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Life Cycle Costing: An Assessment of Practicability for Consumer Products

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National Bureau of Standards
Washington, D. C. 20234

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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, ***Secretary***
Edward O. Vetter, ***Under Secretary***
Dr. Betsy Ancker-Johnson, ***Assistant Secretary for Science and Technology***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Acting Director***

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SUMMARY

Background

Interest in the application of life cycle costing (LCC) to consumer products has evolved with the growing national effort to provide comparative product performance information for consumer products. Adequate information is not available at present to a purchaser of major consumer durable products. Although the purchaser is aware of the initial cost, he generally does not have a precise idea of the magnitude of costs (including energy, operations, maintenance, repair, and disposal) he is likely to incur during his ownership. Further, the purchaser usually does not have a good indication of the relative benefits (performance over time) that will be received from alternative brands of a given product. Proposed legislation (Senate Bill S.643: Consumer Product Testing Act of 1975) would have given NBS the responsibility for "...the development of consumer product test protocols...." This included the average annual cost of operation, durability, maintenance requirements, frequency of repair, and other elements of LCC. The Energy Policy and Conservation Act of 1975 (Public Law 94-163, Sec. 325) and the Department of Commerce Voluntary Consumer Product Information Labeling Program both provide the means for utilization of LCC analysis and dissemination of results to consumers. Because of the continued interest and need for consumer product performance and ownership cost information, this project was initiated to address and assess the difficulties encountered in the application of LCC to consumer products.

Objectives

The principal objective of this study was to develop an understanding in "life" performance measurement and cost characterization for consumer products. This study was aimed at determining the practicability for applying LCC to consumer products. Additional objectives were to assess the state-of-the-art in application of LCC and "life" testing and to identify technical barriers to its application in order to make recommendations for appropriate future NBS activities.

Technical Concepts

The products for which LCC or extended performance information are of potential value in aiding better purchase choices include those for which:

(1) operating costs or servicing costs are significant compared to purchase price,

(2) energy utilization per unit output varies over time,

(3) output performance deteriorates over time, and/or

(4) expected "life" varies for non-repairable products.

The determination of the full cost characterization, that is, the assessment of the LCC of a consumer product, is crucially dependent upon the measurement of the performance of a product. The reason that product performance plays such an important role in determining the LCC is that many of the components in the LCC formula cannot be completely specified unless the manner by which a product performs its intended function throughout its "life"--that is the life cycle performance (LCP)--is completely determined. Performance of a product is a measure of a specific function or set of functions for which a product was intended. As such, performance is measured in terms of the product's output and the efficiency with which it transforms input to output. Measuring performance over time has two elements: the first is measuring changes in the nature of the output, and the second is measuring changes in the input-output transformation efficiency. Both changes can be characterized as performance degradation that inevitably occurs to manufactured products.

Maintenance and repair activities are intended to deal with performance degradation. Maintenance is an action performed on satisfactorily operating equipment to keep it performing satisfactorily. Repair is an action performed on an equipment showing performance failure, restoring it to a satisfactory level of performance by fixing or replacing parts. Both maintenance and repair affect LCP, because output and input-output transformation efficiency are affected by such activities. They also affect LCC since both activities entail the consumption of economic resources. The repair activity necessitates the defining of performance failure which is some threshold level of performance below which the produced output is deemed unacceptable. In conjunction with LCP, such a threshold level may be designated as the minimum acceptable performance level (MAPL). The immediate significance of MAPL is in determining performance failure and the need for repair activities. More significantly, however, MAPL acts as the basis from which the concept of LCC is formulated.

With respect to a given LCP and its associated MAPL, LCC may be defined as the initial purchase price and disposal costs plus whatever monetary expenses incurred over time to maintain LCP above the MAPL. Such expenses consist of cost for input (such as energy) plus maintenance and repair expenses. The above definition, however, is incomplete since LCP can be maintained above MAPL indefinitely provided sufficient cost is incurred. At best, LCC should be defined in terms of some prespecified time periods, say, 3, 5, 10, or 15 years.

Moreover, durable products, especially complex ones with many components, are repairable and hence can be kept serviceable indefinitely if necessary repairs are made. When to repair and when to stop repairing ultimately depends on relative costs of repairing and replacement. The concept of useful life therefore embodies economic as well as engineering considerations. For products which perform an "essential" function, e.g., freezers and cars, the cost and inconvenience incurred from repeated failures makes reliability also a consideration in the repair or replacement decisions.

A requirement in expressing LCC is reconciling the stream of costs incurred over different time periods. The recognized method for comparing expenditures occurring at different points in time is discounting to some benchmark period. The approach takes into account the time value of money and converts all costs to a present value. Such LCC computations provide a framework to compare alternative product choices.

The development of an LCC/LCP estimation methodology must account for the factors affecting LCC and LCP in actual use. The conditions under which products are used vary greatly and these conditions affect the level of performance to varying degrees. It is impractical to attempt to account for all possible contingencies associated with a product's use. One approach is to characterize, through careful field analysis, "normal" use and environmental conditions which can be used to specify standard test conditions. Also a functional analysis of the product would yield important performance attributes. Based upon this information, laboratory test methods can be developed which either simulate the use and environmental conditions using manufacturer recommended maintenance procedures or can be correlated with actual field results.

The development of representative ownership costs is derived from combining the technical outputs from the laboratory with the value of necessary input requirements from field analysis. The cost estimation framework may account for the variations in input costs across the nation as well as conditions of use or environment, which could make aggregation or average values misleading to consumers. The above discussion points out the importance of considering the totality of a product's physical characteristics, and the variations in use and environmental conditions to make valid estimates of LCP and LCC for consumer products.

State-of-the-Art Assessment

There exists a well developed body of literature concerning the statistical techniques for analyzing "life" test data. The test methods from which the data are generated, however, are rarely reported in the literature.

Many tests either exist or are being developed to measure how well products perform their intended function. These tests are being developed through such organizations as the Association of Home Appliance Manufacturers and the American Society for Testing and Materials. Life testing is now being conducted by individual manufacturers for development, quality conformance and follow-up field evaluations. These test methods, however, are generally unavailable to the public due to the proprietary nature of these tests. Life testing is comparative and often tests terminate when specific minimum goals are achieved, not necessarily "end of life." For example, a component is replaced because a less expensive substitute is found. If testing indicates the replacement lasts longer than its predecessor the test may terminate prior to failure. Very few "life" test methods are agreed upon industry wide.

The General Services Administration presently uses a "LCC" criterion for procuring selective consumer products. The LCC criterion includes a projected energy cost plus an initial purchase price but not maintenance and repair costs. While this may be a step toward including energy conservation in a purchase decision, it is a strictly limited concept of LCC.

The relatively advanced state of LCC analysis for weapons procurement by the military may be accounted for by the fact that rather stringent and complete control can be achieved by the military on the operation, maintenance, and repair activities associated with the use of weapons. Because of such control, costs associated with operation, maintenance and repair activities are predictable and controllable. Hence, planning on the basis of LCC information becomes easily implementable. Similar observations apply to industry's and government's uses of durable equipment: for example; the aircraft fleet by the commercial airlines, automobile fleet by the car rental companies, and police car fleet by the various local police departments. A similar observation, however, cannot be applied to the use of consumer durables. The general absence of control on activities and the resulting difficulty in predicting costs make the LCC analysis of consumer durables a much more difficult topic of research.

Observation of the state-of-the-art leads to a conclusion that the application of LCC to consumer products is not immediately practicable. Although the elements of technical knowledge are available for such an application, the total body of knowledge is insufficient. This can be characterized by the availability of statistical techniques for testing but the unavailability of standardized LCP test methods. The inability to gain access to company test methods and field experience for consumer products also hinders LCC development efforts. These data are needed to correlate laboratory test results to actual field experience and to establish the test conditions, based upon use and environmental conditions in the field. Therefore, additional efforts are required to push the state-of-the-art in order to make LCC practicable for consumer products.

<u>Work to be Done</u>

If LCC information is to be made available to consumers for new products, there are a series of problems which must be addressed and resolved. At the present time, elements of LCC available for consumer products include initial purchase price and installation costs, a projection of maintenance costs (based upon manufacturers recommendations), and for certain appliances energy costs when units are new. Factors in the LCC formula which are ill-defined and for which information is lacking include: product life, operating cost, repair cost, discount rate and salvage value. Efforts intended to provide manufacturers with a basis for testing consumer products and estimating cost of ownership must address both the definitions for the above factors and provide techniques for assigning values. The basic areas requiring future investigation in order to develop the capability to generate LCP and LCC information include: information on consumer product use, laboratory test development and validation, rules for test application, and techniques for cost estimation.

For the purpose of planning long-term research, both engineering and economic disciplines must be utilized. Engineering research should be oriented toward simulation of use and environmental factors, the automation of test procedures and the development of a basis for accelerated testing. A successful program requires development of techniques for gathering operational information relative to a product's use, use environment, maintenance, repair, and "life" for non-repairable products.

Economic research essential to the translation of LCP information into LCC information is the valuation of the LCP input factors. Tasks must be directed toward the development of procedures to yield cost estimates for operating cost factors, repair requirements and consideration of the use of the discount rate for consumer product cost characterization. Another area for future research concerns the question of how "best" to provide consumers LCC information. This question relates to product selection, information content, complexity, format and the vehicle for presentation of comparative LCC information, and impact assessment.

During the course of this study, it was not intended that any laboratory based efforts be conducted. The information obtained was, therefore, based upon observations of industry testing and available literature, documenting statistical techniques for handling data, and limited test method development. In order to obtain "first hand" knowledge of the problems associated with LCP test method development and LCC, it is recommended that laboratory and field data collection efforts be initiated.

Two LCP demonstration projects are proposed: the first to integrate into a test method user effects inherent in the operation of a small hand-held product, and the second to characterize extended performance for a larger consumer product. These research efforts relate directly to the longer term engineering tasks and provide necessary experience to gain additional insights into the problems of conducting LCP test method development and LCC analyses for consumer products.

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LIFE CYCLE COSTING: AN ASSESSMENT OF PRACTICABILITY FOR CONSUMER PRODUCTS

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This report assesses the practicability for applying the life cycle costing (LCC) approach to consumer products. The report provides a basis for understanding: the potential for application, benefits and effects of LCC; the basic concept of LCC; its interaction with performance, and the state-of-the-art of "life" testing as it relates to developing extended performance test methods for consumer products. The report reviews information now obtainable and barriers to labeling consumer products with LCC information. An observation is made that application of LCC to consumer products is not immediately practicable. The basic areas requiring further investigation are identified, long term research goals are suggested and activities deserving immediate attention are described.

1. INTRODUCTION

1.1. Study Objectives

The principal objective of this study was to develop an understanding in extended performance measurement and cost characterization for consumer products.[1] This initial study was aimed at determining the feasibility of applying life cycle costing (LCC) to consumer products. In studying the feasibility of LCC, additional objectives were to assess the state-of-the-art in application of LCC and "life" testing, and to identify technical barriers to its application for consumer products. Understanding the problems inherent in application of LCC provides a basis for the formulation of a long-term plan to develop the necessary resources for testing and evaluating consumer products. Based upon project findings, recommendations were to be made for future NBS activities in extended performance evaluation of consumer products.

1.2. Background

The concept of LCC is not new; it has been used by industry for years as a technique for evaluating alternative investment costs of equipment and plant. The military likewise has been using it in comparing economic characteristics of alternative weapons and transportation systems. The

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[1]The term extended performance is used, throughout this report, to indicate evaluation of a product's capability to continue its intended function over time with use.

LCC technique takes into account the total costs of ownership and accounts for the timing of cash outlays and the time value of money. However, the application of LCC to consumer products is new. Interest in the application of LCC to consumer products has evolved with the growing national effort to provide comparative product performance information for consumer products. A 1974 Massachusetts Institute of Technology (MIT) report estimates that in 1972 there were nearly 115 million television sets and 330 million major appliances in use in the United States.[2] The retail value of products shipped in 1972 totaled $5.4 billion for home electronics and $7.5 billion for major appliances. Power costs for operating these products are estimated to have been $5.0 billion. Repair and servicing costs in 1972 are conservatively estimated to have been $1.5 billion for radio and television repairs and about $900 million for appliance repair.

Adequate information is not available to a purchaser of major appliances (freezers, room air conditioners, refrigerators, water heaters, etc.). Although the purchaser is aware of the initial cost of competing alternatives of major equipment, rarely does he have any idea of the magnitude of costs he is likely to incur during his ownership of that equipment (including energy, operations, maintenance, repair, and disposal costs). Further, the purchaser rarely has any indication of the relative benefits (performance over time) that will be received from different equipment alternatives. This is not only true for consumers, but is also usually the case with large volume purchasers, such as Federal, State, and local government agencies and industry.

This perception of the need to provide consumers with comparative performance and ownership cost information has resulted in several legislative proposals, thus far unsuccessful, to provide a mechanism to generate the needed information. Legislation proposed in the 94th Congress supported the need for more and better information. Senate bill S643 (Consumer Product Testing Act of 1975), introduced by Senator Magnuson; would have given NBS the responsibility for "...the development of consumer product test protocols...." This included the average annual cost of operation, durability, maintenance requirements, frequency of repair, and other elements of life cycle costing. The Federal Trade Commission (FTC) had supported this bill and its chairman told the Senate Commerce Consumer Subcommittee "that the bill would help alleviate the problem of a lack of information by encouraging manufacturers to utilize more comparable and informative advertising and would provide an incentive for them to improve their products."[3]

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[2]Center for Policy Alternatives, The Productivity of Servicing Consumer Durable Products, Massachusetts Institute of Technology with the Charles Stark Draper Laboratory, Inc., Report No. CPA-74-4, 1974, p. 7.

[3]"FTC Supports Bill on Test Standards," The Washington Post, November 12, 1975, p. A23.

The national concern for energy conservation has resulted in legislation requiring manufacturers to label appliances with the average annual cost of energy consumed.[4] This concern for energy efficiency, however, has led to a process which measures a product when it is new and does not account for possible degradation or improvements (break-in) with use. If projections are based upon initial values to generate average cost estimates efficiency changes occurring during product use may cause misleading information to be disseminated. Also, the trade-offs which may be taking place are not readily evident to consumers. There are many unconfirmed concerns relative to how product performance changes with use. Are products becoming more prone to require repair? Do products change their relative rank with use? How should consumers consider energy savings versus an increase in purchase price? Are other cost or performance factors being masked?

In addition, manufacturers are responding to consumers' interest in product quality through increasing their use of advertising claims relating to performance free from repair or at significant annual energy cost savings. The basis for these claims are presumably those test methods and data compiled by individual manufacturers, not standardized across the industry. The FTC is responsible to assure the validity of such claims, and has interacted with at least one industry (vacuum cleaners) to encourage development of standard test methods upon which to base their extended performance claims.

The Government Accounting Office has recommended the use of LCC procurement by the Federal Government.[5] The General Services Administration (GSA) has responded by participating in the NBS sponsored Experimental Technology Incentives Program (ETIP) and employing a modified LCC technique to procure air conditioners, refrigerator/freezers, ranges and water heaters. However, the LCC experiment of GSA/ETIP, while including energy conservation in the purchase decision, falls short of the LCC concept, since it neglects an essential element, i.e., how products perform over time. State and local government purchasing officials have expressed their interest in using the LCC technique for their procurements as well.

The relatively advanced state of LCC analysis for weapon systems and plant equipment by the military and industry may be attributed to their control over operation, repair and maintenance activities. A

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[4]Public Law 94-163, Sec. 322, "The Energy Policy and Conservation Act of 1975."

[5]Government Accounting Office, "Ways to Make Greater Use of the Life Cycle Costing Acquisition Technique in DOD," May 21, 1973. While addressing use of LCC in DOD, the report suggests civilian agencies could achieve lower costs per unit of service life by using LCC.

similar observation cannot be made for consumer products. It is this difficulty in predicting use conditions and their interactions with the product which presents the challenge in application of LCC to consumer products. The manufacturers who appear to have developed considerable experience in "life" testing and gathering repair data for products are jealously guarding their knowledge as trade secrets.

The characterization of a product's LCC presents challenging problems. Product characteristics are time-dependent (i.e., changes occur as products are used and/or as time passes). Product use may be carefree, require regular maintenance and frequent or occasional repair. Use patterns and environmental factors introduced by the variation in expected function or geographical distinctions further complicate LCC characterization. These acknowledged variations must be considered in any process for estimation of LCC, including test method development. Therefore, laboratory test methods must include a set of standard conditions which have been related to representative use patterns and environmental conditions. In addition, decisions rules and procedures for incorporating maintenance and repair actions during testing must also be specified.

The Department of Commerce Voluntary Consumer Product Information Labeling Program provides the means for utilization of LCC analysis and dissemination of results to consumers. Because of the continued interest and need for consumer product performance and ownership cost information, this study was initiated to address and assess the difficulties posed by the application of LCC to consumer products.

1.3. Approach

This study was initiated to objectively assess the practicability of applying the life cycle costing approach to consumer products. The major emphasis of legislative proposals has been on providing point of sale information for new[6] products in order to compare product characteristics such as durability, operating costs, repair cost, and other elements of LCC. In order to assess the difficulties in providing such information, this project was directed at understanding: the potential application, benefits and effects of LCC; the basic concept of LCC; its interaction with performance, and the state-of-the-art of "life" testing as it relates to developing extended performance test methods for consumer products. Based upon these combined assessments of LCC, extended performance and the state-of-the-art of life testing; potential areas were to be identified where further investigation would be warranted.

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[6]Throughout this report the term "new" product is used to differentiate a new product from a used product and does not refer solely to products using a new technology.

It was not intended that any laboratory based efforts be conducted during the course of this initial effort. Information was, therefore, obtained from economic and technical literature documenting the use of LCC, test methods, and statistical techniques for handling "life" data. In addition, contacts and visits were made with trade associations, universities, government agencies and manufacturers for test methods, data or practices relating to measurement of consumer product performance and/or estimated useful life.

2. POTENTIAL APPLICATION, BENEFITS, AND EFFECTS OF AN LCC PROGRAM

2.1. Potential Application of an LCC Program

An LCC program's objective is to improve consumer purchase decisions through the provision of extended performance and cost characterization for selected consumer products for which present information is inadequate. The products for which LCC or extended performance information are of potential value in aiding better purchase choices include those where:

(1) operating costs or servicing costs are significant compared to purchase price,
(2) energy utilization per unit output varies over time,
(3) output performance deteriorates over time, or
(4) expected "life" varies for non-repairable products.

Likely outputs might be labels giving average annual cost of ownership information, and information indicating how a product will perform at various intervals of use (or time as appropriate). Such information could be used to make comparative evaluations for competing products as well as provide information for repair versus replacement decisions. The information could be given on labels at point of sale, or alternatively, booklets might be distributed by trade associations (such as the Association of Home Appliance Manufacturers directory) or other public or private organizations giving comparative data by manufacturer and model. Another output, better maintenance policies enabling reduction of LCC, might also result based upon testing and the inverse relationship of maintenance to repair and operating costs.

2.2. Industry Benefits and Drawbacks

Companies not "life" testing their products could potentially benefit from a test procedure generated by a program for extended performance testing of consumer products. The test results may yield a basis for product redesign; either to reduce cost of production without affecting performance, or perhaps to increase performance (a product improvement) without increasing costs of production. Of course, the trade-offs between performance and production cost are of major concern to manufacturers. The tests might also provide a basis for modification of warranty provisions. In the case of technologically new products or new designs, information available from tests which offer good prediction of actual field experience is especially valuable. For manufacturers with products which are more efficient or more durable, LCC information would facilitate their ability to market their products for a higher purchase price. A potential benefit from such a program is a reduction in consumer dissatisfaction, due to a better understanding of expected product performance. This could result in dramatic cost savings through a reduction in returned products thereby saving valuable economic resources.

Some industry drawbacks should also be discussed when contemplating such a program. First, there are many costs manufacturers will have to absorb or pass on to consumers. These costs are associated with the plant space required to conduct tests and to equip test facilities. Continuous costs for conducting tests are incurred from product destruction, labor to conduct tests and analyze results, operating overhead (administrative, record keeping, etc.), and information dissemination.

Another possible drawback is the effect upon the present marketplace. The process of brand identification and advertising relating to corporate image is very influential in terms of consumers' making product choices. The more complete the objective and quantitative information regarding a product the less important becomes the subjective images created by advertising. Corporations having captured a large portion of the market are reluctant to get into advertising "duels" comparing performance or price.[7]

2.3. Consumer Needs and Benefits

At the present time consumers seem to have a "temporal myopia," or indifference to the operating cost of products relative to the initial purchase price. This condition can be explained by a combination of factors including: the lack of exposure to quantitative representation of operating and repair costs; and in this environment of inadequate information, a further lack of education required to make proper use of such information if it were to be provided. It must be recognized that any program designed to provide such quantitative information (and break the present buying pattern) must be coupled with a program to educate consumers in how to use such information.

The information provided by an LCC information program could benefit consumers directly by providing:

(1) a basis to compare (trade off) the initial purchase price against the costs of ownership for alternative product choices over a use period,
(2) information on maintenance policies resulting in lower costs for repair and operation,
(3) a basis for evaluating the value of service contracts,

[7]A recent example is the amount of effort the manufacturer of a popular over-the-counter drug expended in order to have a comparative advertisement by a competing manufacturer removed or substantially modified.

(4) better product design resulting from increased industry testing and product improvements perhaps without increased purchase cost,
(5) a fair basis upon which to evaluate advertising claims about extended performance or long-term cost savings, and
(6) increased consumer satisfaction, because information would permit a better match between consumer requirements and product capabilities.

2.4. Public Costs and Benefits

A successful LCC program would require considerable Federal Government resources. The previously mentioned educational program would require development of appropriate educational material and its public dissemination, through yet to be determined channels. Information dissemination could be kept to point of sale material provided by manufacturers, however, the formating of information requires research into how consumers could best use such information. Alternatives to point of sale information provided by manufacturers should also be explored. Test development and cost characterization activities, discussed in other sections of this report, require both technical and monetary resources.

In addition to direct benefits for consumers and industry, public benefits should also be expected. One such benefit is the capability to evaluate the trade-offs being made with regard to such public policies as energy and materials conservation. It could lead to some aggregate measures for relating, for instance, the energy conservation requirements against durability, which has implications for materials conservation.

3. TECHNICAL CONCEPTS

As discussed in the first chapter, the principal objective of this study is to develop an understanding of extended performance measurement and cost characterization for consumer products. The determination of the full cost characterization, that is, the assessment of a consumer product, is in turn crucially dependent upon the measurement of the performance of a product. The reason that product performance plays such an important role in determining the LCC is that many of the components in the LCC formula cannot be completely specified unless the manner by which a product performs its intended function throughout its life--that is the life cycle performance (LCP)--is completely determined. In fact, one of the key reasons why LCC has been applied in various military and industrial contexts, but only scarcely applied in the consumer field, is that the manner by which products will be used, maintained, and repaired is much more accurately known and controlled in the former compared to the latter.

The arrangement of the subject material in this chapter is as follows: first appears a presentation of the definition of product performance in general and a discussion of life cycle performance specifically; second, the life cycle cost formula is presented and discussed in some detail; and, third, the chapter closes with a discussion of LCP and LCC estimation methodology.

3.1. Life Cycle Performance

3.1.1. Introduction

In order to define life cycle performance (LCP), it is necessary to examine first the concept of performance. Performance is measured in terms of the product's output and the efficiency with which it transforms input to output. Life cycle performance is the performance measured over the "life" of a product. Time, however, entails the consideration of two additional product attributes: reliability and durability. Reliability refers to the probability of performance nonfailure for a period of time, whereas durability refers to the lasting quality of a product.

The measurement of product performance, reliability and LCC necessitates the stipulation of the conditions under which measurements are taken. Standard conditions are generally specified, based upon use and environmental factors, representative of the product's expected use environment. Furthermore, since the determination of a failure is a key element in reliability and LCC its clarification is important. The minimum acceptable performance level (MAPL) will be defined as the lower bound of the set of performance levels which are considered to be satisfactory under standard conditions. (This value may be based on requirements to meet some objective or may be selected arbitrarily. For some products it may be anything greater than zero: the product either works or it doesn't.) Failure occurs when performance falls below the MAPL threshold.

The following sections will discuss each one of these concepts in greater detail.

3.1.2. Concept of Performance

3.1.2.1. Definition

Product performance is an important product attribute. It is a measure of a function or a set of functions for which a product was designed and produced determined under standard conditions. The amount of cool air generated by an air conditioner, the pneumatic support provided by an automobile tire, and the impermeability of a raincoat to water are some examples of consumer product performance. For a class of consumer products, performance is a significant factor affecting a consumer's purchase decisions. Performance, however, is not the only significant product attribute. Attributes like safety, aesthetic appeal, status appeal, and style may affect consumers' purchase decisions as much or more than performance. Clothing, furniture, cosmetics, and even automobiles are illustrative of this point.

An initial classification and segregation of consumer products would sharpen the focus of the present discussion in view of the variation in the relative significance of performance among consumer products. Two independent classifications may be made: durable-nondurable on one hand and active-passive on the other. The distinction between durable and nondurable products is a matter of degree although economists use an arbitrary one-year period as the dividing line. For the present discussion, however, products used over any length of time will be regarded as durables. Such ambiguity in definition results from considering products such as vacuum cleaners which on the average are produced to operate without repair for about 500 to 600 hours. The actual ownership duration for vacuum cleaners is several years because the actual operating time per use period is short.

The active-passive classification is based upon the type of output. Active products transform some input to physically different output. For example, the input, electricity, is transformed to such outputs as suction power for vacuum cleaners, cooling of air for air conditioners, light for light bulbs, and heat for electric ovens. Other products, such as automobile batteries, undergo a chemical rather than physical transformation of input to output. Passive products, on the other hand, do not require physical transformation of input to output; rather, they provide outputs by their presence. Automobile tires, furniture, paint, and architectural glasses fall into this category.

Because both LCP and LCC analyses involve measuring performance and cost over time, they apply only to the durable class of products. The applicability of the respective analyses to the active and passive products differs considerably, however. The difference is based on the presence or absence of the input-output transformation efficiency element; this element applies only to the active class of products. The active and durable class consists of appliances and similar equipment such as lawn mowers. For them, performance may be described through measurement of both the product outputs and the efficiency of transforming the inputs to the outputs. For the passive and durable class of products, only the pattern of change in outputs is relevant. This means in turn that for passive-durables the question of life cycle performance is of interest, expecially the durability and reliability, but life cycle cost becomes less important since the initial purchase price dominates LCC.

3.1.2.2. Product Quality

The understanding of the concept of performance and its relationship to output and input-output transformation efficiency is facilitated by studying the more basic concept of product quality which may be defined as the summary expression of all attributes a product imparts to a consumer. In general use, product quality represents the "value" with which consumers assess the worth of products. The following quote from the Wall Street Journal illustrates this point.[8]

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[8]Wall Street Journal, September 29, 1975.

> Recession, inflation and the resulting tight budgets have led consumers to put increased stress on quality. Is the interest in quality likely to persist?...
>
> This same price sensitivity has increased for consumers' interest in quality. The consumer movement got under way long before inflation reached double-digit territory, but the upsweep in prices obviously hasn't made consumers any less unhappy with shoddy products. Some appliance makers this year have reported increased demand for the goods at the top of their lines.

More formally, product quality is what affects a consumer's utility function, or satisfaction, when he evaluates a product's worth. Whether product quality can be objectively measured is not the main issue. Whether measured or not, a consumer must base his judgment on what he knows or thinks he knows. If his perception and judgment turns out to be incorrect, he ends up purchasing products unsuited to his actual needs.

Product quality can best be conceptualized as a vector with product attributes as its elements, as shown below:

$$\begin{array}{c}\text{Product}\\\text{Quality}\end{array} = \begin{bmatrix} \text{output} \\ \text{input-output transformation efficiency} \\ \text{reliability} \\ \text{durability} \\ \text{safety} \\ \text{style} \\ \text{ease of use} \\ \text{aesthetic appeal} \\ \vdots \end{bmatrix}$$

The conventional economic wisdom is that a consumer is knowledgeable about these elements so that he can rationally assess the product's worth to him. In reality, of course, the converse holds true especially for complex products like consumer durables. The current interest in studying performance of consumer products is based on accepting the fact that consumers are ignorant of the nature and magnitude of many of the important elements and that they have to be informed in order to make rationale purchase decisions.

Although many of the elements in the product quality vector affect performance and cost, the first four elements are of greatest importance to the study of LCP and LCC. Whereas the first four elements affect performance and cost directly the remainder do so indirectly through the first four. Elements such as safety and style may increase cost. For example, the Consumers Union's proposed safety standard for lawn mowers, if implemented, is expected to raise the cost for safer lawn mowers substantially. The various emission controls incorporated into automobile engines not only increase operating cost but may increase maintenance and repair costs as well. The following discussions thus will focus on the four direct-effect elements.

Among the four, the most critical attribute is the input-output transformation efficiency. It is, in fact, the production function for the active class of consumer products. Given the same amount and form of input, the product with the more efficient production function will normally generate more output. Typically for consumer products, input-output transformation efficiency is described by a simple ratio. Two well-known ratios are the miles-per-gallon (MPG) for automobiles and the energy-efficiency ratio (EER = $\frac{\text{Btu}}{\text{Wh}}$) for room air conditioners. These ratios are used to compare different brands or models of the same class of product. Other things being equal, those giving more output--miles driven or heat removed--for the same amount of input are deemed more desirable. In this way, input-output transformation efficiency becomes the most readily usable single descriptor of performance for active consumer products.

3.1.2.3. Nature of Output

The output of a product, it may be recalled, is an element of a product quality vector. One characteristic of a product's output is that it is physically measurable. This applied not only to the active class of products but also to the passive class. The insulating ability and transparency of architectural glasses, supportability of chairs, and protecting ability of paint are all examples of the outputs of passive products that can be objectively measured. It is this objective measurability that forms the basis for translating output to performance.

Another characteristic of product's output is its multidimensionality. Products often may have a single purpose and the description of how well this purpose is accomplished provides the product's output. The incandescent light bulb provides illumination, the television set receives and produces a picture, and the clothes dryer removes moisture. These may be referred to as the primary aspect of product output. The products, however, provide other kinds of outputs. Besides illumination, the color of the light may be of importance for light bulbs. Besides the speed of removing moisture, the degree of wrinkle freeness may be of importance for clothes dryers. The latter type of outputs may be referred to as the secondary aspect of product output. For specific measurement purposes, the primary and, in some instances, the secondary outputs are of importance to characterize performance.

3.1.3. Concept of Life Cycle Performance

3.1.3.1. Definition

Life cycle performance of a consumer product is the performance of the product measured over the entire life of the product. The elements being introduced in this definition are: (1) time dependence of performance, and (2) product life. The first element pertains to reliability and the second to durability, both having been noted previously as elements of the product quality vector. Reliability and durability will be discussed in the following subsection.

Measuring performance over time has two elements: measuring changes in the nature of the output, and measuring changes in the input-output transformation efficiency. Both changes can be characterized as performance degradation that occurs to manufactured products. The two types of changes may, however, be discussed separately. Performance degradation for outputs may occur to primary and/or secondary aspects of output. Diminished amount of light emitted by a light bulb is a primary aspect degradation whereas an increase in wrinkles during clothes drying is a secondary aspect degradation.

Performance degradation for input-output transformation efficiency may also be divided into two categories. For the first case, more input is required to produce the same output as before, and, for the second case, more input cannot be provided and therefore remains constant while the output level is decreased. Water heaters with lime deposits and air conditioners with clogged filters fall into the first category since more energy over longer duration is needed to generate the same output. "Aged" light bulbs and vacuum cleaners with worn motors fall into the second category since the voltage applied to a light bulb cannot be controlled by the user and operating a worn vacuum cleaner longer does not increase greatly the amount of dirt removed.

3.1.3.2. Effects of Reliability and Durability

The significance of reliability and durability is based on the fact that they characterize the pattern of performance over time. We have defined failure as performance falling below the MAPL under standard conditions. Reliability pertains to the probability of failure in a given time period. The higher the probability of failure, the lower the reliability, and vice versa. An example of performance failure for a vacuum cleaner may include not only a complete breakdown but very weak suction power insufficient to remove dirt. The precise setting of a failure threshold is a subject to be taken up with respect to a specific product and the conditions underlying its use and is of no concern in the present discussion.

The concern over reliability necessitates two kinds of action on the part of the consumer. These are maintenance and repair. Maintenance is an action performed on satisfactorily operating equipment to keep it performing satisfactorily. Repair is an action performed on an equipment showing performance failure, restoring it to a satisfactory level of performance by fixing or replacing parts. Both maintenance and repair affect LCP, because output and input-output transformation efficiency are affected by such activities. They also affect LCC since both activities entail the consumption of economic resources.

Durability is the lasting quality of a product; it is the ability to endure prescribed use conditions and environmental factors over the useful life. It is important to distinguish between the concepts of durability and useful life since they do not necessarily mean the same thing. Durability is a quality possessed by a product when it is produced. How long a product actually lasts depends not only on durability but also on the manner by which it is used and environmental factors associated with its use. Moreover, durable products, especially complex ones with many components, are repairable and hence can be kept serviceable indefinitely if parts are available and necessary repairs are made.

When to repair and when to stop repairing ultimately depends on relative costs of repairing and replacement. The concept of useful life therefore transcends that of durability. "Catastrophic failure" or unavailable parts ends both useful life and durability. However, there are many differences among use environments, consumers' maintenance policies, preferences for newer products and the latest "gadgetry," budget constraints, etc. These may end the useful life of a product under some conditions, but not necessarily the durability--another owner might use the same product for a much longer period. It can be seen that useful life embodies economic as well as engineering considerations; as such, the discussion of useful life will be taken up later when LCC is analyzed.

3.1.3.3. Minimum Acceptable Performance Level (MAPL)

It was noted in the preceding subsection that the concept of reliability necessitates defining a performance threshold level below which is the region of performance failure. In conjunction with LCP, such a threshold level may be designated as the minimum acceptable performance level (MAPL). The immediate significance of MAPL is in determining performance failure and the need for maintenance and repair activities. More significantly, however, MAPL acts as the basis with which the concept of LCC is formulated.

The relationship between LCP and MAPL for a product may be depicted in the following figure.

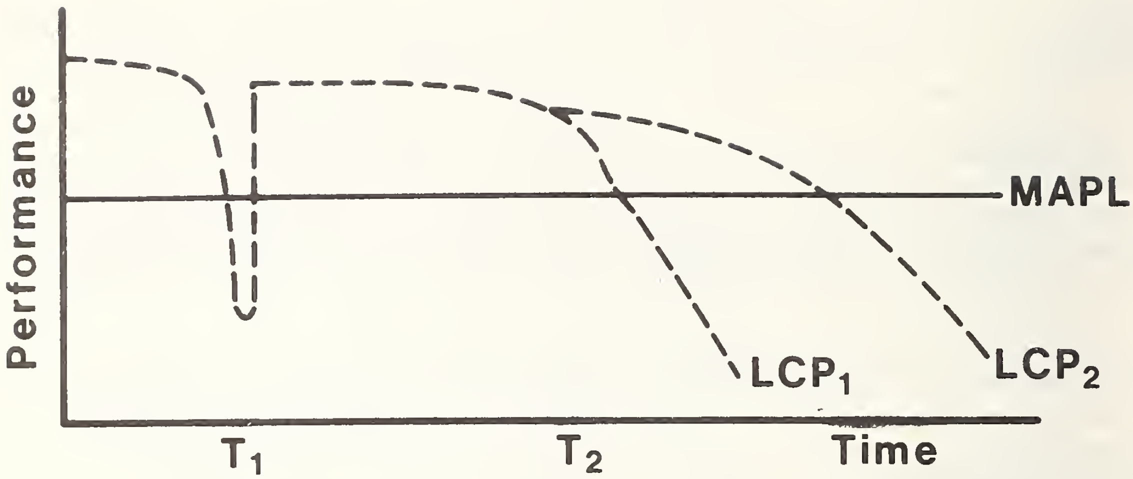

Figure 1. Comparison of MAPL and LCP curves

In Figure 1, the portion of LCP below MAPL at T_1 represents performance failure. The actual shape of LCP, of course, could be affected greatly by maintenance and repair activities. The divergence of LCP_1 and LCP_2 at T_2 represents alternative maintenance activity which affects the course of LCP. Although the figure represents MAPL as a single attribute being measured, it may be desirable to designate more than one performance attribute for tracking the determination of the MAPL. In such cases, there may be several figures similar to the one shown here.

With respect to a given LCP and its associated MAPL, life cycle cost (LCC) may be defined as the initial purchase price plus whatever monetary expenses are incurred over time to maintain LCP above MAPL. Such expenses consist of cost for input (such as energy) plus maintenance and repair expenses. The above definition, however, is incomplete since LCP can be maintained above MAPL indefinitely provided sufficient cost is incurred. At best, LCC should be defined in terms of some prespecified time periods, say, 3, 5, 10, or 15 years. A more complete discussion on LCC must wait until the concept of LCC is analyzed in more detail, which is the topic of the following section.

3.2. Life Cycle Cost

3.2.1. General Expression of LCC Formula

A basic LCC equation may be expressed as follows:

LCC = (Fixed Cost) + (Variable Cost) + (Disposal Cost)

Fixed cost consists of initial purchase price plus transportation and installation cost (or logistics cost), all of which constitute a sunk cost to the purchaser whether the product is used or not. Fixed cost is incurred prior to the product ever being used. Disposal cost may be a positive or negative value depending on particular circumstances. If some scrap value can be salvaged, it becomes a negative cost; if the final disposal incurs cost, positive. Both fixed and disposal costs refer to one-time expenses whose values are independent of the generation of outputs.

It is the variable cost component which depends on the outputs produced over time. The variable cost component consists of operating, maintenance, and repair costs. These costs are interdependent. A higher intensity of use resulting in a greater operating cost would call for higher levels of maintenance and repair costs than otherwise. Likewise, a thorough and frequent maintenance program, resulting in higher maintenance costs, would result in lower operating and repair costs than otherwise.

One necessary requirement in expressing LCC is reconciling the stream of costs incurred over different time periods. (The time period may be any prespecified unit although the most conventional and useful period is a year.) The recognized method for comparing expenditures occurring at different points in time is discounting to some benchmark period. This approach takes into account the time value of money and converts all costs to present value or to an equivalent annualized cost.[9] The full expression of the LCC formula then can be shown as follows.

$$LCC = PLC + \sum_{t=1}^{N} \left[\frac{1}{(1+r)^t} [(OC)_t + (MTC)_t + (RC)_t] \right] + \frac{1}{(1+r)^N} (DC)$$

where,

- LCC = present value of costs incurred during N periods,
- PLC = consumer's initial price and logistics (i.e., transportation and installation) cost,
- r = discount rate (per period),
- OC = operating (energy, water, etc.) cost for specified maintenance, repair, and use conditions,
- MTC = maintenance cost,
- RC = repair cost, and
- DC = disposal cost (This item becomes negative if a consumer received money when disposing of an old product.)

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[9]See Grant, E. L. and W. G. Ireson, Principles of Engineering Economy, 5th ed., Ronald Press, New York, 1970.

Since the above LCC expression is quite general, specific forms of the variable cost elements must be worked out for each specific product.

3.2.2. Analysis of LCC Components

3.2.2.1. Greater Importance of the Variable Cost Component

Although three distinct cost components comprise consumer product LCC, it is only the variable cost component that requires detailed analysis. The initial price and logistics cost component (PLC) as well as the disposal cost component, which arise respectively at the initial and terminal time points, represent given market data to a consumer. For a consumer, the value of PLC, especially the initial price, is a given datum which he can affect minimally. He may to some extent affect the disposal cost, but its value is small relative to the overall LCC. Moreover, its value occurs in the future which is highly discounted so that the disposal cost becomes an item of small significance in LCC analysis. The variable cost component, on the other hand, can be affected by a consumer; therefore, his attempt at reducing cost becomes a meaningful activity. The level of operating cost depends on his use patterns greatly. The levels of maintenance and repair costs are affected by whom he relies on for such services, how frequently he uses them, and whether he himself undertakes some or all of such service activities. Analysis of LCC thus becomes, in effect, the analysis of its variable cost component.

3.2.2.2. Analysis of the Variable Cost Component

The knowledge of input-output transformation efficiency, reliability, and durability affords a good basis for generating the variable costs, viz., operating cost, maintenance cost, and repair cost. Since product performance specifies the production of some specified level of output for each consumer durable, operating cost is derived directly from the quantity of input consumed and externally given input prices. The derivation of life cycle cost (LCC) requires, however, that some specified performance level, i.e., the minimum acceptable performance level (MAPL), must be maintained or exceeded throughout the life of a product. This means in turn that maintenance and repair activities must be provided in order to maintain the input-output relationship in such a way that the resulting performance level stays above the MAPL. In short, operating, maintenance, and repair costs are derivable from the time trace of inputs and outputs.

Unlike industrial durables a maintenance schedule may not be rigidly specified or followed for most consumer durables. Hence, although operating cost is incurred with use, and repair cost must be incurred when performance failure occurs, maintenance cost is a discretionary item to a consumer. The nature of maintenance, however, is such that it has positive relationship to performance efficiency and an inverse relationship to repair frequency. That is, maintenance cost inversely affects both operating cost and repair cost so that there exists possible trade-offs among the variable costs of the LCC formula. This means that it is possible for a consumer to arrange his operating, maintenance, and repair costs in such a way as to reduce the overall variable costs and hence the LCC of a particular product. An individual who conscientiously changes the crankcase oil of his automobile at frequent intervals is behaving in such a manner.

3.2.2.3. Concept of Economic Life

The concept of life is ambiguous as applied to consumer products. Since products are repairable, they can be made serviceable indefinitely (although parts may only be available for 10 or 15 years). This means then that the distinction in the meanings of life and durability needs further clarification.

It is desirable to distinguish the terms durability and life as they apply to consumer durables. Durability is a lasting quality of a product; it pertains to characteristics of a product incorporated at the time of its production. Some may be built sturdily and some may not, so given the same use conditions, the sturdily built product should last longer. Life, on the other hand, is somewhat ambiguous in the present context. Unlike living organisms, time *per se* contributes only incidentally to a product's aging process--it is use frequency or use cycle that causes wear, which eventually results in failure. Durability of a product is thus determined by the efforts of manufacturers--what materials are used, what designs are chosen, and what manufacturing and quality control processes are employed. Life of a product, on the other hand, is determined by the relationship between cost and performance. It is based on the consideration of whether owning a product is economically justifiable measured in terms of the LCC to maintain the MAPL.

The explanation of the concept of life of a product is facilitated by an alternative presentation of LCC data. Rather than summing the present and all future discounted costs to derive a single expression, costs for each period may be examined individually. For any period, summing all costs (e.g., PLC, operational, maintenance, and repair) arising in that period results in the total costs for that period. If the total costs for each period are summed successively, the resulting expression is the total ownership cost. Finally, dividing the total ownership cost by successive values of periods results in average ownership cost. The average ownership cost for a given period represents the value of LCC applicable uniformly from the first to that particular period. In the graphs below, the total ownership cost is depicted in Figure 2 and average ownership cost in Figure 3.[10]

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[10]It is assumed in drawing the cost curves that operating cost remains constant while maintenance and repair costs grow at an increasing rate as a product "ages."

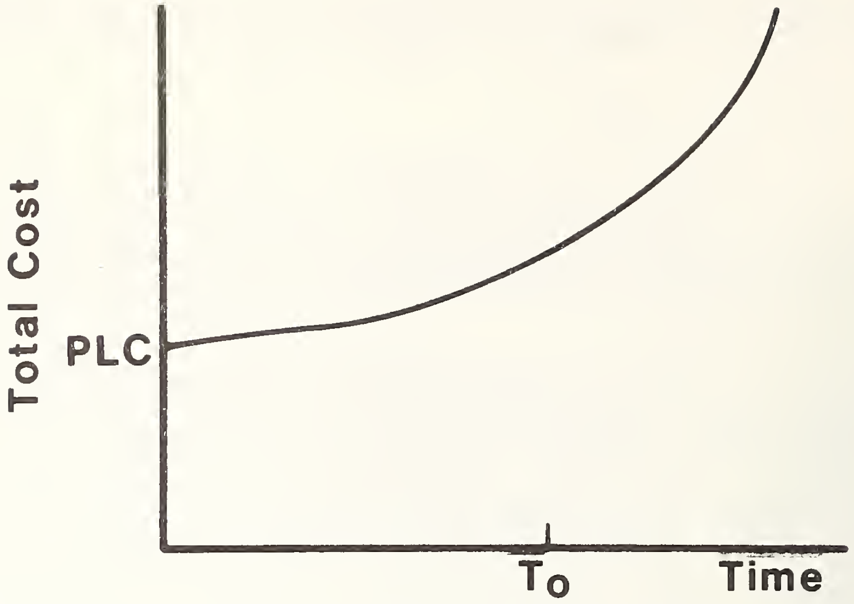

Figure 2. Total ownership cost

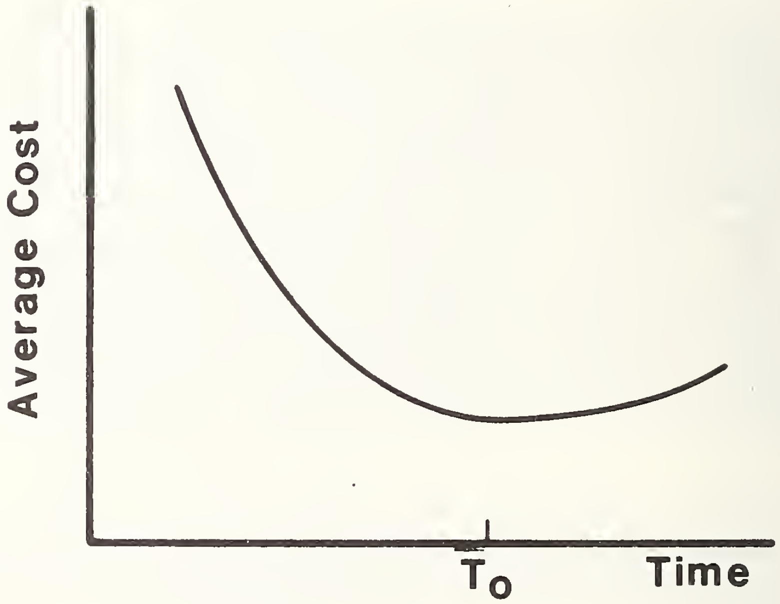

Figure 3. Average ownership cost

In Figures 2 and 3 minimum average cost is achieved at period T_o. The U-shaped form of average ownership cost curve is based on two general observations. First, the initial price and logistics cost (PLC), i.e., the fixed cost component, of consumer products is typically large relative to the variable costs during the early phase of use. Second, as use frequency increases, maintenance and repair costs (the variable cost component) become larger. The first observation accounts for the initially falling average cost curve and the second observation to its subsequent rise.

The point in time at which a consumer may decide to terminate his use of a product can be examined in terms of a average ownership cost curve. The average ownership cost curve indicates the average cost of ownership at each point along the time axis. Other things being equal, it pays for a consumer to use a product up to the point of minimum average cost. This would be the case if a new product he purchases to replace the old one possesses the same average cost curve. If not, his disposal and replacement decision must reflect the differences in the average cost curve of the new product. The average cost curves could differ in two ways. First is a general price inflation which would push up the overall cost curve so that the minimum level of the new curve is higher than the minimum of the old one. In this case, it pays for the consumer to keep using his old product until the average cost of the old product reaches the minimum of the new product. This phenomenon appears to have taken place recently with respect to purchasing new automobiles. The second possibility is technological improvement that lowers overall cost curve so that it now pays to replace the old one with a more efficient product even though the former's minimum cost has not been reached. This phenomenon seems to apply to the replacement practices of color television sets during the early Sixties as the initial purchase price came down with newer technology.

The average ownership cost, then, may be used to define the economic life of consumer durables. Unlike the durability characteristic which may be an initial product attribute, a product's economic life to a consumer can depend on economic conditions associated with subsequent product use.

It is still not possible to determine a repairable product's life in terms of LCC since the concept of life in the conventional sense is irrelevant. At best. LCC can be used to determine economic usefulness of a consumer product, i.e., its economic life.[11]

3.3. LCP/LCC Estimation Methodology

3.3.1. Discussion of Estimation Methodology

3.3.1.1. Factors Affecting LCP/LCC in Actual Use

A basic premise throughout the present discussion has been that performance can be objectively measured. Performance has been defined as outputs generated by a product where the outputs are physically quantifiable entities. The generation of outputs consumes input or inputs whose prices constitute use cost. LCP is the time trace of performance while LCC is the total cost required to maintain LCP above the MAPL.

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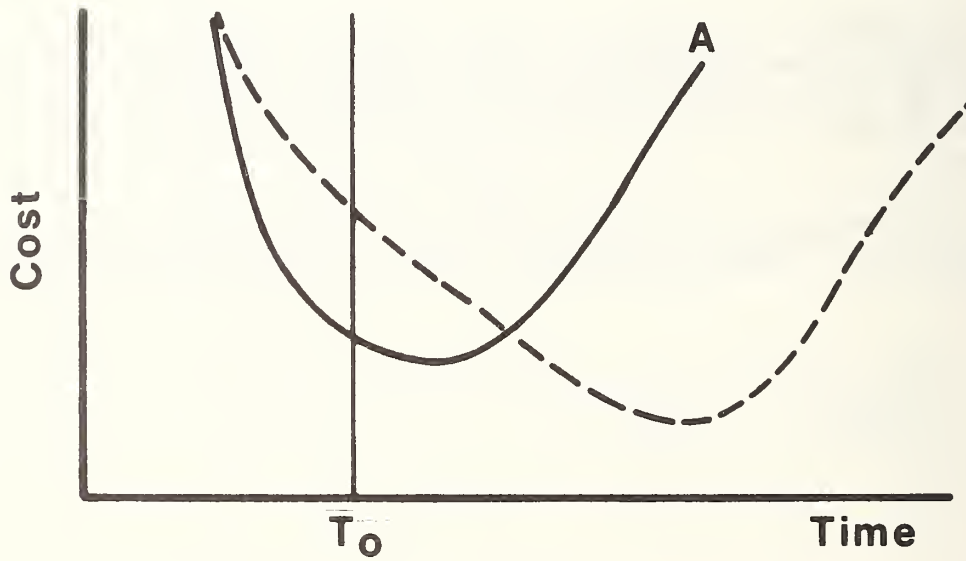
[11]The concept of average ownership cost may be used as a decision criterion to choose among alternative products with similar function (or more typically among competing brands of the same product) when none is presently owned. Other things remaining the same, a prospective purchaser would choose that product or brand having a lower minimum average ownership cost value if the length of ownership is indefinite. If, however, the length of ownership is specified, the product or brand having the lower average ownership value at the specified point in time will be chosen. In the graph below, product B will be chosen if no time restriction is specified. If the length of ownership is specified at T_o, product A will be chosen instead.



To assume that the only factor affecting a product's LCP and LCC is the product's initial physical characteristics is an oversimplification. The actual conditions under which consumer products are used vary greatly, and these conditions affect the level of performance to varying degrees. Because the initial physical characteristics of a product form the intrinsic factor affecting its performance, the other factors will be designated as external factors. The relationship between the intrinsic and external factors can readily be illustrated by comparing the miles-per-gallon value associated with a new automobile as tested by the Environmental Protection Agency and the gasoline consumption efficiency variations achieved by the automobile in actual use.

3.3.1.2. Types of External Factors

Two types of external factors may be defined: use environment and user characteristics. Use environment designates the physical conditions associated with using a product. User characteristics, on the other hand, designate the user's peculiar consumption patterns. Both the use environment and the user characteristics can vary from beneficial to detrimental. For example, a water heater may be used in a hard water area with or without a water softener, and the user may set the thermostat high or low and consume a great deal or a little hot water.

The important point is that the various external factors must be considered together with the product as a system. The external factors may interact with the product to cause disturbances in the input-output transformation taking place. The study of LCP and LCC thus may necessitate as much emphasis on the analysis of the external factors as the initial physical characterization of a product.

3.3.2. Developing Standardized Laboratory Testing Methods

3.3.2.1. Reasons for Development

The basic objective of this report is to examine the feasibility of estimating LCP and LCC values which can be used by consumers for their pre-purchase evaluations. If the product of interest has been in use without modification for a long while, the applicable LCP and LCC data may be collected through a survey of actual users. Typically, however, consumer products of an active and durable kind undergo steady evolutionary modifications. Occasionally some new technology is introduced, such as the introduction of electronics technology to the consumer appliance field. Because of these product changes, and because of the need to derive estimates with a more precisely controlled environment, there is a need to develop laboratory testing methods.

What is called for then is the development of standardized laboratory test methods. Standardized methods, once developed, should enable both manufacturers and other interested parties to objectively test and compare their results, thus providing consumers with an objective basis for evaluating and comparing products. The standardized test method to measure the energy efficiency ratio of room air conditioners, for example, does already serve such a function.

A more immediate cause for standardized test methods is the sheer complexity involved in testing consumer durable products. Because of the variability of the external factors that affect a product's performance, the possible types of use simulation, and the institutional diversity of the maintenance and repair service industry, some standardized ground rules for testing must be predetermined. Otherwise, various test results cannot be meaningfully compared.

3.3.2.2. Implications for Laboratory Testing and Cost Estimation

The actual development of standardized test methods is outside the purview of this report. What is of importance for this report is listing the conditions that must be specified in order to develop such test methods. Three such conditions may be listed: specification of the external conditions, the technique for simulating use and environmental conditions, and the ability to correlate laboratory test results with actual use data.

It is impractical to attempt to account for all possible contingencies associated with a product's use. One approach is to characterize through careful field analysis "normal" use and environmental conditions. The "normal" use and environmental factors can be used to specify standard conditions for test. Also a functional analysis of the product would yield important performance attributes. Based upon this information, laboratory test methods can be developed using manufacturer recommended maintenance procedures, which either simulate the use and environmental conditions or can be correlated with actual field results. The laboratory tests yield an indication of a product's potential for performance as distinct from its expected performance or actual useful life based upon actual surveys. The actual useful life is dependent upon many factors. These factors include the design of the product, the environment it is subjected to, the care of the owner in its use and maintenance, the features and functions of the product relative to newer models, and the economics of the repair or replacement decision. A product can be burned up in a fire or dropped shortly after purchase with virtually no use. But these events cannot be predicted by laboratory testing. The laboratory tests provide objective results, based upon the standard conditions stipulated in the test procedures, and indicate a product's potential for use by consumers. The outputs of laboratory tests are: (1) necessary input requirements, (2) measurements of performance attributes, and (3) required repairs, all three related to a time and use scale.

The development of representative ownership costs is derived from combining the technical outputs from the laboratory with the value of necessary input requirements from field analysis. The cost estimation framework may account for the variations in input costs across the nation as well as conditions of use or environment, which could make aggregation or average values misleading to consumers. The above discussion points out the importance of considering the totality of a product's physical characteristics, and the variation in use and environmental conditions to yield valid estimates of LCP and LCC for consumer products.

4. STATE-OF-THE-ART

This section describes the results of project efforts to: (1) search the literature for documented test methods and statistical approaches used to evaluate "life" performance for products, (2) characterize industry "life" test methods for consumer products, (3) determine how the Federal Government is using "life" testing and life cycle costing and (4) make observations on what the present state-of-the-art suggests for development of objective "life" performance test methods.

4.1. <u>Literature Search</u>

4.1.1. Scope of Search

The objectives of the literature search were to collect information from the published literature about the state-of-the-art of life testing for consumer durables, and to search for documented test methods for consumer durables.

The following journals were searched; some were searched in part and others were searched wholly:

Journals covered:

Transactions of the ASME: Journal of Engineering for Industry
Transactions of the Institute of Radio Engineers

IEEE Transactions on Reliability
IEEE Transactions on Industry Applications
Consumers' Research
Consumer Report
Industrial Engineering

Quality Progress
Quality Management and Engineering
Industrial Quality Control
Journal of Quality Technology
Journal of American Statistical Association
Technometrics

Operational Research Quarterly
Operations Research

1975 ASTM Annual Standards, Part 41
The Association of Home Appliance Manufacturers Standards
Appliance Manufacturer
Appliance

4.1.2. Life Testing Literature

The great emphasis on reliability of components and final assemblies by the electronics industry has spearheaded the advancements of life testing. At the present time life tests are an accepted practice of manufacturers and are conducted by their engineers. In a life test, a number of similar components or assemblies are operated in a carefully controlled environment until all or a preassigned number of the units have failed. What constitutes a failure must be defined in advance. A life test will generally be an expensive proposition in both time and money. The units that are destroyed will not be eligible for repair in many cases, and very reliable units will have to be run for very long times before useful failure data become available.[12]

There is considerable literature on the models and statistical methods for life test, and over one thousand papers are referenced in the bibliographies on life data analysis by Mendenhall and Govindarjulu.[13,14] Davis and Goldsmith discussed some practical considerations of a life test, and their paper is cited extensively herein because it discussed the whole process of a life test.[15] The authors start out by stating that the first step in designing or selecting a life-test plan is to review and clearly define the objective(s) of the test. Life tests may be generally classified as having one or more of the following purposes: (1) exploration of product characteristics; (2) lot-by-lot product acceptance; (3) qualification of a design and/or a process; (4) qualification of a manufacturer (skills and equipment); and (5) surveillance of (3) and (4) above on a continuing basis. While a life test may have only a single objective, it is evident that in many situations it would be desirable to run tests for more than one reason. Accordingly, a given life-test plan may be designed so as to embrace two or more of the general objectives listed earlier.

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[12] N. H. Roberts, Mathematical Methods in Reliability Engineering, McGraw-Hill Book Company, 1964.

[13] W. Mendenhall, "A Bibliography of Life Testing and Related Topics," Biometrika Vol. 45, 1958.

[14] Z. Govindarajulu, "A Supplement to Mendenhall's Bibliography on Life Testing and Related Topics," Journal of American Statistics Association Vol. 59, 1964.

[15] H. J. Davis and B. P. Goldsmith, "Life Test--Some Practical Considerations." Industrial and Quality Control, June 1961.

Methods of evaluating performance are:

(1) Functional tests under in-use conditions. Since actual performance in field equipment is the final criterion of performance of any component, life tests under actual use conditions would seem to be the most desirable method of evaluation. Yet, the wide variety of conditions to which identical types of equipment or systems may be subjected and the variations introduced by operating personnel make field tests most difficult to handle. Field life tests must be handled with great caution.

(2) Simulated functional test under in-use conditions. Since the hazards of loosely coordinated field testing are so great, simulated functional tests are often used. A far greater degree of control can be exercised on such tests, because they are usually much more compact, and subject to close supervision of the testing agency. One problem here is to ensure that the simulated conditions do in fact represent field conditions, so that conclusions drawn from simulated tests may reasonably be extended to predict field performance.

(3) Accelerated functional test under in-use conditions. Because of the long duration of tests necessary on components with low failure rates, attempts are often made to accelerate the tests by increasing the severity of electrical, mechanical, or thermal test conditions. Here the desired objective is to get failure information which can be correlated with field performance under more normal conditions.

(4) Environmental profiles. Specifications on many components now call for tests under a variety of conditions, where the environment is changed according to a predetermined pattern. This pattern usually involves programmed changes in physical environment and electrical conditions, over the domain of parameters to permit prediction of performance in a broad range of field conditions. Environmental profile tests may be considered forms of simulated or accelerated tests and require all the caution in design and interpretation previously discussed in this connection.

All life tests are dynamic with respect to test conditions and environment as well as time. Some variations in test conditions and environment are carefully programmed into the testing routine, e.g., heater cycling, vibration and fatigue tests, temperature and humidity cycling, and thermal strain tests. Unintentional variations, however, should be minimized to assure repeatability of test results. Examples of unintentional variations are: poorly regulated electrical supplies which may have a disastrous result on long-life performance, equipment unwittingly exposed to thermal shock (open window near temperature sensitive equipment), and rough handling.

4.1.3. Accelerated Life Testing

A recent survey paper by Nelson covered methods for planning and analyzing accelerated life tests.[16] There is considerable literature on accelerated testing, but most of the literature is narrow in scope and presents test results on specific materials and products. Accelerated testing has been applied to many materials and products. The following short list indicates some of the varied applications. Work on temperature-accelerated testing of electrical insulation is surveyed by Goba.[17] Specific applications of such testing are described by Hahn and Nelson, and Nelson.[18,19] Examples of fatigue testing of metals are described by Weibull.[20] An application of accelerated testing of solid state electronic devices is presented by Peck.[21] An application to dielectric breakdown of capacitors is given by Endicott, et al.[22] An example of voltage-accelerated dielectric breakdown of insulating fluid is given by Kaufman and Meador.[23] Test results for capacitors corresponding to

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[16] W. Nelson, "A Survey of Methods for Planning and Analyzing Accelerated Tests," IEEE Transactions on Electrical Insulation Vol. EI-9, 1974.

[17] F. A. Goba, "Bibliography on Thermal Aging of Electrical Insulation," IEEE Transactions on Electrical Insulation Vol. EI-4, 1969.

[18] G. J. Hahn and W. Nelson, "Regression Analysis for Censored Data--Graphical Method. General Electric Research and Development Center, Schenectady, N.Y., TIS Rep. 70-C-294, 1970.

[19] W. Nelson, "Planning and Statistical Analysis of Accelerated Life Tests--Methods for Complete Data," General Electric Research and Development Center, Schenectady, N.Y., TIS Rep. 70-C-294, 1970.

[20] W. Weibull, Fatigue Testing and The Analysis of Results, Pergamon, 1961.

[21] D. S. Peck, "The Analysis of Data from Accelerated Stress Tests," Reliability Physics 9th Annual Proceedings, 1971.

[22] H. S. Endicott, B. D. Hatch, and R. G. Schmer, "Application of the Eyring Model to Capacitor Aging Data," IEEE Transactions on Component Parts Vol. CP-12, 1965.

[23] R. B. Kaufman and J. R. Meador, "Dielectric Tests for EHV Transformers," IEEE Transactions on Power Apparatus and Systems Vol. PAS-87, 1968.

increases in applied voltages and ambient temperatures are reported by Levenback.[24] Stitch, et al., report the accelerated tests of microcircuits using both temperature and voltage as accelerated stresses.[25]

A technique for accelerated life testing under study at the Massachusetts Institute of Technology offers potential for relating field failures to accelerated laboratory failures.[26] Using the technique, some specimens were tested to failure under accelerated conditions, while others were tested partly under normal conditions and partly under accelerated conditions, and a graphical procedure was used to predict "life" under normal conditions. Experimental test results were reported for light bulbs, electric hand drills, electric motors, and ball bearings.

Many statistical methods for analysis of accelerated test data have been developed for specific applications. However, most such methods are general and may be used in other applications involving different life distributions, other accelerating variables and other relationships between life and the accelerating variables.

Accelerated test data are interpreted and analyzed in terms of a model. Such a model for product life consists of a life distribution and relationships for the distribution parameters in terms of the accelerating variables. Distributions commonly used to represent life are the log normal, Weibull, and exponential distributions. Relationships commonly used to represent the relationship between life and the accelerating variables are the Arrhenius relationship and the inverse power law.[27]

Three basic methods for analysis of accelerated test data are:

(1) Graphical methods. Graphical methods for analyzing data involve two plots: (a) on probability paper for the assumed distribution; and

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[24]G. J. Levenback, "Accelerated Life Testing of Capacitors," IRE Transactions on Reliability and Quality Control PCRQC-10, 1957.

[25]M. Stitch, G. M. Johnson, B. P. Kirk, and J. B. Brauer, "Microcircuit Accelerated Testing Using High Temperature Operating Tests," IEEE Transactions on Reliability Vol. R-24, 1975.

[26]E. Rabinowicz, et al., "A Technique for Accelerated Life Testing," Transactions of the ASME, August 1970, pp. 706-710.

[27]The Arrhenius relationship is the chemical kinetics equation which has been used to calculate the effect of temperature on failure rate. The inverse power law is used when the life of a component is an inverse power function of the accelerating variable. The life equation $\Theta = KV^{-n}$ is called the inverse power law, since the life value (Θ) is calculated by multiplying a constant (K) by the accelerating variable (V) raised to the inverse of the nth power.

(b) on appropriate plotting paper on which the assumed relationship between life and stress is a straight line. The graphical methods are simple to use and are easy to understand and present to others;

(2) Maximum likelihood methods. Maximum likelihood methods are extremely versatile and may be used for almost any distribution and relationship, but they are computationally laborious and thus for ease require special computer programs, and

(3) Linear estimation methods. Linear estimation methods include ordinary least squares regression methods for fitting a linear relationship to data, that is, one which is linear in the unknown parameters in the relationship. Linear estimation methods are also computationally laborious, but they can be either programmed for computer assistance or computed manually.

4.2. Description of Industry Testing of Consumer Products

4.2.1. Purpose of Testing

Industry testing can be characterized as having three purposes, development, conformance, and field evaluations, each being conducted during different phases of product evolution. Development tests are conducted on prototypes of new products or on new components for current products to ensure their meeting design goals. Conformance tests are performed on products off the production line to assure quality goals being met.[28] And finally, field tests are conducted to reveal weak components in products which should be improved in order to yield better performance or to decrease frequency of repair. The field test results could lead to product improvement redesign, which in turn would generally require development type testing to assure product modifications improve the product and introduce no new problems.

4.2.2. Industry "life" Testing

Industry wide test methods for consumer products to measure product "life" were, with the exception of two products, not available. Incandescent lamps and vacuum cleaners were the exceptions. Incandescent lamps are tested using a GSA test method accepted by the industry.[29] Canister vacuum cleaners, following several years of work by ASTM Committee F-11, can be tested using an approved ASTM standard method for life evaluation.[30]

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[28] James E. Murphy, "Reliability Conformance Testing of Commercial Products," Quality Progress, July 1973, pp. 15-17.

[29] The Interim Federal Specification, Lamp, Incandescent (Electric, Large Tungston-filament), W-L-00101G, January 15, 1969.

[30] See Appendix A (A.5) for a more complete description of this test method.

Although not intended to measure product "life," a significant source of uniform life test methods accepted by industry involves various safety related component tests. The Underwriters' Laboratories and the American Gas Association have many tests which are essentially minimum performance standards. The intent is to assure that products operate safely and, when they fail, fail safely. These tests define minimum "life" criteria and may include "harsh" operating conditions to assure the long-term safety of products under severe conditions of use.

Apparently, the needed push to encourage a cooperative industry development of life test methods for consumer products has not materialized. Such cooperative efforts generally emerge when a powerful buyer desires additional information about the product he is purchasing and many suppliers are competing for the sale. Evidently, the appliance manufacturers have been successful in demanding "life test" information from their suppliers, e.g., components are advertised as having achieved satisfactory performance for a stated number of hours.[31] Also, the Society of Automotive Engineers has set standards for products which are used either in the production or the operation of automobiles. These product tests provide information concerning the minimum expected "life" operating at a satisfactory level of performance under the test conditions. The manufacturers use this information to select components with adequate reliability and to look for alternative suppliers.

Advertising claims may provide another reason for joint cooperative test method development. The claims made by manufacturers regarding the performance of their products in advertising must be substantiated. The Federal Trade Commission (FTC) has in the past required substantiation of many claims. In the case of vacuum cleaners, the industry has joined together through ASTM to develop test methods for many aspects of the vacuum cleaner. Included among the information to be provided from testing is the capability to remove dirt, the capability to perform without requiring service, and the wear imposed upon carpets in the process of cleaning. It should be noted that the hotel industry, a large consumer for vacuum cleaners, encouraged the ASTM work. And subsequently, the FTC has expressed their interest in test methods which would enable cleanability and service life to be used as advertising claims rather than the power rating of motors.

In addition to the effort to collect industry accepted test methods, attempts were made to obtain company accepted life test methods. Appendix A provides examples which demonstrate that "life" testing is an accepted practice for a variety of consumer products by industry. The test methods described in Appendix A include automobiles, air conditioning and refrigerator compressors, washing machines, television sets, and vacuum cleaners. These test methods are being used both for design and quality

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[31]Such advertisements to the appliance industry are found in Appliance and Appliance Manufacturer, see for example Appliance, November 1976, p. 59 and Appliance Manufacturer, November 1976, p. 33 and p. 99.

conformance. Although the problem of relating laboratory test results to actual use by consumers is recognized, these tests demonstrate that introducing untested products is considered an unacceptable practice.

The documentation for product-specific company-accepted test methods for "life" testing was generally not made available to the project team. Discussions with engineering managers for several companies indicated two reasons. First, engineering judgment provides the basis upon which test decisions are made. Often the tests may be developed by an engineer for a specific purpose (generally to compare alternative designs). During this process, the engineer uses his "best judgment" regarding how long to test and his past experience regarding the relationship of the laboratory test to expected results in field use. Such testing is intended to satisfy the engineering department and other management personnel that basic minimum requirements are being met prior to commitment to production release. Although internal documentation may be required, there is no reason to share the information with the public or competitors. Secondly, test methods which have been developed to predict long term use of products are valuable tools for product change evaluation. The ability to test product improvements and cost reduction design changes and to estimate their effect on performance, including warranty costs, provides competitive advantage. Such test methods may have evolved from many years of testing and relating test results to field experience. This combination of engineering judgment coupled with field experience results in tests which permit comparison of alternative designs for evolving products. The "base line" for comparison is the previous model or component under test. This does not necessarily allow for an objective comparison between competing products of different manufacturers. The prevailing competitive atmosphere together with the general lack of an objective means for interproduct or interlaboratory comparisons inhibits the general dissemination of company-developed test methods.

4.2.3. Performance Testing

The Association of Home Appliance Manufacturers (AHAM), the American Society of Heating, Refrigerating and Air-conditioning Engineers Inc. (ASHRAE), the American Gas Association (AGA), and the American Refrigeration Institute (ARI) have published a number of performance test methods for consumer products. These tests are intended to measure product attributes. Some of the tests include "life" tests for components of the products required to meet minimum life standards.[32]

AHAM standards state that the purpose of the standard is to establish a uniform procedure for determining the performance and rating of a product under specified test conditions, and the standard is not intended to preclude the exercise of ingenuity in testing or to prevent improvement in product design and performance.

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[32]See, for example, Appendix B (B.7).

Of all the standards published by AHAM, only refrigerators, freezers and room air conditioners have the follow-up voluntary certification program to indicate the implementation of such standards. Appendix B includes excerpts from existing performance measurement test methods for air conditioners, refrigerators and freezers, water heaters, clothes dryers and washers, dishwashers and electric ranges.

4.3. Government Use of Life Cycle Costing

The military has for the past decade experimented with use of LCC in their procurements. The Federal Supply Service, on the other hand, has only recently committed themselves on a limited basis to the use of LCC as a procurement technique. This section will summarize how the Federal Government is presently using LCC.

4.3.1. Military Use of LCC

The military has recognized the importance of considering total systems cost when making procurement decisions. This came about through a recognition that for a typical large weapon system operating costs contribute approximately three-quarters of total systems costs. In the case of the B-52 aircraft, as of 1972, research, development, and testing accounted for 2 percent; acquisition accounted for 21 percent, and operations accounted for 77 percent.[33] The effect of this increasing burden of operating costs has been a reduction in the proportion of the defense budget available for new weapon acquisition. "The decline of real purchasing power for new weapon acquisition from 30 to 20 percent of the defense budget in the past decade is generally attributable to the gradual increase in that fraction of the budget devoted to operation and maintenance and military personnel over this same period."[34] Therefore, the military has been emphasizing the use of life cycle cost analyses for both evaluation of alternative weapon systems, as well as redesign of systems to lower life cycle costs.[35] The efforts also involve predicting future costs for new systems.

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[33] Boeing Company, Life Cycle Cost/System Effectiveness Evaluation and Criteria, Document No. D180-17648-1, p. 19.

[34] Russel R. Shorey, "Managing Downstream Weapons Acquisition Costs," Defense Management Journal, January 1976, p. 10.

[35] For examples of Department of Defense use of LCC models see
Lawrence E. Daver, et al., "A summary and Analysis of Selected Life Cycle Costing Techniques and Models," Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, August 1974, AD-787 183,
Marco R. Fiorello, "Getting 'Real' Data for Life-Cycle Costing," Rand Corporation, Santa Monica, California, January 1975, AD-A010 960, and
Thomas W. Otto, Jr., "Life Cycle Cost Model," U.S. Army Electronics Command, July 1975, AD-A013 369.

In addition to projections of future costs, the military has also used retrospective analyses to determine useful life based upon a minimization of average system costs. "The economic life of the M39A2 Series 5 Ton Trucks...has been assessed by determining the mileage at which the average system cost per mile (costs associated with the acquisition, shipping and maintenance of the truck) is minimized (truck economic life)."[36] The trucks are retired when they reach the mileage corresponding to useful life.

Case studies of smaller scale Department of Defense purchases using life cycle costing were also found. Examples include purchase of replacement of siding on family housing,[37] aircraft tires,[38] lead acid storage batteries,[39] and non-magnetic diesel engines.[40]

4.3.2. General Services Administration (GSA) Use of LCC

The Federal Supply Service (FSS) in cooperation with ETIP has participated in a procurement experiment to use a modified LCC approach for four consumer products.[41,42] The experiments are "to determine whether it is feasible to stimulate the development, production, and marketing of energy-efficient products through the use of Government purchasing practices."[43] Of course, GSA's objective is also to save Government funds.

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[36]Raymond Bell, et al., "Vehicle Average Useful Life Study for Truck, 5 Ton, 6x6, M39A2 Series," Technical Report No. 128, Army Materiel Systems Analysis Activity, June 1975, p. 15.

[37]DOD Casebook Life Cycle Costing in Equipment Procurement, LCC-2, July 1970, Case 2.

[38]Ibid., Case 5.

[39]GSA, Federal Supply Service, Life Cycle Costing Workbook, "Applying LCC in the Federal Supply Service," December 1973, p. 1-1.

[40]Ibid., p. 1-13.

[41]See P. Clare Goodman, "A Survey of Manufacturers' Views on the ETIP Procurement Experiment, Volume One: Refrigerator-Freezers," NBSIR 75-954, December 1975.

[42]Ibid., Volume Two: Water Heaters, NBSIR 76-983, January 1976.

[43]Ibid., Volume Three: Ranges, NBSIR 76-1027, February 1976, p. 1.

The basis for the FSS supplier selection uses a truncated version of the general LCC formula.[44]

$$LCC_L = PLC + \left[\sum_{T=1}^{N} \frac{1}{(1+r)^T} \right] C$$

where, LCC_L = limited LCC

PLC = purchase price + shipment cost

N = most appropriate value for life

r = most appropriate discount rate

C = operating energy cost when new.

4.3.3. Government Developed "Life" Test Methods

This section summarizes two examples of Government developed life test methods. The purpose and motivation for their development differ. In the case of incandescent lamps, GSA uses the test method to qualify manufacturers' products for procurement. In the case of automotive tires, the National Highway Traffic Safety Administration (NHTSA) has responded to a Congressional mandate to establish a "uniform tire quality grading system" for the provision of objective information for consumers.

The following discussion relates for these two consumer products the purpose of the test methods and the events which have transpired in providing information on them in the marketplace. The test method for incandescent lamps is used to check a randomly selected sample of lamps from manufacturers requesting to be listed on the GSA Qualified Products List.[45,46] Manufacturers once qualified can participate in the bidding process for Government procurements. The test specifies test conditions and procedures for measuring lamp performance for life, light output, and power consumption.

The Federal Trade Commission (FTC) promulgated a trade regulation rule, which went into effect in January 1971, for the sale of general service incandescent lamps in commerce.[47] The regulation requires disclosure of the electrical power consumed, the light output and the

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[44]See p. 14 for the general LCC formula.

[45]The Interim Federal Specification, Lamp, Incandescent (Electric, Large Tungston-filament), W-L-00101G, January 15, 1969.

[46]See, for example, Federal Qualified Products List of Products Qualified under Federal Specification WL-00101, Lamp Incandescent, February 29, 1972.

[47]Federal Trade Commission, Trade Regulation Rule Relating to Incandescent Lamps (Light Bulbs): Disclosure of Lumens, Life, Cost and Other Data (35 FR 11784), July 23, 1970.

average laboratory life on the sleeves or paper containers in which bulbs are packaged. The FTC further specified these performance values shall be obtained in accordance with the requirements of the GSA Interim Federal Specification W-L-00101G for incandescent lamps previously cited.

The NHTSA, in order to aid the consumer in making an informed choice in the purchase of passenger car tires, intends to establish the Uniform Tire Quality Grading System.[48] The regulation would require motor vehicle and tire manufacturers and tire brand owners to provide information indicating the relative performance of passenger car tires in the areas of tread wear, traction, and temperature resistance. The tread wear test is conducted by operating vehicles on a specific roadway course, approximately 400 miles in length.

The history of the Uniform Tire Quality Grading System indicates some of the difficulties in implementation of such a scheme. Congress set September 1968 as the date for the proposal of the rules with regard to tire grading. The NHTSA has published proposals in the Federal Register five times since 1971. The latest rules were published in May 1975 to become effective on January 1, 1976. The tire industry filed a suit against the rules in the sixth District Court of Cincinnati, Ohio, in December 1975. The court has placed a stay on the rules since that time.

4.4. Summary and Observations

There exists a well developed body of literature concerning the statistical techniques for analyzing "life" test data. The test methods from which the data are generated, however, are rarely reported in the literature.

Many tests either exist or are being developed to measure how well products perform their intended function. These tests are being developed through such organizations as AHAM and ASTM. Life testing is now being conducted by individual manufacturers for development, quality conformance and follow-up field evaluations. These test methods, however, are generally unavailable to the public due to the proprietary nature of these tests. Life testing is comparative and often tests terminate when specific minimum goals are achieved, not necessarily "end of life." For example, a component is replaced because a less expensive substitute is found. If testing indicates the replacement lasts longer than its predecessor, the test may terminate prior to failure. Very few "life" test methods are agreed upon industry-wide. The Underwriters' Laboratories and American Gas Association have "life" tests designed to indicate if minimum performance goals are achieved for safety related product components.

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[48]Federal Register, Vol. 40, No. 103, May 28, 1975, pp. 23073-23083.

The Federal Government has become directly involved in LCC in three major areas:

(1) Establishing test methods for use by manufacturers to label products with "life," e.g., incandescent lamps (operating hours) and automobile tires (comparative tread wear measure),

(2) Using LCC criteria to set maintenance and retirement policies for military products, and

(3) Using LCC criteria for procurement of large systems and some consumer products.

The GSA/ETIP LCC criterion now in use for consumer product procurements is limited to inclusion of a projected energy cost plus an initial purchase price. While this may be a step toward including energy conservation in a purchase decision, it is a strictly limited concept of LCC.

The relatively advanced state of LCC analysis for weapons procurement by the military may be accounted for by the fact that rather stringent and complete control can be achieved by the military on the operation, maintenance, and repair activities associated with the use of weapons. Because of such control, costs associated with operation, maintenance, and repair activities are predictable and controllable. Hence, planning on the basis of LCC information becomes easily implementable. Similar observations apply to industry's and government's uses of durable equipment: for example, the aircraft fleet by the commercial airlines, automobile fleet by the car rental companies, and police car fleet by the various local police departments. A similar observation, however, cannot be applied to the use of consumer durables. The general absence of control on activities and the resulting difficulty in predicting costs make the LCC analysis of consumer durables a much more difficult topic of research.

Observation of the state-of-the-art leads to a conclusion that the application of LCC to consumer products is not immediately practicable. Although the elements of technical knowledge are available for such an application, the total body of knowledge is insufficient. This can be characterized by the availability of statistical techniques for testing but the unavailability of standardized LCP test methods. The inability to gain access to company test methods and field experience for consumer products also hinders LCC development efforts. These data are needed to correlate laboratory test results to actual field experience and to establish the test conditions, based upon use and environmental conditions in the field. The GSA/ETIP LCC experiment falls short, since it neglects the essential element of LCP, i.e., how products perform over time. Therefore, additional efforts are required to push the state-of-the-art in order to make LCC practicable for consumer products.

5. WORK TO BE DONE

If LCC information is to be made available to consumers for new products there are a series of problems which must be addressed and resolved. At the present time, elements of LCC available for consumer products include initial purchase price and installation costs, a projection of maintenance costs (based upon manufacturers recommendations), and for certain appliances, energy costs when units are new. Factors in the LCC formula which are ill-defined and for which information is lacking include: product life, operating cost, repair cost, discount rate, and salvage value. Efforts, intended to provide manufacturers with a basis for testing consumer products and estimating cost of ownership, must address both the definitions for the above factors and provide techniques for assigning values. This section will identify areas requiring research, recommend long-term research tasks and immediate tasks appropriate for NBS attention.

5.1. Areas Requiring Investigation

The basic areas requiring further investigation in order to develop the capability to generate ownership cost information include: information on consumer products use, laboratory test development and validation, rules for test application and techniques for cost estimation.

5.1.1. Basis for Laboratory Test Design

Essential to the design of LCP laboratory test method are data which relate how consumers use the product. This area of investigation involves the process of gathering relevant user information to characterize the use environment. A study to examine the consumer use patterns for products must necessarily be specific to the type of product being considered. Information must be obtained which relates the hours of use and mode of use for a product per specified time interval, thereby providing characterization of the "normal," "multi-modal," or "extreme" patterns of use the product is subjected to by consumers. Such information can be collected through placing timers and counters in products and observing large numbers of persons using products. The information would provide a basis for realistic test methods to determine product performance under simulated use conditions over time.

Environmental factors, external to the product, can be diverse and their interactions with the product and use patterns very complex. An understanding of the environmental conditions, e.g., voltage variations, water quality, air quality, humidity, and temperature variations, is also essential to designing a LCP laboratory test method.

Prior to developing a test method minimum levels of performance must be specified. The nature of LCP testing requires the measurement of the time trace of performance. LCP testing also requires that "acceptable" performance be well defined. This becomes necessary in order to make objective determinations for when to make repairs during a test. Such specifications are subjective and with the exception of becoming inoperative open to debate. Nevertheless, a means must be found to resolve this difficulty. Also, identifying failure modes for the product prior to test development provides information useful for assessing how well tests replicate "normal" conditions.

5.1.2. Laboratory Test Method Development

The objective of a test method is to yield performance information which can be related to field use. Even when use and environmental conditions have been well defined there are limitations on the capability to simulate them in a laboratory. Nor is it necessarily desirable to attempt to simulate "all" conditions. Therefore, investigations must concentrate on recognizing significant use and environmental factors which affect performance. The less complicated the test conditions, the less expensive the test and the more likely tests can be made reproducible.

The process of simulating use and environmental factors offers an additional area for investigation. Techniques for automating repetitive loadings and incorporating the user effects in tests are challenging activities.

Many major consumer products have service life expectancies exceeding 10 years.[49] Obviously it is unreasonable to test products for such long durations. Accelerated tests must be developed in order to provide LCP information within reasonable time constraints and without tying up test equipment indefinitely. Accelerated tests reduce the time to failure by making use and/or environmental conditions more severe than normal. Investigations must be initiated to ensure that failure modes are not changing, that aging factors are taken into account and that laboratory test time or cycles can be related back to field use.

5.1.3. Laboratory Test Validation

The process of validating a laboratory test method involves relating the results from the laboratory test to observations made in field use. Such correlations can be made using data routinely reported by manufacturers, collecting field data directly from consumers or conducting controlled field experiments. Each of these methods have both positive and detracting features. Investigation into which techniques or combinations yield acceptable results are crucial to providing evidence that the LCP test methods are acceptable for characterizing product performance.

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[49]Marilyn Ruffin and Katherine S. Tippett, "Service-Life Expectancy of Household Appliances: New Estimates from the USDA," Home Economics Research Journal, March 1975, pp. 159-170.

5.1.4. Rules for Test Application

Once test methods have been developed and validated, rules must be developed to guide manufacturers in their application. These rules involve such issues as the criteria for when to stop a test. With the exception of non-repairable products, products can continue to be repaired and tested indefinitely. Since the LCC information is intended for comparison of new products by potential first owners, one alternative is to use the USDA distribution data for service life expectancy. It is possible to stop testing at the age corresponding to perhaps the 90th percentile of disposal (at this age 90 percent of first owners have discarded the product).

Another issue relates to the number of products that must be tested. This involves the degree of confidence that is required for the values derived from the test. Variations in test results can be attributed to two major sources: (1) the test procedures (repeatability) and (2) the production process (quality control). Also not to be overlooked are the costs for testing which include plant and equipment, personnel and products destroyed during testing. All of these factors must be weighed to ascertain a uniform method for determining how many products to test.

The question of how test results should be reported includes documentation for testing. In cases where test results characterizing LCP must be translated to LCC information the rules for such transformations must be clearly delineated. The methods and formats for presentation of LCC information to consumers presents an additional area for investigation.

5.1.5. Cost Estimation

The translation of LCP information to LCC information requires estimates of cost for the input factors associated with the product's LCP. Methods and procedures must be developed to assign costs to energy, repairs, and other input factors. Also, because the LCC formula uses discounting of future expenses to a present value, an appropriate or agreed upon discount rate is essential prior to LCC computations. Its use for consumer applications requires considerable thought.

5.2. Long-Term Research Goals

For the purpose of planning long-term research, both engineering and economic disciplines must be utilized in order to advance the application of LCC for consumer products. The general goals which are described below are intended to provide potential research support for an operational LCP/LCC program.[50]

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[50] See Appendix C for a listing of the tasks required to implement an operational LCP/LCC program for consumer products.

5.2.1. Engineering Goals

The development of test methods to measure LCP can logically be approached recognizing the diversity which exists among consumer products. For appliances, the user interacts in different ways depending upon the type of appliance. In the case of hand-held appliances the user plays a more direct role. For example, using a hand-held mixer predominantly for making fudge has a more adverse effect on LCP than predominantly using the mixer for meringue. Therefore, although incorporating similar tasks regardless of the product, test method development for hand-held products must account for the direct effect of users on LCP. For larger consumer products the major concern involves their repair and degradation of performance over time. The major emphasis for larger products should be toward the process of developing methods to analyze and cause component failures in the process of characterizing extended performance.

These research goals would incorporate research tasks which would address themselves to the problems enumerated in the previous section. Although this subsection has used an engineering title, a successful program requires development of technique for gathering operational information relative to a product's use, use environment, maintenance, repair, and indications of "life" for non-repairable products. More engineering oriented is the research required to simulate use and environmental factors, to automate test procedures and to develop a basis for accelerated testing.

5.2.2. Economic Goals

Essential to the translation of LCP information into LCC information is the valuation of the LCP input factors. Tasks must be directed toward the development of procedures to yield cost estimates for operating cost factors and repair requirements and the selection of appropriate discount rates.

An important area for future research also concerns the question of how "best" to provide consumers LCC information? This question relates to product selection, information content, complexity, format, the vehicle for presentation of comparative LCC information, and impact assessment.

5.3. Immediate Activities

During the course of this study, it was not intended that any laboratory based efforts be conducted. The information obtained was, therefore, based upon observations of industry testing and available literature, documenting statistical techniques for handling data and limited test method development. In order to obtain "first-hand" knowledge of the problems associated with LCP test method development and LCC, it is recommended that laboratory and field data collection efforts be initiated.

Two LCP demonstration projects are proposed: the first to integrate user effects inherent in the operation of a small hand-held product, and the second project to characterize extended performance for a larger consumer product. These research efforts relate directly to the longer term engineering tasks and provide necessary experience to gain additional insights into the problems of conducting LCP test method development and LCC analyses for consumer products. The demonstration projects should follow the process tasks suggested in Appendix C (C.2).

APPENDIX A.
Examples of Consumer Product Life Testing

In order to demonstrate that "life" testing is an accepted practice for a variety of consumer products in industry, the following examples have been summarized. The test method descriptions illustrate that, although the problems of relating laboratory based tests with actual use by consumers are recognized, the alternative of "blindly" introducing untested products is considered a greater and generally unacceptable risk.

A.1. Automobiles

During a recent conference Ford Motor Company's David J. Barrett, Assistant Chief Engineer - reliability, explained Ford's automobile durability testing.[1]

> "Vehicle and component durability are confirmed through an elaborate series of laboratory and proving-ground tests. We have the equipment and techniques to simulate long term customer usage of a vehicle or its components in the laboratory in a matter of weeks. The durability of components is evaluated through laboratory tests and on prototype vehicles while they are under development, again at the pre-production level and, finally, production parts are analyzed for compliance with our ever higher acceptance standards.
>
> Prototype vehicles are subjected to thousands of miles of "worst-case" testing at our proving grounds; they are operated over cobblestones, square-edged potholes and other road surfaces designed to bend, twist, stress, fatigue and wear out parts. Problems which show up are corrected and the whole process is repeated again.
>
> In addition, we make extensive use of fleet testing to supplement the information gained at our own facilities. Newly designed components are installed on fleet cars, (some of which accumulate in excess of 800 miles a day), to acquire actual service experience on new parts prior to their release for production. Representative production vehicles are also tested on our proving grounds to assure conformance to the same stringent requirements."

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[1]Barrett, David J., Automobile Durability, Workshop on Wear Reduction - Office of Technology Assessment February 23, 1976

A.2 Refrigeration and Air Conditioning Compressors

A paper by Kalivada and Yun on life tests for air conditioning and refrigeration compressors at Copeland Corporation was presented at the 1976 Annual Reliability and Maintainability Symposium.[2] The paper describes the test plans and methodology which are being developed to provide meaningful assurances that failure rate targets on air conditioning and refrigeration compressors will be met or exceeded. The findings of tests are utilized for production audit or design feasibility studies. Production audits for compressors are being conducted for regular as well as for special corrective action programs. Compressors are also subject to qualification tests to meet various regulatory codes and certify their safety and compliance for good design practice.

One of the first requirements perceived at Copeland was a need to run statistically significant numbers of compressors for long periods of time under controlled conditions. Sufficient test stands had to be provided to handle the requirements of four readily identifiable groups of compressors:

1. Development - new compressors and changes to existing ones.
2. Pre-production qualification.
3. Initial production audit.
4. Production audit.

For this reason, 252 new test stands were constructed in four physical sizes, apportioned to handle quantities of compressors in proportion to production volumes. It was estimated that, depending on the test requirements, these stands would be adequate to handle from 1,000 to 1,500 compressors per year. In each stand, pressure controls, timers and temperature recorders are provided so that compressors can be operated 24 hours a day, seven days a week.

One of the major concerns of the test program is to minimize the failure rates of compressors in order to avoid the consequent problems and the costs involved back to the customer and ultimate consumer. At the same time, the systems and applications are complex enough that "zero defects" cannot be economically expected. Establishment of failure rate targets was viewed as a multidisciplinary corporate exercise with both the needs of the customer and the corporate warranty-fund requirements kept in mind. Performance of the product against the goal is measured by analysis of in-warranty compressors returned from customers. Returned compressors are carefully inspected on a sampling

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[2]Kalivoda, Frank and Kyung Woo Yun, "Modeling Mechanical System Accelerated Life Tests," Proceedings 1976 Annual Reliability and Maintainability Symposium, January 1976 (available from IEEE, Piscataway, N.J.) pp 206-212.

basis, classified into over 140 codified failure causes and summarized by the computer information services group for corrective actions by the appropriate corporate function. There is, however, a built-in time lag in this information feedback system. With a warranty period of 20 months, about two years are required after the end of a model year before the data can be considered complete. This is a long time for a high volume manufacturer, and it is the purpose of the accelerated test to bridge this gap and provide the corporation with the assurances it needs.

Air conditioners, refrigerators and heat pumps are all based on the vapor compression cycle. In this cycle, heat is effectively pumped uphill from a low temperature zone to one of higher temperature. This requires the addition of external work, a function performed in the compressor. Since systems of this nature must have expected lives of the order of 15 years, reliability must, therefore, be of prime concern in the design and manufacture of the compressor. The large scale manufacturer of these compressors cannot wait, of course, for the field results for 15 years of production to establish the reliability of his products. Thus some form of "accelerated" testing is required to establish life characteristics in the laboratory.

The current effort in life testing at Copeland is to parallel "normal" load tests with "accelerated" tests in order to obtain the appropriate correlations to field data. This is necessary to insure that no new mode of failure is introduced due to acceleration of the test stresses. Thus, for example, an operating temperature beyond the point of oil breakdown would yield invalid results. Most durable components are tested under an accelerated condition. This is true of problems noted from field returns which often require reliability engineering to identify and simulate the failure mechanism in the laboratory to guide immediate corrective actions.

Life tests under normal load conditions are viewed as basic in establishing a product's reliability level, and are, by nature, long term. The only acceleration factor here is the fact that compressors are run seven days a week, 24 hours a day or about 2,000 hours in three months. Normal load tests are also necessary to verify the validity of accelerated tests. The number of possible combinations of compressor operating conditions is theoretically infinite. In field use, this is indeed a fact. However, for the purpose of compressor life testing, only finite numbers of operating modes can be used from a practical standpoint. This approach can be rationalized since a compressor is expected to run without problem for 15 years unless a certain part is highly stressed due to an "unusual" event. In terms of elevated stress on the various components of the compressor, basic tests of these components are included in compressor life testing. A life test plan may consist of one or all of these tests. The performance of the compressor is generally measured before and after life testing to determine any change. Finally, the compressors are disassembled and all parts inspected.

A.3 Washing Machines

An internal laboratory standing instruction on accelerated washer life tests from a manufacturer is described below for illustrative purposes. It should be noted that this manufacturer no longer produces washing machines. This test procedure was obtained subsequent to the end of production.

The laboratory standing instruction covers the method of determining the condition of an automatic washer upon receipt from the factory or model shop. It also provides a method of auditing the condition of the washer at any time during its life.

The method of determining the condition of an automatic washer includes pre-test observations and taking measurements. The pre-test observations require thorough inspections of the wrapper top panel, back splash, and spin tub and drive assembly for scratches, dents, porcelain chip, missing components, poor workmanship and any other defects.

Measurements to be taken are: maximum and minimum water levels in the tub; wattage and speed of agitation; acceleration and deceleration of spin, wattage and speed of spin; and low voltage operations in agitation and in spin.

All these inspections and measurements are performed for the purpose of quality assurance such that the detection of any defect may start the tracing of the cause of the defect. This standing procedure for inspections and measurements is a part of the process of making sure that the specifications of the product are met.

The life test is carried out by operating the washing machine continuously on normal wash cycle, hot water fill, normal speed and with a 10 pound mixed towel load.

The standing procedure requires technicians to make daily inspection of each machine and stop any machines that are apparently malfunctioning (noisy, water leakage, oil leakage, erratic watt meter trace, etc.). The routine inspection places emphasis on spin tub, agitator, and drive assembly.

If a machine malfunctions or a part fails, necessary corrections, repairs, or parts replacement are to be made to put the machine back in operation.

The life test is performed 18 hours a day which can normally complete 43 washing cycles. It is hypothesized here that a washing machine performs 500 washing cycles a year. Thus, one laboratory working day is equivalent to 0.09 machine years, and it required 116 laboratory working days to accumulate 10 years history of a washing machine.

A.4 Television Sets

Sanford Thayer has reported on examples of reliability test methods now in use in Japan observed during a visit to 19 manufacturing plants.[3] A manufacturer of television sets has correlated field repair requirements to accelerated laboratory test conditions to allow for rapid evaluation of new designs. "The results indicate that for each hour of operation under 95°F, 95% R.H. they should expect about 16.8 hours of operation under field conditions. Other conditions such as vibration and cycling did not contribute to the prediction of field type failures."

A.5 Canister Vacuum Cleaners

The ASTM organized Committee F-11 on Vacuum Cleaners in May, 1972. The Committee has published an approved society standard "Standard Method for Life Evaluation of Air Handling System of Household Canister Vacuum Cleaners."[4] The test provides an accelerated laboratory procedure for determining service-free life in operating hours. End of service free life is determined by either of two criteria, whichever occurs first:

> "Failure - Service-free life is limited by any failure which is not normally repaired by a consumer in the home. Carbon brush wearout is an example of such a failure.
>
> Degradation of Performance - Service-free life is limited by degradation of performance, due to the air-handling system less hose, amounting to 25% reduction in air flow..."

Committee F-11 is also developing a method for life evaluation of household upright vacuum cleaners.

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[3]Sanford B. Thayer, "Reliability Methods in Japan," Proceedings 1976 Annual Reliability and Maintainability Symposium, January 1976, p. 77

[4]ASTM Designation: F411-75, June 1975

APPENDIX B.
Industry Performance Test Methods for
Consumer Products

The Association of Home Appliance Manufacturers (AHAM) has published a number of test methods to measure performance for consumer products. Other organizations also involved with establishing performance tests are the American Society of Heating, Refrigerating and Air-conditioning Engineers Inc. (ASHRAE), the American Gas Association (AGA), and the American Refrigeration Institute (ARI). This appendix includes excerpts from existing performance test methods for air conditioners, refrigerators, and freezers, water heaters, clothes washers and dryers, dishwashers and electric ranges.

B.1 Room Air Conditioners

(A) AHAM RAC-1 (Z234.1-1972), An American National Standard for Room Air Conditioners, Association of Home Appliance Manufacturers, December 21, 1972.

Performance tests for cooling units include a cooling capacity test, a moisture removal capacity test, a recirculated air quantity test, a ventilating air quality test, an exhaust air quantity test, an electrical input test, a power factor test, a maximum operating conditions test, freezing tests, an enclosure sweat test, and a condensate disposal test.

In addition to the tests for the cooling mode, performance tests for heating-cooling units when operated in the heating mode include a heating capacity test, an electrical input test, an application heating capacity test, a maximum operating condition test and an outside coil de-icing test.

(B) ASHRAE STANDARD 16-69, Method of Testing for Rating Room Air Conditioners, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., January 26, 1969.

This standard prescribes a method of testing for obtaining cooling capacities and air flow quantities for rating room air conditioners. Performance determinations on room air conditioners consists of (1) quantitative effects produced upon the air in the space to be conditioned such as cooling and dehumidification in Btu per hour and air flow rates in cubic feet per minute under specified conditions; (2) other data pertaining to the application of the equipment such as the current in amperes and the power input in watts under specified conditions.

B.2 Refrigerators, Combination Refrigerator-Freezers and Freezers

(A) AHAM HRF-2-ECFT, Test Procedure to Determine the Freezer Temperature and Energy Consumption of Household Refrigerators, Combination Refrigerator-Freezers and Freezers, Association of Home Appliance Manufacturers, July 1975.

The purpose of this standard is to establish a uniform and repeatable procedure or standard method for measuring the average freezer temperature and the electrical energy consumption of household refrigerators, household combination refrigerator-freezers and household freezers at specified conditions at an ambient temperature of 90°F.

(B) ASHRAE Standard 13-69 (ANSI B38.1-1970), American National Standard, Methods of Testing for Household Refrigerators, Combination Refrigerator-Freezers, and Household Freezers, Amrican Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1970.

This standard includes methods of testing and methods of determining volumes and shelf areas of freezing and storage spaces for household refrigerators, combination refrigerator-freezers and household freezers. This standard also describes procedures for determining the performance of refrigerators, combination refrigerator-freezers, and freezers under specified laboratory test conditions, and procedures for determining the durability of various components as affected by use or environmental conditions.

The durability test procedures include: (1) handling and storage test which determines the ability of the cabinet, when packaged for shipment, to withstand handling and storage conditions in extreme (high and low ambient) temperatures; (2) external surface condensation test which determines the extent of condensation of water on the external surface of the cabinet under ambient conditions of high relative humidity; (3) internal moisture accumulation test which determines under severe operating conditions the moisture accumulation within the insulation spaces and on the refrigerated surface in the cabinet and the effectiveness of defrost water disposal; (4) current leakage test which measures the quantity of leakage current flowing through the entire electrical insulating system under severe operating conditions; (5) environmental cracking resistance test which determines the cracking resistance of the plastic compartment liners, door liners and breaker strips at operating temperature when coated with 50/50 mixture of oleic acid and cotton-seed oil; and (6) bottom breaker strip(s) impact test which determines the impact resistance of the bottom breaker strips at operating temperature when coated with 50/50 mixture of oleic acid and cotton-seed oil.

B.3 Water Heaters

(A) Electric Water-Heaters, ANSI C72.1-1972, American National Standard for Household Automatic Electric Storage-Type Water Heaters.

The purpose of this standard is to establish a uniform procedure for determining the performance of household automatic electric storage-type water heaters under specific test conditions and to establish certain minimum requirements. Three major performance tests are thermostatic temperature control test which determines the performance of temperature controls; service performance tests which include stand-by performance test and service efficiency test, and diffusion test which determines the degree of mixing of incoming cold water with stored water, a continuous depletion test is also made.

(B) Gas Water Heaters, ANSI Z21.10.1-1975, American National Standard for Gas Water Heaters, Volume I, American Gas Association.

This ANSI standard specifies test methods for 30 different tests for measuring performance of various characteristics/ components of a gas water heater. Among these tests are a combustion test, a burner and pilot operating characteristics test, a pilot burners and safety shut-off devices test, a heat required to supply daily quota of hot water test, a quantity and temperature of hot water test.

B.4 Clothes Dryers

(A) AHAM HLD-1, Performance Evaluation Procedure for Household Tumble-Type Clothes Dryers, Association of Home Appliance Manufacturers, June 1974.

The purpose of this standard is to establish a uniform procedure for evaluating the performance of automatic, semi-automatic and non-automatic home laundry clothes drying equipment. This standard applies to both electric and gas dryers. The standard specifies clothes load, test conditions and methods of loading. The three performance tests are: the moisture removal test which determines drying time and drying efficiency; the clothes temperature measurement test which provides a procedure for measuring the fabric temperature in dryers; and the wrinkling test which evaluates garment wrinkling in a finished dryer load.

(B) HLD-2EC, Standard Method of Measuring Energy Consumption of Household Tumble-Type Clothes Dryers, Association of Home Appliance Manufacturers, August 1975.

The purpose of this standard is to establish a uniform procedure for measuring the energy consumption of household gas and electric tumble-type clothes dryers. Through this standard it is intended that dryers can be evaluated with respect to the energy consumed to dry a standard load under standard conditions. The monthly energy consumption is based on 43 cycles per month.

B.5 Clothes Washers

(A) AHAM HLW-1 (Z224.1-1971), An American National Standard, Performance Evaluation Procedure for Household Washers, Association of Home Appliance Manufacturers, December 1971.

This AHAM standard specifies clothes load, washer setting, water condition (temperature, level, hardness and quantity), and other test conditions. The seven performance tests are: the soil removal test which evaluates the ability of household washers to remove insoluble and heavier-than-water soils from clothes and washing area; the whiteness retention test which evaluates the performance of household washers in maintaining the whiteness of fabrics in relatively unsoiled areas while removing soil in relatively soiled area; the rinsing effectiveness which evaluates the rinsing effectiveness of washers; the water removal test which evaluates the performance of household washers in extracting water from the clothes load; the tangle-free action test which evaluates the degree of clothes tangling among themselves or with any part of the machine caused by the action of washers.

(B) AHAM HLW-2EC, Test Method for Measuring Energy Consumption of Household Clothes Washers, Association of Home Appliance Manufacturers, December 1975.

This AHAM Standard, HLW-2EC, is supplemental to American National Standard Z224.1-1971 and encompasses test methods for determining the energy consumption of washers. The results reported from this test method are considered to be representative of consumer use of this product with regard to energy consumption.

B.6 Dishwashers

AHAM DW-1 (A197.5-1975) American National Standard, Household Dishwashers, Association of Home Appliance Manufacturers, August 1975.

This standard includes definitions, methods for testing and evaluating performance, safety and sanitation characteristics of household dishwashers. The standard methods are intended to provide a means by which different brands and models of dishwashers can be compared and evaluated with respect to characteristics of significance in the use of the product. A principal objective of the test method is to measure the washing performance of dishwashers. Procedures are specified for preparing the test load (dirtying the dishes with food) and evaluating cleaning performance (inspecting the dishes).

B.7 Electric Ranges

AHAM ER-1 (C71.-1972), An American National Standard, Household Electric Ranges, Association of Home Appliance Manufacturers, January, 1972.

The performance and durability-requirements test for surface units are heating time and efficiency, time-to-boil, and durability. All surface units have a minimum life of 3,500 hours "on" time.

The performance and durability requirements tests for ovens include heat loss, thermostat calibration and linearity, baking/browning performance, broiler heat distribution, oven life, thermostat life, and rotisserie performance and endurance. The oven life test specifies that the oven and its component parts and accessories shall show no observable deterioration after 30 days of continuous operation at an average temperature of 260°C (500°F). The thermostat life test specifies that oven thermostat or combination oven thermostat and switch shall have minimum life of 30,000 cycles.

APPENDIX C.
General Research and Product Specific Tasks for an Operational LCP/LCC Program for Consumer Products

The following tasks identify research areas and related subtasks which might be addressed prior to implementation of an operational LCP/LCC program. These tasks have been divided into general and product specific areas for research. The general research tasks are intended to provide methods directly applicable to product specific LCC, while the product specific tasks describe the processes required to derive LCC for consumer products.

C.1 General LCP/LCC Research Tasks

Task 1: Develop, adapt or standardize methods to measure performance over time of consumer products.

Subtasks: (a) Examine means for determination of minimum levels of performance, below which repairs or maintenance are required to define parameters for life testing of products.

(b) Translation of data on consumer use patterns into test conditions to simulate use of products.

Develop procedure to evaluate and characterize consumer use patterns as related to influence on LCP.

Classify products according to:

- degree and type of consumer interaction
- type of use--intermittent vs. constant
- other factors
- interaction with other consumer products

Based upon product classifications, specify scheme for ascertaining consumer use patterns via:

- mail survey
- timers and meters in home
- consumer kept log
- observation of use under controlled conditions
- observation of use in home environment

Determine circumstances where each scheme or combination should be used.

(c) Translation of data on environmental factors into test conditions to simulate use of products.

Determine critical environmental factors which influence the LCP of products, such as electrical energy characteristics, water quality, humidity, temperature, etc.
Identify information source data on critical factors:

- utility companies--public service commissions
- measurements in homes
- literature surveys
- manufacturers records
- FPC/EPA

(d) Examine means for evaluating LCP in the laboratory.

Determine or develop means to simulate use and environmental factors including need for:

- special environmental chambers, other facilities
- incorporation of user effects
- automation of cyclical loading
- accelerated testing

Establish guidelines applicable to rules for test application to address such questions as:

- number of products to be tested
- how long to test

Task 2: Determine means of imputing monetary costs to elements of LCP

Subtasks: (a) Examine alternative economic forms for expression of sales and test data in monetary terms -
Develop and evaluate cost estimation models which incorporate initial installation, maintenance, repair and energy costs.

(b) Develop methods for establishing monetary costs associated with servicing appliances including repairs, maintenance and parts by

- monitoring service charges for selected products
- searching records of service agencies willing to participate
- examining recommended fee schedules for repairs/ service, parts catalogs and suggested price lists and
- examine use of the discount rate as applied to consumers purchases

(c) Develop methods for establishing monetary costs associated with energy.

Task 3: Develop program to disseminate LCP/LCC data through mix of channels to include specification of format, complexity, content and amount of information.

Subtasks: (a) Examine literature and conduct surveys to evaluate effectiveness of existing dissemination channels including

- product point-of-sale materials
- retail sales personnel
- print or broadcast advertising media
- public or private consumer educational programs
- consumer rating publications

(b) Use various "test vehicles" to ascertain (by market purchasing segments) how people react, who influences purchase and how they accept "test vehicle."

Task 4: Develop framework for impact analyses for consumers, producers and society.

Subtasks: (a) Develop cross-sectional surveys on consumer purchase patterns to be distributed prior to and after distribution of LCP/LCC data to assess program effectiveness. Examine data to ascertain:

- changes in consumer purchase patterns
- whether consumers are using LCP information
- potential "program" changes which could aid consumers to use of LCP/LCC information.

(b) Determine producer survey activities necessary to characterize product performance, quality control and production costs and competition and pricing structure prior to introduction of LCP/LCC data to enable evaluation of impacts.

(c) Examine the data presented for LCP/LCC to assess its influence over:

- trade offs, e.g, performance level vs. durability
- quality control and production cost
- pricing, competition, sales and changes in market structure.

Determine the degree and extent of producer participation in the LCP "program."

(d) Examine the potential impact of LCP/LCC data to consumers relative to positive and negative effects on

- rate of inflation
- energy and materials conservation
- employment (especially geographical redistribution)
- consumer expenditures

Task 5: Devise method for selecting products and attributes for test method development and value specification.

Subtasks: (a) Adopt and develop approach similar to proposed Senate bill S643 (Consumer Product Testing Act of 1975).

(b) Develop procedure for use of sounding boards and other consumer representation channels.

(c) Incorporate assessment of technical and economic feasibility.

C.2 Product Specific LCP/LCC Process Tasks

The tasks which follow are necessary in order to develop LCP/LCC information.

Task 1: Identify performance attributes important to LCP/LCC.

Task 2: Establish use and environmental conditions/distributions

Task 3: Determine critical set(s) of use and environmental factors influencing LCP/LCC.

Task 4: Identify common in-use failure modes.

Task 5: Develop operational simulation which results in failure modes similar to field failure modes.

Subtasks: (a) Determine measurements required to provide adequate documentation.

(b) Establish criteria for failure.

Task 6: Correlate test failures to field failures including relationship and range of stresses for which relationship holds.

Task 7: Establish LCC estimation framework.

Task 8: Collect field cost data for translation of LCP to LCC including energy, service, parts, etc.

Task 9: Perform LCC analyses.

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This report assesses the practicability for applying the life cycle costing (LCC) approach to consumer products. The report provides a basis for understanding: the potential for application, benefits and effects of LCC; the basic concept of LCC; its interaction with performance, and the state-of-the-art of "life" testing as it relates to developing extended performance test methods for consumer products. The report reviews information now obtainable and barriers to labeling consumer products with LCC information. An observation is made that application of LCC to consumer products is not immediately practicable. The basic areas requiring further investigation are identified, long term research goals are suggested and activities deserving immediate attention are described.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Accelerated testing; consumer products; cost estimation; life cycle costing; life cycle performance; life testing, and performance testing

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