

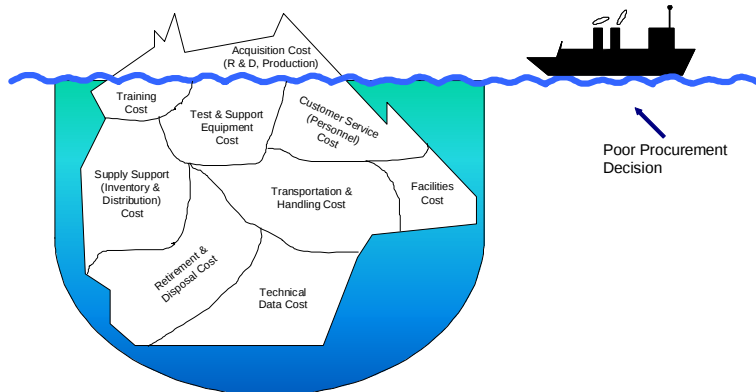


RTO PUBLICATION

SAS-069

Code of Practice for Life Cycle Costing

(Code de bonne conduite pour une
évaluation du coût global
de possession)



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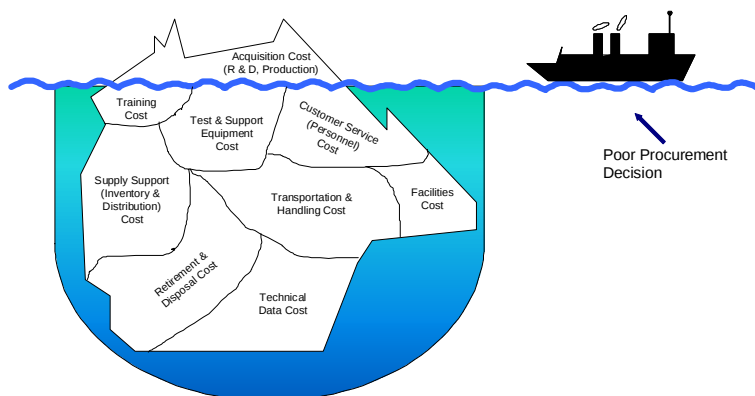


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Preface

The purpose of this document is to familiarise the reader on the application and use of life cycle costing for a system of interest (including individual weapon systems, system of systems, and military and business software) from an early conceptual stage in the product life cycle through to disposal.

It provides illustrations on the types of life cycle cost studies that can be conducted and examples to demonstrate the benefits of conducting life cycle costing to inform the decision making process.

This handbook was prepared as part of the NATO Research Technology Organisation, System Analysis and Studies Panel, Task Group 069 and was based on the work conducted by SAS-028, SAS-054 and AC/327 WG3 and is in accordance with AAP-48.

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Code of Practice for Life Cycle Costing

(RTO-SAS-069)

Executive Summary

The objective of the SAS-069 task group was to produce a Code of Practice that draws on the conclusions and recommendations of SAS-054 and to produce a practical guide to the use of life cycle costing methods and models in a succinct booklet form.

The purpose of this booklet is to familiarise anybody interested in life cycle cost analysis on the application and use of life cycle costing for a system of interest (including individual weapon systems, system of systems, and military and business software) from an early conceptual stage in the product life cycle through to disposal.

The booklet provides illustrations on the types of life cycle cost studies that can be conducted and examples to demonstrate the benefits of conducting life cycle costing to inform the decision making process.

Code de bonne conduite pour une évaluation du coût global de possession (RTO-SAS-069)

Synthèse

L'objectif du groupe opérationnel SAS-069 était de fournir un code de bonne conduite qui tire les conclusions et les recommandations du SAS-054 et de fournir un guide pratique d'utilisation des méthodes et des modèles d'évaluation du coût global de possession sous forme d'une notice succincte.

L'objet de cette notice est de familiariser toute personne intéressée par l'analyse du coût global de possession avec l'application et l'utilisation de la méthode de détermination de ce coût pour un système digne d'intérêt (comprenant des systèmes d'armes individuelles, un système de systèmes et des logiciels militaires et de gestion) tout au long de son cycle de vie depuis le premier stade de la conception du produit jusqu'à son élimination.

La notice fournit des illustrations sur les types d'études de coût global de possession qui peuvent être effectuées et des exemples afin de démontrer les avantages d'une évaluation de ce coût global de possession pour renseigner le processus de prise de décision.

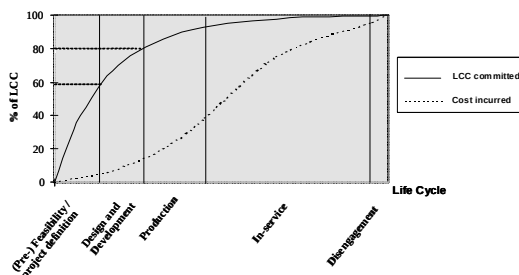
Chapter 1 – WHAT IS LIFE CYCLE COSTING?

1.1 DESCRIPTION

Life cycle costing is the discipline or process of collecting, interpreting and analysing data and applying quantitative tools and techniques to predict the future resources that will be required in any life cycle stage of a system of interest.

The life cycle costs which are the output of this process include not only the costs of the acquisition but also other costs that are logically attributed to the programme throughout its life. The concept of “total ownership” or “whole life” cost is related but broader in scope. Detailed cost related definitions can be found in the NATO RTO SAS-028 report [1]. When used as a key measure, it can reflect differences in alternative procurement options and support solutions expressed in monetary terms.

Simply put, life cycle costing is a powerful technique that supports the analytical processes by which managers can make the most cost-effective decisions on options presented to them at differing life cycle stages and at different levels of the life cycle cost estimate. Note however that life cycle cost is just one of many criteria (e.g. operational need, government constraints) that could influence an investment decision.



The greatest opportunity to reduce life cycle costs usually occurs during the early stages of a programme

WHAT IS LIFE CYCLE COSTING?

1.2 USE OF LIFE CYCLE COSTING

The principles and practices of this booklet apply to systems of interest, including individual weapon systems, system of systems, and military and business software.

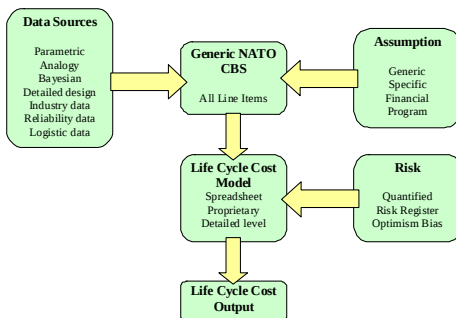
Life cycle costing is not an exact science. A life cycle cost estimate does not provide the exact figure for the costs; it merely gives an insight into the major cost factors and it may also help to compare alternative solutions. It highlights the magnitude of the costs and identifies areas for potential cost savings as well as areas for technical and organisational improvements.

Life cycle costing should not be considered as a one-off task but should be recognised as an ongoing activity throughout the project life cycle.

1.3 LIFE CYCLE COSTING PROCESS

The method(s) and model(s) used to develop the life cycle cost estimates will depend upon the availability of data, the purpose of the cost estimate and the time available to conduct the work.

Once the scope (objective, requirements and constraints) of the life cycle cost study has been established the overall cost estimating process can commence. It may be necessary to undertake several iterations following the first set of results due to the availability of more data, clarification of the assumptions or just general refinement. The process is completed with the presentation of the results, assumptions and financial implications. This process is described in more detail in Chapter 4.



Various data sources and cost estimating techniques can be used to derive the likely life cycle costs of the System of Interest.

1.4 LIFE CYCLE COST PLAN

In order to control the process a life cycle cost plan should be developed and maintained throughout the life cycle of the system of interest. The purpose of the life cycle cost plan should be to provide the stakeholders with a clear understanding of the life cycle costing requirements and how it can be used to support their life cycle management plan. The life cycle cost plan must therefore provide sufficient detail on:

- What is the life cycle cost analyst going to do?
- How does it link in with other associated activities?
- Who is going to do it?
- How is the analyst going to do it?
- When is the analyst going to do it?
- How are the life cycle costs going to be presented?



Chapter 2 – WHY DO LIFE CYCLE COSTING?

2.1 NATO GUIDANCE

The NATO ALP-10 guidance [2] states that all multi-national programmes must implement a life cycle cost programme. However, this should not be considered a burden as it will provide full visibility of all the costs in the overall programme and system of interest.

2.2 MOTIVATION AND APPLICATION

A life cycle cost estimate, done properly, is the single best metric for measuring the value for money of defence resources. This metric, in turn, is useful in wide range of applications including:

- Evaluating alternative solutions and source selection.
- Assessing the affordability of the programme.
- Managing existing budgets.
- Developing future expenditure profiles.
- Evaluating cost reduction opportunities.
- Evaluating areas of financial risk and uncertainty.
- Improving the business processes of the organisation.
- Analysing Capability Portfolios.



Minimise the risk of cost growth by developing realistic and well documented life cycle cost estimates.

WHY DO LIFE CYCLE COSTING?

2.3 BENEFITS

There are clear and unequivocal benefits to be gained by all the stakeholders through undertaking a life cycle cost analysis on the system of interest. These include:

- Providing a better insight of all the costs in the programme and identifying the key cost drivers for potential cost savings.
- Providing a realistic planning programme and budgeting through a methodical and consistent estimating approach.
- Providing the basis for measurement of effective organisational and logistic scenarios and provisions.
- Providing a measure to evaluate two or more technically different solutions to assist the decision making process.

Chapter 3 – WHO CAN BENEFIT FROM LIFE CYCLE COSTING?

Life cycle costing is a very useful process to support the control and management of all the mandatory and stakeholders' multi-criteria requirements in the most effective and economical way.

The stakeholders in the life cycle are those who have a justifiable claim to be allowed to influence requirements which defines the system of interest. These include, but are not limited to:

- Those affected by the system of interest, such as clients and suppliers;
- Project and programme managers who are concerned for the system of interest to succeed;
- Regulators such as defence decision makers, local and state governments and standardisation bodies; and
- Those involved in the development, acquisition and support organisation such as engineers, architects, planners and financial personnel.

A clear understanding of the life cycle cost principles, methodologies and techniques will enable all these people to apply life cycle cost to their defence programmes and to successfully deliver and control the system of interest throughout its life cycle.



Chapter 4 – WHAT IS REQUIRED TO CONDUCT LIFE CYCLE COSTING?

4.1 OBJECTIVE

Prior to any costing activity it is essential to define what is to be estimated and understand what the estimates will be used for (e.g. setting budgets, options evaluation, pricing).

The system of interest could range from a large turnkey project (e.g. a major capital investment), a stand-alone system (e.g. individual platforms such as a ship, aircraft or tank) to a worldwide application (e.g. theatre(s) of operation and use). The approach to be adopted needs to be tailored to suit the questions to be answered, the costing requirements and the availability of suitable data. With some variation (to the level of detail), the same basic approach to life cycle costing can be applied to all projects regardless of their specifications.

4.2 REQUIREMENTS

A requirement is a singular documented need of what a particular product or service should be or do. It is a statement that identifies a necessary attribute, capability, characteristic, or quality of a system in order for it to have value and utility to a user.

A clear understanding of the requirements, which is a statement of needs, relating to the system of interest is essential to conduct life cycle costing.

There are three (3) main categories of requirements and each one of them represents a specific area of the stakeholder's and user's interest for the new system of interest:

- Operational requirements are a set of information representing all identified needs of the stakeholder, in order to fill an existing operational gap.
- Technical requirements are the information deriving from the translation of the stakeholder operational requirements into a set of measurable technical specifications of the new system of interest.

- Performance requirements represent the services that the new system of interest should provide to the user, according to the stakeholder requirements.

Analysing the stakeholder requirements is called the Requirements Analysis Process and is performed during the Conceptual Stage of the Life Cycle Stages ISO 15288 [3].

In order to define the Stakeholder requirements, the steps of the Stakeholder Requirements Definition Process, as described in AAP-48 [4] must be followed.

Once the requirements are defined then the estimation of the life cycle cost of the system of interest can begin.

4.3 IDENTIFICATION OF CONSTRAINTS

The identification of the constraints is required as they will influence the life cycle costing process. There are two types of constraints.

4.3.1 External Constraints

Though the benefits of life cycle costing are recognised, the approach for its use and implementation could vary from Nation to Nation, due to:

- Time constraints imposed by decision makers.
- Potential high number of organisations involved.
- Limited and suitable resources to support life cycle costing.

4.3.2 Internal Constraints

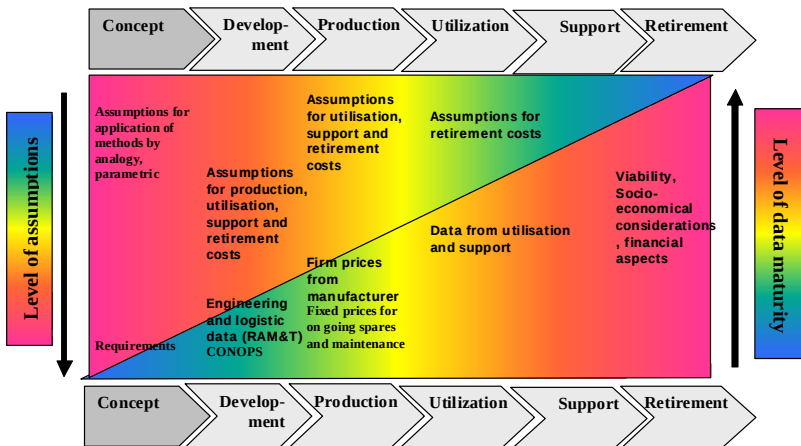
These constraints are inherent to:

- Data availability.
- Limited and suitable resources to conduct life cycle costing.
- Maturity of requirements definition.
- Economic and Commercial conditions.

4.4 DATA

Data is required in order to conduct a life cycle cost analysis. In terms of time, effort, and resources consumed, collection of data is a major part of the life cycle costing effort. Life cycle costing is a data driven process, as the amount, quality and other characteristics of the available data often define what methods and models can be applied, what analyses can be performed, and hence, the results that can be achieved.

The figure below illustrates the relationship between data maturity and level of assumptions to be applied.



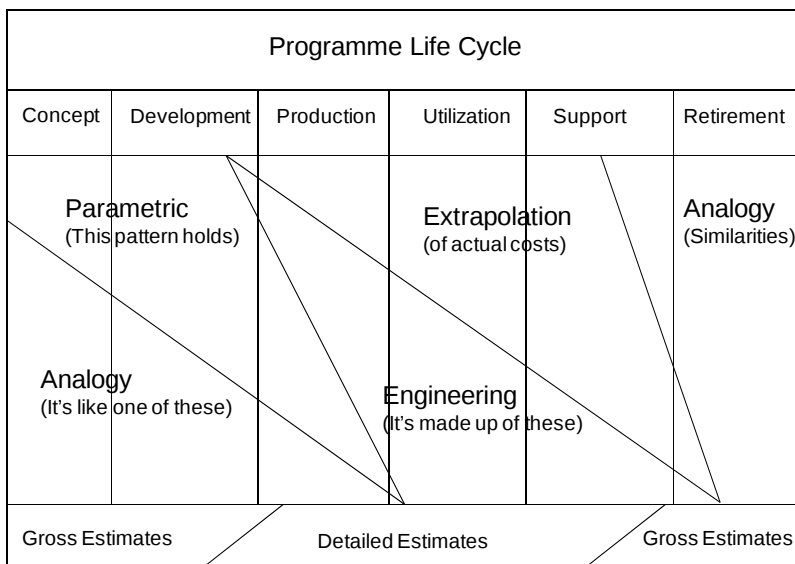
The amount and quality of data available often increases in time with the maturity of the system of interest, and the level of assumptions decreases. As more data becomes available less assumptions have to be made, and more detailed methods can be used to estimate costs.

Chapter 7 gives more details on data collection, data sources and data normalisation.

4.5 METHODS

Previous study findings have confirmed that almost all nations use a similar process to develop life cycle cost estimates; that the quality of the available data nearly always determines the method to be applied; and, in addition, that the type of study also influences the process and the selection of the appropriate method.

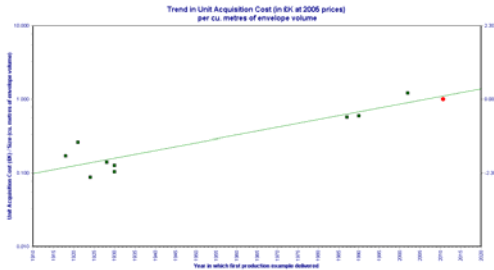
The figure below shows an example of the most common application of methods in each stage of the programme life cycle. A more detailed overview of appropriate methods can be found in the report of NATO RTO SAS-054 [5].



Cost Estimating Methods

To improve the confidence on the results, two or more alternative methods should be used for each major cost breakdown structure element whenever possible. However, the use of alternative methods should always be evaluated from a cost-benefit point of view.

Typically, further confidence can be gained by conducting a trend analysis to place the programme cost and time estimates in context with previous historical outcomes as illustrated in the figure below.



*Here an estimate
is compared with
known previous
programme
outcomes to
provide
confidence in
the estimate.*

4.6 ASSUMPTIONS

The lack of information (e.g. data related to an operational scenario, system life and support organisation) of any kind or in any stage makes it necessary to identify and record assumptions in order to develop a complete life cycle cost of the system of interest.

In order to maintain an appropriate audit trail it is necessary to record and document all changes to data and assumptions during the estimating process.

It is good practice to undertake a sensitivity or “what if” analysis on key assumptions. An example would be to examine how maintenance costs would vary with different values of system reliability.

4.7 COST BREAKDOWN STRUCTURE

A Cost Breakdown Structure (CBS) is used to ensure that all relevant costs related to the system of interest are considered. This may be defined as an organised list of all cost items related to the life cycle of a system or programme. A CBS must satisfy some requirements such as:

- Being easy to develop, use and update;
- Sufficiently comprehensive to include all relevant cost items;

- Being clear in terms of cost definitions;
- Be flexible in order to be adapted to different systems; and
- Comparable to other cost breakdown structures enabling decision makers to make option analyses.

Life Cycle Cost can be broken down in a number of ways. Examples of breakdowns are:

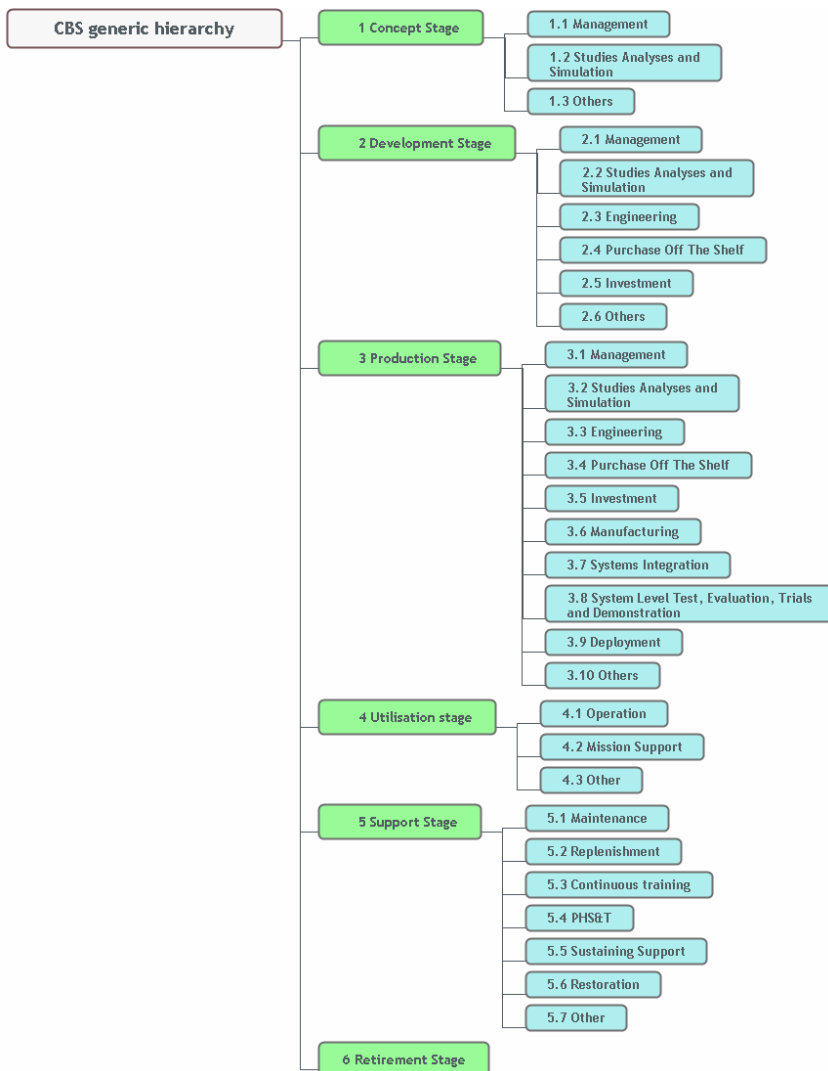
- By time (year, month, or life cycle stage).
- By type of costs (direct, indirect, linked, variable or fixed).
- By product (systems, subsystems, components).
- By process/activity (management, engineering, maintenance, etc.).
- By resources (personnel, equipment, consumables).
- By organisation:
 - Unit, service branch, etc.;
 - Nation (multi-national programme); and
 - Public/private company.

Most of these breakdowns are not mutually exclusive, and a CBS will typically involve a combination of a number of these types of breakdowns. More details about developing a Cost Breakdown Structure can be found in the NATO RTO SAS-028 report [1].

It is quite common to develop or illustrate a CBS as a tree structure, as it is in the example shown below. This gives an instant overview of a CBS, based on stages and activities.

For large, complex and very detailed CBS structures, however, it is useful to assign a numeric order code to each cost element in the CBS.

WHAT IS REQUIRED TO CONDUCT LIFE CYCLE COSTING?



4.8 RISK AND UNCERTAINTY

Life cycle cost estimates of any new system of interest will inevitably contain uncertainty and risk. Much effort is required to accurately estimate the system development and production costs, as well as future decades of operation and maintenance costs. At the end of this estimation process a cost estimate is produced which is stochastic rather than deterministic with uncertainty and risk determining the shape of the distribution. The definition of each term is given as:

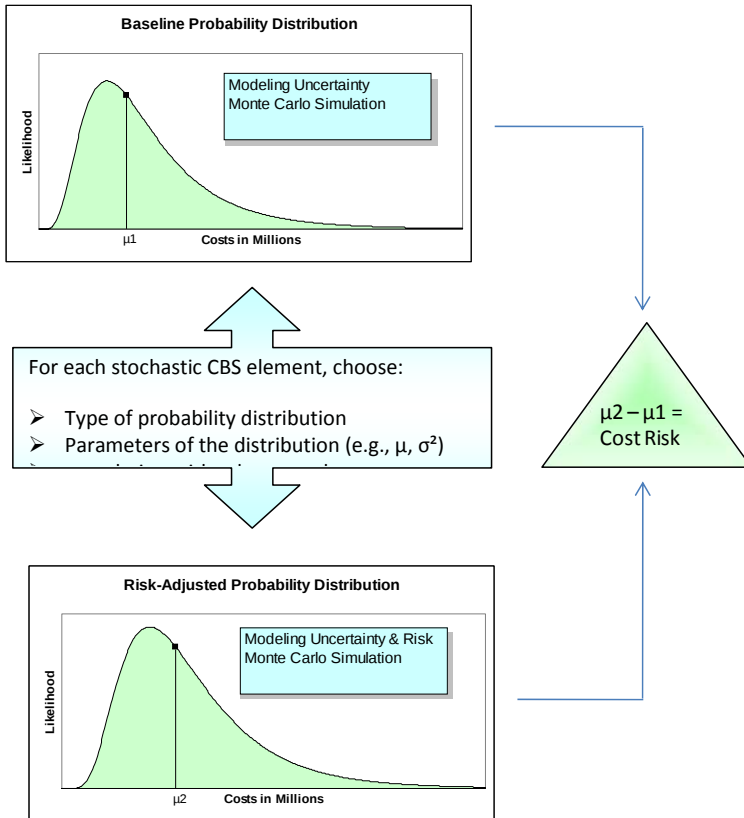
- **Uncertainty** is the variance associated with the data and assumptions.
- **Risk** is the consideration of potential adverse events and has two components:
 - 1) The probability of occurrence of an unfavourable event, and
 - 2) The consequences of that event.

Conducting risk and uncertainty analysis on life cycle cost estimates of the systems of interest is required to fully understand the possible variances in programme estimates in terms of cost.

By conducting risk and uncertainty analysis decision makers can determine what degree of risk may be acceptable (e.g. the probability of exceeding the budget).

While there is a wide variety of methods and models for conducting risk and uncertainty analysis on life cycle cost estimates, the principle for estimating risk and uncertainty given in the figure below is highly recommended.

By using this process for the estimation of risk and uncertainty, decision makers can budget a programme at a specific cumulative percentage level of risk and they will be able to know the financial impact of specific risk events.



Principles of Estimating Risk and Uncertainty

4.9 PRESENTATION AND REPORTING

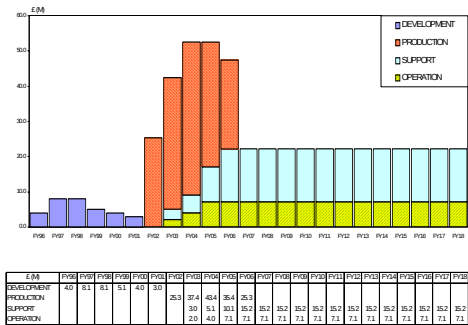
The results of cost studies are very important, as they should provide the stakeholders with an answer to their question. It is therefore very important that the results should be presented and reported in a manner that the stakeholders can easily understand.

WHAT IS REQUIRED TO CONDUCT LIFE CYCLE COSTING?



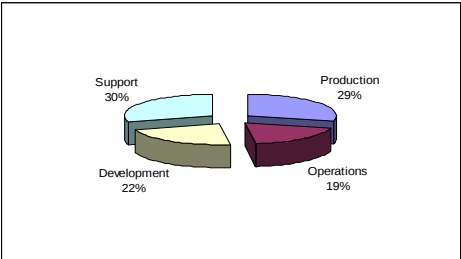
Results can be presented in a wide range of tabular and graphical forms. The favour is to include graphical presentations of the results wherever possible. This enables the widest possible audience to have a clear picture of the overall results while retaining the detailed tabular presentations for those that require them.

Two typical forms of graphical presentation (the spend profile and cost allocation pie chart) are shown below. These figures indicate costs at a high level but can also be used to present a more detailed level as required. For presentation purposes these costs have been truncated at Financial Year (FY) 18.



*Example of a
Baseline Life
Cycle Cost
Spend Profile*

*Example of a Life
Cycle Cost Allocation*

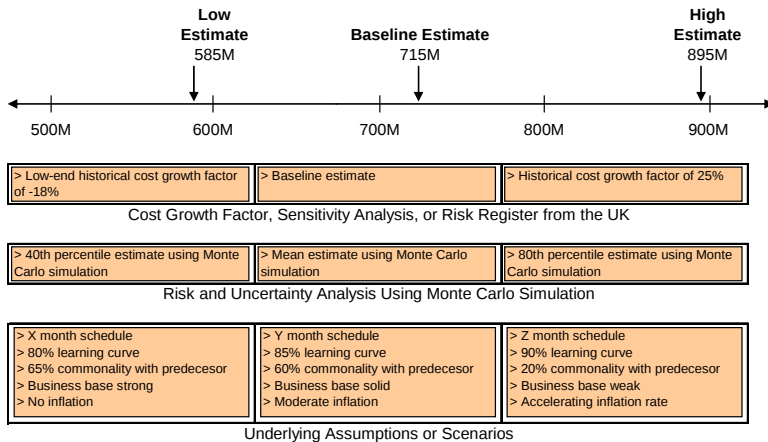


Note: The cost allocation percentage shown in the example above should not be considered as being representative of all life cycle cost estimates.

The output of the life cycle cost study should be a report incorporating the results and conclusions as well as a presentation on the basis of those results. It should include a full definition of the aims and conduct of the study, the definitions of the options studied, the costing boundary considered and the assumptions underlying the cost elements.

The figures above represent single point estimates with no consideration to the presentation of uncertainty and risk. The following figure presents a recommended approach for communicating results of a life cycle cost estimate to senior decision makers (see [6]).

The top line shows a three point range of estimates, and conveys the idea that a cost estimate is not a single number but rather a continuum or distribution of possible values.



Recommended Presentation of Cost Estimating Risk Analysis

The top two shaded bars of the figure show the results of a historical trend analysis on similar programmes and the results obtained from the risk and uncertainty analysis reported at a given percentile. The bottom shaded section, which should always be included in the presentation of the estimate, shows the key assumptions or scenarios associated with the low, baseline, and high estimates.

This approach will lead to the establishment of a sound, well-structured methodology for the conduct of and presentation of life cycle cost estimates.

4.10 MULTI-NATIONAL ASPECTS

The life cycle cost estimates for multi-national programmes follow the same principles as defined for national ones. However, some specifics must be considered and it is worth identifying the special requirements regarding life cycle costing on multi-national programmes.



***NATO ALP-10 guidance
states that all multi-national
programmes must implement
a life cycle cost programme***

A significant added value of a multi-national programme is the possibility to achieve savings by common procurement and support. Therefore the scope of the multi-national life cycle cost studies could be focused on the evaluation of alternatives linked to the development of commonalities.

The basic principle for multi-national life cycle cost estimates is the definition of a common framework managed centrally by the entity in charge of the management of the Programme. This entity could be a Pilot Nation or an International Programme Office or a NATO Agency.

The common framework should include:

- The selection of common life cycle cost models that allow an easy interface with those defined at national level.
- A common Cost Breakdown Structure based for example on the generic CBS as presented at sub-section 4.7.
- Development of shared data and assumptions by considering common aspects and nations specifics.
- Definition of a reference currency and the exchange rate.

WHAT IS REQUIRED TO CONDUCT LIFE CYCLE COSTING?

Included in the cost estimates, some specific requirements such as fair return on investment, deployment assumptions and the previously conducted national cost estimate must be carefully considered.

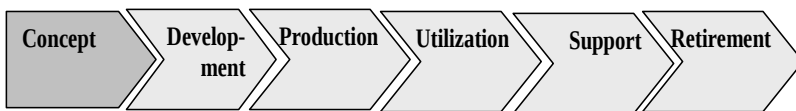


Chapter 5 – WHEN TO CONDUCT LIFE CYCLE COSTING?

The approach taken to conduct life cycle costing is highly dependent on the life cycle stage of the system of interest as this determines the availability of data and the technical maturity of the system.

NATO, through the AAP-48 Life Cycle Stages and Processes [4], has adopted ISO 15288 System Engineering – System Life Cycle Process [3] for dividing the life cycle into the following stages.

Each stage requires a different approach in conducting Life Cycle Costing. For more details how to conduct a Life Cycle Cost Analysis in each stage, please refer to Chapter 6.



5.1 CONCEPT STAGE

The concept stage starts after the decision to fill a capability gap with a materiel solution and ends with the requirements specification for this materiel solution.

5.2 DEVELOPMENT STAGE

The development stage is executed to develop a system of interest that meets the user requirements and can be produced, tested, evaluated, operated, supported and retired.

5.3 PRODUCTION STAGE

The production stage is executed to produce or manufacture the product, to test the product and to produce related supporting and enabling systems as needed.

5.4 UTILISATION STAGE

The utilisation stage is executed to operate the product at the intended operational sites, to deliver the required services with continued operational and cost effectiveness.

5.5 SUPPORT STAGE

The support stage is executed to provide logistics, maintenance, and support services that enable the continued system of interest in operational and sustainable service. The support stage is completed with the retirement of the system of interest and termination of support services.

5.6 RETIREMENT STAGE

The retirement stage provides for the removal of a system of interest and related operational and support services and to operate and support the retirement system itself. This stage begins when a system of interest is taken out of service.

5.7 ADDITIONAL ASPECTS

- AAP-48 describes the stages and processes to be followed in developing and procuring a new system in order to fulfil a capability gap. At some point in the NATO life cycle, the decision has to be made either to develop a new system or to procure an off-the-shelf system (e.g. make or buy decision). If the decision is made to buy a system of interest the following type of Life Cycle Cost studies can be performed:
 - Supporting the tender evaluation process.
 - Comparing alternative solutions or options on costs, in order to choose the best solution.
 - Determining the total life cycle costs.
- It is not uncommon to repeat or refine the types of studies as the programme progresses through the stages of the life cycle.

- The utilisation stage starts at the same time as the support stage and together they are often referred to as the in-service stage. The utilisation stage ends when the system of interest is taken out of service.

Life cycle costing should not be considered as a one-off task, but should be recognised as an ongoing activity throughout all stages of the life cycle.

Life cycle costing should, in each stage of a programme, support stakeholders in making 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 Performance Indicators or Key User Requirements.



Chapter 6 – LIFE CYCLE COSTING DURING THE LIFE CYCLE STAGES

6.1 INTRODUCTION

This chapter describes the appropriate estimating methods and likely applications of life cycle costing across the various life cycle stages for a system of interest.

6.2 CONCEPT STAGE

The greatest opportunity to reduce life cycle costs usually occurs during the early stages of a programme. The concept stage is where decisions are made when the amount of supporting information is at a minimum.

The types of studies conducted at this stage are typically: high level balance of investment, cost benefit analysis and cost-effectiveness plots utilising life cycle cost as one of the key measures.

Since cost and performance data is likely to be immature care should be taken to avoid new conceptual proposals being given unwarranted advantage in comparison with those that have been more thoroughly explored. For this reason, the processes employed to support and undertake conceptual studies rely on:

- Qualitative approaches such as military judgement and subject matter experts to draw on operational evidence and technology application opportunities.
- Quantitative approaches that will employ mathematical modelling of physical system behaviour (principal measurable attributes) within the context of representative operational or business situations.

6.2.1 Input

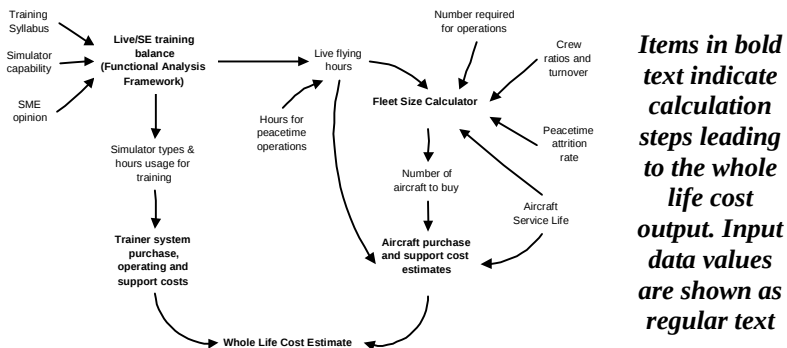
Input data will be derived from the requirements documentation, outline concept of operation and operational analysis.

6.2.2 Output

The LCC output from this stage should support the decision as to whether the options being considered are feasible. The LCC output from this stage should also support the requirements definition process.

6.2.3 Types of Studies

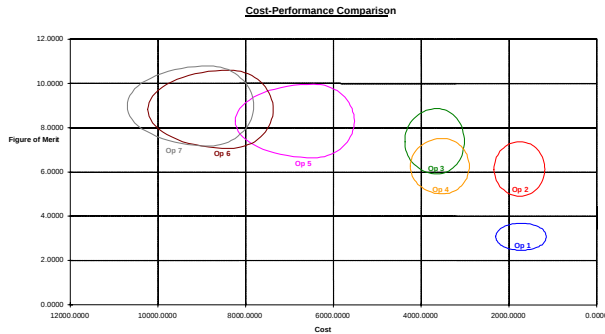
Some examples¹ of the type of studies in the concept stage are Cost Benefit Analysis and Cost Effectiveness Analysis. Cost Benefit Analysis is widely accepted as a vital support tool for economic analysis on defence programmes. The example shown below explores the benefits trade-off between live flying, synthetic training environments and aircraft in-service life in the provision of current and future heavy lift helicopter and light utility helicopter, rotary wing capabilities.



A cost-effectiveness analysis helps to identify, from a number of proposed options offering the best value for money. This type of analysis includes only an assessment of military and financial issues therefore its results must be considered alongside other factors (e.g. industrial, diplomatic) that might influence the decision.

¹ Figures reproduced with kind permission from HVR Consulting Services Ltd.

Cost-effectiveness plots are more commonly used. The size of the bubble show the uncertainty in the data and method used



6.2.4 Estimating Methods

Typical methods used for developing a cost estimate at this stage are Bayesian, Parametric, Analogous, Expert Opinion or Rule of Thumb techniques.

To overcome the lack of data found at this stage, life cycle cost estimates can be produced using proprietary estimating tools containing embedded Cost Estimating Relationships such as ACES, FACET, PRICE and SEER.

6.2.5 Risk and Uncertainty Assessment

In the absence of data required to perform a detailed risk analysis, an alternative, appropriate to this stage, is to apply percentages to a bottom-line estimate. These adjustments should be based on data from past, similar projects and calibrated for the unique characteristics of the programme under consideration. The table below taken from the UK Joint Service Publication 507 [7] shows a build up of these percentages that should be factored to the cost estimate when any of the following conditions is applicable.

Project Information	Percentage Total Cost Uplift
Complexity of the contract structure	7%
Late contractor involvement in design	7%
Inexperience or poor contractor capabilities	4%
Immature Information Management controls	5%
High degree of design complexity	10%
High degree of technical innovation	17%
Immaturity or inadequacy of the business case	18%
Immature or poor management team	5%
Immature or poor project intelligence	18%
Unknown Legislation/Regulations	5%
Immature Technology	18%

These values can then be applied to provide an illustration of “optimism bias” in a programme review.

6.3 DEVELOPMENT STAGE

This stage of a programme calls for design engineering work aimed at full validation of the system requirements and ensures complete system integration to the point where production contract action can be taken.

6.3.1 Input

At this stage much information from the concept stage should be available together with in-house historical data, results from early tests and technical demonstration.

In addition, the Concept of Operations document and the requirement documentation should be used in conjunction with information provided by the supplier to refine the life cycle cost estimates.

6.3.2 Output

On completion of this stage life cycle costing will be sufficiently comprehensive and complete to support the production objective and provide a realistic forecast of the likely life cycle cost.

6.3.3 Type of Studies

Examples of the studies in the development stage are:

- Affordability studies; and
- Tender evaluation.

6.3.4 Estimating Methods

At this stage the life cycle cost estimates will be developed by using engineering (bottom-up) estimates supported by analogy cost estimating, parametric cost estimating, historical trend analysis.

6.3.5 Risk and Uncertainty Assessment

The risk and uncertainty will be measured at a detailed level utilising a quantified detailed risk register and recognised risk simulation models. There should also be mitigation plans for all the major risk areas and the cost of undertaking these mitigation actions should also be included in the cost estimates.

At the completion of this stage the life cycle cost output should be a detailed account of the uncertainties of the line items contained in the Cost Breakdown Structure along with a comprehensive risk analysis in terms of cost impact.

6.4 PRODUCTION STAGE

This stage incorporates the production investment and the manufacture of a system of interest, sub-system or equipment in a plant or factory using series manufacturing techniques.

6.4.1 Input

The input data and assumptions for life cycle costing from earlier stages will be supplemented by data provided by industry through a response to an

invitation to tender or similarly a request for quotation. This may also include a response to a life cycle cost questionnaire that will provide details on system and component reliability (e.g. MTBF, MTTR) and costs.

At this stage industry would provide Firm prices for manufacture broken down into detail for audit and negotiating purposes. Also, budgetary or Fixed (allowing agreed variation) prices for ongoing spares and maintenance should be available.

In addition Earned Value Management data can be used if provided by the supplier.

6.4.2 Output

The output of the life cycle cost analysis will support the negotiating process by establishing a “should cost” or “investment appraisal” for comparison with the industry quotation.

6.4.3 Type of Studies

Besides the aforementioned establishment of a “should cost” or “investment appraisal”, a review and update of the financial element of the systems life cycle management plan can be undertaken during the production stage.

During production a study should be undertaken to assess how the forecasted costs compare to the actual cost.

Other life cycle costing studies may be initiated if there is radical change brought about by the failure to achieve the forecasted plan or a change in policy or procurement strategy.

6.4.4 Estimating Methods

The primary method to be used in this stage is the engineering (bottom up) methods using the detailed Cost Breakdown Structure populated from actual data from industry.

In order to provide confidence in the life cycle cost estimate a second method should be performed using analogy or parametric methods.

An important aspect in this stage is the consideration of the relationship between the reduction of production time and the quantities produced. Care must be taken to ensure that all cost benefits arising from increased quantities (learning factor) must be taken into account.

6.4.5 Risk and Uncertainty Assessment

During the production stage all the risks will be reviewed and managed on a regular basis. Mitigation plans will be put into action and their progress monitored. This will be a comprehensive management and analysis activity and will regularly report the possible outcomes in cost and schedule to the project manager.

6.5 UTILISATION STAGE

In the utilisation stage the system of interest will operate at the intended operational sites to deliver the required capability with continued operational and cost effectiveness in accordance with the user requirements.

During the utilisation stage the system of interest is continuously monitored for performance in accordance with user requirements, e.g. by In-Process Reviews (IPR), to determine how the system can be made more efficient and effective. Another way to monitor the performance of the system of interest is to conduct a User Satisfaction survey to determine if the system of interest performs accurately and reliable.

Operations with the system of interest continue as long as it can be effectively adapted to respond to an organisation's requirements. The need for a major modification or upgrade of the system of interest may arise from a change in the threat, a deficiency identified in the system, a recommendation from the operators or an opportunity to reduce costs. When modifications or changes for upgrade are identified as necessary, the system may re-enter the concept or the development stage.

The utilisation stage starts at the same time as the support stage and together they are often referred to as the in-service stage. The utilisation stage ends when the system of interest is taken out of service.

6.5.1 Input

In order to pursue a cost effective utilisation of the system of interest, input data is required. This data will be derived from information from earlier stages, like the use study, operational requirements or earlier conducted cost studies. Also, information related to personnel, training, infrastructure/facilities and consumables is required.

Furthermore, assumptions and data related to deployment are required. Especially in multi-national operations recording these inputs is vital to estimate costs of alternatives for common utilization.

Finally, during this stage information from users, e.g. user satisfaction or operating experience and other actual data information will be gathered.

6.5.2 Output

The main output of cost analyses in this stage is the cost of operating the system of interest. These costs are primarily driven by the stakeholder's operational doctrine and the assigned mission, the operational environment of usage, the operating rate (up-tempo), and the ability skills and the efficient training of the personnel.

This output will support decision makers to forecast future costs, manage existing budgets and undertake options analysis where necessary. The forecasting of future expenditure requires a sound knowledge of the actual utilisation profiles. Actual costs can also be compared with earlier estimates.

When analysing this output together with the user's satisfaction forms a cost effective utilisation of the system of interest can be obtained.

6.5.3 Type of Studies

During the utilisation stage studies are conducted in order to refine or validate the life cycle cost estimate of the systems in use by using actual recorded data. This should always be in line with the Measure of Effectiveness obtained for a given life cycle cost estimate.

Also at this stage, any change in the costs of operating the system of interest can be analysed, as a result of a change in operational use. Furthermore, the cost of deployment can be determined and analysed.

In addition to the traditional studies conducted during this phase on evaluating cost reduction opportunities, studies on the likely costs and other implications on the phasing out of the systems are likely to be conducted.

For multi-national programmes, alternatives for common operations can be evaluated.

6.5.4 Estimating Methods

Methods employed during the utilisation stage include system dynamics and discrete event simulation to provide dynamic predictive outcomes. Additionally, a parametric method could be used. In order to capture actual costs methods such as activity based costing can also be used.

6.5.5 Risk and Uncertainty Assessment

Risk and uncertainty analysis at this stage usually takes the form of a sensitivity analysis around the major cost drivers related to the operation and support of the system of interest.

6.6 SUPPORT STAGE

In the support stage, support services (including maintenance) necessary to maintain the readiness and the operational capability of the system of interest will be provided.

In order to provide the best possible support services to the system of interest a specific support (including maintenance) concept must be followed in accordance with NATO or National maintenance policy. The support concept shall be established early in the programme. The support concept will satisfy user specified requirements for sustaining support performance at the lowest possible life cycle cost.

An important part of the support concept is the support plan describing the support organisation, the support process and the support resources and facilities.

During the support stage the support concept will be refined and validated. A key role in this process is the optimisation of costs.

The support stage starts at the same time as the utilisation stage and together they are often referred to as the in-service stage. The support stage ends when the system of interest is taken out of service.

6.6.1 Input

In order to pursue a cost effective support of the system, input data is required. This data will be derived from the operational requirements, the support concept and information from earlier stages, such as the integrated logistic support study (including data related to the supply chain, reliability, etc.), requirements related to support or earlier conducted cost studies. Also information related to support personnel, training support personnel, infrastructure/facilities, spare and repair parts, documentation, test and support equipment and tools, Packaging, Handling, Storage and Transportation (PHST) or contract data is required.

Furthermore for multi-national programmes, assumptions and data related to common support solutions are required. Especially in multi-national operations recording these inputs is vital to estimate alternatives for commonalities.

Finally, during this stage information and operating experience from support personnel and other actual data information will be gathered.

6.6.2 Output

The main output of cost analyses in this stage is the cost of supporting the system of interest. These costs are primarily driven by the stakeholder's support concept, the operational environment of usage, the operating rate (op-tempo), and the ability skills and the efficient training of the personnel.

This output will support decision makers to forecast future costs, manage existing budgets related to the support of the system of interest and to undertake options analysis where necessary. The forecasting of future expenditure requires a sound knowledge of the actual support costs. Actual costs can also be compared with earlier estimates.

When analysing this output together with the user's satisfaction a cost-effective utilisation of the system of interest can be obtained.

6.6.3 Type of Studies

During the support stage studies are conducted in order to refine or validate the life cycle cost estimate of the support of the system of interest by using actual recorded data. This should always be in line with the Measure of Effectiveness obtained for a given life cycle cost estimate. The actual data may also be used to validate earlier estimates.

At this stage also the change in costs of supporting the system of interest can be analysed, as a result of any change in operational use or support concepts. Furthermore, obsolescence and life extension studies can be conducted and the cost of upgrades and modifications can be determined and analysed.

For multi-national programmes, alternatives for common support solutions can be evaluated.

6.6.4 Estimating Methods

Methods employed during the support stage include system dynamics and discrete event simulation to provide dynamic predictive outcomes. Additionally, parametric methods can be used. Also optimisation methods can be used. In order to capture actual costs methods such as activity based costing can be used.

6.6.5 Risk and Uncertainty Assessment

Risk and uncertainty analysis at this stage usually takes the form of a sensitivity analysis around the major cost drivers related to the operation and support of the system of interest.

6.7 RETIREMENT STAGE

This stage starts with an intention to retire the System of Interest. However, the decision to retire a system of interest and the studies (including an estimate of likely revenue and expenses) related to this decision may be conducted at an earlier stage in the project life cycle.

A system may enter the retirement stage for several reasons, including: a change in operational requirements, a change in the socio-political

environment (e.g. personnel mines), system obsolescence, increasing support costs, etc.

In addition, a system of interest may be retired earlier than planned due to a change in strategic priorities.

6.7.1 Input

A number of considerations are made to support the disposal decision making process. These considerations are predominantly based on market opportunities and the impact from new legislation. The inputs required to support the life cycle costing process therefore include, but may not be limited to:

- A market survey conducted to establish the potential viability of sale and scrap value. This is not as clear cut as previously experienced. A number of commercial companies throughout the world have taken this as an opportunistic venture by providing facilities to handle toxic material such as asbestos in response to overcoming the change in legislation. Therefore, the scrap value of the raw material alone can be superseded and increased by selling the complete asset to a licensed disposal company.
- Determination of the residual value of the system of interest to support baseline comparisons.
- A review of the financial liabilities arising from environmental and legislative impacts. For example the changes in maritime legislation have resulted in the scrapping of all single hull tankers wishing to use international territorial waters and recognised shipping canals.

It is expected that the life cycle cost analyst will be a recipient of the findings from these studies to support the subsequent cost analysis.

6.7.2 Output

By conducting a life cycle cost analysis the following options can be assessed:

- Re-deployment (can the equipment be used for training/instructional use, as a heritage/museum asset, for spare recovery, etc.).

- Reclamation, recycling, re-manufacture (is there a possible other use as opposed to disposal).
- Sale (potential customers).
- Disposal at cost.

6.7.3 Type of Studies

Analyse options for retirement.

6.7.4 Estimating Methods

Predicting cost estimates for equipment disposal is not dissimilar to the methods employed at the concept stage. The most common methods of estimating the likely disposal cost currently used is by analogy and parametric. These methods are well established and can calculate the negative and positive financial impact depending on the alternative disposal options being assessed. To avoid error, it is essential that as much historical data as possible is gathered and evaluated to provide a degree of 'normalisation' such that a 'like for like' basis is achieved.

6.7.5 Risk and Uncertainty Assessment

The identification of risk for this stage will be conducted at a very high level. It is likely to be a combination of single line statements and will probably contain a mixture of issues as well as risks. The cost analyst will need to distinguish the difference between them in order to ensure that only those appropriate risks are to be included in the cost risk analysis.

Where there is no risk register or risk record then another approach would be to employ an optimism bias technique. Here it could be employed to redress overly optimistic tendencies by making empirically based adjustments to the cost estimates (see Sub-section 6.2.5).

At the very minimum, the life cycle cost estimate produced at this stage should include or indicate the level of financial risk exposure and liabilities.



Chapter 7 – DATA COLLECTION, FORMATS AND EXCHANGE

Data is required in order to conduct a life cycle cost analysis. In terms of time, effort and resources consumed, collection of data is a major part of any life cycle cost study. Life cycle costing is a data driven process as the amount, quality and other characteristics of the available data often defines what methods and models can be applied, what analysis can be performed, and hence, the results that can be achieved.

7.1 DATA EVOLUTION

As a system progresses through the life cycle, the types of data available evolve in a number of ways. The characteristics of the available data will change as well as the progress of the life cycle. Early data will tend to be softer and be in a more aggregated form, because hard numbers and detailed information will not yet be available.

7.2 DATA SOURCES

Life cycle costing requires a wide variety of data and these must be collected from an even wider variety of sources. When preparing a cost estimate, analysts should consider all credible data sources. A distinction can be made between internal and external data:

- **Internal data** can be defined as data generated internal to the programme.
- **External data** is provided by a data source outside the programme. External data sources can be industry or other military branches or other organisations.

In order to collect data from external sources cost estimators and the programme managers may use templates for a life cycle cost questionnaires as part of an Invitation to Tender, Request for Information, Request for Quotation or Request for Proposal.

7.3 DATA FORMATS AND EXCHANGE

Electronic exchange of data between multiple databases from industry and governments (e.g. Enterprise Resource Planning systems) can be time consuming if data formats and data models differ. A number of standards exist for the exchange of data. NATO has introduced STANAG 4661 [8] for life cycle data exchange which is based on ISO 10303-239 Product Life Cycle Support [9]. However, it is important to understand that the ISO represents only information relating to product data and provides no support for life cycle costing data.

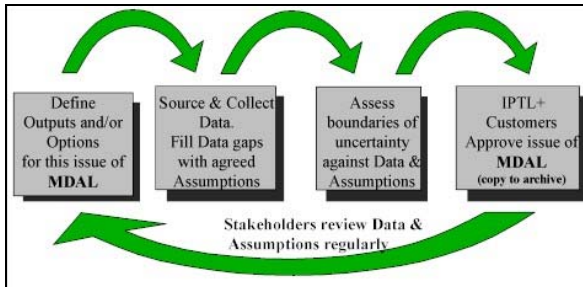
7.4 DATA NORMALISATION

Raw data for life cycle costing originates from a variety of sources. There is generally a lack of uniformity in the data and therefore a certain amount of normalisation is unavoidable. Generally, data normalisation covers changes and adaptations to make it applicable for use in a cost model. The main areas of data normalisation include:

- Adjusting all data to a Base Year. This will facilitate the analysis of the financial data on a comparative basis.
- Appropriation of constant and current year cost data to account for anticipated inflation.
- Selection of correct indices for conversion.
- Selection of correct exchange rates.
- Adjusting costs and/or data for technical specifications such as size, weight, complexity, maturity, etc.
- Adjusting costs and/or data or performance data for different operating profiles, temperatures, mileage, etc.
- Adjusting prices for lot sizes, learning curves, producer capability, etc.

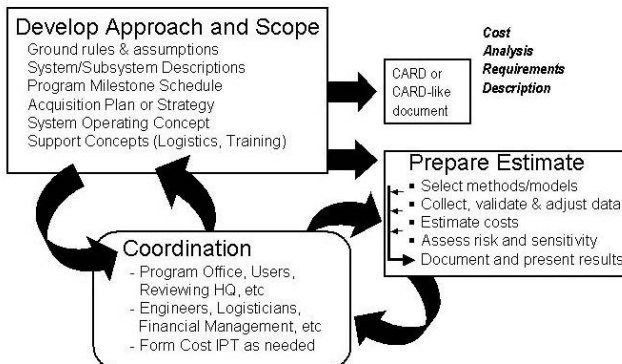
7.5 DATA RECORDING

Various mechanisms are used to gather data (e.g. questionnaire, databases, ERP Systems). It will be necessary to generate a single document to capture and record all the data used for the life cycle cost estimate.



The Master Data and Assumptions List needs to be dynamic and iterative. It must also reflect the basis of the cost estimate at any given point in time and provide a sound data audit trail.

Similarly, much of the information needed is often available in other programme documents. The Cost Analysis Requirements Description or the Master Data and Assumptions List should stand alone as a readable document but can make liberal use of appropriate references to the source documents to minimise duplication and effort.





Chapter 8 – FUTURE DEVELOPMENTS – USING PORTFOLIO ANALYSIS TECHNIQUES IN DEFENCE APPLICATIONS

8.1 INTRODUCTION

Life cycle costing is a discipline that is constantly in development. One of the new developments foreseen is using capability portfolio analysis techniques in defence applications. This new development may also have an impact on the way that life cycle costing is conducted in the future.

8.2 PORTFOLIO ANALYSIS

Portfolio analysis is a technique of measuring the allocation of scarce resources to satisfy strategic objectives. It is commonly described as “a dynamic decision process,” “a resource allocation process,” or a “manifestation of a business strategy”. In government as well as in the private sector, portfolio analysis helps senior management determine where and how to invest for the future. In short, it is a technique to determine how to best spend limited funding.

Three basic goals of portfolio analysis are:

- Managing the trade-off between risk and return;
- Establishing a healthy balance of projects in terms of maturity, cost, and risk; and
- Selecting only those projects that meet the long-term, strategic goals of the organisation.

For the private sector, the value of a project is typically measured by return on investment (ROI), or discounted projected net earnings divided by investment funds. On the other hand, in a national defence setting, ROI might be expressed in terms of future flows of military capability divided by life cycle costs.

8.3 METHODOLOGY

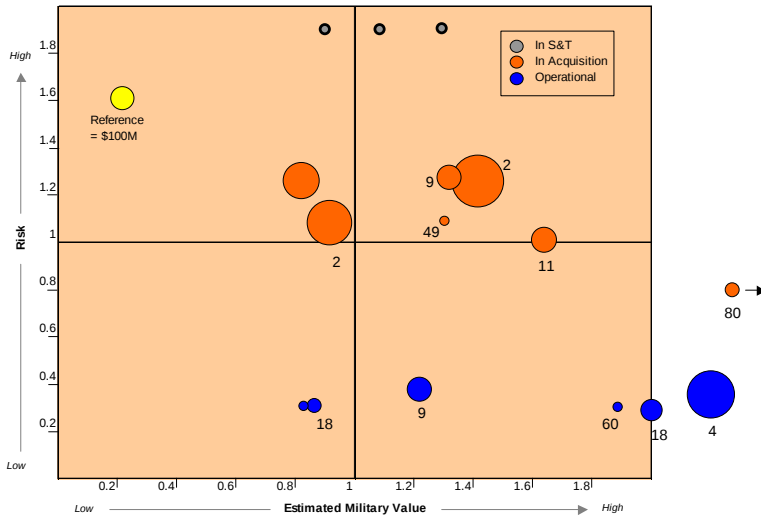
In defence planning, capability is defined as [10]:

“... the enduring ability to generate a desired operational outcome or effect, and is relative to the threat, physical environment, and contributions of coalition partners.”

Measuring capability is difficult. It requires specifying one or more war fighting scenarios and assessing the importance of strategic, operational, and tactical tasks, and alternative weapon systems, needed to achieve mission objectives. An amalgam of informed opinions from subject matter experts and knowledge of the performance characteristics of an entire set of weapon systems are usually employed in this endeavour.

Depending upon where a system is in its acquisition cycle, costs might need to be estimated for science and technology, development, production, operation and support. These costs should be estimated in constant costs, with risk and uncertainty assessed.

Meshing capability assessments with the life cycle cost estimates yields a risk-reward bubble diagram for the portfolio, with an example shown below for mine countermeasure warfare. Here, the bubbles represent the costs of current and prospective weapon systems in the portfolio. They are sized according to resources to be expended, i.e. estimated life cycle costs. The ROIs are the numbers associated with the bubbles. Roughly speaking, they equal capability divided by bubble size.



8.4 BENEFITS

Armed with the results of the life cycle cost estimates and capability assessments, data are displayed to illustrate portfolio balance, systems value and strategic fit. Ideally, results can be generated near real-time so that decision makers can conduct what-if questioning with answers provided in short order.

Portfolio analysis promises to give stakeholders valuable metrics, including the risks and uncertainties of costs, capabilities, and requirements, with which to make more informed decisions on the allocation of scarce defence resources. As noted above, life cycle cost analysis is a critical component of this work.



Chapter 9 – BIBLIOGRAPHY AND USEFUL WEBSITES

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