the Monte Carlo simulation approach to uncertainty assessment.

In summary, this report provides comprehensive information on uncertainty assessment of construction cost estimates. The approach is similar to the confidence index approach discussed in Chapter 4.

6. User's Manual for a Probabilistic Estimating System, Technical Report prepared by the Standing Committee on Cost Engineering, Federal Construction Council, Building Research Advisory Board, Commission on Sociotechnical Systems, National Research Council, National Academy of Sciences, Washington, DC, 1980.

The committee recognized that in any construction process the amount of the low bid, determined by the bidders, is influenced by many factors that cannot be assessed precisely by government estimators. In view of its findings, the committee recommended and the FCC approved the development of a computer-based probabilistic cost estimating system for use by the various federal construction agencies. This system was completed in early 1979, and it serves as the basis for this report. The Probabilistic Estimating System (PES) asks the estimator to express his/her knowledge of possible variations through use of a low, medium, and high estimate of price and quantity for each cost element. The low estimate is defined as one by which the actual value would probably be exceeded nine times out of ten. The medium estimate has five chances in ten of being exceeded. The high estimate has one chance in ten of being exceeded.

This report provides a good guideline for a probabilistic estimating system; however, no updating procedure is outlined and the model is data base oriented.

7. Risk Analysis and Decision Models in the Planning of Housing Projects, by Jorge A. Machado, Report No. R72-44, Structures Publication No. 345, Massachusetts Institute of Technology (MIT), June 1972.

This report reviews the concept of net percent value calculation with relationship of risk and time. Though it provides some wisdom on uncertainty in housing investment decisions, this report is not considered valuable for the purpose of military construction design construction projects since most are not housing projects.

8. Probabilistic Elements of Cost Estimating for Buildings, by Rodney J. Alberts, Report No. R72-4, Structures Publication No. 323, MIT, February 1972.

This report reviews the theoretical implications of probabilistic cost estimating procedures. It is concluded that if certain general conditions are met, the method of assuming a normal distribution will provide satisfactory results. Otherwise, it will be necessary to perform a Monte Carlo simulation or a numerical integration of the convolution integral. Although it contains some valuable information, this report is not directly applicable for military construction design projects.

9. "Economic Risks in Energy Conservation Strategies," by A. D. Russell, Building and Environment, Vol. 16, No. 2 (1981), pp 109-121.

This article suggests an approach to dealing with risk in LCC which seems logical, but not easy. A parameter is defined as the investor's attitude toward risk, which is a subjective judgment:

> Once the estimate of LCC and its standard deviation (σ_{LCC}) are available, the problem remaining becomes one of selecting the best alternative. The first step in this process is to screen the

alternatives using the concept of an efficient frontier. The principle behind the notion of an efficient frontier may be stated as follows: for a given mean value of LCC, the decision maker will always select the alternative which minimizes risk as measured by the standard deviation; for a given value of standard deviation, the decision maker will always select the alternative which yields the lowest expected value of LCC.

After screening the alternatives as described above, the remaining candidates must be ranked. Several methods of ranking may be utilized. Two are suggested here. They both require the assumption that LCC is a normally distributed random variable.

The first approach involves the case of expected utility theory, in which an exponential utility function is assumed. The expected utility can be expressed as:

$$U = \overline{LCC} - \frac{1}{2} \alpha \sigma^2_{LCC}$$

The value computed using this equation is commonly known as the uncertainty equivalent or risk-adjusted value of the investment. It can be interpreted as the cost of a zero-risk alternative, which is equal to one that costs less but has higher risk. The difference between LCC and the value computed using the equation is the risk premium the investor is willing to pay.

Russell also suggests selecting the alternative that minimizes the probability of LCC exceeding some specific budget. Or, the value of LCC for each alternative that yields a specified probability of being exceeded can be computed. The alternative selected is the one that minimizes the absolute value of LCC. The approach is date-based and not clearcut in terms of military construction applications.

10. "Range Estimating -- Managing Uncertainty," by Lou Lewis, AACE Bulletin, November/December 1977.

This article emphasizes the importance of range estimation over single-point estimation in dealing with uncertainties. While advantage of range estimation is argued convincingly, the article does not specify a clearcut procedure as to how a range can be established.

11. "How Good is Your Estimate? or Constructing a Risk Analysis Program to Evaluate Construction Project Estimates," by Robert C. Doyle, AACE Bulletin, May/June 1977.

This article discusses a method to determine escalation and contingency allowances. The question "how good is your estimate?" remains unanswered.

12. "Range Estimating -- Coping With Uncertainty," by Michael W. Curran, Proceedings AACE 20th Meeting, Boston, 1976.

This article discusses a procedure to deal with uncertainty using range estimates. It also introduces a concept of confidence factor as an estimator's belief that a critical element's actual cost will materialize anywhere in the favorable part of its range. The confidence factor's complement is the chance of an overrun. The advantages of range estimating are explained clearly.

13. Handbook of Industrial Engineering, edited by Gavriel Salvendy (Wiley Interscience, 1982).

A procedure using the Beta distribution is given in Chapter 9.2 by Phillip F. Ostwald:

> The following procedure is based on a method developed for PERT. It involves making a most likely cost estimate, an optimistic estimate (lowest cost), and a pessimistic estimate (highest cost). These estimates are assumed to correspond to the beta distribution, which can be symmetrical or skewed left or right. With the three estimates made, a mean and variance for the cost element can be calculated as
>
> $$E\ (C_i) = \frac{L + 4M + H}{6}$$
>
> $$\text{var}\ (C_i) = \frac{(H - L)}{6}^{2}$$
>
> where $E(C_i)$ = expected cost for element i
> L = lowest cost, dollars
> M = modal value of cost distribution, dollars
> var (C_i) = variance of cost for element i
>
> If several elements are estimated this way, and if their costs are assumed to be independent of each other and are added together, the distribution of the total cost is approximately normal. This follows from the central limit theorem. There must be several elements to satisfy the conditions of the central limit theorem.

$$E(C_T) = E(C_1) + E(C_2) + \ldots + E(C_n)$$

and

$$\text{var}(C_T) = \text{var}(C_1) + \text{var}(C_2) + \ldots + \text{var}(C_n)$$

where $E(C_T)$ is the expected total cost in dollars and var (C_T) is the variance of total cost in dollars. This method is very similar to the confidence index approach.

This method is very similar to the confidence index approach.

4 CONFIDENCE INDEX APPROACH

The CI approach[2] is one method that has been recommended for Army use in quantitative assessment of uncertainties in LCCA. The denominator of the CI ratio indicates some measure of dispersion for the probability distribution of the difference between the two PWs. Therefore, the CI ratio represents a form of t- or z-statistic in traditional statistical hypothesis testing. This model is:

Step 1. Use the high and low 90 percent estimates and the best estimates to calculate the high-side and low-side differences for each cost.

Step 2. Determine whether these differences are within 25 percent of each other for each cost. If so, continue; if not, the CI method is not appropriate.

Step 3: Determine the difference in the net PWs of the two alternatives, based on best estimates. This is the numerator of the CI approach.

Step 4. Compute the PW of the larger of the high-side and low-side differences for each cost, and compute its square. Add the squared PWs of all cost differences for both alternatives, and find the square root of this sum. This is the denominator of the CI ratio.

Step 5. Divide the result of step 3 by the result of step 4 to obtain the confidence index. Use this CI to evaluate the results of the original PW calculations as follows:

a. If the CI is below 0.13, assign a low confidence to the results of the LCCA. (A confidence index below 0.13 means that, in the long run, the alternative with the lower computed LCC will incur the lower actual costs in fewer than 5 1/2 out of 10 cases.)

b. If the CI is between 0.13 and 0.25 inclusive, assign a medium confidence to the results of the LCCA. (A confidence index between 0.13 to 0.25 means that, in the long run, the

[2]Smith, Hinchman, Grylls Associates, Inc., Draft Economic Studies for Military Construction: Handbook for Life Cycle Cost Analysis During Project Design, Contract No. DACA-87-80-C-0245 (U.S. Army Corps of Engineers, Huntsville Div., April 1983).

alternative with the lower computed LCC will incur the lower actual costs in about 9 or 10 cases out of 15.)

c. If the CI is greater than about 0.25, assign a high confidence to the results of the LCCA. (A confidence index above 0.25 means that, in the long run, the alternative with the lower computed LCC will incur the lower actual costs in more than three cases out of five.)

5 STATISTICAL TESTING OF DIFFERENCE BETWEEN TWO LCC VALUES

This method is based on the statistical test of hypotheses--a standard comparison technique. It is used as a validation of the CI method.

The following assumptions are made in order to assess uncertainty as to the degree of confidence (high, medium, or low) of the alternative which yields lower LCC:

a. All cost elements are independent.

b. Irrespective of the shape of the individual distribution of each cost element, the LCC of each alternative is normally distributed with mean and standard deviation as follows:

Mean, μ = LCC

Standard deviation $\sigma = \sqrt{\sum_i \sigma_i^2}$

where σ_i^2 represents the variance of ith cost element (e.g., M&R).

Suppose on the basis of LCC, Alternative A is more economical than Alternative B and therefore the difference, $\Delta = LCC_B - LCC_A$ is positive. The distribution of Δ is normal having

Mean, $\mu_\Delta = LCC_B - LCC_A$

Standard Deviation, $\sigma_\Delta = \sqrt{\sigma_B^2 + \sigma_A^2}$

Level of Significance

Traditionally, the level of significance is defined as the probability of rejecting a true hypothesis. Thus, if 0.60 is selected as the probability of accepting a true hypothesis, that is:

$$P(LCC_A < LCC_B) = 0.60$$

then 1-0.60 = 0.40 is the probability of $LCC_B - LCC_A = \Delta$ being negative. Thus, the level of signifance, $\alpha = 0.40$. At this level, the null hypothesis, H_o: $\Delta \leq 0$ will be rejected if

$$z = \frac{\Delta}{s_\Delta} \geq 0.25$$

where s_Δ represents an estimate of σ_Δ.

Similarly, if α is chosen to be 0.45 then H_o will be rejected if

$$z = \frac{\Delta}{s_\Delta} \geq 0.13.$$

Note that when H_o is rejected, implicitly, the alternative hypothesis, H_A: $\Delta > 0$ is accepted, that is $LCC_B - LCC_A$ is significantly positive.

Testing Procedure

Step 1. Consider the null hypothesis H_o: $\Delta \leq 0$ and alternative hypothesis H_A: $\Delta > 0$.

Step 2. Compute $z = \frac{\Delta}{s_\Delta}$

where $\Delta = LCC_B - LCC_A$

and s_Δ = best linear unbiased estimate of standard deviation of Δ .

Step 3. For $\alpha = 0.40$, $z_\alpha = 0.25$ (obtained from standard normal distribution table).

Step 4. Reject H_o if the z calculated in step 2 is larger than the z obtained in step 3; otherwise, accept H_o.

Step 5. Draw conclusion: If H_o is rejected, Δ is significantly positive. In other words, design A is more economical than design B with probability of making an error $\alpha = 0.40$. Testing is complete. Skip step 6 and step 7. If H_o is accepted than proceed with step 6.

Step 6. For $\alpha = 0.45$, $z = 0.13$ (obtained from standard normal distribution table).

Step 7. Compare z calculated in step 2 with z_α obtained in step 6. If $z \geq 0.13$, then the design A is more economical than design B with probability of making mistake $\alpha = 0.45$. If $z = < 0.13$, then H_o cannot be rejected; therefore, design A and design B LCC's are not significantly different even if Δ is positive.

Comparison of Confidence Index Approach with Traditional Testing

The testing procedure described in the preceding section implies the following:

If Δ is positive (name design A and B such that Δ is always positive), then

Design A is more economical than design B with "high" confidence if $z = \frac{\Delta}{s_\Delta} \geq 0.25$.

Design A is more economical than design B with "medium" confidence if $z = \frac{\Delta}{s_\Delta} \geq 0.13$ but less than 0.25.

or

Design A is more economical than design B (remember Δ is positive) with "low" confidence if $z = \frac{\Delta}{s_\Delta} < 0.13$.

The confidence index approach and the traditional statistical testing procedure are fully consistent because $z = \frac{\Delta}{s_\Delta}$ is a constant multiple of CI.

Specifically, in the CI formula, the denominator is a close approximation of 1.7 times s_Δ used in traditional Z-test for an estimate of σ_Δ. In fact, the denominator of the CI formula represents an estimate for one-half of the 90 percent range which for a normal distribution represents 3.4 times the standard deviation.

In conclusion, let $\Delta = LCC_B - LCC_A$ and define f_Δ: probability distribution function of Δ which is normally distributed with mean μ_Δ and standard deviation σ_Δ.

<u>Case I</u>. With <u>no</u> uncertainty assessment, if $\Delta > 0$ select A as better alternative since LCC_A is less than LCC_B.

<u>Case II</u>. With uncertainty assessment, define confidence factor

$$K = \int_0^\infty f_\Delta .$$

Select A with "high" confidence if $K \geq 0.60$, which implies $CI \geq 0.25$ (note that CI is approximately $\frac{\Delta}{1.7 s_\Delta}$) .

Select A with "medium" confidence if $0.55 \geq K < 0.60$, which implies $0.13 \leq CI < 0.25$.

Select A with "low" confidence if $K < 0.55$, which implies $CI < 0.13$.

6 CONCLUSIONS AND RECOMMENDATIONS

It is recommended that the confidence index method be used in the technical manual on life cycle costing. The advantage of the approach is its simplicity. However, the decision criteria (confidence level) may require some adjustment after field experience. Both the statistical testing approach and the confidence index method are theoretically sound and computationally convenient. Depending on the data available, estimates of the standard deviation may require previous experience and subjective judgment.

Most research in uncertainty assessment of LCCA has concentrated on Monte Carlo simulation, with very little work done in measuring LCC variability by quantitative approaches to establish its distribution. With computer technology, it may no longer be difficult to establish probability distributions of LCC and its variability measurement with respect to the various factors of uncertainty. Risk assessment without thoroughly investigating the cost estimating relationship (CER) is not advisable. Further effort should be made to establish relationships between LCC and various factors causing uncertainties in cost estimation.

In almost all the literature that was reviewed, a common concern is expressed as to how an estimator, designer, cost engineer or a contractor will estimate the low, medium, or high values for each cost component. This step is one of the most important items in uncertainty assessment. For each cost element the cost behavior pattern must be clearly understood and established with respect to major activity levels such as number of square feet or number of units. In order to deal with uncertainty and cost control, setting up materials, labor, and overhead standards is critically important. Three separate guidelines should be prepared for estimation of low, medium, and high values in order to avoid estimating single value and multiplying by factors to obtain high and low values.

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