Life-Cycle Costing: Practical Considerations

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The history and methodology of life-cycle costing are presented and analyzed, contrasting the potential benefits of the technique with the difficulties of its application. Examples and a short survey of the literature are given.

I. Introduction

The concept of life-cycle cost (LCC) of a system came into vogue in the sixties when the Department of Defense (DOD) began to recognize the fallacy of making procurement choices solely on the basis of prices bid. Studies of weapons systems and other procurements revealed that acquisition costs were typically smaller than costs of ownership such as the cost of labor and materials required to operate and maintain the system.

In recent years increasing attention has been paid to the need to consider all the costs of developing, installing, and using a system over its entire lifetime. As a consequence, LCC methodology has been developed and used as an aid to planning and decision-making in a broad range of governmental and industrial applications (see the bibliography in Section VI).

This report explains the LCC method, discusses its benefits and usefulness, and outlines some of the practicalities and problems involved in its application. Several examples from the LCC literature are given as illustrations and a bibliography is included to aid further study.

II. Life-Cycle Cost Methodology

The LCC of a system is conventionally defined as the present value, at the beginning of operation of the system, of all costs of the system. Symbolically,

$$LCC = \sum_{k=-(m-1)}^{n} \frac{C_k}{(1+i)^k}$$

where m is the number of years in the development/acquisition phase, n the operational lifetime, i the interest (discount) rate, and C_k the cost incurred in the kth year. To apply the formula, one must carry out the following key tasks:

(1) Estimate the useful life of the system.

(2) Estimate the yearly costs over the life-cycle.

(3) Choose a discount rate.

Task 1 often turns out to be more significant and difficult than it would appear to be. A discussion is given in Section V.

Task 2 is the most challenging part of the LCC analyses. The major categories of costs to be estimated are:

(1) Research and development, testing and evaluation.

(2) Production and/or acquisition.

(3) Operation and maintenance.

(4) Salvage.

Within these broad areas it is necessary to identify specific cost items to be estimated. For example, the maintenance costs for the Air Force's Electronically Agile Radar (EAR) system were broken down as follows:

(1) Initial and pipeline spares.

(2) Replacement spares.

(3) On-equipment maintenance.

(4) Off-equipment maintenance.

(5) Inventory and supply management.

(6) Support equipment.

(7) Training and training equipment.

(8) Management and technical data.

These eight items were found to be comprised of 115 data elements.

Once the appropriate cost items are identified, how should their costs be estimated? Some items, like acquisition prices, are usually easy. Others, like operations and maintenance (O&M), suggest the need for a large and accurate data base, organized so as to be useful for the required analysis. Ideally, such a data base would indicate things like expenditures of labor and materials needed for similar systems (or subsystems).

Since a data base approaching the ideal is seldom available, how can the required estimates be obtained using only partial, inaccurate data obtained from experience with previous systems?

Several approaches are popular, as can be seen from investigation of the literature surveyed in Section VI. One consists of using *cost-to-cost estimating relationships* based on the idea (or observation) that certain costs can be tied to other related costs in a fixed ratio. This is particularly appealing when good data are available for a few key cost items. It may even be feasible to relate certain costs to the *prices* of system components or spares.

Another approach is called *non-cost to cost estimating*, which attempts to relate the costs to be estimated to appropriate non-cost variables of system components, such as performance or operating characteristics, reliability, size, or complexity. In its ultimate form, this approach seeks to derive a mathematical model (e.g., a regression model) that fits cost items to appropriate variables based on experience with previous systems.

Less ambitious though potentially useful schemes include the use of *specific analogies* with past systems or components to estimate costs of a new system and, if all else fails, consulting expert opinion (to get an expert guess).

Once the task of estimating yearly costs over system lifetime is accomplished, it may seem as though task 3, choosing a discount rate, would be quite simple. This is perhaps true, because the rate is merely a reflection of the "time value of money" and can be chosen in line with prevailing rates for government borrowing. However, such rates do fluctuate, and the difference in effect between an 8% rate and a 10% rate, say, can be crucial in comparing two alternatives where one involves much higher initial costs and lower recurring costs. An approach to the selection of discount rates (and the related problem of anticipating inflation rates) is presented in Section V.

III. Examples of Life-Cycle Costing

Reference 3 gives an interesting example, the results of a life-cycle cost analysis for an early warning radar. The cost components are given as percentages of the total LCC and are shown in Table 1. This example is typical of many in the literature that show the predominant contributors to LCC to be operation and maintenance costs, which here account for 72% of the total. Within both the operation and maintenance categories, labor costs are predominant in this example. Total labor costs (including training) represent 47% of the LCC.

Obviously, it is not easy to obtain good cost estimates for a list of categories such as these. Estimating repair labor, for example, requires consideration of multiple factors like failure rates, average time to repair, and hourly wages. Clearly, even the best possible estimates will be subject to error and uncertainty. However, as the example indicates, a much more costly error would be committed by neglecting entirely the costs that are hard to estimate.

Another example of life-cycle costing is given in Ref. 4, which analyzes the data problems incurred in estimating the life-cycle costs for a modern operational weapon system. The results of a life-cycle cost estimate made for the A-7D aircraft are shown in Table 2. The cost estimates were made on the basis of historical acquisition and operating data and are given in 1973 dollars. The acquisition phase covered the period 1967-1973 and the operational lifetime was assumed to be 15 years.

In this example, the unit ownership cost, \$6.8 million, is about 57% of the total LCC and about 31% greater than the unit acquisition cost, \$5.2 million. The authors make the point that the O&M, depot and to a large degree investment costs of ownership are highly sensitive to design, reliability, performance, and maintainability decisions made early in the acquisition stage. In short, as much as 79% of the costs of ownership are influenced by these early decisions. Thus, life-cycle costing can be a means of determining the long-term consequences of any changes in these attributes.

Reference 29 was designed to provide a framework for review of new weapon system life cycle operation and support (O&S) cost estimates and describes methodologies and techniques that the military departments can use to develop and record these estimates. To illustrate the cost estimation techniques given in the guide, an actual annual squadron cost calculation is made for a USAF A-10 Active Force Squadron (24 aircraft). Table 3 gives the detailed results of the calculation. Annual squadron cost estimates are also given, without details, for a National Guard Squadron (\$8.2 M), a Reserve Force Squadron (\$5.7 M) and a Combat Crew Training Squadron (\$7.3 M). For each of these categories there are 18 aircraft per squadron. Using the schedule for delivering aircraft to the force structure, and assuming a 15-year life-cycle period (1976-1990), the force life-cycle O&S cost was estimated to be \$329 M. To reflect the uncertainty in the estimation of each cost variable involved in the cost analysis, a high estimate of \$3445 M and a low estimate of \$3067 M are also listed.

IV. Benefits of Life-Cycle Costing

The chief benefit of life-cycle costing as a tool in economic decision-making is that, by forcing consideration of *all* costs, it frequently yields unexpected results and thereby leads to wiser decisions. As the examples of the previous section suggest, costs of operations and maintenance will often outweigh acquisition costs as a factor of selection among competing systems. In such cases, there is an obvious benefit in making as accurate an assessment of the costs as possible.

An additional benefit of LCC analysis is that the information compiled in using the technique can aid other management decisions – for example, by focusing attention on cost areas that are ripe for reduction. Thus LCC might lead to recognition of the need for new designs, new methods of operation, or new maintenance policies.

In a broader perspective, life-cycle cost can be regarded as one of the parameters describing a potential system to be traded off against system performance capabilities, availability, or the like. Only a systematic quantitative evaluation of all costs can serve as the basis for statements like "An extra x dollars spent on the system will buy y in additional performance."

V. Practical Considerations and Problems

Determining the useful life of a system is generally difficult. If wearout is the determinant of life-length, then the estimation problem is formidable in the case of a new, untried system. Moreover, if obsolescence plays the key role, then the analysis is even harder because a realistic determination of life-length depends much more upon the future availability of and need for improved (or modified) technology than upon the longevity of equipment. Whether a given system will actually be used for the next 5, 10, or 15 years is going to depend not only upon the present analysis of the cost-effectiveness of that system but also upon the future analysis of potential replacements as they become available 5, 10, or 15 years from now. Changes in system requirements or operations policies can, of course, further complicate matters.

Since the LCC method in effect amortizes the acquisition costs over system lifetime, the length of life is an important factor, particularly in the case of high-priced systems. As a means of avoiding the problem of estimating useful life, it is common practice to take arbitrarily chosen standard values for life-lengths.

However, even when arbitrary life-lengths are specified, it is often necessary to consider unequal lifetimes for competing systems. The comparison is facilitated by using the notion of *annualized cost* of a system, which is defined as the constant yearly cost of a hypothetical system having the same LCC. This hypothetical cost stream is uniquely determined by specifying its structure: zero initial cost and constant yearly costs during the operational period (thus amortizing the initial costs of the real system). Comparison of the annualized cost of competing systems having different life-lengths is equivalent to comparing the infinite cost streams generated by renewing each system at the end of every life-cycle.

Some of the difficulties of estimating yearly costs of a system have already been discussed in Section II. Data base inadequacies in the determination of O&M costs are a recurring theme of the case studies in the life-cycle cost literature. Even if this inadequacy can be partially overcome by the sort of estimation approaches described in Section II, there is a further issue to consider – namely, the effect of changes in O&M policies or methods which will be made over the lifetime of the system. To rule out such considerations would be not only unrealistic but self-defeating, because the devising of improved methods of operation and maintenance is a vitally important means of controlling costs.

A statistical approach to the estimation of the effect of future improvements in efficiency has been gaining popularity as an adjunct to life-cycle costing (Ref. 19). This technique uses a *learning curve*, $L(t)$, which starts at 1 at the beginning of operation of the system and decreases over time to describe the factor by which costs in year t should be multiplied to reflect "learned" improvements in efficiency. The choice of such a curve will, of course, depend on the character of the system and its cost components and can be justified by experience with previous systems or the experience of other users of similar systems.

The preacquisition period of system development is one whose associated costs may be hard to assess. Nevertheless, if a life-cycle cost analysis is performed at a very early stage, it is important to consider such costs, inasmuch as they could be saved by aborting the development process. It is equally important to recognize that, just as the *complete* life-cycle cost must include R&D, the relevant quantity for deciding (at an advanced stage of development) whether to proceed to put the system into operation is the *future* life-cycle cost – namely, that part of the total cost which has not yet been incurred (plus whatever might be recovered by deciding not to adopt the system). Funds irrevocably spent should play no role in such a decision, although the complete life-cycle cost may still need to be assessed for reporting and other purposes.

The choice of a discount rate was mentioned in Section II as one of the basic tasks in evaluating a life-cycle cost. In addition to the uncertainties of determining the right value of this rate over the lifetime of the system, one faces the related complication that inflation will increase the yearly costs, e.g., for labor and materials. The standard approach in the literature is to choose a seemingly reasonable value, j, for the inflation rate and another value, i, for the discount rate. Thus, yearly costs are first estimated in *current* dollars (as of the beginning of system operation), then inflated by appropriate powers of $1 + j$, and finally discounted by dividing by powers of $1 + i$, as in the formula for LCC in Section II. The result is that if C_k^* is the kth year cost in current dollars (at the beginning of operation), then

$$LCC = \sum_{k=-(m-1)}^{n} C_k^* \frac{(1+j)^k}{(1+i)^k} = \sum_{k=-(m-1)}^{n} C_k^* V^k$$

where $V = (1 + j)/(1 + i)$. In effect, only the ratio of $1 + j$ to $1 + i$ matters in determining the LCC. What's more, for i and j in the usual range of 0 to 15%, the ratio is approximately a function of the difference $i - j$, the excess of the discount rate over the inflation rate. This difference $i - j$ has historically been greater than zero for most reasonably long periods and has typically been about 2 to 3%. This suggests choosing a value such as $V = 0.975$ for the purpose of the LCC formula. The important thing to observe is that the relative stability of $i - j$ historically (compared to the variability of i and j) gives this conceptualization of the LCC a good deal more assurance as a basis for economic evaluation.

VI. Major Areas of Interest in the Literature of LCC

As we mentioned in Section I, it was in the early 1960's that the interest in life-cycle costing was stimulated by the realization on the part of the DOD that if ownership costs had been considered on many procurements, design selection would have been different. As a result, the DOD made some trial procurements where ownership costs were considered in the award decision. To illustrate the versatility of the new technique, even at that time, we list some of the items selected for the trial, as given in Ref. 3.

(1) Nonmagnetic diesel engines for shipboard use.

(2) Replacement of siding on family housing.

(3) Solid-state 15-MHz oscilloscopes.

(4) Tachometer generators.

(5) Aircraft tires.

(6) Traveling wave tubes.

(7) Computers.

From these cases, initial "life-cycle costing" procurement policy evolved at DOD. Since that time a substantial portion of the literature on life-cycle costing is concerned with its application to specific systems and the problems involved when applied to that system. Refs. 1-8 are illustrations of the many case studies found in the literature.

Because the DOD is a strong advocate of life-cycle costing, many of the documents issued by the department as directives and guides to be used for various aspects of the procurement process include consideration of life-cycle costing. Some of these documents are listed in Refs. 9-12.

A distinctive feature of system cost-effective analysis is the use of the cost categories of research and development, initial investment and annual operating costs. These categories are the major or most often mentioned cost categories found in the LCC literature. Thus, many reports are concerned with system and item cost analysis and with system cost-effective criteria. Refs. 13-18 present some of the writings which fall into this category.

Cost models are used in system, equipment and component selection processes to ensure a proper balance between cost and effectiveness. Although a number of standard models have been formulated, such as accounting models, simulation models, reliability models and economic analysis models, in practice it is almost always necessary to either adapt a standard model or construct a new model which will adequately describe a specific situation. A significant part of the literature is concerned with the construction and use of cost models as they relate to given systems. Refs. 19-24 illustrate this interest.

For many systems, such as sophisticated weapon systems, the concepts of reliability and maintainability play important roles with respect to life-cycle costing. Increasing the reliability of a system and improving system maintainability will reduce the cost and increase the efficiency of the system during its lifetime. Conversely, the financial cost of unreliability can be quite excessive. As a result, part of the literature of LCC discusses this aspect of life-cycle costing. Refs. 25-28 are examples of the interest shown in this phase of LCC.

VII. Conclusion

The value of the LCC concept and the validity of the techniques associated with it are strongly supported by its widespread use in non-defense as well as defense industries. The proven ability of industry to overcome complex problems that arise during the process of life-cycle costing should provide assurance to those contemplating its use, as to the concept's usefulness and versatility.

The principle underlying life-cycle costing is a simple one: determine not only the acquisition costs but also the costs involved in operating and maintaining the system during its lifetime before deciding whether or not to acquire the system.

This being so, one might ask why this valuable decision-making tool was not employed to any great extent until fairly recently. The answer probably lies in the fact that in many cases it is only when a detailed cost analysis is performed that one becomes aware of the magnitude of the nonacquisition costs relative to first costs, as well as the extent of the variability of these costs among the possible alternative systems. Thus, the importance of determining all costs is very often not evident until one performs the analysis, while at the same time there is no apparent reason to perform the analysis until the importance of the results is realized. It was not until this vicious circle was finally broken that the idea of life-cycle costing came into its own.

References

1. "Economic Analysis of Proposed Department of Defense Investments," Department of Defense Instruction No. 7041.3, Enclosure 2, p. 2, Department of Defense, Washington, D.C., Feb. 26, 1969.

2. Sloane, J. W., O'Toole, R. P., Gorden, C., "Baseline Economic Analysis for Erda Photoelectric Conceptual Design and Systems Analysis Studies," Engineering Memo 393-273, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 8, 1975 (an internal document).

3. Earles, D. R., "LCC-Commercial Application, Ten Years of Life Cycle Costing," Proceedings of the 1975 Annual Reliability and Maintainability Symposium.

4. Frorello, M., "Estimating Life-Cycle Costs; A Close Study of the A-7D," Rand Corporation, Santa Monica, Calif., Feb. 1975.

5. "*Case Studies: Life Cycle Costing in Equipment Procurement*," Task 69-3, Contract No. SD-271, Logistics Management Institute, Washington, D.C., July 1969.

6. Kilpatrick, P. S., and Jones, A. L., "Life Cycle Cost Comparisons of Avionic System Design Alternatives," Proceedings of the National Aerospace Electronic Conference, 1974.

7. *Aircraft Field Experience Component Analysis* (Volumes I and II), Document D6-53584, The Boeing Company, Seattle, Washington, Sept. 1968.

8. Boden, W. H., "Designing for LCC," The Magnavox Company, Electronics and Aerospace Systems Convention, 1974.

9. *Acquisition of Major Defense Systems*, DOD 5000.1, Department of Defense, Washington, D.C., July 13, 1971.

10. *DOD Life Cycle Costing Procurement Guide (Interim)*. LCC-1, Department of Defense, Washington, D.C., July 1970.

11. *Economic Analysis and Program Evaluation for Resource Management*, DODI 7041.3, Department of Defense, Washington, D.C., October 18, 1972.

12. *Engineering Management*, Mil-Std-499A, Department of Defense, Washington, D.C., June 17, 1974.

13. Fiorello, M. R., *Getting 'Real' Data for Life-Cycle Costing*, Rand Corporation, Santa Monica, Calif., Jan. 1975.

14. *Guidebook for Systems Analysis/Cost-Effectiveness*, Prepared for U.S. Army Electronics Command, Fort Monmouth, New Jersey, ARINC Research Corporation, Mar. 1969 (AD 688154).

15. Blanchard, B. S., Jr., Lowery, E. L., *Maintainability*, McGraw-Hill, Inc., New York, 1969.

16. Fisher, G. H., *Cost Considerations in Systems Analysis*, R-490-ASD, The Rand Corporation, Santa Monica, Calif., Dec. 1970.

17. Goldman, A. S., *A Note: Problems in Life Cycle Support Cost Estimation*, General Electric Co., Santa Barbara, Calif.

18. Goldman, T. A. (ed.), *Cost-Effectiveness Analysis*, Frederick A. Praeger, New York, 1971.

19. Otto, T. W., Jr., *Life Cycle Cost Model, Research and Development*, Technical Report, ECOM-4338, Monmouth, New Jersey, July 1975.

20. *A Generalized Life Cycle Cost Model for Electronic Equipment*, Booz Allen Applied Research, Inc., Study performed for the U.S. Army Electronics Command, Systems/ Cost Analysis Office, Fort Monmouth, New Jersey, March 10, 1970.

21. Hamilton, J. D., *Life Cycle Cost Modeling*, Technical Report No. 68-8, Army Material Command, Alexandria, Virginia, Dec. 1968.

22. O'Flaherty, J., *Weapon System Cost Model Objectives*, Client Report RAC-CA-26, Research Analysis Corporation, McLean, Virginia, Apr. 1971.

23. Paulson, R. M., Waina, R. B., Zacks, L. H., *Using Logistics Models in System Design and Early Support Planning*, R-550-PR, The Rand Corporation, Santa Monica, Calif., Feb. 1971.

24. Strope, D. H., *U. S. Army Missile Command's System-Oriented Cost Model* (Vol. 1), Report RF-TR-67-2, Research Analysis Corporation, McLean, Virginia, Nov. 1967.

25. Alexander, A. J., *R&D in Soviet Aviation*, R-589-PR, The Rand Corporation, Santa Monica, Calif., Nov. 1970.

26. *Use of Warranties for Defense Avionic Procurement*, Final Technical Report RADC-TR-73-249, ARINC Research Corporation, Annapolis, Maryland, June 1973.

27. Calabro, S. R., *Reliability Principles and Practices*, McGraw-Hill Co., Inc., New York, 1962.

28. Czajkowski, A. F., "A Conceptual Design Model for Reliability and Maintainability Analysis," Based on a doctoral dissertation, Oct. 1972.

29. Department of Defense. *Operating and Support Cost Development Guide for Aircraft Systems*, Cost Analysis Improvement Group, May 1974.

Table 1. Life-cycle cost breakdown for an early warning radar

	Percent of LCC
Acquisition costs	
Design, 12%	3.36
Fabrication, 72%	20.16
Installation and Checkout, 14%	3.92
Documentation, 2%	0.56
Total for acquisition	28%
Operation costs	
Personnel, 67%	8.04
Power, 32%	3.84
Fuel, 1%	0.12
Total for operation	12%
Logistic support costs (maintenance)	
Initial spares, 5.4%	3.24
Aircraft ground equipment, 2%	1.20
Initial training, 0.6%	0.36
Replacement spares, 18.5%	11.10
Repair material, 9.5%	5.70
Repair labor, 64%	38.40
Total for logistic support	60%

Table 2. Life-cycle costs for an A7-D aircraft

	M$/unit	Percent of LCC
Acquisition costs		
Airframe, 38%	1.97	16.5
Engine, 13%	0.68	5.6
Electronics, 13%	0.68	5.6
Spares, 20%	1.04	8.7
Other, 16%	0.83	6.9
Total for acquisition	5.20	43.3%
Ownership costs		
O&M, 48%	3.26	27.2
Investment, 15%	1.02	8.5
Depot, 16%	1.09	9.0
Base Support, 10%	0.68	5.7
Fuel, 4%	0.27	2.3
Training, 7%	0.48	4.0
Total for ownership	6.80	56.7%

Table 3. Annual operating and support costs for an A-10 aircraft squadron

	M$	Percent of total
Squadron operations		
Staff and aircraft manpower	1.100	8.90
Base manpower support	3.650	29.52
Aviation fuel	1.043	8.43
Base maintenance material	0.738	5.97
	6.531	52.82
Base operating support		
Base services manpower	0.802	6.49
Miscellaneous personnel support	0.353	2.85
	1.155	9.34
Logistics support		
Depot maintenance	1.263	10.22
Supply depot manpower and material	0.585	4.73
	1.848	14.95
Personnel support		
Training manpower	1.020	8.25
Medical manpower and material	0.215	1.74
Miscellaneous personnel support	0.312	2.52
	1.547	12.51
Recurring investment		
Replenishment spares	0.767	6.20
Aircraft ground equipment	0.136	1.10
Training munitions and missiles	0.381	3.08
	1.284	10.38
	12.365	