10.0 ANALOGY ESTIMATING

10.1 Introduction

This is the second of three chapters providing extensive discussions on one of the three main estimating methodologies - analogy estimating. The reader was first introduced to analogy estimating in Chapter 3, Section 3.3 in the context of the estimating process. This estimating methodology is discussed in detail within this chapter.

10.2 Brief Description

Analogy cost estimates also are called analog, analogous, or comparative cost estimates. Such estimates generally are characterized by use of a single historical data point serving as the basis for a cost estimate or portion thereof. A program cost estimate identified as an analogy cost estimate consists of more than one, and often many, analogy estimates each for one of several elements within the total estimate. While data limitations sometimes force cost estimators to use analogy-estimating methods, it must be pointed out that many believe basing an estimate (or a portion of the estimate) on a single historical cost data point creates considerable risk. One definition of analogy cost estimating, per the *Glossary of Financial Analysis Terms* published by the Systems Analysis Division, Department of the Navy, in 1981, includes the phrase, "based on historical data too limited to allow statistical estimating."

Because estimates are based on extrapolation of a single data point, the comparison or extrapolation process is critical. Often, cost estimators must seek assistance from technical specialists to make the needed comparisons. This help is necessary to develop appropriate quantitative factors or judgments describing complexity, technical, performance, or physical differences between the new item and the item for which cost data are available. Judgments are also needed with respect to the significance of the cost differences found. These judgments often require technical knowledge beyond that of most cost estimators.

Use of analogy estimating methods is advisable when the new system is primarily a combination of existing subsystems, equipment, or components for which recent and complete historical cost data are available. Analogy methods are most useful in situations where rapidly advancing technology and acquisition strategies cause a parametric cost model database to become antiquated quickly. When properly completed and documented, analogy estimates provide a good understanding of how the program description affects the estimate produced. Since analogy cost estimates usually can be prepared quickly (especially if calculated at or near the system level), these methods often are useful as a check of an estimate prepared by other methods.

The fact that a new system rarely is comprised of entirely new subsystems makes analogy estimating methods valuable. Most new programs consist of modified or improved versions of existing components, combined in a new way to meet a new need. When analogy cost estimating methods are employed, the new system is broken down into components that can be compared to similar existing components. The basis for comparison can be in terms of capabilities, size, weight, reliability, material composition, or design complexity.

Analogy cost estimating usually requires the services of technical specialists. However, these estimates should not be confused with what are called "specialists estimates," "engineering judgment estimates," or "expert opinion estimates," whereby an expert is asked to provide a cost estimate, not primarily a technical comparison of an old and new system or component.

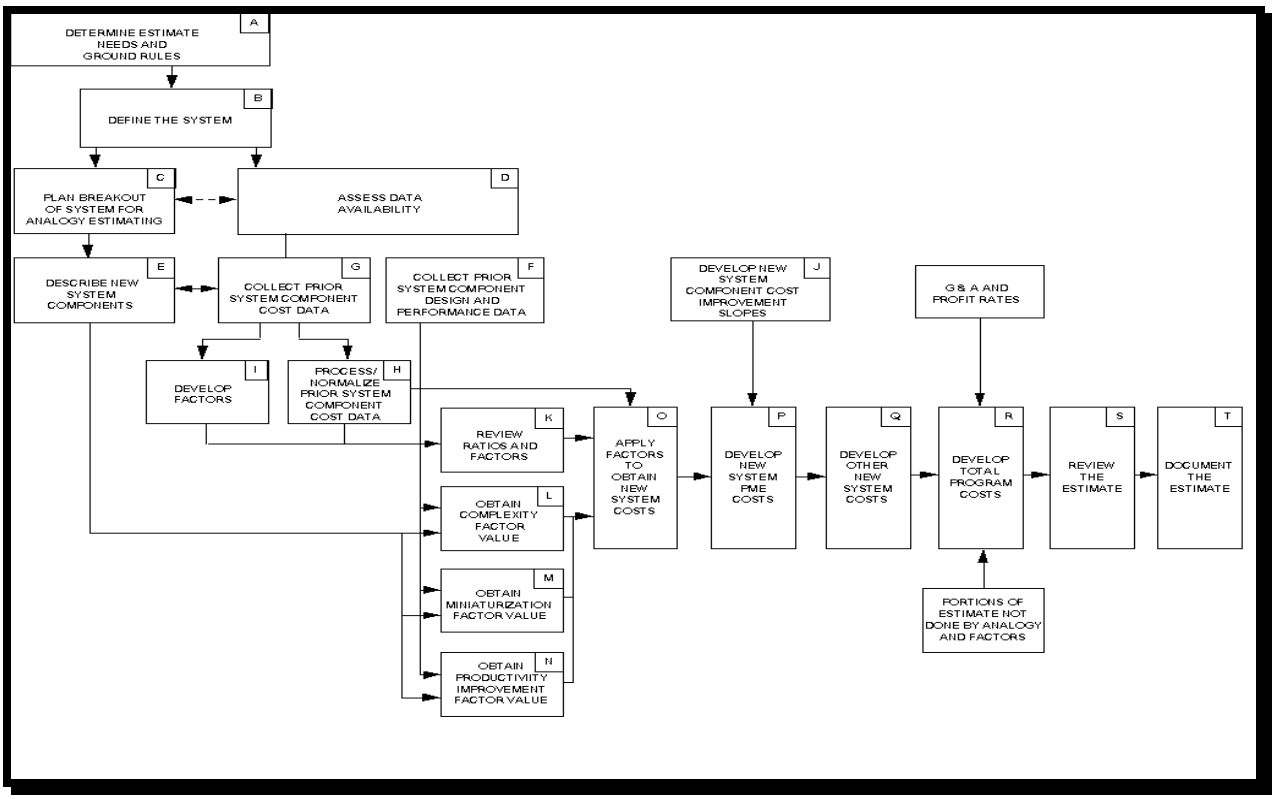
If both production and development program cost estimates are required, analogy estimating methods allow several approaches. The first approach (described in Section 10.3) calls for preparation of separate development and production estimates, each based on data related specifically to development and to production. Alternative approaches use analogy methods to develop production cost estimates for the first unit (or some specified average lot cost) and use historical production to development cost ratios to estimate the development costs. When feasible, the development of separate analogy estimates is preferred.

10.3 Key Analogy Estimate Activities

Figure 10.1 depicts typical key activities involved in making an analogy estimate. Each block represents an activity. Arrows indicate the usual sequence of activities. Dashed lines indicate interactive activities. Some activities must be repeated for each of several system components. Factors are likely to be developed once and used for all or most components. Many analogy estimates are less complex than indicated by Figure 10.1, especially if only one cost element is included. When only a single item is involved, the critical activities (L, M, and N) need to be performed only once. There also is reduced work associated with activities A through F and J. Many activities shown in Figure 10.1 are not unique to analogy estimates.

Typical key activities are described in the remainder of Section 10.3. Each block in Figure 10.1 has a letter in the upper right corner to key it to its associated paragraph in the following text.

Figure 10.1 Analogy Cost Estimating Process



10.3.1 Activity A. Determine Estimate Needs and Ground Rules

Cost estimates differ widely from detailed life cycle cost estimates, which cover activities occurring over periods up to 20 years, to simple estimates for a one time purchase of a single piece of equipment hardware of an existing design. In essence, estimates differ by level of detail or accuracy required. Some estimates need to be as accurate as possible, while others can be less accurate as long as they can be used as an equitable basis for comparing among several alternatives. In addition, some estimates need to be detailed so that costs can be tracked and managed at a lower level. Ground rules and assumptions (e.g., inflation rates to be used, buy quantities, schedules, interactions with other programs, test requirements, etc.) must be defined. The possible requirement for a sensitivity analysis should also be addressed. To facilitate creation of an estimate, estimate objectives, assumptions, and ground rules should be documented at the outset and agreed upon by all, especially program management. Subsequent changes to those plans should also be coordinated with program management.

10.3.2 Activity B. Define the System

Defining the system includes determining:

- Design or physical parameters such as weight, size, material type, and design approach

- Required performance characteristics such as speed, range, computation speed, reliability and maintainability
- Interface requirements with other systems, equipment, and organizations
- Unusual training, operations, and support requirements
- Unusual testing or certification requirements
- Level of technology advance, if any, required
- Known similar systems

10.3.3 Activity C. Plan Breakout of System for Analogy Estimating

Generally, the system to be estimated should be broken down into hardware or activity components. While the total new system may not be similar to a prior total system, many of the components of the new system (e.g., the power supply, computer, or antenna) may be like components of prior systems. The overall objective of this activity is to break out the overall system into components in such a way that:

- Good comparable components from past programs can be identified
- Relatively complete cost and descriptive data on the components from past programs are available
- Technical experts who have or can quickly obtain a good understanding of the differences between the old and new system components are available

The level of detail selected provides both a complete and sound basis for capturing all of the costs. An example of a poor breakout is one where both component and assembly costs are expected to be significant; however, only historical analogy component cost data are available, but historical analogy assembly cost data are missing.

As indicated in the chart, this activity is best done interactively with the next activity (D) to best achieve the overall objectives described above.

10.3.4 Activity D. Assess Data Availability

Three types of data are required:

- Quantity, design, and performance characteristics of the new system components
- Quantity, design, and performance characteristics for components of one or more prior systems

- Cost data for the prior system components.

Since all three of these items for any component must be obtained, cost estimators must assess the availability of the information listed above before making final system component breakout decisions or risk the chance of later finding that the data is not available at the breakout level selected. The technical specialists assisting in the estimate may have to be involved in assessing the availability of component description data.

10.3.5 Activity E. Describe the New System Components

If plans for the breakout are sound, the next step is to describe each of the new system components in terms most comparable to prior system components and which are more likely to reflect cost differences (e.g., weight rather than color). It is important that similar information can be found for the prior system components. This activity is best done in close coordination with the early phases of collecting prior system data, Activity F, to assure that adequate comparable design and performance data will be available.

10.3.6 Activity F. Collect Prior System Component Design and Performance Data

It is generally best to gather data on several characteristics for each component. It is better (but not mandatory) that this data be measurable. The data must be in terms comparable with the information known about the new system. In areas where technology is changing rapidly, such as microelectronics, it is best not to rely on weight or size data. The more recent the prior data the better, since the new system will more likely use similar manufacturing technology. Wherever possible, data should be gathered for several prior system components that are similar to the new system component. Subsequent analysis may show that one prior system component is a better basis for estimating the cost of the new system or that several may be considered in arriving at an estimate for the new system component.

10.3.7 Activity G. Collect Prior System Component Cost Data

As in collecting prior system component design and performance data, it is better to have data on several prior systems. Of course, the prior system component cost data must be for the same items for which the design and performance data was collected. It is desirable to obtain separate cost values for both development and production. In gathering the cost data, it is critical that all cost data collected are defined clearly. Things that should be known about cost values include:

- Exactly what is included in the cost (e.g., software, etc.)

- What year dollars the cost values are in and when the work included in the costs was completed

- What general and administrative (G&A) costs and profit were included in the values

- Where in the sequence of units bought were the items to which the cost values apply

- A breakout of recurring and nonrecurring production costs

- Cost improvement curve slope values experienced during production of the prior system components

The work required to obtain this information will vary widely from estimate to estimate. Analysis of production lot cost data to establish prior system recurring cost first unit (T_1) and slope values probably will be required. The impact of prototyping may have to be assessed. Contracts and the Work Breakdown Structure (WBS) dictionary may have to be reviewed to determine exactly what costs should fall into the full-scale development (FSD), production, recurring, and nonrecurring categories. When prior costs are spread over several years, either: 1) an average year of acquisition value must be established to convert the historical data to the desired constant year, or 2) the costs associated with individual years must be identified and each converted to the desired constant year. The work required to get costs to a constant year must be accomplished before the analysis required to establish slopes and T_1 values. An important part of this step is to assemble all historical financial data in terms of cost only. Therefore, if the available historical data contain G&A and profit, it must be identified, often from contract documents, and removed.

10.3.8 Activity H. Process/Normalize Prior System Component Cost Data

The objective of processing the prior system component cost data is to obtain the following:

- All cost values in a common constant year

- A breakout of all nonrecurring costs from recurring costs

- T_1 values for recurring costs

- A breakout of FSD and production costs, if a developmental program

- Recurring production cost improvement slopes and curve types

- Knowledge of prototype to first production unit cost improvement curve step functions, if any, associated with prior system component production

- Knowledge of anything unusual about prior system costs or uncertainties concerning the cost values obtained

- Nonrecurring to recurring cost ratios

10.3.9 Activity I. Develop Factors Based on Prior System Costs

Sometimes, extrapolating cost elements from past systems to future systems is more logical than using design and performance differences as a basis. One example is program management. Program management is generally estimated as a percent of total prime mission equipment hardware costs. Support equipment, training, and data generally are handled in this manner also.

While such factors may be available (having been developed during other estimates), the prior system data to be used for the estimate should be analyzed to develop such factors. It is always prudent to check the factors developed with similar ones used for other estimates and reconcile any major differences.

10.3.10 Activity J. Develop the New System Component Cost Improvement Slope Values

This is applicable only if there is recurring production or production of multiple prototypes involved. The most logical source of curve slopes is the slope of the prior system as described in Activity H.

10.3.11 Activity K. Review Ratios and Factors

When preparing analogy estimates, cost estimators generally need to rely on judgments made by engineers and other technical specialists. Specialists must be selected because of their knowledge of both the new and prior programs. They should understand design, materials, and manufacturing technology. They also may know reasons why past programs may or may not be representative of work on the new system. Therefore, it is valuable to have them review the ratios and factors developed in Activity H and Activity I as a precaution against using factor or ratio values from a prior system which are not representative of the usual or projected circumstances.

The break between completing Activity K and starting Activity L essentially divides the analogy estimating process into two major parts. Activities A through K can be viewed as getting ready to conduct the estimate. The remaining activities can be viewed as preparation of the estimate itself. If several estimates are needed for different designs or levels of performance, the work involved in Activities A through K will have to be repeated.

10.3.12 Activity L. Obtain Complexity Factor Values

This activity is the foundation of analogy estimating methodology. It must be done carefully and result in an understandable and traceable reason for each complexity factor developed. In essence, the cost estimator is asking a technical specialist who knows both the prior system and the new system the following question. “Assuming no special miniaturization requirement and no manufacturing technology differences (i.e., productivity improvement differences between production of the prior and new system), what should their relative complexity be (i.e., cost ratio)?” This relative complexity should be based on the design and performance differences between the prior and new system. This is not an easy question to answer. Technical specialists generally do not think of complexity as a number directly related to cost differences. In addition, the cost estimator must insist that the technical specialist provide justification for his answer in

terms that others can understand, such as the ratio of number of circuit cards, radiated power ratio, weight ratio, etc. If possible, multiple complexity judgments should be obtained and combined in a logical manner to arrive at a single best complexity value to be used for the estimate.

10.3.13 Activity M. Obtain Miniaturization Factor Values

For some applications such as aircraft, missiles, and space systems, the smaller the subsystem is for a given level of performance, the more costly it is to produce. Sometimes stringent weight and space constraints are placed on subsystems. These constraints can increase costs. The guidance of technical specialists is required to determine if the new system can be expected to cost more due to weight and volume constraints and, if so, how much more. The question of "how much more" should be presented in terms of the ratio of the expected cost of the new system to the expected cost of designing a new system with the same level of performance but with no space and weight constraints. If no added costs are expected, this ratio will be 1.0. All ratios not equivalent to 1.0 should be supported with rationale that is understandable to both the cost estimator, and those who will review the estimate.

10.3.14 Activity N. Obtain Productivity Improvement Factor Values

Just as inflation drives costs up over time, productivity improvements should drive costs down, or at least somewhat offset inflation cost increases. In many cases productivity improvements are not obvious because the product changes so much that the productivity improvement cost benefits get lost or do not materialize. This is true with respect to automobiles. One really does not know what it would cost to build a 1960 Chevy today because new Chevys are very different than 1960 models. However, in agricultural products, such as wheat, corn, etc., where the product is about the same as it was 60 years ago, the constant dollar cost per unit is way down due to productivity improvements. Spectacular decreases in costs per unit of computing capability have been seen in recent years.

Technical specialists should be asked if there has been significant productivity improvement between production of the prior and new systems. If the answer is yes, a judgment is required to assess the cost ratio of producing the new system, using the anticipated manufacturing technology and material costs, to those associated with the prior system. A significant productivity cost improvement will result in a ratio of less than 1.0. A value of 1.0 indicates no significant productivity change. Sound reasons for the ratio selected should be provided.

It is very desirable to obtain separate factor judgments for complexity, miniaturization, and productivity changes because reasons provided to justify each individually should be easier to understand. However, as a practical matter, the technical specialists may argue that they can only give factor values that combine two or even all three factors. The cost estimator will have to decide what course of action is best. However, it is essential that the factors used in any combined factor be identified clearly with respect to which of the three factors are taken into consideration. In addition, the cost estimator must assure that each of the factor areas has been addressed.

10.3.15 Activity O. Apply Factors to Obtain New System Costs

The factors developed in Activities L, M, and N are applied to T_1 values and nonrecurring costs for both FSD and production, as applicable. They are not applied directly to the ratios developed in Activity H and Activity I because these ratios will be applied to new system costs to which the factors have already been applied. In applying the factors, the Equation 10.1 is used.

Equation 10.1

$$C_N = C_P \bullet F_C \bullet F_M \bullet F_P$$

Where:

C_N = *The equivalent cost for the new system*

C_P = *Any T_1, FSD, or production nonrecurring cost for the prior system or system component*

F_C = *Complexity factor ratio*

F_M = *Miniaturization factor ratio*

F_P = *Productivity component ratio*

Where two or more factors are combined, the equation will change accordingly.

10.3.16 Activity P. Develop New System PME Cost Estimates

The T_1 values developed in Activity O must be combined with cost improvement curve slope values developed in Activity J to arrive at total recurring costs for each component. Nonrecurring costs should be developed in Activity O or be based on recurring to nonrecurring cost ratios developed in Activity H. Recurring and nonrecurring costs are added to develop total prime mission equipment (PME) costs for each WBS component (or aggregation of components) addressed. FSD and production estimates must be prepared separately, unless one is to be developed based on the other. Costs for the various components or groups of components involved are summed to get the total new system PME cost for FSD and the specified production quantity of interest.

10.3.17 Activity Q. Develop Other New System Costs with Factors

When making analogy cost estimates, comparisons generally are made between prior and new equipment based on characteristics of the equipment. A common approach is to use the differences in characteristics to extrapolate from the PME costs of prior systems to the PME costs of the new system. When this is done, other elements of cost such as Systems Engineering (SE)/Program Management (PM), spares, support equipment, training, and data must be added to complete the estimate for the new system. To do this, a cost estimator must use the costs developed in Activities O and P and the factor values developed in Activities H and I. Other sources, such as company history, can be used to develop all non-PME costs for the new system. The costs produced to this point generally cover all costs for a contractor to carry out work on the new system.

10.3.18 Activity R. Develop Total Program Costs

Completion of Activities P and Q should provide cost data that can be summed to get the total cost for a contractor to provide the new system. Profit and G&A costs must be added to obtain

the total contract prices. Appropriate profit and G&A rate data generally can be obtained either from forward pricing rate agreements for the company involved or from recent history of similar programs. To arrive at the total program costs, all other costs not associated with the prime contractor must be added. This generally includes mission support, Government Furnished Equipment (GFE), and costs to use government test facilities. If the program has several contractors, the total program cost must combine the costs associated with all contractors.

10.3.19 Activity S. Review the Estimate

Because analogy cost estimates require complexity value judgments, which significantly affect the final results, they should be reviewed before preparing final documentation. This review is best performed by other cost estimators or supervisors experienced in analogy cost estimating and, if possible, an engineering supervisor familiar with the equipment. To prepare for such a review, it is often desirable to perform some sensitivity analysis to show how sensitive the estimate is to the various key complexity value judgments.

10.3.20 Activity T. Document the Estimate

Analogy cost estimate documentation has much in common with documentation required for any cost estimate. However, since the final product is tied so critically to the comparison of the prior and future system, the basis for complexity factors given must be discussed clearly in a way that is logically persuasive. Where complexity judgments by technical specialist are used, the specialists and their qualifications should be identified. The same type of information is desirable to support miniaturization and productivity judgments.

The inclusion of a figure like Figure 10.1 in the estimate documentation helps the reader more clearly understand how the estimate was developed. All factors, ratios, slopes, and T_1 values used, for prior and new equipment, should be included and identified clearly. Pictures or drawings also can be helpful to illustrate important design characteristics or differences.

10.4 Additional Guidance

Generally, technical specialists find it difficult to make, and often balk at making, complexity, miniaturization, and productivity improvement judgments. Their concepts of complexity are not necessarily in terms that are directly proportional to cost differences. The cost estimator can sometimes help the technical specialist by providing the relative component costs of several past systems and asking for a relative cost or complexity judgment for the new system with respect to these several past systems.

Some engineers believe that as the complexity ratio from the prior to future system increases, the quality of the analogy decreases. It follows that as the complexity ratios increase much above 2.0, the quality of the estimate is reduced due to the quality of the analogy (unless very convincing rationale is provided to support high complexity values).

While it is desirable to divide a system into components for analogy estimates, little can be gained by breaking out the system below the highest level for which good data are available and for which the technical specialist can make sound complexity judgments.

Where subcontractors were used on past programs and may be used in the future, past subcontract cost values are used with subcontractor G&A and fees included in the analysis. Adjustment might be made in the final estimate, since it generally is not appropriate for the prime contractor to charge a G&A fee for subcontract work. However, it is customary for prime contractors to earn a profit for the value of the subcontracted work.

10.5 Summary

This chapter provides the cost estimator with an overall analogy estimating process, along with detailed explanations for each activity within the process and the interrelationships among activities. Although analogy estimating was described as a very rigorous process, two critical limitations must be kept in mind. First, is the requirement for a detailed technical definition of both the analogous system as well as the system being estimated. Expert judgment becomes the mainstay of this approach and, at the same time, a limitation. Without access to sound expertise, this methodology is difficult to employ. Secondly, once the technical assessment has identified the analogous system, actual cost data on that system must be acquired. Without this, the transition from the analogous system to the current system cannot be made.