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Life Cycle Costing: Concept and Practice

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This paper traces the development of the life cycle costing (LCC) technique in the United States and classifies documented LCC literature by both model type and application. LCC was originally developed as a formal analysis tool by the US Department of Defense. It has now been successfully applied in the industrial and consumer segments. The scope and practice of LCC has been changing over the past few years. Literature in the field supports the idea that the LCC concept has evolved over the years to include facets of system effectiveness in addition to costs. It is also evident that LCC has developed more as a result of specific applications rather than hypothetical models. General system characteristics which contribute to the success of the LCC technique are also identified.

INTRODUCTION

LIFE CYCLE COSTING (LCC), by definition, refers to an analysis technique which encompasses all costs associated with a product from its inception to its disposal. Through LCC one seeks to minimize the cost of obtaining a certain level of output. The general concept of a life cycle cost is not new. As a formal and applied discipline, LCC has been actively pursued since the 1960s in the United States. The US Department of Defense stimulated the development and application of LCC to enhance its cost effectiveness in granting competitive awards. A typical life cycle for a defense system such as an aircraft or special purpose land vehicle may be divided into the following phases: research and development, design, manufacture, installation, operation, maintenance and finally salvage. This type of life cycle is ideal for a LCC analysis since primarily one system user, The Department of Defense, controls the entire cycle. The user in this case maintains control of the system from its conception to its retirement.

From defense systems, LCC has moved into industrial and consumer product areas. Along with this movement, the scope of LCC has evolved. Figure 1 shows a life cycle for a typical industrial-consumer system such as a machine tool or an automobile where the system has two sequential users. Here, each user, whether industrial or consumer oriented, controls only a portion of the actual life cycle of the system. This portion, however, represents the life of the system for the user's purposes and may be the subject of a LCC analysis by the user. Today, LCC studies concentrating on any one or a combination of life phases can be found.

All segments of our economy are becoming more cost conscious in order to enhance their productivity of capital. The classic argument that physical performance measures and acquisition costs are the overriding factors in procurement decisions has tended to be true in the past. Present trends indicate that life costs are becoming more important in all marketing areas. Design to cost and LCC concepts are being practiced to a greater extent today than ever before in government, industry, service, and consumer segments. In most cases, decisions are not entirely cost based, but costs play an important part in most decisions.

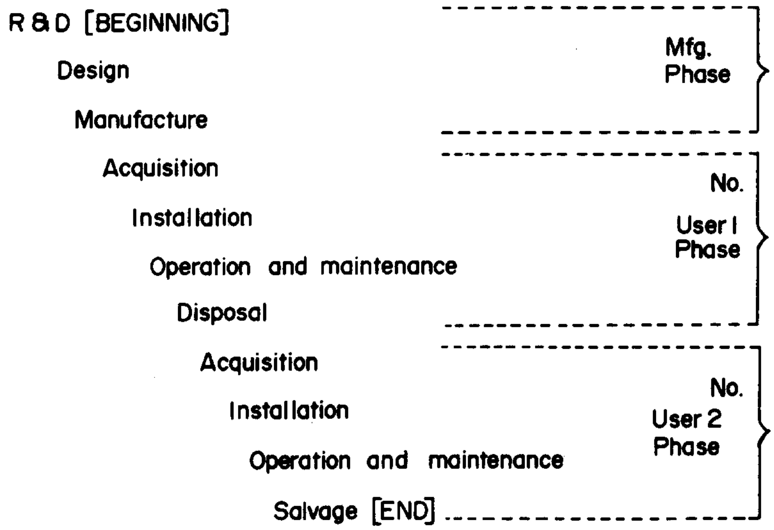

FIG. 1. *Typical industrial–consumer system life cycle for two users.*

MODELS

Modeling is a useful tool when one seeks to study system performance and cost characteristics. Fisher [43] states that a cost model may be viewed as an integrating device designed to facilitate the analytical process of bringing together various factors on the input side and relating them to some type of output-oriented capability. Model input in general will consist of descriptive information and resource categories. Quantifying input information requires estimation. Estimation in turn requires estimating procedures. These procedures may range from educated guesses to highly sophisticated mathematical techniques. Estimation techniques may be external to the model or they may be incorporated in it via sub-models, such as regression techniques, etc. Model output (as well as input) is usually a function of the specific purpose of a cost study. Output may vary from one number to a detailed breakdown of predicted costs by time periods, complete with dispersion measures.

LCC models vary a great deal in their scope and form. Earles [36] discusses the fact that there is no standard LCC model. He states that LCC models have progressed along four lines: total cost models (true LCC models), logistic support models (operation phase models), design trade models (design stage models), and level of repair models (maintenance oriented models). Dover and Oswald [32] present a taxonomy of LCC models available to US Air Force managers. They identify six classes of models: accounting models (models which sum LCC components), cost estimating relationship models (models used to analyze design alternatives), heuristic models, failure free warranty models (models used to analyze extended warranty periods), reliability models (used to apportion reliability and maintainability), and economic analysis models (models dealing with general cost effectiveness).

Most LCC models have been structured relative to the model builder's purpose(s) and resources, rather than to specific systems or types of systems. This has led to the development of models on a case-by-case basis with little regard for universal application. McCullough [91] expresses doubt as to the feasibility of setting out beforehand, in a cookbook fashion, a set of procedures that would result in a successful model of any given system. However, he maintains that clear methodologies for such models can be developed beforehand on a conceptual basis. With respect to military programs, Kernan and Menker [75] state that LCC procurement provisions must be individually tailored to each program to obtain a proper contractor–contractee relationship. They also stress that procurements made on a

LCC basis be reviewed at an appropriate point in time to assess the contractor's success in achieving his LCC commitment.

Fisher [43] sets forth some guidelines on the design of a cost model. He maintains that:

1. cost analyses are basically an art, often requiring an experimental process;

2. one should highlight those factors which are most relevant and suppress those which are relatively unimportant to the problem at hand;

3. the model should develop a meaningful set of relationships among objectives, alternatives, costs, and utility;

4. provisions should be made to treat uncertainty explicitly; and

5. assumptions underlying the model must be made explicit.

Cost models may range from simple to complex and may be used only one time or reused frequently. They are essentially predictive in nature. The process being modeled, the life cost of a system, is usually a stochastic process involving many parameters which may not be independent. Such parameters as the system's physical environment, usage demand, reliability, maintainability, labor, energy, taxes, inflation, time value of money, etc. may heavily influence its life cycle cost. The literature related to LCC models may however be classified along three general lines: conceptual, analytical (well-structured), and heuristic (ill-structured analytical). Table 1 gives bibliographic references under various classifications such as general costing methodology, general LCC concepts, LCC models, and LCC applications.

Conceptual models consist of a set of hypothesized relationships expressed in a qualitative framework. They usually pertain to a spectrum of systems. Conceptual models are generally constructed at a macro level. They allow for a minimum of detail and little ability to quantify a specific system's cost characteristics.

Many conceptual models can be found in the literature. One of the oldest and most widely used conceptual LCC models is shown in Fig. 2. This model illustrates the phase-cost relationships of a system over time. Research and development costs consist of resources required to develop a system to a point where it can be introduced for operation. Investment costs are one time outlays required to introduce the system to an application. Operating costs are recurring outlays which are required to operate, maintain, and restore the system over a given period of time. A systems cost model consisting of a cost-performance matrix approach is discussed by Seiler [118]. Goldman and Slattery [55] conceptualized a theoretical cost-availability model with respect to performance and economic tradeoffs. This model was described in terms of iso-availability curves made up of abstract functions of reliability and maintainability all within a cost framework. Fricker [47] has argued, primarily from a conceptual standpoint, that reliability and maintainability considerations, as expressed through availability, represent 'cost drivers' which will have a large impact on LCC optimization. The availability (A) is quantified by expressing the actual operating time as a percentage of the scheduled operating time. It can be seen that availability is directly dependent on reliability and maintainability as follows:

$$A = \frac{\text{m.t.b.f.}}{\text{m.t.b.f.} + \text{m.t.t.r.}}.$$

Where m.t.b.f. and m.t.t.r. are the mean time between failures and mean time to repair, respectively.

Most conceptual models are not highly formal or mathematical. In many cases they are helpful and serve to stimulate thought processes. However, they are limited when it comes to applied analyses.

Analytical models

Analytical models typically consist of a set of mathematical relationships which are designed to describe a certain aspect of a system. Usually, they are accompanied by a set of underlying assumptions. These assumptions tend to restrict or limit the model's ability to reflect the actual system's performance. The magnitude of this limitation is usually directly related to the complexity of the system. A wide variety of analytical models have been documented in LCC and related areas. These range

TABLE 1. CLASSIFICATION OF REFERENCES BY SUBJECT AREA

Area	References
Costing (general guidelines, concepts, etc.)	1, 3, 10, 12, 19, 20, 22, 25, 27, 28, 36, 40, 43, 46, 49, 60, 65, 66, 70, 78, 80, 81, 84, 89, 91, 93, 96, 104, 105, 118, 123, 131, 133, 136, 148, 151, 152, 153, 154
LCC (general guidelines, concepts, etc.)	6, 7, 9, 11, 14, 31, 39, 42, 48, 59, 63, 67, 68, 69, 77, 85, 88, 90, 94, 99, 100, 101, 103, 106, 107, 119, 122, 129, 138, 158, 161
LCC Models	
Analytical (well-structured)	1, 4, 6, 7, 8, 17, 21, 29, 30, 31, 37, 45, 46, 50, 52, 57, 61, 70, 72, 77, 81, 93, 96, 98, 99, 107, 111, 113, 122, 124, 129, 132, 133, 135, 141–147, 150, 152, 153
Conceptual	13, 15, 18, 35, 44, 47, 51, 55, 56, 118
Heuristic (ill-structured analytical)	35, 64, 80, 106, 108, 109, 148, 151, 155
Applications	
Aquisition (defense systems)	37, 52, 144, 147
Air conditioning	45, 146
Air filters	4
Architecture	130
Availability, Maint., Reliab.	2, 5, 34, 47, 50, 76, 87, 109, 124, 150
Avionics systems	16, 17, 24, 33, 35, 62, 82, 95, 102, 112, 121, 134, 135, 137, 155
Dryers	23
Electronic systems	41, 53, 54, 83, 86, 125
Energy	58, 61, 73, 97, 110, 114, 115, 120, 132, 140, 159
Insulation material	30
Law enforcement facilities	71
Lifting appliances	79
Logistics	21
Plant construction, design	26, 57, 98, 111, 157, 160
Procurement (defense systems)	7, 8, 29, 75, 145
Production, consumer products	127, 128
Public buildings	15, 74
Refrigeration	126
Standardization (equipment)	113
Weapon systems	18, 38, 44, 72, 92, 116, 117, 139, 141, 142, 143, 149, 156

from models covering very specific aspects of a system to models which address total system LCC.

Relatively specific LCC models include the product research and development model described by Freiman [46], Dixon and Dean's [30] building insulation selection model, and Avery's [4] air filter LCC model. A test equipment analysis model was developed by Rosenberg and Witt [113]. Misra and Ljubojevic [96] developed a cost-redundancy-reliability model, and Brook and Barasia [17] describe a LCC model which they developed to study automatic test support systems. Other models include Townsend's [135] parametric cost model, White and Thomas' [152] model, Kabak's [70] overall cost-availability model, Werden's [150] optimum LCC-availability model, Dickinson and Sessen's [29] LCC model which considers external failure losses

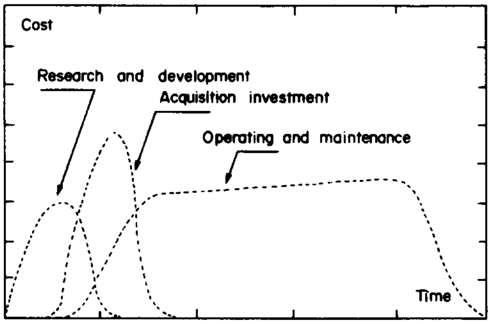

FIG. 2. *General phase–cost relationships for a system.*

and spares, and finally, Wild's [153] computerized event tree model.

Analytical models also vary greatly in their mathematical sophistication. The Federal Supply Service [141] developed a series of extremely simple LCC models for their procurement needs. Gordon [57] developed a worksheet approach to LCC analyses in the construction trade and Rich [111] describes a simple LCC approach to plant design. Kirk [77] discusses a cost framework, the Uniform Building Component Format (UNIFORMAT), which was developed to allow initial and LCC data to be collected, organized, and applied. This model defines a number of cost elements and a general LCC procedure for the building industry.

Many LCC models have also been described which rely on complex mathematics and data bases. Christensen and Voytek [21] describe a relatively complex computer data base model. Solomond and Marseglia [124] have documented a combinatorial policy model they developed. Muglia, Cici and Waln [99] describe a LCC model which they developed based on cost estimate relations broken down into major system phases. Dixon and Anderson [31] discuss some of the design to cost management tools which the US Defense Department uses. They discuss a Mission Completion Success Probability Model, a Design to System Performance/Cost Model, and a Design to System Performance/Cost/Effectiveness Model. Ahmed and Schenk [1] developed a maintenance policy-availability-cost optimization model. McNichols and Messer [93] describe an availability-cost minimization model which makes use of Lagrange multipliers. Timsans, McNichols, and Berry [133] extended the model described in [9]. Galetto [50] discusses a differential theory-systems effectiveness model.

Heuristic models

Heuristic models (ill-structured analytical models) usually use rules of thumb or strategies that are intuitively appealing, but are not guaranteed to produce optimum solutions. They can however be incorporated to simulation models. Wood [155] describes a general purpose simulation technique to determine the cost effectiveness of different levels of reliability and maintainability for a training aircraft. Another heuristic model has been developed by Kolarik [80] to analyze the availability-cost aspects of farm machinery. Other various Monte Carlo cost-analysis techniques are described in texts such as Thuesen, Fabrycky & Thuesen [131] and Canada [20]. Heuristic models are usually tailored to specific applications rather than to broad problem classes and are not documented in the literature to the same extent as analytical models.

APPLICATIONS

The US Department of Defense and their contractors have used LCC and design to cost techniques for a number of years. Dover and Oswald [32] provide a taxonomy of military oriented LCC models and discuss models used in various US Air Force programs. LCC techniques have also been adapted to many non-defense systems. One prominent area of application is in the building construction and leasing industry. A number of states have either passed or are now considering passage of legislation which requires a LCC analysis to be performed on state facilities under consideration for construction or leasing, Kirk [77]. Kelsey [74] describes the Florida Energy Conservation in Buildings Act of 1974 which pertains to any state financed building over 5000 square feet as follows:

> "the act stipulates that no state agency will lease, construct, or have constructed a facility without having secured, from the Division of Building Construction and Maintenance of the Department of General Services, a proper evaluation of life cycle costs as computed by a qualified architect or engineer."

The Columbian Rope Company of Auburn, New York, claims that by using a LCC design approach on their $7 million plant, they saved

$5.5 million in terms of a 20 year life cycle for the plant [160]. Estimated savings in buildings usually result from increasing the initial investment to curb energy consumption in the structure. However, many designers, architects, and engineers still find it difficult to persuade developers and owners to consider LCC, rather than initial cost alone. Sometimes, as in the case of the 38 storey Federal Reserve Bank of Boston, a LCC approach may actually reduce initial cost as well as operating and maintenance costs by forcing designers to become extremely cost conscious in all aspects of their design [159]. Other LCC case descriptions are made by Ruegg [114], Griffith [58], and Stamm [126] with respect to solar energy, daylighting, and refrigeration, respectively.

The Federal Supply Service [155] has documented case studies in procuring window air conditioners, water heaters, refrigerator-freezers, and high-speed computer ribbons for government installations. These studies were used to determine successful bidders. Substantial savings over the life time of the equipment were reported, with the exception of the computer ribbons where "no obvious cost savings were attributed to LCC because the low initial price bids won anyway." Process industries including waste processing have begun to think in terms of life cycle costs. There is a growing recognition on the part of engineers and specifiers that the true cost of an item is its initial purchase cost plus maintenance, repair, replacement cost, etc. [157].

CONCLUSION

Since the early 1960's, a large amount of effort and thought has been channeled into the LCC analysis field. As a result a growing recognition of the life cycle cost concept in all segments of our economy has developed. However, the development of a truly universal LCC model appears to suffer due to the following: (1) varying degrees of systems required performance, specifications, etc., (2) levels of sensitivity to schedule changes, designer-user interface, etc., (3) special characteristics of systems such as operational readiness, maintainability, etc., (4) special environment, (5) effects of reliability growth, maintenance learning process, etc., (6) integrity of data, future projection, etc., (7) varying degrees of comprehensiveness versus accuracy, . . . etc. It seems then that specific systems by virtue of their characteristics lend themselves to LCC. Such systems normally (1) possess high operating and maintenance costs relative to initial investment, (2) have the potential to be modified via design and operating practice to trade off costs in categories such as research and development, manufacturing, initial investment, and (3) represent a high volume need in terms of system numbers.

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