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COST ANALYSIS AND LIFE CYCLE COST USES IN IMPROVING THE MILITARY CAPABILITIES

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Abstract:
Military assets, and mostly the expensive ones are generally appraised at the acquisition stage on the basis of their total life cycle costs. This study provides a theoretical foundation and a parametric cost model for forecasting the life cycle cost for the C-27J Spartan airplane.

Key words: life cycle costs, parametric model, methods, maintenance cost, repair, exchange, flight profile

1.Introduction

Accurate cost estimation of military equipment plays a crucial role in any military acquisition strategy. Military assets are generally appraised at the acquisition stage on the basis of their total life cycle costs (LCC). Life cycle costing is an economic assessment that looks beyond the initial purchase cost of an item. It also includes the cost of operating and maintaining the item over its entire operational life. This technique was designed in the early 1960s for procurement purposes in the US Department of Defence.

The purpose of a LCC model is to estimate the overall costs of an item. It can be used as an evaluation tool in two situations. The first situation occurs when assessing the economic impact of a given investment such as the procurement of new equipment. If the decision has already been made, LCC can assist in budget allocation [Liu, 2006]. The second takes place when comparing various alternative courses of action with the objective of choosing the best way to use scarce resources [Fabrycky and Blanchard, 1990]. In this case, LCC assists in selecting the alternative that ensures quality at minimal cost [Fuller, 2010].

From the perspective of the equipment user, LCC may be subdivided into three categories: Acquisition cost, ownership cost, and disposal cost. The acquisition cost includes the purchase price and the cost of potential equipment improvements. Ownership cost is composed of operation and maintenance (O&M) costs. O&M costs may include consumables, engineering services, repairs, overhaul and spares. Maintenance cost can be grouped in two categories: scheduled and unscheduled maintenance costs. Sheduled maintenance is generally programmed and suggested by the manufacturer for prevention purposes. Unscheduled maintenance is not programmed and it can be caused by equipment failures. Disposal cost occurs when equipment is withdrawn from service.

O&M is an important facet of the total ownership costs of military equipment. The cost of operating and maintaining equipment can exceed the cost of capital over the life of the equipment [Solomon and Sokri, 2013]. With greater national interest in reduced public spending, emphasis would be placed on O&M from the cost standpoint. However, when attempting to apply life cycle costing concepts, analysts have been thwarted by the lack of accepted methodology to arrive at appropriate decisions (Al-Hajj, 1998).

Life cycle costs are summations of cost estimates from inception to disposal for both equipment and projects as determined by an analytical study and estimate of total costs experienced during their life. The objective of LCC analysis is to choose the most cost effective approach from a series of alternatives so the least long term cost of ownership is achieved.

LCC analysis helps engineers justify equipment and process selection based on total costs rather than the initial purchase price. Usually the cost of operation, maintenance, and disposal costs exceed all other costs many times over. Life cycle costs are the total costs estimated to be incurred in the design, development, production, operation, maintenance, support, and final disposition of a major system over its anticipated useful life span [DOE 1995]. The best balance among cost elements is achieved when the total LCC is minimized [Landers 1996].

2.The role of Life Cycle Costs (LCC) in NATO

2.1 The use and limitation of the life Cycle Costs

LCC is the total sum of the direct, indirect, recurring, non-recurring and other related costs incurred, or estimated to be incurred, in the design, development, production, operations, maintenance and support of a major system over its anticipated life span. The LCC analysis is a typical task that starts early in the life cycle of the project and must be carried out throughout the entire life cycle of the system [NATO Logistic Handbook].

The use of life cycle costs should, support the process by which managers can make the best decisions on options presented to them. These options may include evaluation of future expenditure, comparison between alternative solutions, management of existing budgets, options for procurement and evaluation of cost reduction opportunities. Life cycle costing is also used for affordability assessment and determining the cost drivers associated with the Key User Requirements.

Life cycle costs must be used as a benchmark against which options can be measured for ‘value for money’ during the acquisition/production and in-services phases.

However, it must be appreciated that the greatest opportunities to reduce life cycle costs usually occur during the early phases of the programme (as shown in Figure 1-1). It follows therefore that life cycle costs is used as a decision and optimisation criteria in the search of the best compromise between performance, cost and time.

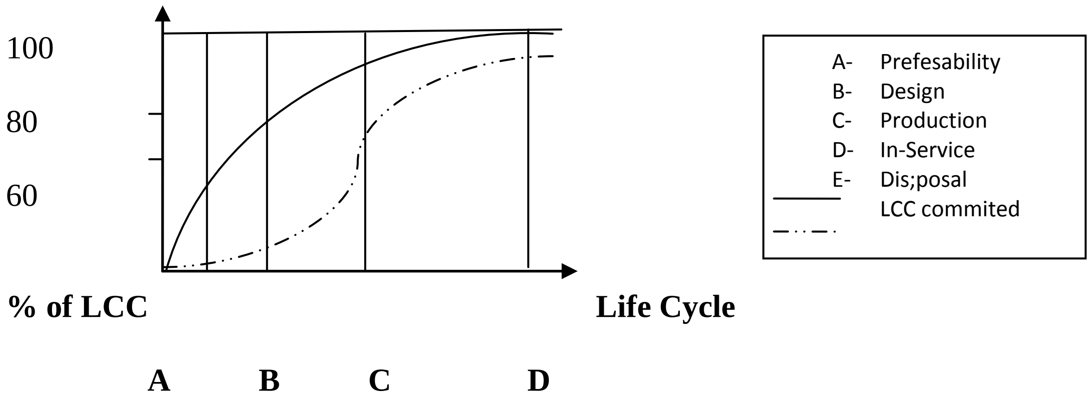

Fig.1.1 Traditional LCC Committed versus Incurred Cost Curve

Life cycle costs should be recognised as an ongoing activity throughout the life cycle to evaluate all programme changes and exploit cost saving opportunities. Although this report focuses on the importance of conducting life cycle cost analysis, it should be recognised that there are limitations of such an analysis. Some of the limitations are (Reference: LCC Tutorial by Paul Barringer and David Weber):

• Life cycle costing is not an exact science. A life cycle cost analysis does not provide an exact number of the costs; it merely gives an insight in the major cost factors and an insight into the magnitude of the costs.

• The life cycle cost estimate is only an estimate. Estimates can never be more accurate than the inputs and the inputs are often estimates themselves or expert opinions

• Life cycle cost models require volumes of data and only a few handfuls of data is likely to exist when conducting the estimate. Therefore many assumptions have to be made. The life cycle cost estimate therefore only counts given the assumptions used. If one of the assumptions changes, it is possible that the cost estimate will change too.

• Life cycle cost results are used for several purposes and, in some instances, are not compatible. For example, the life cycle cost used for a comparison or a trade-off study may not always be suitable for budgeting purposes.

These limitations should be carefully considered when conducting a life cycle cost analysis.

2.2 Phases and the use of life cycle costing

It is recognized that individual nations may use their own nomenclature for these early phases (e.g. user requirement, system requirement, etc.) and may conduct their own pre-feasibility or early conceptual work to assess the level of their capability gap. For clarity and consistency the NATO nomenclature has been used throughout. However, the processes and techniques described here are equally applicable to national and multi-national programmes.

Early in the project life cycle, studies need to address the capability gap, the numbers of equipment or platforms required and the technologies that can help to fill the gap at lowest cost. This requires a ‘strategic’ approach that can provide a capability to look at the ‘big picture’. At this phase in the life cycle it is unlikely that the costs can be identified in a great deal of detail, rather an understanding of the holistic1 values (i.e. the whole is more than the sum of its parts) in terms of the primary cost breakdown structure elements and the uncertainty surrounding these figures is required. The level of life cycle costing at this phase will support the NATO MND (Mission Need Document) and ONST (Outline NATO Staff Target).

It is important to recognize in these early phases that only broad estimates or a range of estimates will be available – it is more important to ensure that they are as complete as possible (e.g. nothing large is missing).

Once the NST (NATO Staff Target) has been developed, the focus turns to the performance, cost and time envelope of various options that will meet the NST. Forecasts of the likely life cycle costs for new equipment(s) and platform(s) are needed so that the cost breakdown structure can be developed and extended to reflect the acquired knowledge of the expected system characteristics and associated costs.

The life cycle costs at this phase will support the NSR (NATO Staff Requirement) by providing reasonably accurate estimates of development and production costs. However, due to the likely lack of design data the in-service costs will be more uncertain.

During the project definition phase the usage patterns and system design will mature to provide a much improved basis for establishing more accurate in-service costs.

When the preferred options are identified, industry is generally asked to provide information and compete for its supply. Assessments of the bids are conducted on a life cycle cost basis and need to address all the economic and financial requirements set out by each nation. At this stage the cost breakdown structure should be fully developed such that all the cost elements are identified.

For in-service equipment a forecast of the costs for the remaining life is required. This will assist in any budget adjustment studies and provide a realistic baseline upon which to measure and compare with the effect of change due to utilization, incremental updates, overhauls or even the procurement of new equipment.

In summary, it is not possible or desirable to collect and analyze information at the same level of detail throughout the life cycle although there should be a common thread in terms of programme phases, cost breakdown structure grouping and resource consumption. What should be seen is a life cycle cost estimate that evolves, in terms of detail, as the programmes progresses through the different phases.

3. Organisation And Ownership Of The Life Cycle Cost

3.1 Owner of the LCC

The life cycle cost analyst or manager should be the owner of the development of any life cycle cost estimate and the configuration management of the supporting documentation.

The role of the life cycle cost analyst is to ensure the smooth running and facilitation of the total life cycle cost management process. In summary, the analyst should be responsible for:

• Ensuring that an appropriate life cycle cost management plan is in place and updated where necessary.

• Supporting the programme by providing robust and credible life cycle costs in a timely manner.

• Ensuring that the life cycle costing process is appropriate, workable and supports the programme requirements.

• Eliciting life cycle cost information from both the government and contractor project teams.

• Reviewing all assumptions and contractual change notices from the project teams and advising the programme manager of any points of issue.

• Providing guidance and assistance for the cost risk analysis and associated reports.

• Ensuring the smooth running and facilitation of the total life cycle cost management process, including the regular reporting procedures.

To achieve the above in the most practicable, auditable and robust manner it may be necessary to conduct the life cycle cost analysis using multiple methods and/or independent experts. This will depend on the overall value of the likely programme costs and the level of robustness needed for the government approval process.

3.2 Typical applications of life cycle costing

One of the principal objectives of life cycle costing is to reduce or control the life cycle cost by assessing the financial impacts of the decisions taken about the complete system.

Three broad classes of applications rely on the output from life cycle costing and are discussed in detail below. These are:

• Determining the forecast of future spending.

• Examining comparisons between alternative solutions (e.g. alternative assets, design trade-off, supply chain analysis, etc.).

• Supporting the tender evaluation process.

In all cases, the output of the life cycle costing provides information to support the decision making process. Note however, that cost is just one of many criteria that could influence the decision. Other criteria such as operational effectiveness, technical risk, political and industrial policy constraints, etc., also have to be considered in the decision making process and are sometimes more important than cost.

3.3 Determine the Forecast of Future Spending – Defence Budget Planning Applications

Budget planners are often confronted with choices between several distinct systems (e.g. aircraft or UAV or missiles; ships or forward bases, etc.). The life cycle cost estimate can help the decision process by addressing the following typical questions:

• In consideration of long term planning applications (~10+ years):

• What will be the cost of the systems currently being designed (both in terms of money spent annually and of the number of service personnel required to man the systems)?

• What is the best ratio between money spent on investment (new systems or upgrades of old ones') and that spent in order to keep the readiness of currently available systems?

• In consideration of short term planning applications (~next 1 to 4 years):

• How many systems (or individual platforms) can we afford (now) and still maintain some flexibility in future budgets (considering their estimated in-service costs)?

3.4 Examining Comparisons between Alternative Solutions

Comparative studies are particularly valuable in the early stages of planning when the primary objective is to establish an efficient and economical course of action. Comparative studies are, actually, used throughout all phases of a system's life cycle; they are also used in selecting in-service options such as in-house or contractor support.

An analytical comparison of the operational effectiveness, suitability and life cycle cost of alternative programmes that satisfy established capability needs is referred to as AoA (Analysis of Alternatives).

An AoA broadly examines multiple elements of programme alternatives including technical risk, design maturity and cost. AoAs are intended to:

• Illuminate the risk, uncertainty and the relative advantages and disadvantages of the alternatives being considered.

• Show the sensitivity of each alternative to possible changes in key assumptions.

• Help decision makers in determining whether or not any of the proposed alternatives offer sufficient operational and/or economic benefit to be worth the cost. As a general rule, the preferred alternative is the alternative that provides the greatest amount of benefits in relation to its cost.

3.5 Supporting the Tender Evaluation Process

In the tender evaluation process the life cycle costs can be used to ensure that the contract award is made to the tenderer who offers a system that meets all technical and availability requirements at minimum life cycle cost. The cost of investment in reducing maintenance resources and the cost of lifetime support will be weighed against the cost of investment in the overall system. The resulting life cycle cost will therefore be beneficial to the overall tender evaluation process.

To establish a cost-effective in-service phase it is essential to consider operating and maintenance issues at the same time as the procurement of the system. The life cycle cost from the evaluation process can often be used as a baseline for negotiation on contractor logistic support contracts.

The choice of a proper time period (system life) in the life cycle cost evaluation process must be considered. For example, many parameters can influence the selection of a well balanced time-period.

Very often the total technical life of a system may not be the most appropriate time period for the life cycle cost evaluation. A shorter time-period takes more consideration of the initial acquisition costs, and a longer time-period takes more consideration of the recurrent ownership costs.

Figure 2-1 presents the life cycle costs for two competing systems A (green) and B (red). The initial acquisition price for System B is less expensive than for System A. However, System A has lower annual cost for ownership than System B. At year 10 the cost-lines intersect, and after year 10 System A has a lower life cycle cost compared to System B. The example shows the complexity of choosing the "correct" time period to include in a tender evaluation. This example clearly demonstrates that the selection of a life cycle time period must be tailored and well balanced to fit its purpose.

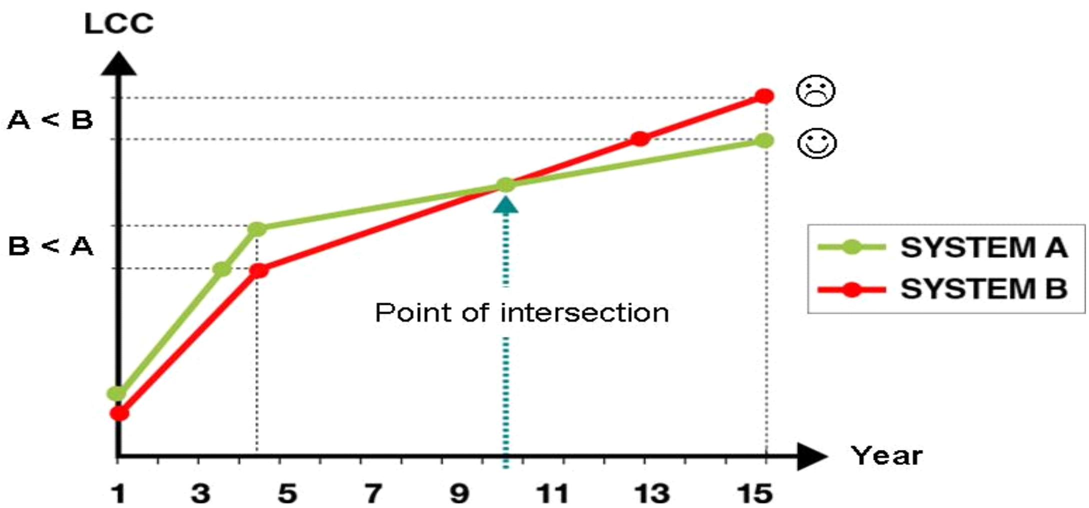

Fig. 2.1: Example of Time-Period Consideration.

To ensure that all the tenders are impartially evaluated it is vital that the cost breakdown structure is defined by the procurement agency. This should include a definition of all the cost elements. Sufficient data on the likely use of the system should also be included in the request for quotation. This will improve the prospective supplier's ability to independently assess and possibly improve their offer.

It is recommended that a life cycle cost questionnaire is issued with the request for quotation so that the procurement agency can conduct an independent comparative life cycle cost evaluation on all the tenders. This will improve the understanding of the tender offer and provide a degree of credibility in the life cycle cost results.

However, before the request for quotation is issued, it is important that all the preparatory work has been independently conducted and that the Key User Requirements are well balanced between functionality and likely costs.

A life cycle cost evaluation starts with the quality of the submitted tender data. In most cases it is necessary to iterate the process several times in order to obtain clarification and to explore opportunities for improvements. Figure 2-2 shows the tender evaluation process with specific feedback to the tenderers in order to exploit opportunities for cost reduction. The tender evaluation process is completed by documenting the LCC results in an evaluation report before the contract can be awarded.

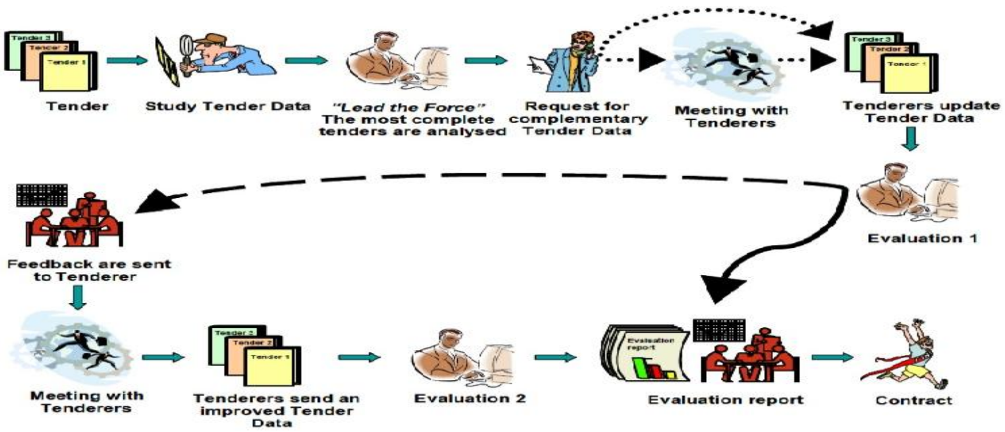

Fig.2.2 tender evaluation process

4.Methods for estimate the LCC

4.1 Literature overview

LCC analysis has been an active research area in the military sector. The other sectors appear to make acquisitions of capital items simply on the basis of initial purchase cost [Woodward, 1997]. This literature it is divided into three main approaches to estimating LCC: (i) engineering approach, (ii) analogy, and (iii) parametric method [Fabrycky and Blanchard, 1990]. Later on it was identified the use of a variety of methods.

4.2 Overview of the methods

A different approach may be used for each area of the estimate so that the total system methodology represents a combination of methods. Sometimes a second method may be used to validate the estimate.

When choosing an estimating method, the cost estimator must always remember that cost estimating is a forecast of future costs based on a logical interpretation of available data. Therefore, availability of data will be a major factor in the estimator's choice of estimating methodology.

The best combination of estimating methods is the one which makes the best possible use of the most recent and applicable historical data and systems description information and which follows sound logic to extrapolate from historical cost data to estimated costs for future activities.

An example of this is would be to use data gathered through expert opinion combined with methods for simulation to obtain reliable data to conduct simulations on different support behavior.

These values can then be used in the parametric techniques employed in estimating the total life cycle costs for the programme.

The following table shows how the methods have been organized for easy reference.

Method Category Methods	**Method Category Methods**
Optimisation Linear programming	Heuristics
Simulation	System Dynamics Discrete Event Monte Carlo
Calculation/Estimation	Analogy Parametric Bayesian Engineering Catalogue Rule of Thumb Expert Opinion
Decision Support Analytical Hierarchy Process	Multi-Criteria Decision Analysis

Table 1

A short description for some of the most frequent use of the methods will be presented in the next pages.

4.3 Engineering Approach

The engineering approach assigns costs to each element of the asset and then combines them into a total for the whole asset. This approach is time consuming and requires a huge amount of detailed data to perform the calculations. Sandberg et al. (2005), for example, presented a model for LCC prediction in the conceptual development of jet engine components. The model evaluates manufacturing and post-manufacturing activities and gives LCC feedback on potential design changes.

4.4 Analogy Approach

The analogy approach uses similar systems to estimate cost when needed data are not available. This method is used to gain a rapid assessment of the LCC of a new system. Compared to the engineering approach, this cost comparison method has the significant advantage of exploiting relatively few data. But it has the drawbacks of being relatively inaccurate and requiring a high degree of judgment to draw analogies. To study how the costs of maintaining military aircraft change as aircraft age, Dixon (2006), for example, used an analogy between commercial aviation and military aviation. The author found that airline maintenance costs grow at a fairly sharp rate in the first six years of age, increase moderately between 6 to 12 years, and grow slightly after the 12 years of aircraft ownership. This study also suggests that different types of aircraft maintenance costs, e.g., airframe maintenance versus engine maintenance, may show different cost patterns. Even if one can assume that the commercial airlines' experience is meaningfully analogous to the Air Force's experience, there are limits to this analogy. No profitable commercial airline would operate an aircraft like the military do. For instance, military aircraft commonly fly 500 hours per year whereas commercial aircraft fly thousands of hours per year.

4.5 Parametric Approach

The parametric approach applies econometric techniques to historical data to identify the major cost drivers of a given system and determine their effects on its LCC. The estimated parameters are then used in the cost estimating relationships of the analyzed systems. A growing body of literature recognizes the parametric method as an effective approach to forecast the LCC. Brandt (1999), for example, formulated a parametric cost model to determine the annual O&M costs of U.S. Navy surface ships. Using standard regression and data analysis techniques, the author developed cost estimating relationships for three major cost drivers: ship light displacement1, ship overall length, and ship manpower. Kiley (2001) used regression analysis to estimate the relationship between an aircraft's characteristics and operating tempo and its O&M costs. Results indicate that spending on O&M for aircraft increases by 1% to 3% for every additional year of age, after adjusting for inflation. Younossi et al. (2002) explored most of the possible performance and technology parameters that affect the development and production costs and the development schedules of engines. These authors employed least-squares regression methods to develop a series of parametric relationships for forecasting the development cost, development time, and production cost of military turbofan engine programs.

Other methods have also been suggested for life cycle costing. Emblemsvag (2001), for example, suggested the activity-based costing (ABC) method to estimate the life cycle cost. This accounting-oriented methodology identifies activities and segregates their direct and indirect costs to identify their respective cost drivers. ABC has mostly been used in fixing the price of products and improving production processes. However, ABC requires extensive activity-cost data and is not easily employed to forecast the life cycle cost. The literature has also used the proportional models to estimate the life cycle cost. These models predict the future O&M costs of aircraft, for example, simply by multiplying the historical cost per flying hour and the estimated number of flying hours (Wallace et al., 2000). Wallace et al. (2000) showed that these models are not able to adequately predict future costs during periods of radically different flight behavior. They indicated that during the First Gulf War proportional models overestimated removals by more than 200%. Unger (2007) stated that the proportional models may misestimate budgets when the relationship between cost and usage is either nonlinear or includes nontrivial fixed costs. The presence of fixed costs in the average cost factor would cause an exaggeration in estimated budget for a given number of flying hours. More recently, Maybury (2011) showed that the forecast of national procurement spending could not be improved using flying hours as an explanatory variable.

The literature has also used multimethodology or mixed methods to enhance forecasting quality. Parker (1991), for example, used an accounting model and a parametric model to evaluate alternative configurations within the same life cycle cost model. The accounting model was used to examine activities such as planning, engineering design, production, distribution, maintenance, and equipment disposal. The parametric method was utilized to determine cost estimating relationships during the cost determination phase of life cycle costing. More recently, Desmier (2012) used analogy and parametric approaches to forecast national procurement costs for F-35A aircraft. The author based his analogy on the assumption that the F-35A fleet fulfills the same mission profiles as the CF-18 fleet. Considering life cycles of 20 and 30 years, the parametric approach used the spending and usage history of the CF-18 fleet to define the trend in spending for the F-35 fleet. An interesting review of published case studies can be found in Korpi and Ala-Risku (2008). This paper also provides directions for further research on the LCC concept.

While many important findings have been reported in the military sector, the existing models on LCC still suffer from a lack of generality and simplicity. The existing models are usually tied to specific systems. These models cannot generate general insights because their validity, assumptions and results need to be tied to data from these specific systems. The lack of generality and simplicity also seems to be an unavoidable consequence of the use of time series theory while building models. Another feature of the existing models is that the project horizons remain highly arbitrary. LCC is not always bound to the optimal replacement horizon. A key implication of the arbitrary horizon is that overall costs of equipment are reduced (amplified) if the horizon is considerably shorter (longer) than the optimal age.

Building on the existing literature, this paper seeks to address these deficiencies. Generality and simplicity are achieved by developing a minimal model that focuses on the most relevant aspects of equipment. As discussed in Greenfield and Persselin (2003), Maybury (2009), and Sokri (2011), age is thought to replace all related factors affecting the equipment O&M costs. For an aircraft, examples of such factors include (but are not limited to) engine cycles, number of sorties and flying hours. The range of applicability of such formalism is very large. It can be applied to any kind of heavy military equipment. A dynamic programming procedure is also developed in this paper to identify the optimal planning period. This planning period, referred to below as the optimal assessment horizon, is the length of time costs are accumulated. It actually corresponds to the optimal replacement horizon of military equipment.

5.Models of the LCC

5.1 Definition

In everyday cost analysis language, the terms models and tools are often used with the same understanding.

"A Cost Model: is a set of mathematical and/or statistical relationships arranged in a systematic sequence to formulate a cost methodology in which outputs, namely cost estimates, are derived from inputs. These inputs comprise a series of equations, ground rules, assumptions, relationships, constants, and variables, which describe and define the situation or condition being studied. Cost models can vary from a simple one- formula model to an extremely complex model that involves hundreds or even thousands of calculations. A cost model is therefore an abstraction of reality, which can be the whole or part of a life cycle cost."

Using this definition, both a graphic description of the relationships that represent the abstraction or simplification of reality as well as a series of connected, specially developed computer programmes, can be a model.

5.2 Overview of models

This section is presenting different models that are currently in use by the nations. The first conclusion that can be drawn from the matrices is that no specific model for a certain phase is mandatory for any nation. Many nations do, on the other hand, have some recommendation on what type of model that should be used.

To begin with, among the models used by the nations, four different types of models have been categorized. These are: models for optimisation, simulation, estimation and for decision support. Each is briefly described below.

5.3 Estimation Models

This represents a broad spectrum of models that are used at the core of the life cycle costing process.

Estimation models are all types of models dealing directly with the estimation and calculation of cost.

The estimation of cost can, in turn, be supported by some other type of method, but in the case of the estimation model the main objective is to come to some sort of conclusion as to the level of cost for a system or sub-system.

Since this is a wide model category there are many examples of the estimation type models being used, both in terms of commercially available and those developed in-house. One common feature often found is that all the models employ a defined cost breakdown structure. These models are often tailored to a specific programme and, for those developed in-house are often implemented in a spreadsheet environment.

5.4 Decision Support Models

In this category, many types of operational research models with the purpose of choosing or ranking between different alternatives can be found. The models are typically based on soft management science approaches such as analytical hierarchical process or on multi-criteria decision analysis techniques.

5.5 Simulation Models

This category contains all the models based on one of the simulation methodologies outlined **Table 1**.

This therefore includes models using system dynamics and discrete event simulation. In addition, models using Monte Carlo simulation have also been included.

5.6 Optimisation Models

This category contains all the models that are based on some type of optimisation method, be it mathematical programming, heuristics, or other types of optimisation approaches. These models are most frequently used as support methods for the life cycle cost estimation process. For example, they are frequently employed to determine stock levels, maintenance regimes and supply chain impacts.

5.7 Desired model attributes

The characteristics of a high quality cost estimates are:

- Accuracy;
- Comprehensiveness;
- Ability to Replicate and Audit;
- Traceability;
- Credibility; and
- Timeliness.

Each of the above should demonstrate these quality characteristics in the following ways:

• **Accuracy** – Cost estimating relationships (CERs) will be the result of regression analysis with good curve fits and minimal error bands, making them valid predictors of cost. Estimates should be unbiased, not 'low balled' or overly conservative, but based on an assessment of the most likely costs. Underlying data will have been correctly normalised for technical baseline and for inflation using appropriate guidance. The time phasing of the estimate should also be logical and accurate.

• **Comprehensiveness** – Estimates should use a cost breakdown structure that is at a level of detail appropriate to ensure that cost elements are neither, omitted or double-counted. All the cost driving ground rules and assumptions must be detailed in the documentation of the cost estimate.

• **Replicability and Auditability** – The estimate should be presented in a cost breakdown structure and work breakdown structure that is fully traceable to the system specification. The estimate documentation should include source data, significance and goodness of fit statistics for CERs, clearly detailed calculations and results and explanations for why a particular method or reference was chosen. An independent reviewer must be able to follow the estimating process, repeat the calculations and arrive at the same answer.

• **Traceability** – Data should be traceable back to the source documentation.

Without these characteristics the estimate will not be **credible**, which is the most important quality of a good estimate and the benefits just discussed will be much harder to realise. Finally, an estimate must be **timely**. The best estimate in the world does no good if it is too late to provide decision makers the insight needed.

A cost model must therefore be able to demonstrate that it meets the characteristics listed above and is fully documented in order to justify the life cycle cost estimate produced.

6.Life Cycle Cost and Models

6.1 Life Cycle Cost Tree

The basic tree for LCC starts with a very simple tree based on the costs for acquisition and the costs for sustaining the acquisition during its life as shown in Figure 5.1.

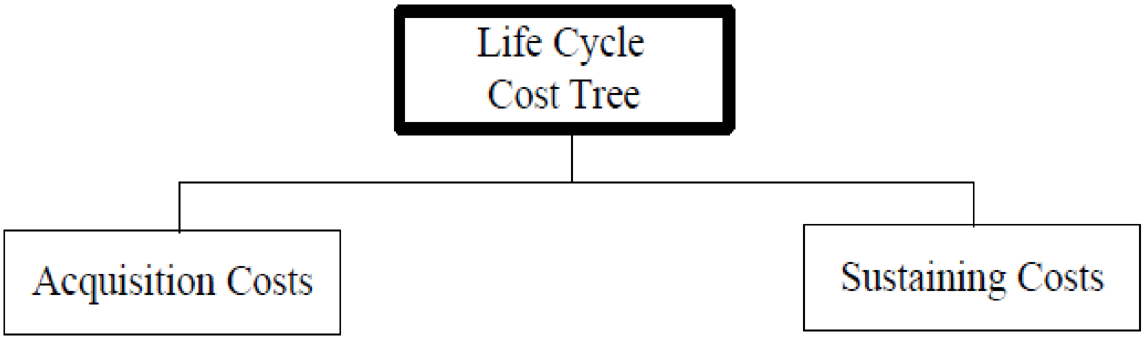

Fig. 5.1

Acquisition and sustaining costs are not mutually exclusive. If you acquire equipment or processes, they always require extra costs to sustain the acquisition, and you can't sustain without someone having acquired the item. Acquisition and sustaining costs are found by gathering the correct inputs, building the input database, evaluating the LCC and conducting sensitivity analysis to identify cost drivers.

The first obvious cost (hardware acquisition) is usually the smallest amount of cash that will be spent during the life of the acquisition and most sustaining expenses are not obvious. Finding LCC requires finding details for both acquisition and sustaining costs with many details involved in the effort

Acquisition costs have several branches for the tree as shown in Figure 5.2.

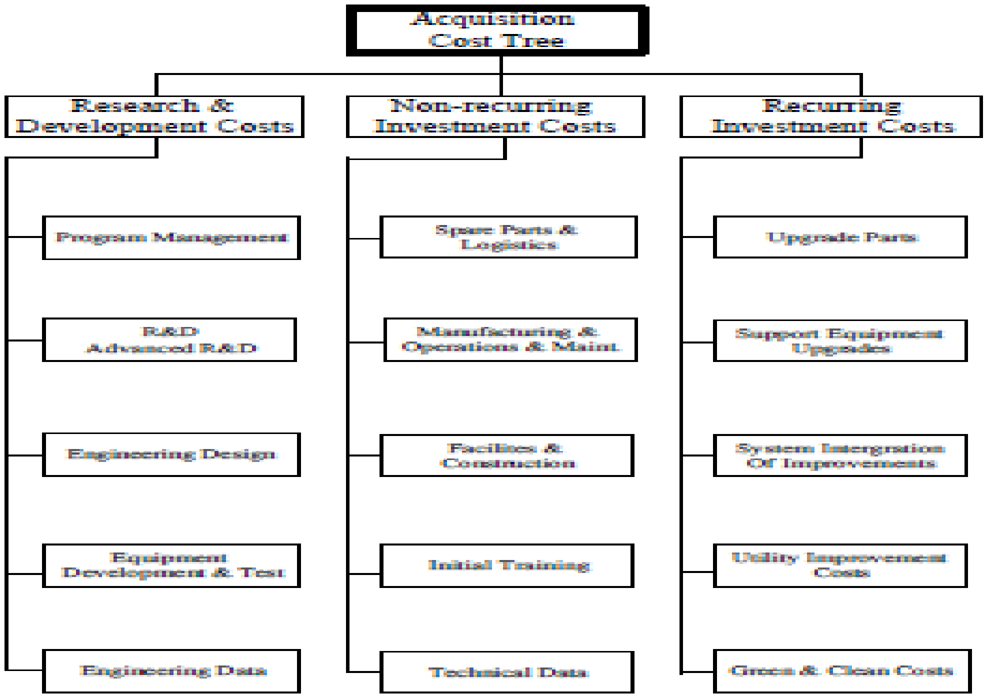

Fig. 5.2

Each branch of the acquisition tree also has other branches which are described in detail in other references [SAE 1993] and [Fabrycky 1991].

Sustaining costs have several branches for the tree as shown in Figure 5.3.

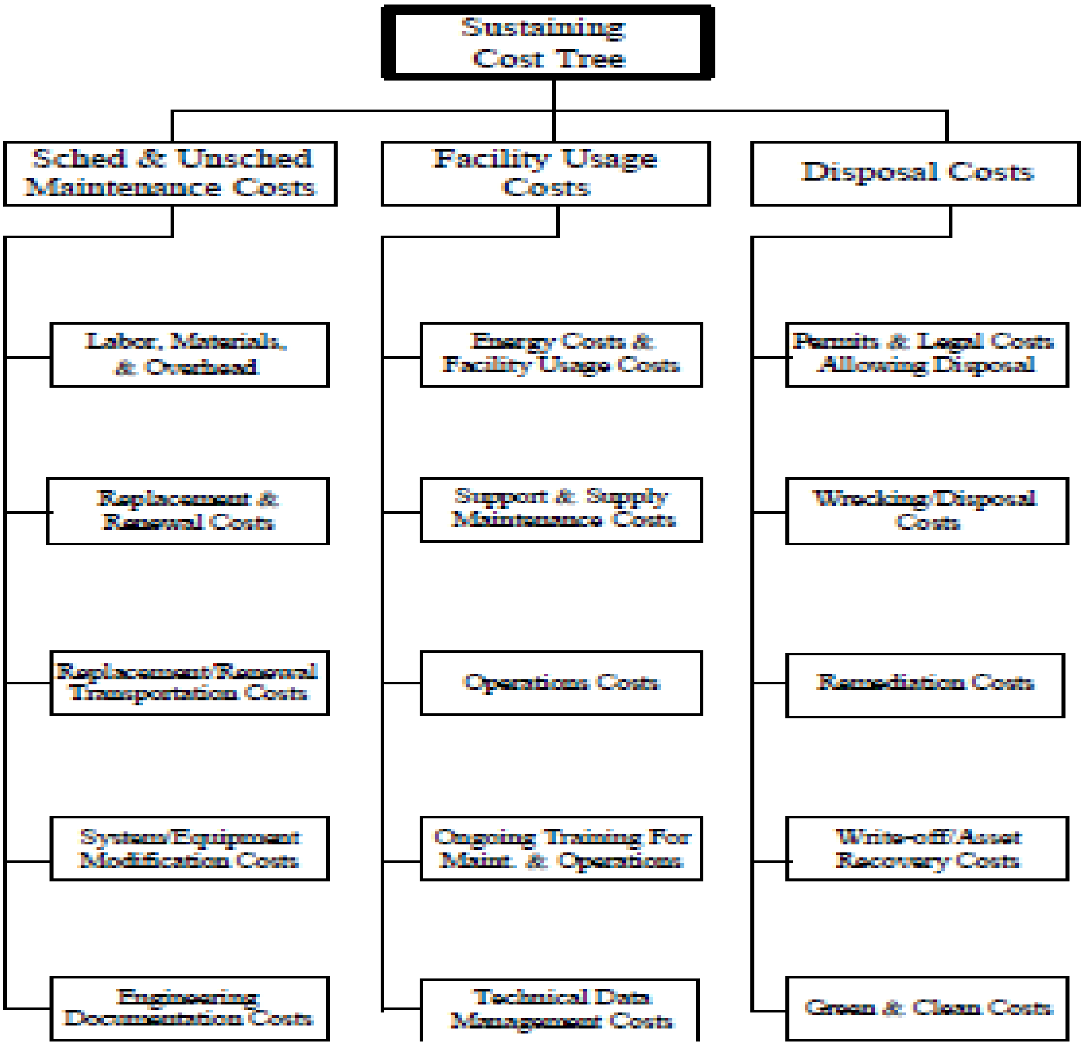

Fig. 5.3

What cost goes into each branch of the acquisition and sustaining branches? It all depends on the specific case and is generally driven by common sense. Consider the details under each category which is shown below. Of course, building a nuclear power plant to generate electricity requires special categories under each item of acquisition cost and sustaining cost. Building a pulp and paper mill or modifying coker drums at a refinery to prevent characteristic over-stress which occurs during quench cycles would have different cost structures than for building a nuclear reactor.

Include the appropriate cost elements and discard the elements which do not substantially influence LCC.

Consider these alternative LCC models as described by (Raheja 1991):

1) LCC = non-recurring costs + recurring costs,

2) LCC = initial price + warranty costs + repair, maintenance, and operating costs to end users;

3) LCC = manufacturer's cost + maintenance costs and downtime costs to end users.

4) LCC = acquisition costs + operating costs + scheduled maintenance + unscheduled

maintenance + conversion/decommission.

6.2 Example of LCC model

SAE (SAE 1993) has a LCC model directed toward a manufacturing environment The SAE model breaks down the costs as shown in Figure 5.4.

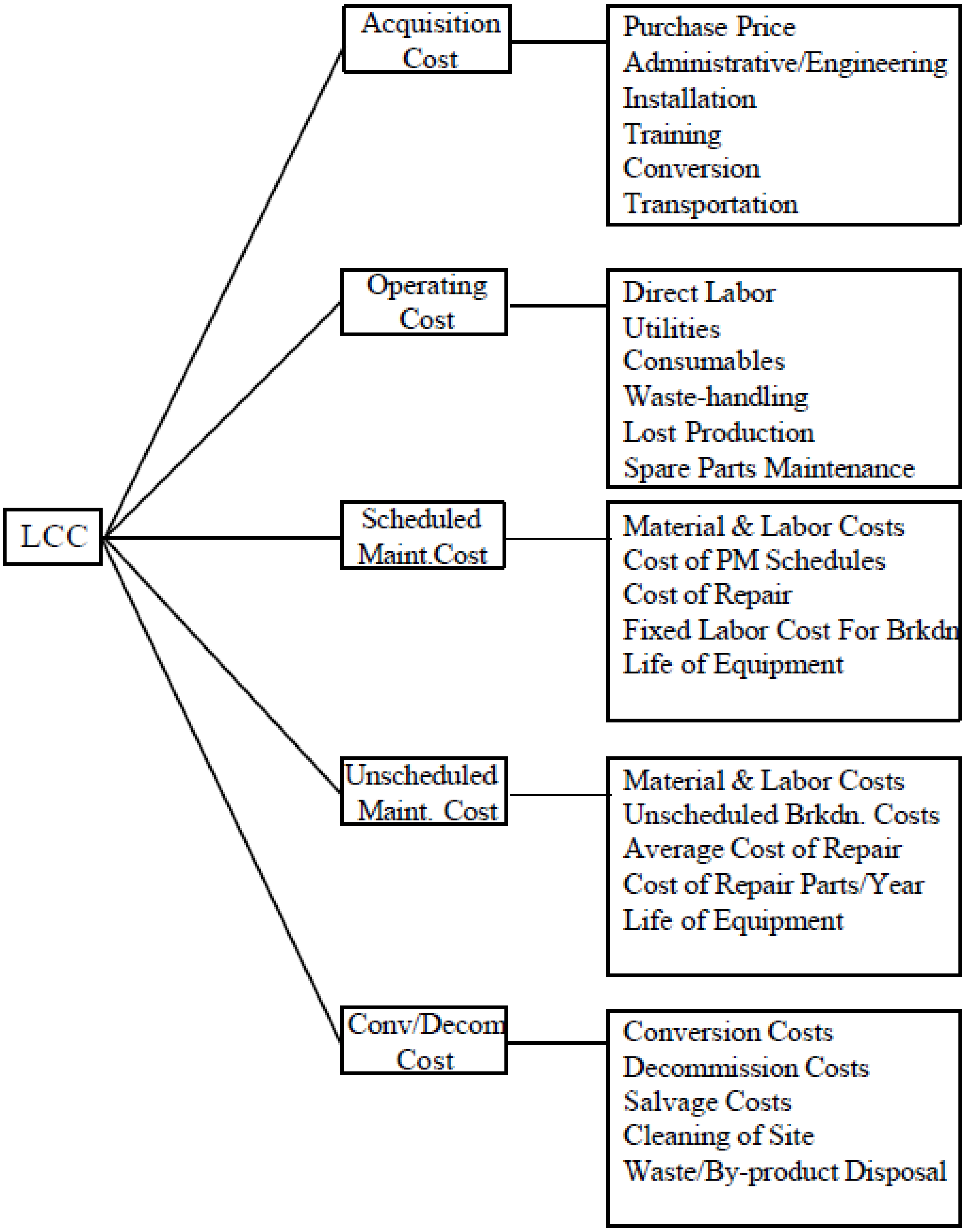

Fig. 5.4

The LCC models above, and much more complicated models described in the British Standards BS-5760 (BSI 1983), include costs to suppliers, end users, and "innocent bystanders"—in short, the costs are viewed from a total systems perspective. LCC vary with events, time, and conditions. Many cost variables are not deterministic but are truly probabilistic. This usually requires starting with arithmetic values for cost and then growing the cost numbers into the more accurate, but more complicated, probabilistic values.

7.Model case study for C-27J Spartan

7.1 General consideration for"in-house" parametric model

The analysis is based on C-27J aircraft fleet, composed from 7 aircrafts. The time frame is 2014 - 2018.

The lifecycle costs analysis was completed and is presented as a comparison for two separate options: repair costs versus exchange costs for 5 years.

The analysis was also completed with two separate utilization scenarios: 150 flight hours per aircraft annually and 200 flight hours per aircraft annually.

The most likely maintenance model was chosen based on the follows:

- Aircraft spares (including estimates for parts with high replacement rates such as tires
- Scheduled programmed interval maintenance and inspections
- Major component and airframe overhaul maintenance (e.g. propeller, landing gear, power plant overhauls)
- Operating costs, e.g. fuel, fuel additives, lubricants, oxygen, etc.
- Training for maintenance and navigation personnel is included
- The initial investment cost is included and it was shared for the 30 years.

Application of this model it have the purpose to identify the maintenance costs as part of the LCC. This model could be extent/modified with other inputs in order to keep a most accurate LCC of the C-27J fleet.

7.2 Costs and calculation of the LCC

The LCC was calculated, basically for the two flight profiles (150FH and 200FH) and based on two maintenance approaches (cost of spares repairing and cost of spares exchange). These two maintenance approaches is giving minimum costs and bigger time of return for repairing and bigger cost and minimum time of return for exchange.

Acquisition cost is equal and is shared annually on the entire life cycle of the aircrafts.

Scheduled maintenance includes all types of checks incurred within the time frame.

Unscheduled maintenance does not include manpower, but includes repairing costs (repairing/exchange).

Services, includes annual fixed costs referring at Technical Publication Updating and Technical Assistance – on line support.

The minimum pool of spares cost is considered based on fixed price of the spares for every year as is in the annex of the maintenance contract.

Operational costs include POL (Petroleum, Oil and Lubricants) products costs and training of the personnel air and ground crew based on the two flight profiles.

Different types of scheduled maintenance are presented as follows:

	2014	2015	2	2017	2018

/C			**016**		
701	HS1, A1, B1	HS1, HS2, A3	H S1, A1	HS1	HS1, A1, B1,C1
702	HS1, A1, B1	HS1, HS2, A3	H S1, A1	HS1	HS1, A1, B1,C1
703	HS1,	HS1, HS2, A1, B1, A3	H S1	HS1, A1	HS1
704	HS1,	HS1, A1, B1,	H S1	HS1, A1	HS1
705	HS1,	HS1, A1, B1	H S1	HS1, A1	HS1
706	HS1	HS1, A1	H S1	HS1, A1, B1	HS1,

Table 2

The flight profile is presented in the table below:

FH/YEAR/A/C	**No. of A/C**					**TOTAL**
						FH
200	.400	.400	.400	.400	1.400	7.000
150	.050	.050	.050	.050	.050	5.250

Table 3

The acquisition costs is presented in the next table and results from the unit price of acquisition for one aircraft divided with 30 and then multiplied with the no. of the aircraft.

Acquisition cost - shared	6.521.669	6.521.669	6.521.669	6.521.669	6.521.669	**32.608.345**

Table 4

Scheduled maintenance, unscheduled maintenance and services costs are presented in the table no. 5, 6 and 7, the figures were calculated starting from the price catalogue, with a historical data base assumption for the unscheduled maintenance which could occur.

Scheduled maint. Costs	**2014**	**2015**	**2016**	**2017**	**2018**	**TOTAL**
Repair Costs	522.929	210.590	1.678.595	594.419	596.731	**3.603.264**
Exchange	6	2	3.	6	6	**5.**

Costs	01.368	37.221	035.791	78.280	76.881	**229.541**

Table 5

Unschedule maint Costs	**2 014**	**2 015**	**2 016**	**2 017**	**2 018**	**T OTAL**
Spares repair	6 70.000	6 70.000	6 70.000	6 70.000	6 70.000	**3. 350.000**
Spares exchange	7 60.000	7 60.000	7 60.000	7 60.000	7 60.000	**3. 800.000**

Table 6

Services	**2 014**	**2 015**	**2 016**	**2 017**	**2 018**	**T OTAL**
Technical Assistace	6 80.000	6 80.000	6 80.000	6 80.000	6 80.000	**3. 400.000**
Technical Publication Updating	2 50.000	2 50.000	2 50.000	2 50.000	2 50.000	**1. 250.000**
TOTAL	9 30.000	9 30.000	9 30.000	9 30.000	9 30.000	**4. 650.000**

Table 7

The pool of spares costs is also considered based on historical database and by an estimation of a defection rate, total figures being calculated by product between unit price and estimated quantities.

Pool of spares	**2 014**	**2 015**	**2 016**	**2 017**	**2 018**	**T OTAL**
Spare & Consumables Acquisition	1. 400.000	8 50.000	6 00.000	1. 200.000	1. 400.000	**5. 450.000**

Table 8

Operational costs were calculated starting from initial offer made on tender process by the year 2006 after which was applied a multiplication factor of 4 units.

POL & Training	2014	2015	2016	2017	2018	TOTAL
POL - 200FH	2.140.600	2.140.600	2.140.600	2.140.600	2.140.600	**10.703.000**
POL - 150FH	1.605.450	1.605.450	1.605.450	1.605.450	1.605.450	**8.027.250**
Training for Crew + Eng - 200FH	887.600	887.600	887.600	887.600	887.600	**18.730.250**
Training for Crew + Eng - 150FH	665.700	665.700	665.700	665.700	665.700	**26.757.500**
Operational Costs - 200FH	3.028.200	3.028.200	3.028.200	3.028.200	3.028.200	**15.141.000**
Operational Costs - 150FH	2.271.150	2.271.150	2.271.150	2.271.150	2.271.150	**11.355.750**

Table 9

The Life Cycle Costs per flight hour was calculated dividing the total costs presented in Table 10 to the respective flight hours presented in the Table 3. The calculation and results are made for the two flight profile – 200 FH and 150 FH.

LCC / FH	2014	2015	2016	2017	2018	5Y avg.
TOTAL LCC Repair 200FH / FH	9.338	8.722	9.592	9.246	9.390	**9.258**
TOTAL LCC Exchange 200FH / FH	9.458	8.805	10.625	9.370	9.512	**9.554**
TOTAL LCC Repair 150FH / FH	11.729	10.908	12.068	11.607	11.800	**11.622**
TOTAL Exchange 150FH / FH	11.890	11.019	13.446	11.772	11.962	**12.018**

Table 12

A graphic representation of the Life Cycle Cost for the next 5 years is illustrated on the chart below:

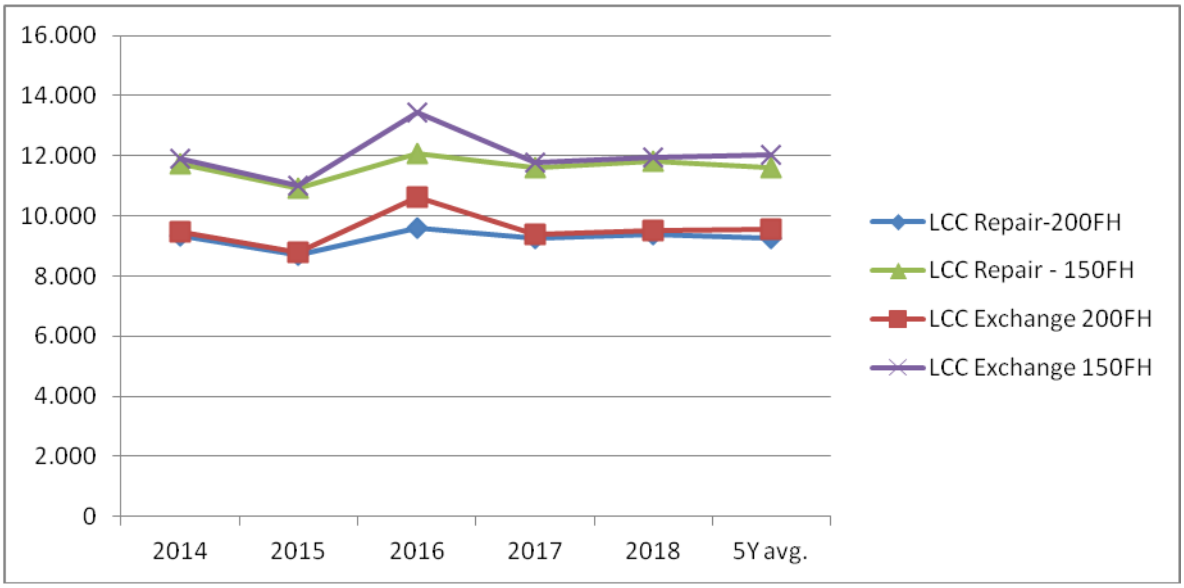

Fig 6.1

8. Conclusion

Life cycle costs of a system consist of all costs to be made by the owner of the system from the whole procurement process (design, production, acquisition, et.) to the end of service and disposal. A very useful instrument for decision on acquisition process, but still an estimation depending on the inputs requested. I consider it is more useful to forecast the future expenses of a system.

This is a generic definition of Life Cycle Cost and does not give a decisive answer about how the elements or expenses can be attributed to a system. In fact many nations uses their own approach to calculate the LCC, based on their available information and on the acquired system. There are many models, including mathematic models, but nations are also developing "in-house" models which are more appropriate to their needs.

Concerning the case study results is it obvious the fact that less flight hours we fly the higher costs we pay. But the chart presented shows us also a very useful information about strategies should be applied to the budget and contract management, due to the fact the exchange approach (red line) of flying 200 hours it costing less than repair approach (green line) of flying 150 hours. That means is more effective and less timely consuming (shorter terms of delivery) to repair spares by exchange in the case of flight profile of 200 hours instead of flying 150 FH and choosing the repairing approach which have longer time of delivery.

9. References:

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[5] Task Group SAS-069, *Code of Practice booklet for Life Cycle Costing,* Research and Technology Organization, 2009, 64 pages.
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