APPENDIX C

LIFE-CYCLE COST-ANALYSIS PROCESS

Many of our day-to-day decisions, as they pertain to the design and development of new systems and the reengineering of existing systems, are based on *technical* performance-related factors alone. *Economic* considerations, if addressed at all, have dealt primarily with initial, procurement and acquisition costs only, and not the "downstream" costs associated with system operation and maintenance support. Yet these downstream costs, which often constitute a significant portion of the total life-cycle cost of a system, are highly influenced by the decisions made in the early phases of system development. In other words, the early decision-making process must consider the *total* spectrum of costs if economic benefits are to be gained in the long term. The consequences of the short-term approach often practiced in the past have been rather detrimental overall, as conveyed in Section 1.2 (Chapter 1). Total cost visibility, as illustrated in Figure C.1, is a *must* if the risks associated with the decision-making process are to be properly assessed.

Life-cycle costing includes the consideration of *all* future costs associated with research and development (i.e., design), construction, production, distribution, system operation, sustaining maintenance and support, system retirement, and material disposal and/or recycling. It involves the costs of all technical and management activities throughout the system life cycle; that is, customer activities, producer and/or contractor activities, supplier activities, and consumer or user activities. Although the influencing of these costs can best be realized during the early phases in the development of a *new* system, as conveyed in Figure C.2, benefits can also be gained through the identification and evaluation of high-cost contributors for *existing* systems already in use. In other words, the applications and benefits that can be gained through the accomplishment of life-cycle cost analyses are numerous, as shown in Figure 3.40 (Chapter 3).

In performing a life-cycle cost analysis, there is a series of steps one may follow. These steps are briefly described in Figure 3.38 and are conveyed in the context of

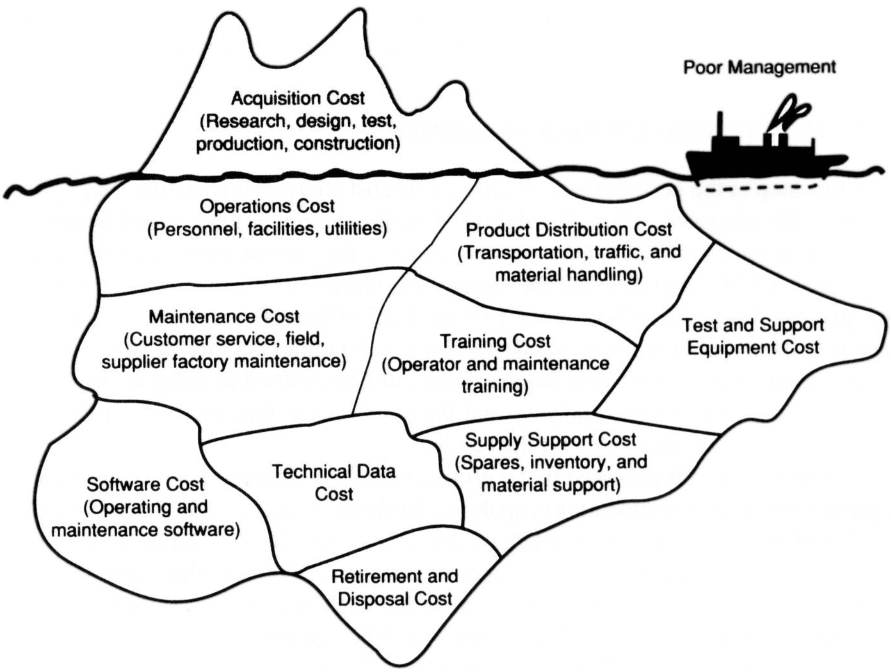


Figure C.1 Total cost visibility.

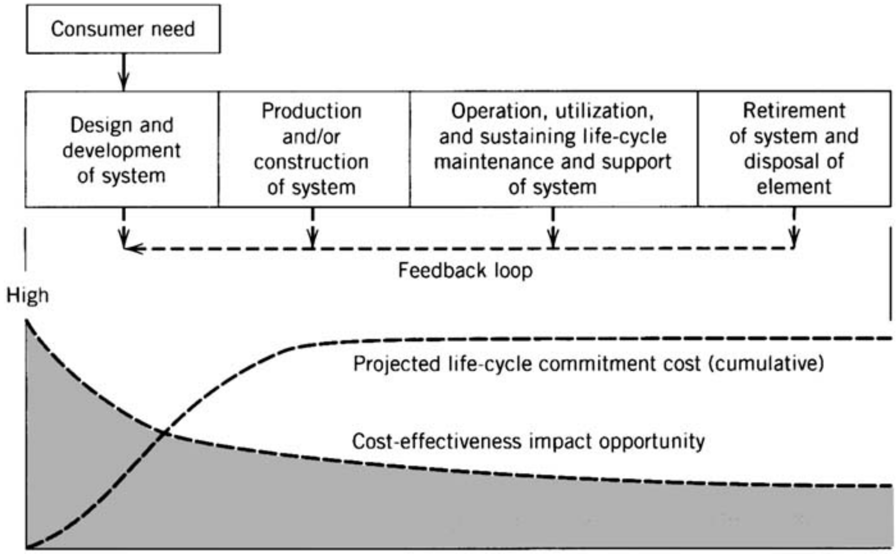


Figure C.2 Opportunity for impacting cost-effectiveness in the system life cycle.

the overall process in Figure 3.41. The purpose of this appendix is to provide some additional explanation covering each of the steps identified in Figure 3.38.

C.1 DEFINE SYSTEM REQUIREMENTS

The first step in the performance of a life-cycle cost analysis is to define the problem, identify the proposed technical solution, describe the operational requirements and the maintenance concept for the system, identify the critical technical performance measures (TPMs), and describe the system configuration in functional terms; that is, the process described in Sections 2.1 through 2.7 (Chapter 2). Depending on where one is in the system life cycle, the definition may be rather cursory or more in-depth. In any event, the basic system requirements must be defined in order to provide the necessary structure for the analysis, and the assumptions that are made at this point may have a significant impact on the results.

In Figure C.3, it is assumed that a ground vehicle in development requires the incorporation of a communications capability. Multiple quantities of the vehicle will be deployed to three different geographical locations, (i.e., 20, 20, and 25 at each location, respectively), performing a variety of missions. Although there are variations from one location to the next, it is assumed that each vehicle will be utilized on the average of 4 hours per day, 360 days per year. The equipment must enable communication with other vehicles at a range of at least 200 miles, overhead aircraft at an altitude of up to 10,000 feet, and with a centralized area communications facility. The system must have a reliability mean time between failure (MTBF) of 450 hours, a corrective maintenance downtime ($\overline{M}ct$) of 30 minutes, a maintenance labor hours per system operating hour (MLH/OH) requirement of 0.2, and a unit life-cycle cost not to exceed $20,000. The equipment will be functionally packaged in units (i.e., Units A, B, and C) and, in the event of failure, the problem will be isolated to the unit level, faulty units will be removed and replaced with spares and sent back to the intermediate level of maintenance for corrective action, and so on.

In the figure, the system operational requirements and the maintenance concept have been defined to the depth that will allow for the accomplishment of a life-cycle cost analysis during the late conceptual design or early preliminary design phase. The next step is to describe the system, and the mission(s) that is to be performed, in *functional* terms by accomplishing a top-level functional analysis. See Figure 2.12 (Chapter 2); the communication system can be described in a similar manner, followed with an evaluation of each functional block to determine the resource requirements that will provide the basis for functional costing (see Figure 2.17).

C.2 DESCRIBE THE SYSTEM LIFE CYCLE AND IDENTIFY THE MAJOR ACTIVITIES IN EACH PHASE

Given the definition of system requirements and the identification of functions, it is appropriate to provide a time line for these requirements in terms of the life cycle. In Figure C.3, the planned life cycle is 12 years. In other words, it is assumed that there is a

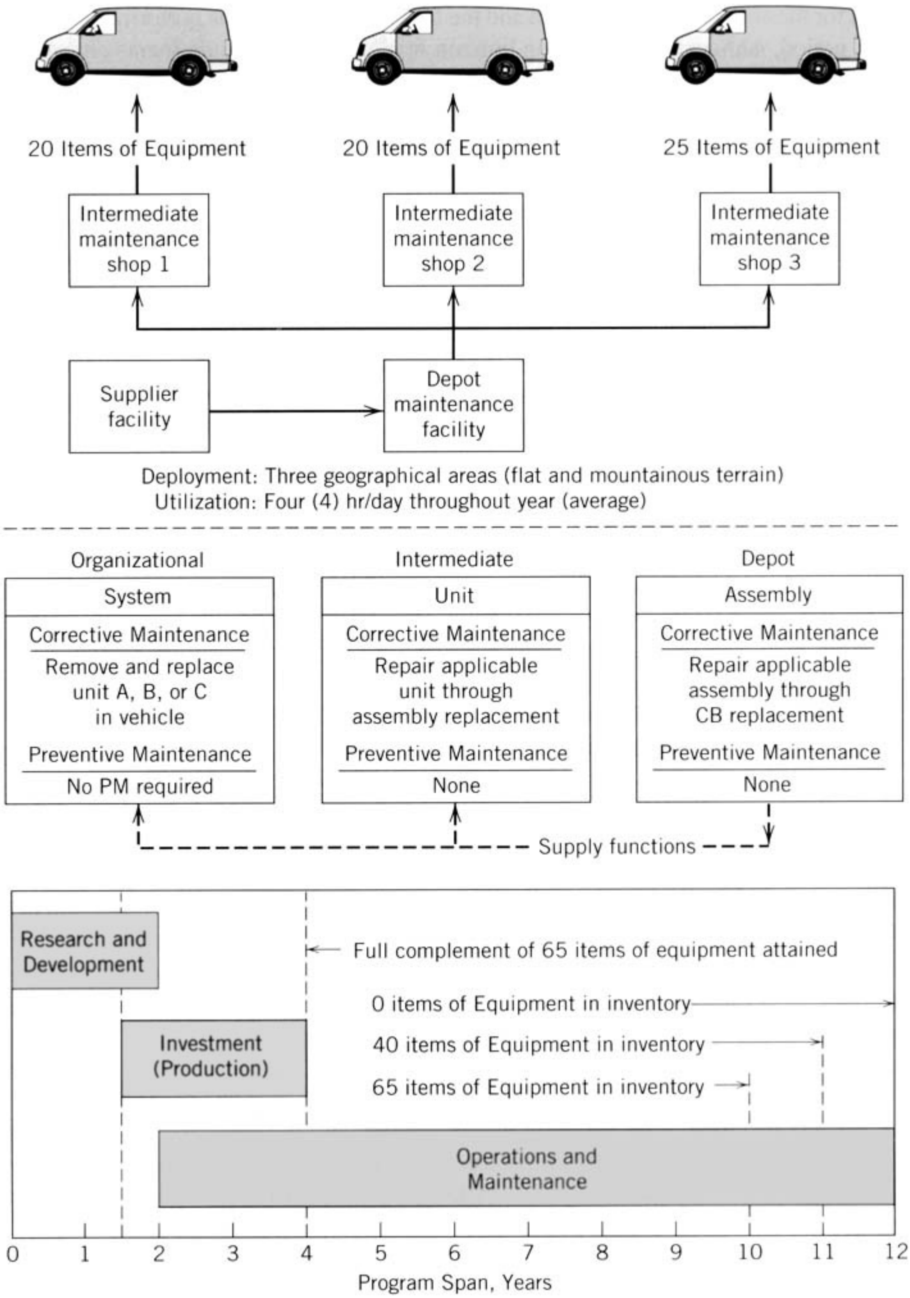


Figure C.3 Communication system requirements.

need for the communication system and the functions that are to be performed for a 12-year period. Although this planning horizon may change (as requirements change), a baseline must be established. Thus, the 12-year period and the major activities identified in the figure will be assumed herein. The activity categories identified in the figure (i.e., research and development, investment/production, and operations and maintenance) form the basis for the development of a cost breakdown structure (CBS).

C.3 DEVELOP A COST BREAKDOWN STRUCTURE (CBS)

The functions described through the functional analysis can be broken down into subfunctions, categories of work, work packages, and, ultimately, the identification of physical elements. From a planning and management perspective, it is necessary to establish a top-down framework that will allow for the initial allocation and subsequent collecting, accumulating, organizing, and computing of costs. For a typical project, this may lead to the development of a work breakdown structure (WBS) prepared to show, in a hierarchical manner, all of the elements of work that are necessary to complete a given program. As shown in Section 6.2.4 (Figure 6.12), a summary work breakdown structure (SWBS) may be developed initially, followed by one or more individual contract work breakdown structures (CWBS) designed to address specific elements of work that are covered through some form of a contractual arrangement. It is the SWBS that provides a good basis for the development of a cost breakdown structure (CBS) used in life-cycle cost analyses, primarily because its intent is to cover *all* future activities and associated costs; that is, research and development, construction/production, distribution, operation and maintenance support, and retirement activities.

The CBS is intended to show all future functions/activities, broken down to the depth necessary to provide the appropriate level of visibility and tailored to the system configuration in question. Ultimately, the CBS will lead to the identification of a product and/or a process, with the objective of establishing a structure that can be initially used for the top-down allocation of costs during the conceptual design phase (refer to Section 2.8) and subsequently for the bottom-up collection of costs for the purposes of accomplishing a life-cycle cost analysis. Figure C.4 provides an illustration of a sample cost breakdown structure (CBS), and Figure C.5 provides an abbreviated example showing how each category of the CBS should be described in terms of what is included, how the costs are calculated, and the basis for accomplishing such. The CBS provides a vehicle for looking at costs from a *functional* perspective. As one proceeds with the life-cycle cost analysis, costs are estimated for each year in the planned life cycle and are summarized for each category in the CBS.[1]

[1]The cost breakdown structure (CBS) should be tailored to the system in question. In Figure 3.39, another example is presented. If the system is very "software-intensive," then Category *Crs* should be broken down to show more detail. If the system is very "operator-intensive" (e.g., a ground radar tracking station requiring a large number of operating personnel), then Category *Cop* should be expanded. On the other hand, if Category *Cin* is too detailed for the purposes of a given analysis, then one can summarize the costs accordingly. The objective is to provide *visibility* relative to key functional activities.

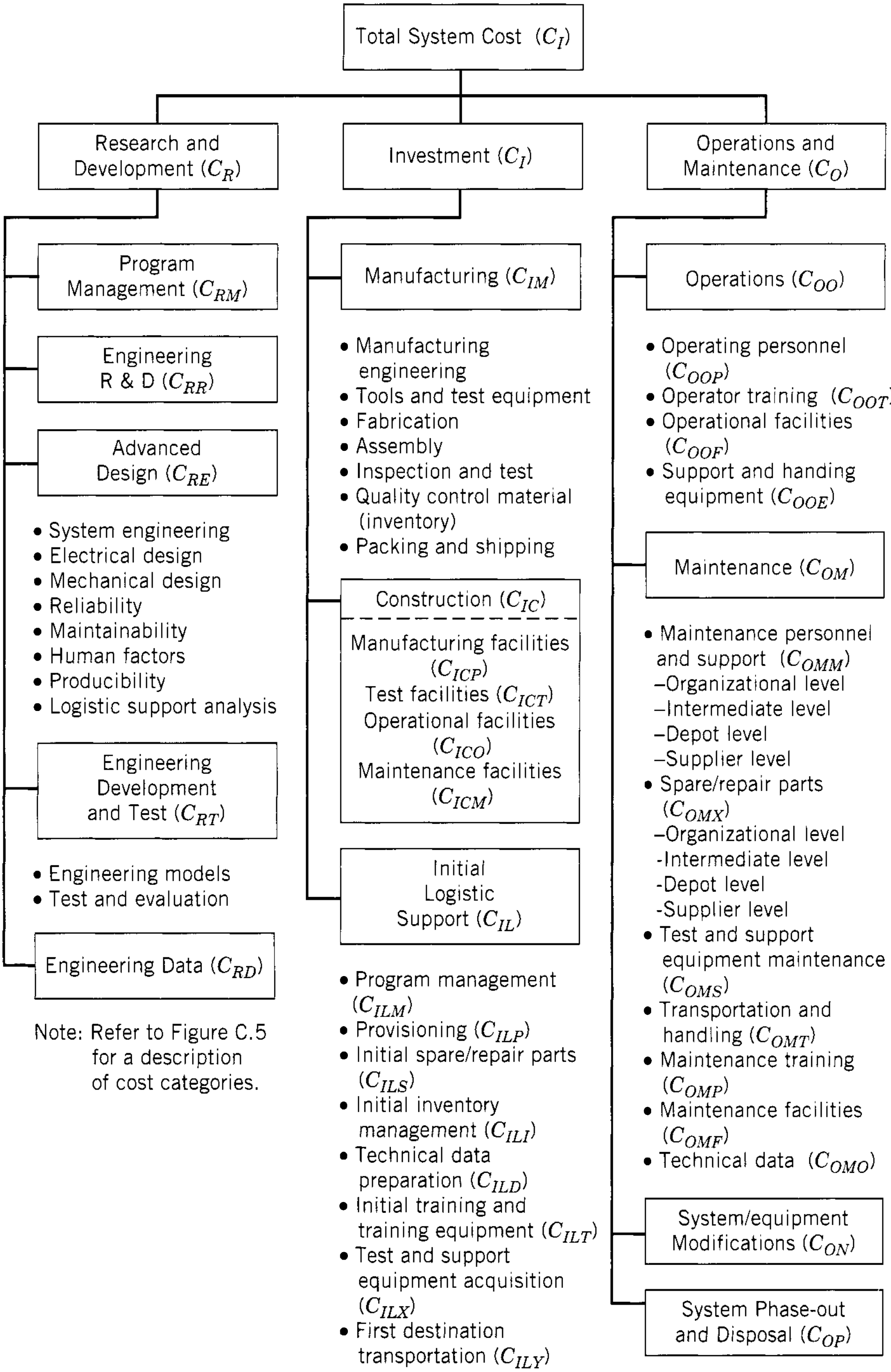


Figure C.4 Cost breakdown structure (CBS). *Source:* LOGISTICS ENGINEERING AND MANAGEMENT 4/E by Blanchard, Benjamin S., © Reprinted with permission of Pearson Education, Inc., Upper Saddle River, NJ.

Cost Category (Figure C.4)	Method of Determination (Quantitive Expression)	Cost Category Description and Justification
Total system cost (C)	$C = C_R + C_I + C_O$ $C_R = R$ and D cost C_I = Investment cost C_O = Operations and maintenance cost	Includes all future costs associated with the acquisition, utilization, and subsequent disposal of system/equipment.
Research and development (C_R)	$CR = C_{RM} + C_{RR} + C_{RE} + C_{RT} + C_{RD}$ C_{RM} = Program management cost C_{RR} = Advanced R&D cost C_{RE} = Engineering design cost C_{RT} = Equipment development/ test cost C_{RD} = Engineering data cost	Includes all costs associated with conceptual/feasibility studies, basic research, advanced research and development, engineering design, fabrication and test of engineering prototype models (hardware) and associated documentation. Also covers all related program management functions. These cost are basically nonrecurring.
Investment (C_I)	$C_I = C_{IM} + C_{IC} + C_{IL}$ C_{IM} = System/equipment manufacturing cost C_{IC} = System construction cost C_{IL} = Cost of initial logistic support	Includes all costs associated with the acquisition of systems/ equipment (once design and development have been completed). Specifically, this covers manufacturing (recurring and nonrecurring), manufacture-ing management, system construction, and initial logistic support.
Operations and maintenance (C_O)	$C_O = C_{OO} + C_{OM} + C_{ON} + C_{OP}$ C_{OO} = Cost of system/equipment life-cycle operations C_{OM} = Cost of system/equipment life-cycle maintenance C_{ON} = Cost of system/equipment life-cycle modifications C_{OP} = Cost of system/equipment phase-out and disposal	Includes all costs associated with the operation and maintenance support of the system throughout its life cycle subsequent to equipment delivery in the field. Specific categories cover the cost of system operation, maintenance, sustaining logic support, equipment modifications, and system/ equipment phase-out and disposal. Costs are generally determined for each year throughout the life cycle.

Figure C.5 Description of cost categories (partial).

Cost Category (Reference Figure C.4)	Method of Determination (Quantitive Expression)	Cost Category Description and Justification
Transportation and handling cost (C_{OMT})	$C_{OMT} = [(C_T)(Q_T) + (C_P)(Q_T)]$ C_T = Cost of transportation C_P = Cost of packing Q_T = Quantity of one-way shipments $C_T = [(W)(C_{TS})]$ W = Weight of item (lb) C_{TS} = Shipping cost ($/lb) C_{TS} will, of course, vary with the distance (in miles) of the one-way shipment. $C_P = [(W)(C_{TP})]$ C_{TP} = Packing cost ($/lbs) Packing cost and weight will vary depending on whether reuseable containers are employed.	Initial (first destination) transportation and handling costs are covered in C_{ILY}. This category includes all sustaining transportation and handling (or packing and shipping) between organizational, intermediate, depot, and supplier facilities in support of maintenance operations. This includes the return of faulty material items to a higher echelon; the transportation of items to a higher echelon for preventive maintenance (overhaul, calibration); and the shipment of spare/repair parts, personnel, data, etc., from the supplier to forward echelons.
Maintenance training cost (C_{OMP})	$C_{OMP} = [(Q_{SM})(T_T)(C_{TOM})]$ Q_{SM} = Quantity of maintenance students C_{TOM} = Cost of maintenance training ($/student-week) T_T = Duration of training program (weeks)	Initial maintenance training cost is included in C_{ILT}. This category covers the *formal* training of personnel assigned to maintain the prime equipment, test and support equipment, and training equipment. Such training is accomplished on a periodic basis throughout the system life-cycle to cover personnel replacements due to attrition. Total costs include instructor time; supervision; student pay and allowances while in school; training facilities (allocation of portion of facility required specifically for formal training); training aids and data; and student transportation as applicable.
Operational facilities cost (C_{OOF})	$C_{OOF} = [(C_{PPE} + C_U)(\%\ \text{Allocation}) \times (N_{OS})]$ C_{PPE} = Cost of operational facility support ($/site) C_U = Cost of utilities ($/site) N_{OS} = Number of operational sites *Alternative Approach* $C_{OOF} = [(C_{PPF})(N_{OS})(S_O)]$ C_{PPF} = Cost of operational facility space ($/square foot/site). Utility cost allocation is included. S_O = Facility space requirements (square feet)	Initial acquisition cost for operational facilities is included in C_{ICO}. This category covers the annual recurring costs associated with the occupancy and maintenance (repair, paint, etc.) of operational facilities throughout the system life-cycle. Utility costs are also included. Facility and utility costs are proportionately allocated to each system.

Figure C.5 *(Continued)*

C.4 ESTIMATE THE COSTS FOR EACH PHASE OF THE LIFE CYCLE

The next step is to estimate the costs, by category in the CBS, for each year in the system life cycle. Such estimates must consider the effects of inflation, learning curves when repetitive processes or activities occur, and any other factors that are likely to cause changes in cost, either upward or downward. Cost estimates may be derived from a combination of accounting records, cost projections, supplier proposals, and predictions in one form or another.

In Figure C.2, the early stages in the system life cycle is the preferred time to commence with the estimation of costs, because it is at this point when the greatest impact on total system life-cycle cost can be realized. However, the availability of good historical cost data at this time is almost nonexistent in most organizations, particularly the type of data that pertain to the downstream activities of operations and support for similar systems in the past. Thus, one must depend heavily on the use of various cost-estimating methods in order to accomplish the end objectives.

As shown in Figure C.6, as the system configuration becomes better defined in a developmental effort, the use of direct engineering and manufacturing standard factors based on past experience can be applied, as is the case for any "cost-to-complete" projection on a typical project today (e.g., cost per labor hour). On the other hand, in the earlier stages of the life cycle when the system configuration has not been well defined, the analyst must rely on the use of a combination of analogous and/or parametric methods developed from experience with similar systems in the past. The objective is to collect data on a "known entity," identify the major functions that have been accomplished and the costs associated with these functions, relate the costs in terms of some functional or physical parameter of the system, and then use this relationship in attempting to estimate the costs for a new system. A goal is to identify the applicable technical performance measures (TPMs) for the system in question and estimate the cost per a given level of performance (e.g., cost per unit of product output, cost per mile of range, cost per unit of weight, cost per volume of capacity used, cost per unit of acceleration, cost per functional output, etc.). Costs can be related to the appropriate blocks in the functional description of the system. Figures C.7 and C.8 provide some simple illustrations of considerations in cost estimating. However,

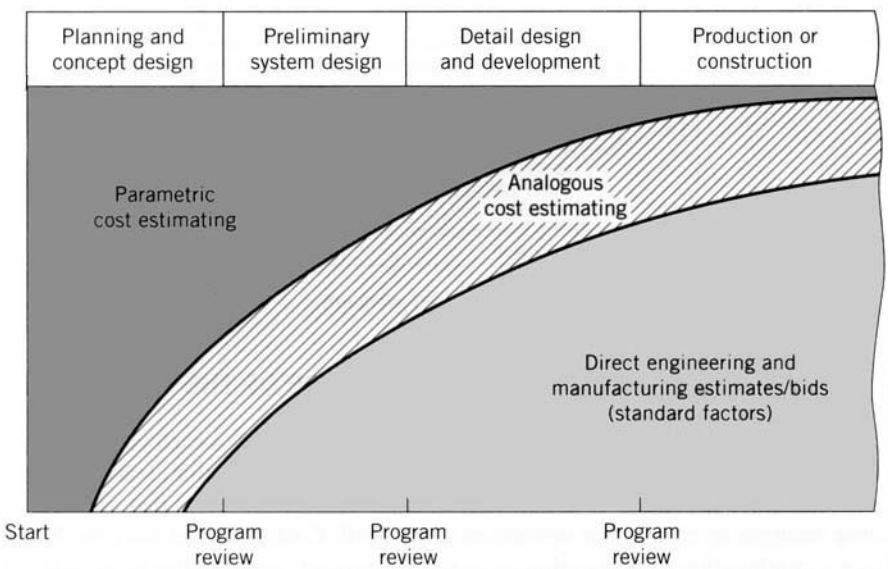
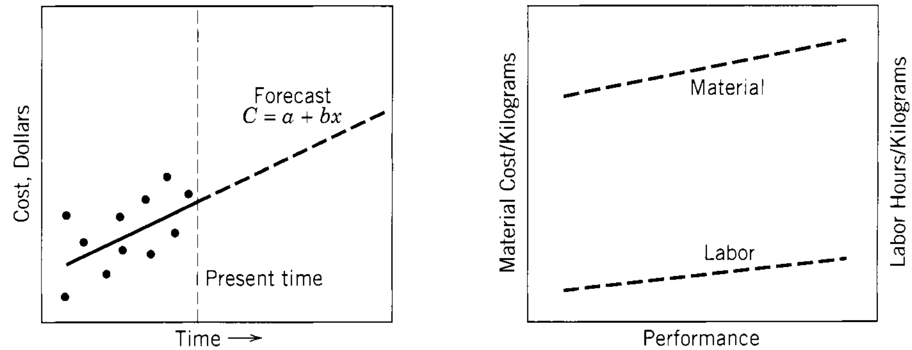


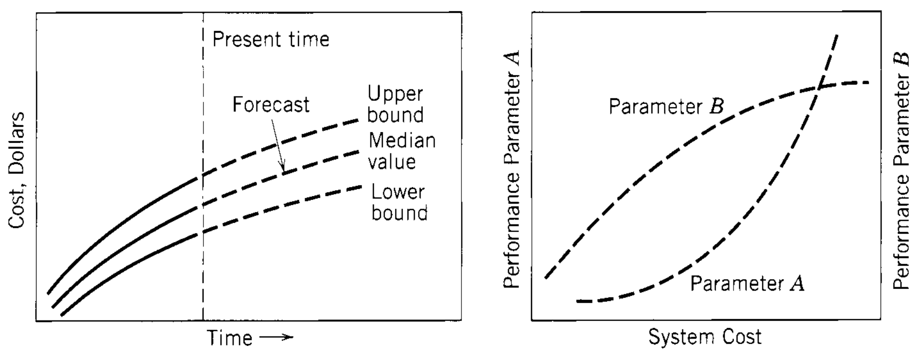
Figure C.6 Cost estimation by program phase.



Forecast Presenting Cost
Trend Based on Historical Data

Linear Relationships
of Several Parameters

Cost-estimating relationships—simple linear functions.



Forecast Using Delphi
Estimates for Cost Projections

Nonlinear Relationships of
Several Parameters

Cost estimating relationships-simple nonlinear functions

Figure C.7 Cost-estimating relationships (CERs).

care must be exercised to ensure that the historical information used in the development of cost-estimating relationships (CERs) is relevant to the system configuration being evaluated today. CERs based on the mission and performance characteristics of one system may not be appropriate for another system configuration, even if the configuration is similar in a physical sense. Thus, costs must be related from a *functional* perspective.

To be effective in total cost management (and in the accomplishment of cost-effectiveness analyses) requires full-cost visibility allowing for the traceability of all costs back to the activities, processes, and/or products that generate these costs. In the traditional accounting structures employed in most organizations, a large percentage of the total cost cannot be traced back to the "causes." For example, "overhead" or "indirect" costs, which often constitute more than 50% of the total, include a lot of

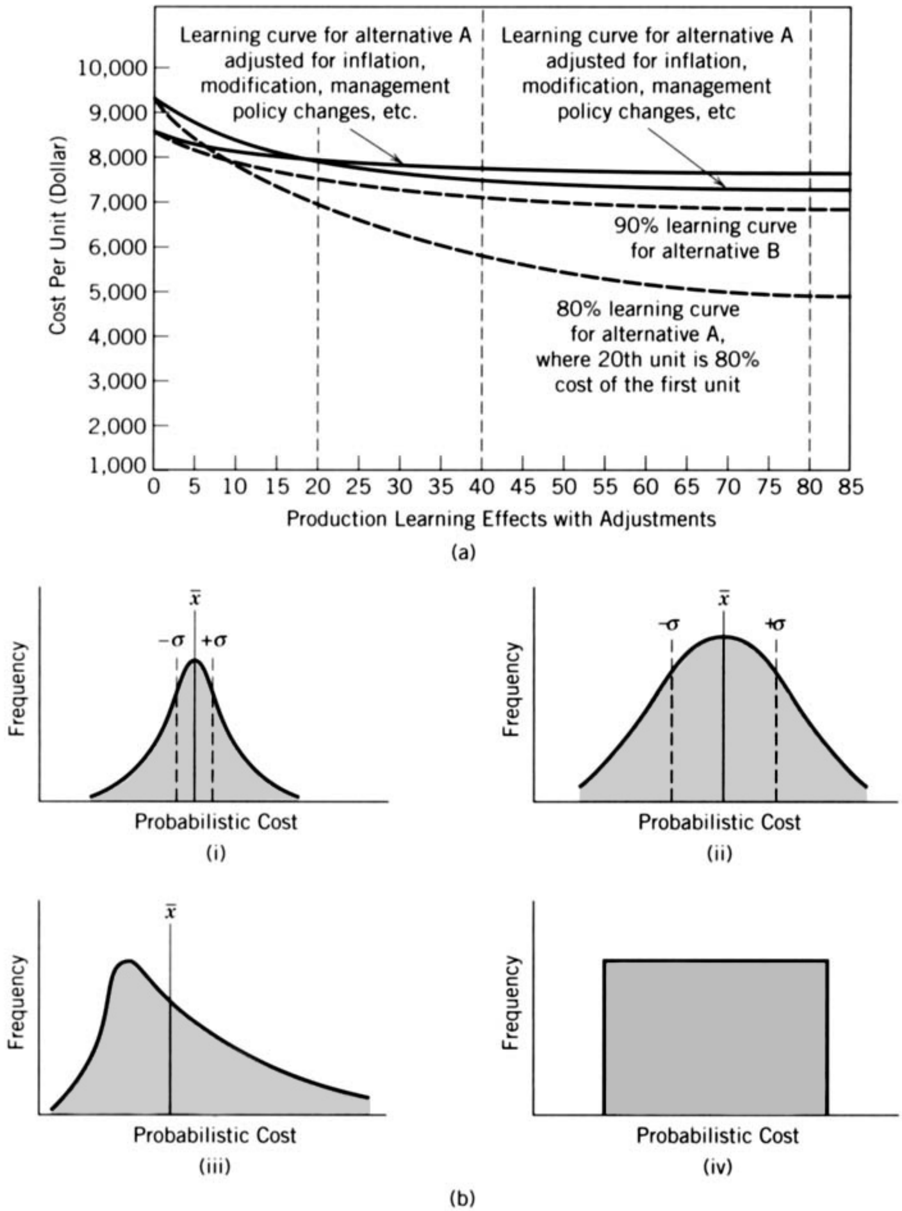


Figure C.8 (a) Learning curves and (b) the probabilistic aspects of costs.

management costs, supporting organization costs, and other costs that are difficult to trace and assign to specific objects (refer to the overhead costs in Figure 6.27). With these costs being allocated across the board, it is impossible to identify the actual "causes" and to pinpoint the *true* high-cost contributors. As a result, the concept of *activity-based costing* (ABC) has been introduced.[2]

Activity-based costing is a methodology directed toward the detailing and assignment of costs to the items that cause them to occur. The objective is to enable the "traceability" of *all* applicable costs to the process or product that generates these costs. The ABC approach allows for the initial allocation and later assessment of costs by function. It was developed to deal with the shortcomings of the traditional management accounting structure whereby large overhead factors are assigned to all elements of the enterprise across the board without concern for whether they directly apply or not. More specifically, the principles of ABC include the following:

1. Cost are directly traceable to the applicable cost-generating process, product, and/or a related object. Cause-and effect relationships are established between a cost factor and a specific process or activity.
2. There is no distinction between direct and indirect (or overhead) costs. Generally, 80 to 90% of all costs are traceable, and nontraceable costs are not allocated across the board, but are allocated directly to the organizational unit(s) involved in the project.
3. Costs can be easily allocated on a *functional* basis; that is, according to the functions identified in Figures 2.13 and 2.16 (Chapter 2). It is relatively easy to develop cost-estimating relationships in terms of the cost of activities per some activity measure (i.e., the cost per unit output).
4. The emphasis in ABC is on "resource consumption" (versus "spending"). Processes and products consume activities, and activities consume resources. With resource consumption being the focus, the ABC approach facilitates the evaluation of day-to-day decisions in terms of their impact on resource consumption downstream.
5. The ABC approach fosters the establishment of cause-and-effect relationships and, as such, enables the identification of the "high-cost contributors." Areas of risk can be identified with some specific activity and the decisions that are being made associated with this activity.
6. The ABC approach tends to eliminate some of the cost doubling (or double counting) that occurs in attempting to differentiate as to what should be included as a "direct" cost or as an "indirect" cost. Without the necessary visibility, there is the potential for including the same costs in both categories.

Implementation of the ABC approach, or something of an equivalent nature, is essential if one is to do a good job of total cost management. Costs are tied to objects

[2]J. R. Canada, W. G. Sullivan, and J. A. White, *Capital Investment Analysis for Engineering and Management*, 2d ed. (Upper Saddle River, NJ: Prentice-Hall, 1996); 1996; and P. T. Kidd, *Agile Manufacturing: Forging New Frontiers* (Reading, MA: Addison-Wesley, 1994).

and viewed over the long term, and such a perspective facilitates the life-cycle cost-analysis process. An objective for the future is to persuade the accounting organizations in various companies/agencies to supplement their current end-of-year financial reporting structure to include the objectives of ABC.

C.5 SELECT A COMPUTER-BASED MODEL TO FACILITATE THE ANALYSIS PROCESS

In the selection of a computer-based model, one must ensure that the tool selected does what is expected, is sensitive to the problem at hand, and allows for the visibility needed in addressing the system as an entity, as well as any of its major components on an individual-by-individual basis. The model must enable the comparison of *many* different alternatives and aid in selecting the best among them rapidly and efficiently. The model must be *comprehensive,* allowing for the integration of many different parameters; *flexible* in structure, enabling the analyst to look at the system as a whole or any part of the system; *reliable,* in terms of repeatability of results; and *user-friendly.* So often, one selects a computer model based on the material in the advertising brochure alone, purchases the necessary equipment and software, uses the model to manipulate data, and believes in the output results without having any idea as to how the model was put together, the internal analytical relationships established, whether it is sensitive to the variation of input parameters in terms of output results, and so on. The results of a recent survey indicate that there are more than 350 computer-based tools available in the commercial marketplace and intended for use in accomplishing different levels of analysis. Each was developed on a relatively "independent" or "isolated" basis in terms of selected platform, language used, input data needs, and interface requirements. In general, the models do not "talk to each other," are not user-friendly, and are too complex for use in early system design and development.

When using a model, it is essential that the analyst become thoroughly familiar with the tool, know how it was put together, and understand what it can do. For the purposes of accomplishing a life-cycle cost analysis, it may be appropriate to select a group of models, combined as illustrated in Figure C.9 and integrated in such a manner that will enable the analyst to look not only at the cost for the system overall, but at some of the key functional areas representing potential high-cost contributors. The model(s) must be structured around the cost breakdown structure (CBS) and in such a way that will allow the analyst to look at the costs associated with each of the major functions. Further, it must be *adaptable* for use during the early stages of conceptual design as well as in the detail design and development phase.

C.6 DEVELOP A "BASELINE" COST PROFILE

Through the application of various estimating methods, the costs for each CBS category and for each year in the system life cycle are projected in the form of a cost profile. The worksheet format presented in Figure C.10 can serve as a vehicle for recording costs, and the profile shown in Figure C.11 can represent the anticipated cost stream.

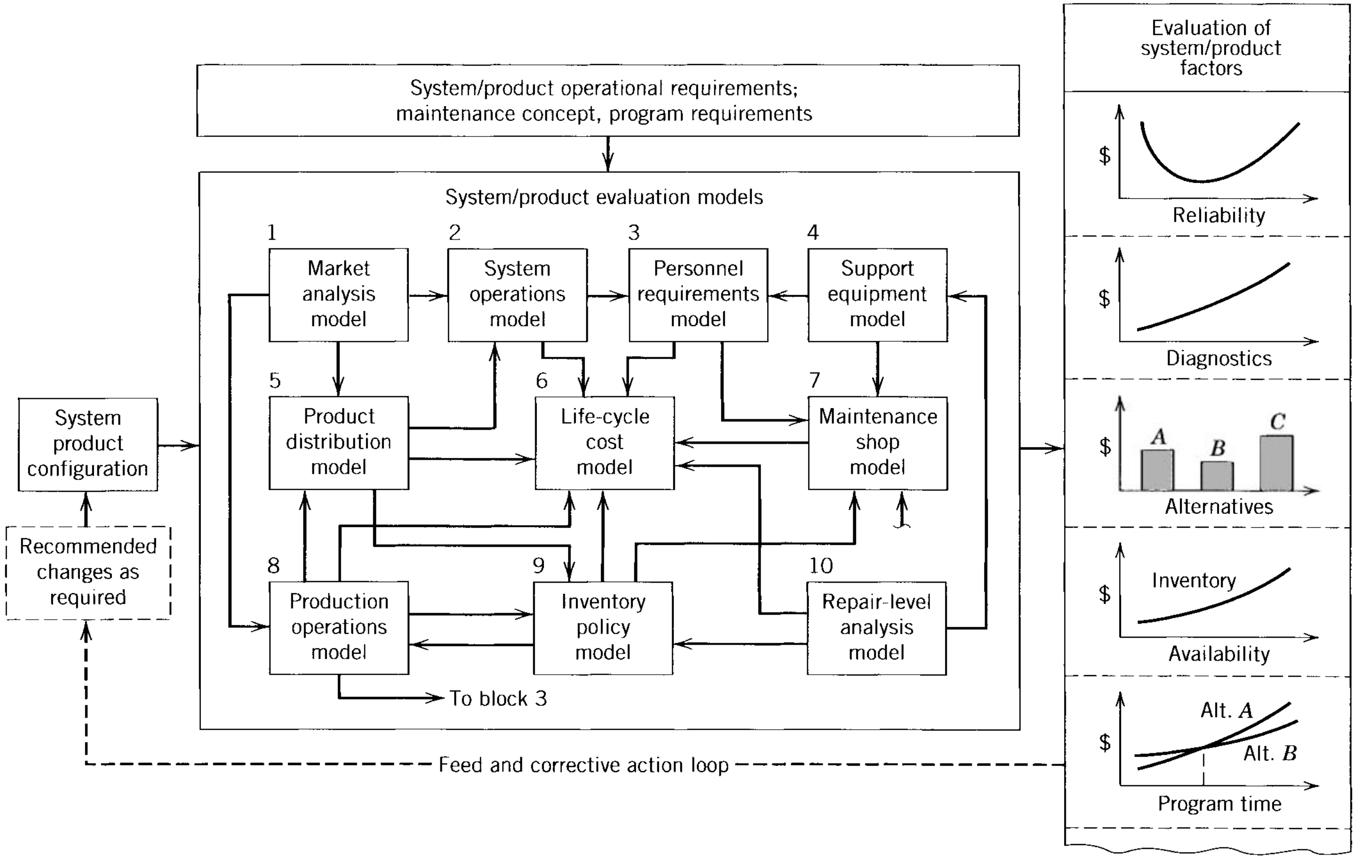


Figure C.9 Example models in life-cycle costing.

Program Activity	Cost Category Designation	Cost by Program Year ($)												Total cost ($)	Percent Contr. (%)
		1	2	3	4	5	6	7	8	9	10	11	12		
Alternative A															
1. Reserach and development cost	C_R														
a. Program management	C_{RM}														
b. Engineering design	C_{RE}														
c. Electrical design	C_{RED}														
d. Engineering data	C_{RD}														
2.															
3.															
Others															
Total Actual Cost	C														
Total P.V. Cost (10%)	$C_{(10)}$														
Alternative B															
1. Research and development cost	C_R														
a. Program management	C_{RM}														
b. Engineering design	C_{RE}														
Etc.															

Figure C.10 Cost collection worksheet.

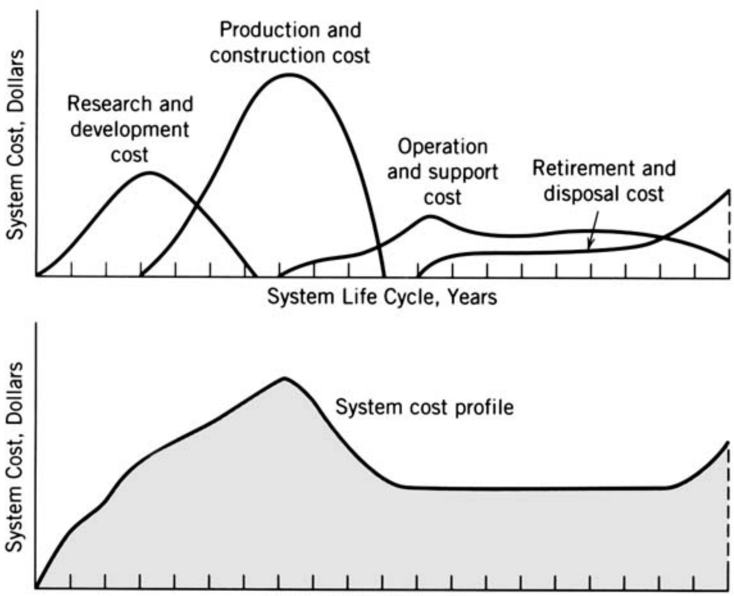


Figure C.11 Development of a cost profile.

In developing profiles, it may be feasible to start out with one presented in terms of *constant* dollars first (i.e., the costs for each year in the future presented in terms of today's dollars) and then develop a second profile by adding the appropriate inflationary factors for each year to reflect a *budgetary* stream. In comparing alternative profiles, the appropriate economic analysis methods must be applied in converting the various alternative cost streams to the *present value* or to the point in time when the decision is to be made in selecting a preferred approach. It is necessary to evaluate alternative profiles on the basis of some form of *equivalence.*[3]

C.7 DEVELOP A COST SUMMARY AND IDENTIFY THE HIGH-COST CONTRIBUTORS

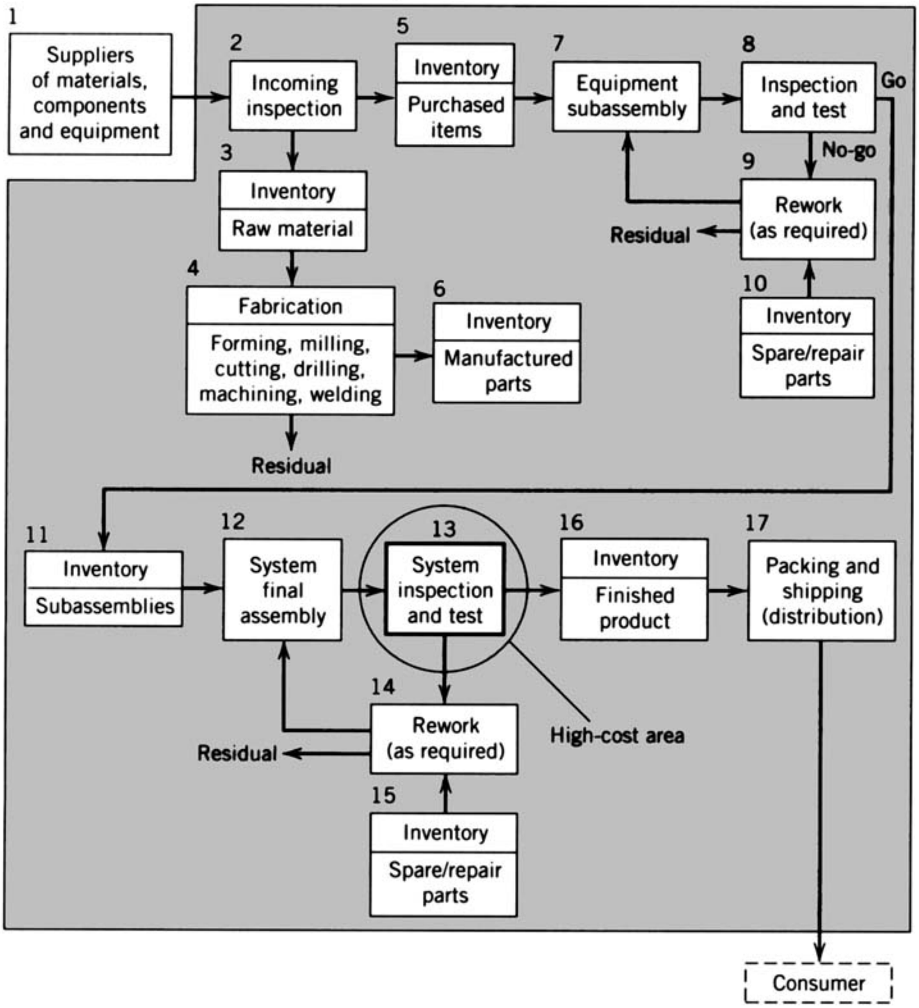
In order to gain some insight pertaining to the costs for each major category in the CBS and to readily identify the *high-cost contributors,* it may be appropriate to view the results presented in a tabular form. In Figure C.12, the costs for each category are identified along with the percent contribution of each. Note that in this example, the high-cost areas include the initial costs associated with "facilities" and "capital equipment" and the operating and maintenance costs related to the "inspection and test" function being accomplished within the production process. For the purposes of product and/or process improvement, the "inspection and test" area should be investigated further. Through the planned life cycle, 17% of the total cost is attributed to the operation and support of this functional area of activity, and the analyst should proceed with determining some of the reasons for this high cost.

C.8 DETERMINE THE CAUSE-AND-EFFECT RELATIONSHIPS PERTAINING TO HIGH-COST AREAS

Given the presentation of costs (and the percent contribution) as shown in Figure C.12, the next step is to determine the likely "causes" for these costs. The analyst will need to revisit the CBS, the assumptions made leading to the determination of the costs, and the cost-estimating relationships utilized in the process. It is to be hoped that an *activity-based costing* (ABC) approach was used, or something of an equivalent nature, to ensure the proper traceability. The application of an Ishikawa cause-and-effect diagram, as illustrated in Figure B.4 (Appendix B), may be used to assist in pinpointing the actual "causes." The problem may relate to an unreliable product requiring a lot of maintenance, an inadequate procedure or poor process, a supplier problem, or other such factors.

[3]The treatment of cost streams considering the "time value of money" is presented in most texts dealing with engineering economy. Two good references are (1) G. J. Thuesen, and W. J. Fabrycky, *Engineering Economy,* 9th ed. (Prentice-Hall, 2001); and (2) W. J. Fabrycky, G. J. Thuesen, and D. Verma, *Economic Decision Analysis,* (Upper Saddle River, NJ: Prentice-Hall, 1997). See Appendix A for additional references.

Production Operation-Functional Flow



Cost Category	Cost × 1,000 ($)	% of Total
1. Architecture and design	2,248	7
2. Architecture and design	12,524	39
(a) Facilities	6,744	21
(b) Capital equipment	5,780	18
3. Future operation and maintenance	17,342	54
(a) Incoming inspection	963	3
(b) Fabrication	3,854	12
(c) Subassembly	1,927	6
(d) Final assembly	3,533	11
(e) Inspection and test	5,459	17
(f) Packing and shipping	1,606	5
Grand Total	$32,114	100%

Figure C.12 Life-cycle cost breakdown summary.

C.9 CONDUCT A SENSITIVITY ANALYSIS

To properly assess the results of the life-cycle cost analysis, the validity of the data presented in Figure C.12, and the associated risks, the analyst needs to conduct a *sensitivity analysis.* One may challenge the accuracy of the input data (i.e., the factors used and the assumptions made in the beginning) and determine their impact on the analysis results. This may be accomplished by identifying the critical factors at the input stage (i.e., those parameters that are suspected as having a large impact on the results), introducing variations over a designated range at the input stage, and determining the differences in output. For example, if the initially predicted reliability MTBF value is "suspect," it may be appropriate to apply variations at the input stage and determine the changes in cost at the output. The object is to identify those areas in which a small variation at the input stage will cause a large delta cost at the output. This, in turn, leads to the identification of potential high-risk areas, a necessary input to the risk management program described in Section 6.7 (Chapter 6).

C.10 CONDUCT A PARETO ANALYSIS TO IDENTIFY MAJOR PROBLEM AREAS

With the objective of implementing a program for *continuous process improvement,* the analyst may wish to rank the problem areas on the basis of relative importance, the higher-ranked problems requiring immediate attention. This may be facilitated through the conductance of a Pareto analysis and the construction of a diagram, as shown in Figure C.13.

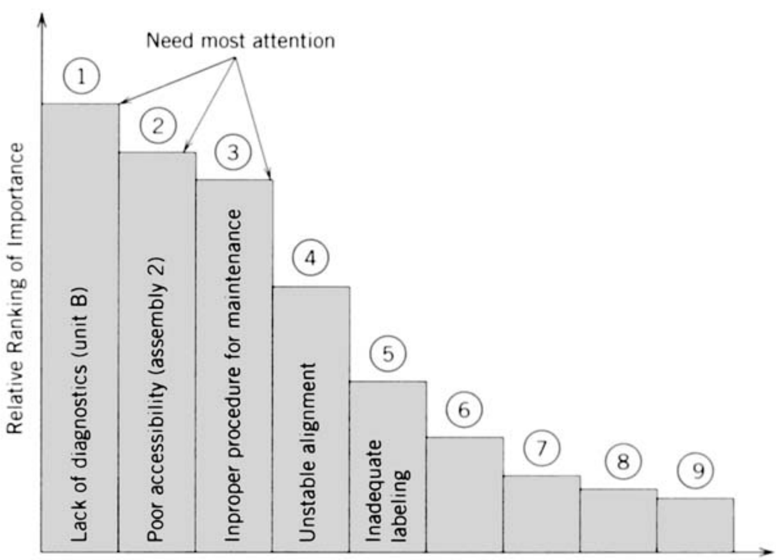


Figure C.13 Pareto ranking of major problem areas.

C.11 IDENTIFY AND EVALUATE FEASIBLE ALTERNATIVES

In referring to the requirements for the communication system described in Section C.1, two potential suppliers were considered through a feasibility analysis; that is, Configuration A and Configuration B. Figure C.14 presents a *budgetary* profile for each of three configurations, with Configuration C being eliminated for noncompliance. For the purposes of comparison on an equivalent basis, the two remaining profiles have been converted to reflect *present value* costs. Figure C.15 presents a breakdown summary of these present value costs by major CBS category and identifies the relative percent contribution of each category in terms of the total. A 10% interest rate was used in determining present value costs.

Although a review of Figure C.15 might lead one to immediately select Configuration A as being preferable, prior to making such a decision the analyst needs to project the two cost streams in terms of the life cycle and determine the point in time when Configuration A assumes the position of *preference.* Figure C.16 shows the results of a break-even analysis, and it appears that A is preferable after approximately 6.5 years into the future. The question arises as to whether this break-even point is reasonable in considering the type of system and its mission, the technologies being utilized, the length of the planned life cycle, and the possibilities of obsolescence. For systems in which the requirements are changing constantly and obsolescence may become a problem 2 to 3 years hence, the selection of Configuration B may be preferable. On the other hand, for larger systems with longer life cycles (e.g., 10 to 15 years and greater), the selection of Configuration A may be the best choice.

In this case, it is assumed that Configuration A is preferable. However, when the cost profile for this alternative is converted back to a *budgetary* projection, it is realized that a further reduction of cost is necessary. This, in turn, leads the analyst to Figure C.15 and the identification of potential *high-cost* contributors. Given that a large percentage of the total cost of a system is often in the area of maintenance and sup-

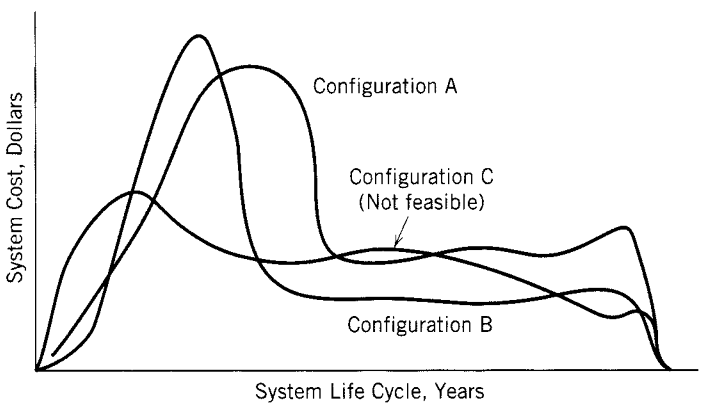


Figure C.14 Alternative cost profiles.

Cost Category	Configuration A		Configuration B	
	Present Cost	% of Total	Present Cost	% of Total
1. Research and development	$70,219	7.8	$53,246	4.2
(a) Management	9,374	1.1	9,252	0.8
(b) Engineering	45.552	5.0	28,731	2.3
(c) Test and evaluation	12,176	1.4	12,153	0.9
(d) Technical data	3,117	0.3	3,110	0.2
2. Production (investment)	407,114	45.3	330,885	26.1
(a) Construction	45,553	5.1	43,227	3.4
(b) Manufacturing	362,261	40.2	287,658	22.7
3. Operations and maintenance	422,217	46.7	883,629	69.4
(a) Operations	37,811	4.2	39,301	3.1
(b) Maintenance	382,106	42.5	841,108	66.3
-maintenance personnel	210,659	23.4	407,219	32.2
-spares/repair parts	103,520	11.5	228,926	18.1
-Test equipment	47,713	5.3	131,747	10.4
-Transportation	14,404	1.6	51,838	4.1
-Maintenance training	1,808	0.2	2,125	0.1
-Facilities	900	0.1	1,021	Neg.
-Field data	3,102	0.4	18,232	1.4
4. Phaseout and disposal	2,300	0.2	3,220	0.3
Grand Total	$900,250	100%	$1,267,760	100%

Figure C.15 Life-cycle cost breakdown (evaluation of two alternative configurations).

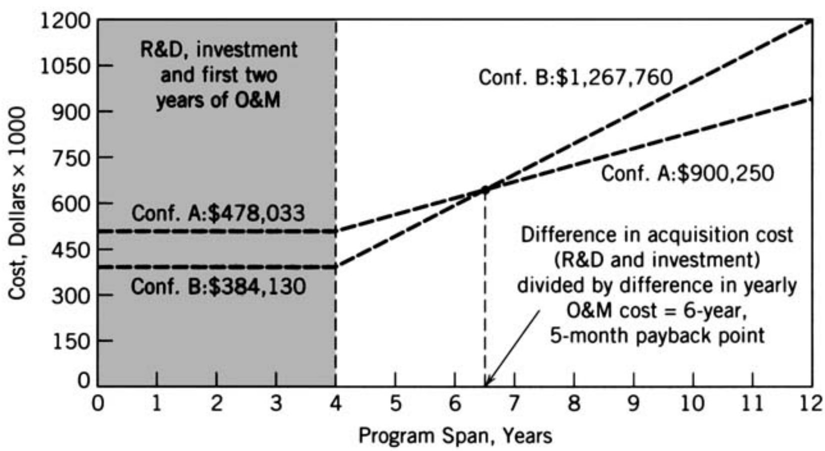
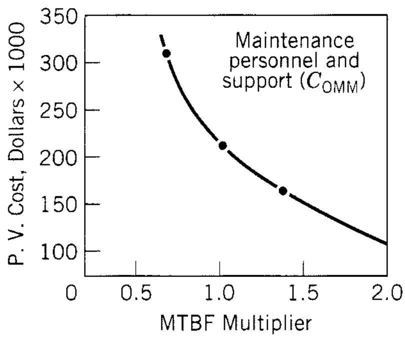
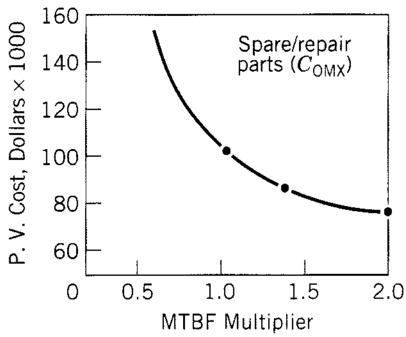


Figure C.16 Break-even analysis.





MTBF Multiplier	P.V. Cost, Dollars (C_{OMM})
0.67	223.140
**1,00	210.659
1.33	162.325
2.00	112.565

**Baseline configuration A

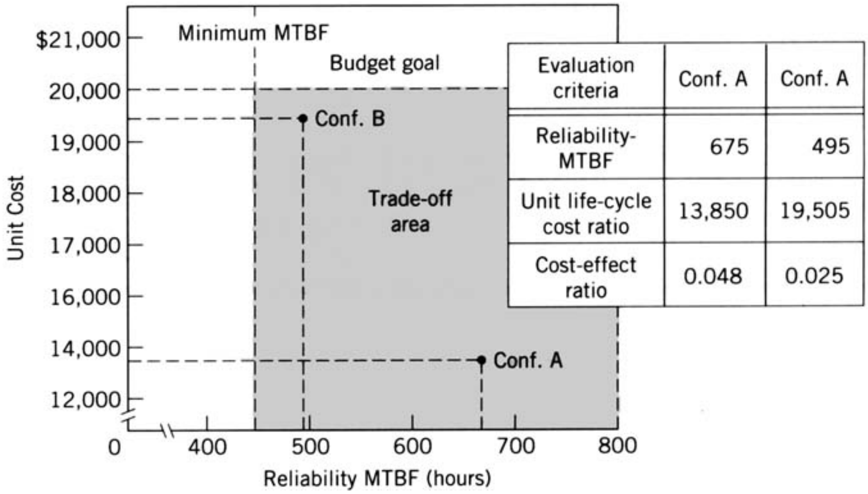
MTBF Multiplier	P.V. Cost, Dollars (C_{OMX})
0.67	199.576
**1,00	103.520
1.33	92.235
2.00	80.130

**Baseline configuration A

Figure C.17 Sensitivity analysis.

port, one might investigate the categories of "maintenance personnel" and "spares/repair parts," representing 23.4% and 11.5% of the total cost, respectively. The next step is to identify the applicable cause-and-effect relationships and to determine the actual causes for such high costs. This may be accomplished by being able to trace the costs back to a specific function, process, product design characteristic, or a combination thereof. The analyst also needs to refer back to the CBS and review how the costs were initially derived and the assumptions that were made at the input stage. In any event, the problem may be traced back to a specific function in which the resource consumption is high, a particular component of the system with low reliability and requiring frequent maintenance, a specific system operating function that requires a lot of highly skilled personnel, or something of an equivalent nature. Various design tools can be effectively utilized to aid in making visible these causes and to help identify areas where improvement can be made; for example, the failure mode, effects, and criticality analysis, the detailed task analysis, and so on.

As a final step, the analyst needs to conduct a sensitivity analysis to properly assess the risks associated with the selection of Configuration A. Figure C.17 illustrates this approach as it applies to the "maintenance personnel" and "spares/repair parts" categories addressed earlier. The objective is to identify those areas where a small variation at the input stage will cause a large delta cost at the output. This, in turn, leads to the identification of potential high-risk areas, a necessary input to the risk management program described in Section 6.7.



Evaluation criteria	Conf. A	Conf. A
Reliability-MTBF	675	495
Unit life-cycle cost ratio	13,850	19,505
Cost-effect ratio	0.048	0.025

Figure C.18 Reliability versus unit life-cycle cost.

C.12 SELECT A PREFERRED DESIGN APPROACH

The cost issue having been addressed, it is necessary to view the results in the context of the overall cost-effectiveness balance illustrated in Figure 1.24 (Chapter 1). Although the emphasis here has been on cost, the ultimate decision-making process must consider both sides of the spectrum; that is, *cost* and *effectiveness*. For example, the two alternative communication system configurations discussed earlier must meet the reliability and cost goals described in Section C.1. In Figure C.18, the shaded area represents the allowable design trade-off "space," and the alternatives must be viewed not only in terms of cost, but in terms of reliability as well. As indicated in Section 3.4.12, the ultimate decision may be based on an overall cost-effectiveness ratio or some equivalent metric.