Abstract: Rapid advancement in technology with resultant obsolescence and non-availability of currently used components and devices, force industries to continuously upgrade and modernize existing systems in order to ensure equipment sustainment. Decisions taken during the initial planning, design and up-grade, can significantly influence the Total Cost of Ownership (TCO) of a system. The process of identifying and documenting all the costs involved over the life of an asset is known as Life Cycle Costing (LCC).

Despite existing life cycle costing models, descriptions and practicable suggestions for conducting life cycle cost analyses, no systematic anatomy on actual implementations of life cycle costing methods exist in Indian context including defence procurements. This research reviews literatures on life cycle cost models and applications to provide an overview of life cycle costing employment and implementation feasibility. It further examines the requisite attributes of life cycle cost analysis methods needed to effectively and flexibly project long term cost requirements.

Most of the life cycle costing models and applications are far from ideal. This research will highlight the difficulty of conducting a reliable life cycle cost analysis and point out typical problems that should be carefully considered before drawing conclusions from the life cycle costing analysis in Indian context.

Life cycle costing needs to be related to sound economic principles, if it is to be useful. Cost models have to be used in conjunction with models predicting operational performance, than in isolation. Although cost and operational analysts may simultaneously be making predictions about the same project, they go about their tasks in quite different ways using quite different techniques. The question of why this should be so and whether it is desirable, will be raised. This creates some confusion about what constitutes a life cycle cost ‘model’ and hence a simple classification and modeling structure will be described to clarify matters within the Indian context. The final end state of ibid research work is envisaged, “To provide a systematic methodology for successful application of life cycle costing techniques in reducing the TCO in the Indian context.”

Keywords: Life Cycle Costing (LCC); Total Cost of Ownership (TCO)
LIFE CYCLE COSTING IN THE INDIAN CONTEXT

1. **Introduction**

   Rapid advances in technology with resultant obsolescence force systems managers to continuously upgrade and modernize existing systems in order to ensure equipment supportability. Decisions made during initial system design and upgrade planning can significantly influence the cost of ownership of a system. Owners, users and managers need to make decisions on the acquisition and ongoing use of many different assets including items of equipment and the facilities to house them. The initial capital outlay cost is usually clearly defined and is often a key factor influencing the choice of asset given a number of alternatives from which to select. (Stephen Sanford Chafee, 1996)

   In order to minimize life-cycle costs as well as optimize system design parameters, front end planning must include the analysis of costs to operate, support, up-grade and eventually dispose of the system as an integral part of the design and production planning process. The initial capital outlay cost is, however, only a portion of the costs over an asset’s life cycle that needs to be considered in making the right choice for asset investment. The process of identifying and documenting all the costs involved over the life of an asset is known as Life Cycle Costing (LCC).

   Life cycle cost management includes the processes required to determine which resources (people, equipment, services, material etc.) and what quantities of each should be used to perform project/system activities, develop an estimate, of the associated cost and allocate them to individual work items. These processes are aimed to estimate system life cycle cost for decision making and budget allocation and to ensure that the system activities are performed within the approved budget and according to the operational requirements fixed.

   Each phase of the systems life-cycle has a set of unique cost drivers that the cost analyst must evaluate. This includes (but is not limited to) procuring raw materials, constructing and maintaining support facilities, establishing industrial processes and retooling existing capability, hiring, training and managing personnel, wages, energy consumption, inventory maintenance, storage, packaging and delivery, as well as environmental protection requirements spanning production through disposal phases of the life-cycle. The basic concept of Life-Cycle-Costing means to take into account not only the manufacturing cost, but also to consider the operational and disposal costs.

2. **Objectives of Life Cycle Costing**

   Life cycle costing analysis can be carried out during any phase of an asset’s life cycle. It can be used to provide input to decisions regarding asset design, manufacture, installation, operation, maintenance support, renewal/refurbishment and disposal. The objectives of life cycle costing are:
• Minimize the total cost of ownership of the Utility’s infrastructure to its customers and giving a desired level of sustained performance.

• Support management considerations affecting decisions during any life-cycle phase.

• Identify the attributes of the asset which significantly influence the life cycle cost drivers so that the assets can be effectively managed.

• Identify the cash flow requirements for projects.

3. **Life Cycle Costing and Total Cost of Ownership**

Life cycle costing is a cost management tool designed to evaluate financial consequences of an item, system or facility over its lifespan, expressed in terms of equivalent cost, using baselines identical to those used for initial cost. Life cycle costing is used to compare various options by identifying and assessing economic impacts over the life of each option. [Dell’Isola & Kirk, 2003]

![Figure 1: Life Cycle Cost, consisting of Acquisition Costs, Operations and Maintenance](image)

Kawauchi & Rausand [1999] state that it is easily understood that the total cost of a product throughout its life cycle comprises not only acquisition costs, but also many other cost categories, including such “ownership costs” as operation costs, maintenance costs, logistics costs, etc. As shown in figure 1 above, ownership costs may be higher than acquisition costs. It is believed that a typical range of ownership costs is 60% to 80% of total
life cycle costs. If ownership costs are not considered at purchasing a particular product, it is likely to become surprised by the growing ownership costs after the purchase. It is therefore important to try to minimize life cycle costs in an early phase of the product life cycle. [Kawauchi & Rausand, 1999] As mentioned above, total system cost is often not visible, particularly those costs associated with system operation and support. The cost visibility problem is due to an “iceberg” effect, as is illustrated in figure 1 above.

4. **Scope of a Life Cycle and Life Cycle Costing**

In literature life cycle costing is mainly described in general. It is hard to find specific industry-related use of life cycle costing methods. It gives the impression that life cycle cost as a decision tool is universally applicable. This seems to be incorrect since there is a difference in, for example, standard products and customer specific products like defence related products. There is also a difference in approach regarding life cycle costing between a seller and the buyer.

Life cycle cost is an important factor in design and life cycle management. Due to characteristics of different product or systems, many life cycle cost analysis methods and models are developed. Basic elements involved in all these methods/models remain same. All core issues related to life cycle costing are as given at figure 2 Woodward, D. (1997) [7]. Basic elements of life cycle costing are as given below:-

![Figure 2 - Core issues related to Life Cycle Costing](image)

- **Concept/definition** Costs accrue in connection with the concept during the specification or planning phase.

- **Design/development** Costs for engg design, tech documentation and prototype development & testing are combined.

- **Production** These costs contain the expenses for production and sale of the product on the contractor side. Therefore they represent the order value of the whole distribution system. The costs for installation and getting into operation of the system are not included in this part.
- **Installation** Costs generated on site by installation before the system goes into operation.

- **Operation** Costs arise to operate and to sustain the operation of the whole system. Among other things these costs include expenses for power losses of overhead lines or transformers, controlling and staff training.

- **Maintenance** Calculation of the complete maintenance expenditures due to different strategies incl training, support structure & spares and repair parts e.g. time or condition based or corrective.

- **Disposal/Reclamation** Costs for work, material and disposal in conjunction with the rebuild of the existing system. This may incl hazardous material disposal, resale valuation or residual disposal.

- **Miscellaneous Data** Miscellaneous data which has to be used for the calculation of the lifecycle cost for example interest rate, inflation rate and useful lifetime of the equipment.

Even though the elements mentioned above are straightforward but situation is further complicated by some additional problems related to the actual determination of system and/or product cost. The current trends of inflation and cost growth, combined with these additional problems mentioned below, have led to inefficiencies in the utilization of valuable resources. Systems and products have been developed that are not cost-effective. It is anticipated that these conditions will become worse unless an increased degree of cost consciousness is assumed by engineers. Problems of cost estimation are as under:-

- Total system cost is often not visible, particularly those costs associated with system operation and support. The cost visibility problem is due to an “iceberg” effect, as is illustrated in figure 1[Kawauchi & Rausand, 1999].

- Individual cost factors are often improperly applied. Costs are identified and often included in the wrong category; variable costs are treated as fixed (and vice versa); indirect costs are treated as direct costs; and so on.

- Existing accounting procedures do not always permit a realistic and timely assessment of total cost. In addition, it is often difficult (if not impossible) to determine costs on a functional basis.

- Budgeting practices are often inflexible regarding the shift in funds from one category to another, or from year to year, to facilitate cost improvements in system acquisition and utilization.

Life Cycle Cost must be determined by identifying the applicable functions in each phase of the life cycle, costing these functions, applying the appropriate costs by function on a year-to-year basis and then accumulating the costs over the entire span of the life cycle. Life cycle cost must include all producer and consumer costs if it has to be complete in all respect.
5. **Formulation of Life Cycle Costing Process**

All the elements mentioned above form important part in formulation of basis for life cycle costing model. Kaufman has provided one of the most important contributions towards formulation of life cycle costing model, whereby he developed a formulation based on the eight-step approach indicated below and shown in figure 3. (Kaufman 1970) [8] Steps in formulation of Life Cycle Costing model are as given:-

**Figure 3 – Life Cycle Costing Process**

- **Step 1** - The operating profile (OP) describes the periodic cycle through which the equipment will undergo and indicates when equipment will or alternatively will not be working. It comprises the modes of start up, operating and shut down.
- **Step 2** - Whilst the OP tells us the proportion of time the equipment will be operating or not operating, the utilization factors indicate in what way equipment will be functioning within each mode of the OP. Thus, even within the 'operating' mode, a machine might not be working continuously.
• Step 3 - Every cost element or area of cost must be identified.

• Step 4 - The critical cost parameters are those factors which control the degree of the costs incurred during the life of the equipment. The most significant of these are:
  - Time period between failures (Kaufman's 'MTBF')
  - Time period between overhauls
  - Time period of repairs (Kaufman's 'MTTR')
  - Time period for scheduled maintenance
  - Energy use rate.

• Step 5 - All costs are first calculated at current rates.

• Step 6 - "All costs (despite the fact that Kaufman only mentioned labour and material) need to be projected forward at appropriate rates of inflation. The difficulty in projecting such figures should not be underestimated, since lack of precision here can lead to inaccuracy in the final calculations. However, inflation rates, like interest rates, have something of the 'self-fulfilling prophesy' to them, and if forecasts from 'experts' are available, then some reliability may be placed upon them.

• Step 7 - It should be recognized that money has a time value and the cash flows occurring in different time periods should be discounted back to the base period to ensure comparability.

• Step 8 - Summing all the cash flows involved will enable the Life Cycle Costing of the asset to be established. Comparisons between competing assets can then be undertaken and the fallacy of opting simply for the asset with lowest capital cost will then be exposed for example the more expensive asset often has a lower total Life Cycle Cost.

The Life Cycle Costing approach identifies all future costs and benefits and reduces them to their present value by the use of the discounting techniques through which the economic worth of a project or series of project options can be assessed.

6. **Life of an Asset/Equipment in Life Cycle Cost Model**

The forecast life of an asset is a major influence on life cycle analysis in view of the exponential nature of the effect of this variable. There are five possible determinants of an asset's life expectancy (David G. Woodward 1997):

- **Functional life** -- the period over which the need for the asset is anticipated.
- **Physical life** -- the period over which the asset may be expected to last physically, to when replacement or major rehabilitation is physically required.
• **Technological life** -- the period until technical obsolescence dictates replacement due to the development of a technologically superior alternative.

• **Economic life** -- the period until economic obsolescence dictates replacement with a lower cost alternative.

• **Social and Legal life** -- the period until human desire or legal requirement dictates replacement.

7. **Cost Estimation Models**

In this section, an impression of commonly used life cycle costing models will be covered. Shortcomings will be pointed out; if possible, the model will be adapted with regard to these specific areas of interest. Theories regarding these models are mainly described in general. The models have become more and more elaborate and their complexity has increased over the years. Life cycle costing models can be broadly classified into the following categories:

- Accounting models (models that sum life cycle cost components).
- Cost estimating relationship (CER) models (models used to analyse design alternatives).
- Heuristic models (ill structured analytical model).
- Failure free warranty models (models used to analyse warranty periods)
- Reliability models (used for reliability and maintainability)
- Economic analysis models (models dealing with general cost effectiveness)

However, in general life cycle costing models classify into three general forms (Sherif and Kolarik (1981)):

- **Conceptual** - Conceptual models consist of a set of hypothetical relationships expressed in a qualitative framework. Conceptual models are generally constructed at macro level.
- **Heuristic** – Ill structured analytical model.
- **Analytical** - Analytic models consist of a set of mathematical relationships, which are used to describe a certain aspect of the system. Such models range from models covering very specific aspects of a system to models, which address total system life cycle cost. Gupta (1983) identifies three types of analytic models:

  - **Design Trade-off Models** - Design trade-off models relate to the design phase of the life cycle cost and attempt to minimise cost to meet a given value of design parameters such as reliability and availability to maximize the value of design parameters for given cost constraints.
- **Total Cost Models** - Total cost models are termed true life cycle cost models and usually encompass the total life of the system. They attempt to minimize the total life cycle cost of the system while maximizing its performance and effectiveness by evaluating various parameters such as reliability, maintainability, availability etc, which affect life cycle cost.

- **Logistic Support Models** - Logistic support models are concerned with the operations phase of the life cycle. Usually the objective of such models is to determine costs for alternative support plans and effect on the system’s effectiveness. They reflect operations cost parameters as variable costs and research, development, test and evaluation and acquisitions costs as fixed costs. These models are inconsistent in that design parameters such as reliability and maintainability heavily influence operations costs and therefore fall short of determining optimal life cycle cost.

Life cycle costing model can be a simple series of cost estimation relationships (CERs). Life cycle costing analysis during the conceptual or preliminary design phases may require the use of basic accounting techniques (Fabrycky and Blanchard, 1991). The most important task in Life cycle costing modeling is the construction of Cost Breakdown Structure (CBS), which shows various cost categories that combine to provide the total cost. Cost breakdown structure should exhibit the following basic characteristics.

- All system cost elements must be considered.
- Cost categories are generally identified with a significant level of activity or some major item of hardware.
- The cost structure and categories should be coded in such a manner as to allow for the analysis of certain specific areas of interest (e.g., system operation, energy consumption, equipment design, spares, maintenance personnel and support, maintenance equipment and facilities). In some instances, the analyst may wish to pursue a designated area in depth while covering other areas with gross top-level estimates. This will certainly occur from time to time as a system evolves through the different phases of its life cycle.
- When related to a specific program, the cost structure should be compatible (through cross indexing, coding etc.) with the contract work breakdown structure (WBS) and with management accounting procedures used in collecting costs.
- For program, where subcontracting is prevalent, it is often desirable and necessary to separate supplier costs (i.e., initial bid price and follow-on program costs) from other costs. The cost structure should allow for the identification of specific work packages that require close monitoring and control.

The analyst must select the proper tools to deal with the complexities of developing time phased cost comparisons for multiple system design and upgrade options which are being championed by many times conflicting technical, economic and political forces. Table below (Stephen Sanford Chafee 1996) provides a summary of cost drivers associated with each life-cycle phase. Each cost element can be broken down into multiple independent parameters aligned with a program’s time phased work breakdown structure. In order to deal
effectively with such a high degree of complexity, the proposed model must accommodate multivariable "what-if" analysis and allow weighting or adjustment of independent input parameters in response to design option selection.

<table>
<thead>
<tr>
<th>LIFE-CYCLE PHASE</th>
<th>COST ELEMENT</th>
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<tbody>
<tr>
<td>Research &amp; Development</td>
<td>• Engineering Design</td>
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<td>• Technical Data Development</td>
</tr>
<tr>
<td></td>
<td>• Prototype Development &amp; Testing</td>
</tr>
<tr>
<td></td>
<td>• Project Management (all phases)</td>
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<tr>
<td>Production</td>
<td>• Product ion Engineering</td>
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<td></td>
<td>• Investment tools/equipment/facilities</td>
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<td></td>
<td>• Manufacturing materials/labor</td>
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<td></td>
<td>• Packaging/Handling/Storage</td>
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<td></td>
<td>• Transportation/Distribution</td>
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<tr>
<td>Operation &amp; Support</td>
<td>• Operation &amp; Maintenance Labor</td>
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<td></td>
<td>• Operational Facilities</td>
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<td>• Personnel Training</td>
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<td></td>
<td>• Maintenance Support Structure</td>
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<tr>
<td></td>
<td>• Spares &amp; Repair Parts</td>
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<td></td>
<td>• Test Equipment</td>
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<tr>
<td></td>
<td>• Documentation Maint./Configuration Mgt.</td>
</tr>
<tr>
<td>Up-grades/Modernization</td>
<td>• Engineering Design</td>
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<tr>
<td></td>
<td>• Prototype &amp; Integration Testing</td>
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<tr>
<td></td>
<td>• Procurement</td>
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<tr>
<td></td>
<td>• Documentation Up-dates/Configuration</td>
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<td></td>
<td>• Installation</td>
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<td></td>
<td>• O&amp;S Personnel Training</td>
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<tr>
<td></td>
<td>• Facilities Upgrade</td>
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<tr>
<td>Disposal/Reclamations</td>
<td>• Hazardous Material Disposal</td>
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<tr>
<td></td>
<td>• Resale Valuation</td>
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<tr>
<td></td>
<td>• Residual Disposal</td>
</tr>
</tbody>
</table>

8. **Uncertainty and Sensitivity**

The need for uncertainty assessments comes from the fact that input data for a life cycle cost analysis are based on estimates rather than known quantities. The data input is, therefore, uncertain. Uncertainty exists in all situations when things are unknown, unpredictable, open-ended or complex. Life cycle costing is highly dependent on the assumptions and estimates made whilst collecting data. Even though it is possible to improve the quality of these estimates with the assistance of historical data and statistical methods, there is always an element of uncertainty associated with these estimates and assumptions (D G Woodward 1997). Implementation phase v/s Cost estimation uncertainty is shown in figure 3. Macedo M C (1978) identified the following five major sources of uncertainty:

- Differences between the actual and expected performance of the system subsystems could future operation and maintenance costs.
- Changes in operational assumptions arising from modifications in user activities.

- Future technological advances that could provide lower cost alternatives and hence shorten the economic life of any of the proposed systems.

- Changes in the price levels of a major resource such as energy or manpower, relative to other resources can affect future alteration costs.

- Errors in estimating relationships, price rates for specific resources and the rate of inflation in overall costs from the time of estimation to the availability of the asset.

![Figure 3 - Cone of Uncertainty](image)

9. **Life Cycle Costing in Indian Context**

India has initiated several policy measures to provide an impetus to arms production in India. However, foreign weapon systems still comprise around 70% of the Indian military arsenal and that India has been forced continually to search for foreign equipment to compensate for delays in domestic weapons programs. It is this paradox which makes the task of finding cost effective options so critical to the acquisition process in India. (Shobhana Joshi, 2010)

Firms in India also started working on concept of life cycle costing so as to compete in the world market. It has also been seen that lot of work has been underway to crystallize the process and procedure to calculate the life cycle costing for a system. There is no doubt that more comparative studies in a wider sample are needed to draw definitive conclusions for life cycle costing to get implemented in Indian Context. Before looking at the methodology for life cycle costing in Indian context, some common parameters can be discussed. These will be equal in all cases.

(a) **Lifespan** - It must be clear which period is taken into account. The longer the lifespan, the higher the risk that several parameters becoming inaccurate. To reduce this inaccuracy, a specific lifespan for each case will be chosen. For example, will the labour or energy costs which are the escalation factors involved be constant over the
next years (thus showing linear growth), or might the economy or environment change in such a way that they create a situation in which these factors cannot be seen as constant.

(b) **Discount Rate** - The discount rate of a specific period can be set at the same value for all assets relevant to this study. However, this rate greatly influences the outcomes of life cycle costing. A high discount rate results in future costs being of minor influence. Unlike the discount rate, the escalation rate will be specific for every case; indeed, it will characterize every item in a single case.

(c) **Disposal** - During the lifespan as well at the end of the lifespan (either demolishing the installation or taking the rest value of the installation into account) the cases have to deal with disposal (residues of the production process). Both items can easily be translated into costs which will be different for the different cases.

Preliminary inputs with respect to Indian industries clearly indicates low penetration of life cycle costing concept as a Decision Making tool. Ab-initio the following gaps have been identified :-

- Lack of awareness about TCO.
- Lack of importance life cycle assigned to sustainment at acquisition stage.
- No impetus for carrying out research and offer solutions to reduce TCO.
- Focus of industry on ‘Know How’ vis-a-vis ‘Know Why’.

10. **Defence Markets Compared to Civil**

The military assets, ranging from tanks, aircrafts, ships and submarines to missiles and C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) systems are no different. As it is, the initial cost of acquisition of these assets is huge but the cost of operating and maintaining them could be substantially higher over their entire life-cycle, generally ranging from thirty to forty years, with or without mid-life upgrades. This signifies its impact on present and future budgetary support by the government. For optimal use of the scarce financial resources, it makes sense to decide about the acquisition or development of asset with a view the life-cycle cost.

Defence markets operate in a rapidly changing security environment as compared to civil markets due to which there is a sense of uncertainty about buyer requirements and performance parameters and involves much greater technological risk to develop. Internal and external uncertainties are based on technology and threat perception respectively. Internal uncertainty is uncertainty due to technological unknowns. Internal uncertainty is especially high in the design phase of a new weapon but also continues into production. External uncertainty is uncertainty in the demand for a weapon due to changes in the external threat, changes in the availability of substitute weapons and so on.(Shobhana Joshi, 2010) While the potential of Life Cycle Costing as a tool for making cost-effective choices in a wide variety
of areas is undeniable, its application in the field of defence purchases has been somewhat limited.


The Model characteristics need to be examined and correlations between these characteristics & the effects of life-cycle costing principles should be the start point. System longevity, performance and cost are the three characteristics that are used to assess the effect of life-cycle costing on the system. The total cost of any system is dependent on the costs incurred to design, manufacture and maintain the system. A main objective of life-cycle costing is to manage and reduce the long term system maintenance costs.

<table>
<thead>
<tr>
<th>Life Cycle Cost Increase</th>
<th>No change in useable life &amp; performance</th>
<th>Life cycle costing not beneficial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life cycle cost no change but some cost go up/down</td>
<td>No change in useable life &amp; performance</td>
<td>More research to find out why changes happening</td>
</tr>
<tr>
<td>Life cycle cost goes down</td>
<td>Increase in Performance parameters</td>
<td>Successful Life cycle costing calculation and Model approved</td>
</tr>
</tbody>
</table>

As mentioned in the table above, a life-cycle costing principle is not only concerned with costs but also related performance and the longevity of the system.

Life cycle costing is driven by reliability, maintainability and supportability. The objective of life cycle costing is to minimise life cycle cost by optimizing reliability, maintainability and supportability. Figure 4 illustrates the relationship between the system operational effectiveness and other design parameters. Life cycle cost will decrease as the reliability increases. Similarly better maintainability and supportability would decrease the maintenance and support cost and hence will decrease the Life cycle costing. However, increasing reliability, maintainability and supportability may require additional resources during the design and product development stage and hence is likely to increase the initial procurement cost. (D Kumar 2000)
The framework for calculating life cycle cost can be very complex depending on the procurement and asset management strategies used by the user. In this paper, we mainly focus on procurement, operation, maintenance and disposal cost, which are more relevant in general.

12. **Mathematical Models for Estimation of Life Cycle Cost**

In this section we develop mathematical models for estimation of various cost elements in the life cycle cost. The main focus is on estimation of in-service cost as the acquisition cost details will be taken from the vendor hence only heads will be covered. Since all the cost elements in the life cycle cost need to be discounted to their present value, all the costs models explained in the subsequent sections are calculated on annual basis and finally discounted using appropriate discount rate. (D Kumar 2000)

(a) **Acquisition Cost** – This cost will be divided into research & development cost and production cost. Sub heads of these costs can be taken from the cost breakdown structure given at para 7.

(b) **In-service cost** – This cost is further subdivided into operating and supporting cost. The supporting cost is mixture of the maintenance and logistics cost.

- **Estimation of Operating Cost**  The operating cost can be divided into two categories, direct operating cost and overhead costs. The direct operating cost is determined by the resources, which are required for

![Figure 4 - Systems Operational Effectiveness](image-url)
operating the asset. The main resources for most of the system are energy consumed by the asset and the manpower required to operate the asset. The energy consumed by the asset will depend on the operational availability of the system calculated on annual basis. The operational availability, Ao, of any asset is given by (D Kumar 2000)

\[
Ao = \frac{MTBM}{MTBM + DT}
\]

where MTBM is mean time between maintenance and DT is down time.

Mean time between maintenance for duration ‘T’ is given as

\[
MTBM = \frac{T}{M(T) + \frac{T}{T_{sm}}}
\]

Where M(T) is the number of failures resulting in unscheduled maintenance and Tsm is the time between schedule maintenance.

Downtime DT can be given as

\[
DT = \frac{M(T) \times MCMT + \frac{T}{T_{sm}} \times MPMT}{M(T) + \frac{T}{T_{sm}}}
\]

Where MCMT is Mean corrective maintenance time and MPMT is Mean preventive maintenance time.

Number of failures M(T) can be evaluated as

\[
M(T) = F(T) + \int_0^T (M(T-x) f(x) dx)
\]

Where F(T) is cumulative distribution of the time-to-failure random variable and f(x) is the corresponding probability density function. If we assume energy cost & manpower cost per unit time is \(C_{ou}\) and the annual usage of the system is T life units, then the annual operating cost is given by

\[
C_o = A_o \times T \times C_{ou}
\]

and if ‘r’ denotes the discount rate then present value of the operating cost for nth period is given by
Total life cycle cost is given as

\[ LCC = A_q + C_{\text{in-service}} \]

\[ LCC = A_q + C_O + C_{\text{Supporting}} \]

\[ LCC = A_q + C_O + C_m + C_i \]

The maintenance and logistics costs are calculated separately taking into account different issues related to each component explained in succeeding paras.

**Estimation of Maintenance Cost**

Main components of maintenance cost are corrective cost, preventive maintenance costs and overhaul costs. The maintenance cost \( C_m \) is as given below:

\[ C_m = M(T) \times C_{cm} + C_{pm} \times \frac{T}{T_{sn}} + \sum_{i=1}^{\delta} \delta_{i,n} \times C_{OH,i} \]

\( C_{cm} \) = Corrective Maintenance

\( C_{pm} \) = Preventive Maintenance

\( \delta_{i,n} = 1, \text{if OH of type i is carried out during period n} \)

\( 0, \text{otherwise} \)

\( C_{OH,i} \) = Avg cost of overhaul of type i

Maintenance cost for period \( n \) is given as

\[ C_{M,n} = \frac{1}{(1+r)^n} \left( M(T) \times C_{cm} + C_{pm} \times \frac{T}{T_{sn}} + \sum_{i=1}^{\delta} \delta_{i,n} \times C_{OH,i} \right) \]

**Estimation for Logistics Cost**

Logistics support costs covers the costs associated with maintaining spare parts, maintenance facility, test eqpt and other logistics such as transportation costs. All these factors are to be calculated on case to case basis.

**Life Cycle Costs**

The total life cycle cost can be calculated by adding all components mentioned above. It has to be noted that models have to be
used as per requirement and for calculating specific component cost in the entire life cycle cost process. It’s a deliberate process which is time consuming but effective way to reduce the life cycle cost of any system. Most important thing which has to be kept in mind is the any error at any stage will have exponential effect in the final costing.

13. **Conclusion**

Life cycle costing is the total discounted dollar cost of owning, operating, maintaining and disposing of the system. There are two major cost categories, “Initial Expenses” and “Future Expenses”. It is difficult to define the exact costs of each expenses category, because at the time of the life cycle study nearly all costs are unknown. However, through the use of reasonable, consistent and well documented assumptions, a reliable life cycle cost analysis can be prepared. In this report we have given a basic idea for life cycle costing analysis alongwith different techniques used in calculating life cycle cost at various stages of the projects. This can be a start point for further studies and crystallization of this concept in Indian context.
REFERENCES


