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A NATO Framework for Life Cycle Costing

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There is a long and documented history of both cost growth and estimating optimism within military system acquisition programmes. This is particularly the case for multi-national programmes. As the nature of future acquisition programmes will be more multi national oriented a common approach is required to generate realistic and consistent life cycle cost estimates for a future system.
This paper presents the findings to date of the NATO Research and Technology Organisation to develop a framework for life cycle costing. This framework consists of a generic cost breakdown structure, methods and models to be used and a guideline for conducting a Life Cycle Cost analysis in all stages of the system life cycle. All this is summarized in a Code of Practice.
The paper concludes presenting the next step in the NATO cost improvement process, i.e. to exercise the guideline for example programmes. An independent cost estimate is conducted on three systems to demonstrate proof of concept. The results of these independent cost estimates will be further used to improve the guideline and the code of practice.

Keywords: cost analysis, life cycle costing, NATO, guideline

1. Introduction

Already in 1998 it was concluded that NATO is lacking a uniform approach on Life Cycle Cost (LCC) analysis (Ref. 1) to be applied in multi national defence acquisition programmes. Nations have their own approach to procure military equipment. E.g. the United States apply the Department of Defence (DoD) directive “The Defense Acquisition System” (Ref. 2) and the United Kingdom use “The Defence Strategy for Acquisition Reform” (Ref. 3) and the Through Life Management approach to deliver and manage projects through the acquisition life cycle (Ref. 4) Other nations have similar approaches. These approaches are all based on national policy, national

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circumstances and refer to national terminology like gates or milestones and do not always match with the NATO acquisition process (Ref. 5).

Life Cycle Cost analysis is recognized as an important part of the acquisition approach. Therefore a number of nations have derived a national approach to cost analysis. E.g. the United States use the Cost Analysis Guidance and Procedures (Ref. 6), The United Kingdom published the forecasting guidebook (Ref. 7) and the Netherlands have a guideline for application of LCC analysis in defence acquisition projects (Ref. 8). However, a number of other nations do not apply a guideline for cost analysis and still only mention in their directives that cost analysis is an important issue to be covered. Furthermore, the national approaches to cost analysis, whether they are structured in a guideline or not, are lacking common definitions and methodologies within the domain of LCC analysis (Ref. 9). As the nature of future acquisition programmes will be more multi national oriented it is essential to have a framework that can be applied to generate realistic and consistent life cycle cost estimates to be applied in multi national defence acquisition programmes.

Also outside the defence scope some international guidelines on LCC analysis exist. A well-known guideline is the application guide on Life Cycle Costing by the International Electrotechnical Commission (IEC) (Ref. 10). Also NASA (Ref. 11) and the FAA (Ref. 12) have published guidelines on cost analysis.

These guidelines are very well applicable in their own domain, but miss the specifics for the defence environment.

As there was no guideline for conducting Life Cycle Cost analysis on multi national defence acquisition programmes, it was decided to develop a framework for such a guideline.

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The objective of this paper is to present the findings to date of NATO Research and Technology Organisation (RTO) to develop this framework. These findings are the results of a number of NATO RTO working groups. These working groups had a broad participation from 12 nations. The experts in these groups have worked together and used their knowledge, expertise, and experience and consulted relevant literature. This led after sometimes long discussions to a framework for life cycle cost analysis that can be applied in a multi national defence environment.

Although the abovementioned approaches and guidelines do not comply completely with the scope of the study they have been used by the groups to feed the discussions and come to an agreement on definitions, approaches, methodologies and models.

The first step in this framework was to develop the generic life cycle cost breakdown structure. The next step was to define methods and models within this framework and to develop a guideline for Life Cycle Costing. All this work was summarized in a Code of Practice for Life Cycle Costing (Ref. 13).

The structure of the paper is as follows. First in Section 2 the basic concepts and definitions of Life Cycle Costing (LCC) are introduced. Section 3 addresses the importance of performing LCC-analysis and the type of stakeholders who can benefit from this analysis. Section 4 provides insight in the life cycle stages of the system of interest requiring a LCC-analysis. Section 5, the main part of this paper, gives an overview of the requirements to conduct a LCC-analysis. The paper concludes by presenting the next step in the NATO cost improvement process, i.e. to exercise the guideline for example programmes to demonstrate the proof of concept.

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2. What is Life Cycle Costing?

Life Cycle Cost (LCC) is used in different ways and the LCC approach analysts and decision makers follow, has necessarily an impact on its definition. As such it is

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important to clarify and present NATO's understanding of concepts like Life Cycle Cost (LCC), Total Ownership Costs (TOC) and Whole Life Costing (WLC). Before introducing these definitions it is important to consider cost related definitions. More details on the definitions and the glossary of LCC terminology can be found in Ref. 9. The following definitions have been adopted:

Linked costs are costs that can be associated to the acquisition, operation, support and disposal of the system.

An example of linked costs is the costs for system specific training.

Non linked costs are costs that cannot be readily associated to the system. Examples of non linked costs are the costs for medical services, ceremonial units, basic general training (not related to a specific equipment), headquarters and staff, academies, recruiters, etc.

Direct costs are costs referring to activities that can easily be allocated to a system or product. An example of direct costs is the costs for a system specific tool.

Indirect costs are costs referring to activities that can be associated to several systems and cannot easily be distributed between them. Indirect costs may include linked costs such as additional common support equipment, additional administrative personnel and non-linked costs such as new recruiters to recruit additional personnel. Another example of indirect costs is the costs for a multi-functional tool.

Variable costs are costs that are affected by the existence of the system. They fluctuate with a characteristic of the system. An example of variable costs is the costs for fuel.

Fixed costs are costs that do not vary because of the existence of the system. An example of fixed costs is the costs for infrastructure.

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Given these definitions, it follows that LCC incorporates all direct costs plus indirect-variable costs associated with the procurement, operations and support and disposal of the system:

LCC: Life Cycle Costs = direct costs + indirect, variable costs

All indirect costs related to activities or resources that are not affected by the introduction of the system are not part of LCC. LCC comprises the marginal costs (both direct and indirect) of introducing a new equipment or capability. The obtained LCC estimate is used as a minimum cost of a system estimate for the analysis of alternatives; it does not include notional allocation of costs, whereas TOC and WLC might do so.

As such, LCC is used to compare options of alternatives, and often for economic analyses.

On the other hand, TOC consists of all elements that are part of LCC plus the indirect, fixed, linked costs.

TOC: Total Ownership Cost = LCC + linked, indirect, fixed costs

These latter may include items such as common support equipment, common facilities, personnel required for unit command, administration, supervision, operations planning and control, fuel and munitions handling. TOC represents all costs associated with the ownership of a system except non-linked fixed costs that are related to the running of the organisation. TOC is used for budgeting purposes, determining the use of services between systems, for optimisation purposes and for financial analysis.

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Finally, WLC consists of all elements that are part of TOC plus indirect, fixed, non-linked costs. These latter may include items such as family housing, medical services, ceremonial units, basic training, headquarters and staff, academies, recruiters.

WLC: Whole Life Cost = TOC + non linked, indirect, fixed costs

In WLC all costs or expenses made by the organisation are attributed to the systems or products they produce. As WLC represents the total budget provision including such element as headquarters costs, it allows the visibility of the complete allocation of funds. WLC is used for a strategic view and high level studies.

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3. Why performing Life Cycle Costing?

The NATO ALP-10 guidance (Ref. 14) states that all multi-national programmes must implement a life cycle cost programme. 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 a wide range of applications, such as 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 and improving the business processes of the organisation.

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. Stakeholders 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, Also regulators such as defence decision makers, local and state governments and standardisation bodies, those involved in the development may benefit. Furthermore acquisition and support organisation such as engineers, architects, planners and financial personnel can

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benefit from a LCC-analysis.

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. The first benefit is that the results of a LCC-analysis provide a better insight of all the costs in the programme and identify the key cost drivers for potential cost savings. It also provides a realistic planning programme and budgeting through a methodical and consistent estimating approach. Furthermore the results of a LCC-analysis provide the basis for measurement of effective organisational and logistic scenarios and provisions. The results of an LCC-analysis can also be used to evaluate two or more technically different alternatives or solutions to assist the decision making process.

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4. Life Cycle Stages

The NATO 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 (Ref. 15), has adopted ISO 15288 System Engineering – System Life Cycle Process (Ref. 16) for dividing the life cycle stages, as presented in Figure 1.

Figure 1. Life Cycle Stages

Each stage requires a different approach in conducting Life Cycle Costing.

For instance, 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. On the other hand, 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.

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Also, 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.

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.

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.

Finally, 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.

Life Cycle Cost analysis should be applied as early as possible in the life cycle of the system of interest, as the greatest opportunities to reduce life cycle costs usually occur during the early phases of the programme (as shown in Figure 2).

Figure 2: Traditional LCC committed versus incurred cost curve

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5. What is required to conduct Life Cycle Costing

Before a LCC-analysis can start many factors have to be determined as they have influence on the way this can be conducted. These factors, including the objective, requirements, identification of constraints and the assumptions are discussed below. Furthermore, the cost breakdown structure, issues related to data collection and methods and models to estimate costs are reviewed. Also uncertainty and risk,

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presentation and reporting and multi-national aspects are discussed as well as recommendations.

5.1. *Objective*

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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, etc). 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.

5.2. *Requirements*

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A requirement is a written statement 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 the user of the product. A clear understanding of the requirements relating to the system of interest is essential to conduct a LCC-analysis. There are three 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.

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Analysing the stakeholder requirements is called the Requirements Analysis Process and is performed during the Conceptual Stage of the Life Cycle Stages ISO 15288 (Ref. 16). In order to define the Stakeholder requirements, the steps of the Stakeholder Requirements Definition Process, as described in AAP-48 (Ref. 15) must be followed. Once the requirements are defined then the estimation of the life cycle cost of the system of interest can start.

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5.3. *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: external constraints and internal constraints.

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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, the potential high number of organisations involved and the limited and suitable resources to support a life cycle cost analysis.

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Internal constraints:

These constraints are inherent to data availability, limited and suitable resources to conduct a life cycle cost analysis and the maturity of the requirements definition.

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5.4. *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

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example would be to examine how maintenance costs would vary with different values of system reliability.

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5.5. *Cost Breakdown Structure*

A Cost Breakdown Structure (CBS) is used to ensure that all relevant cost elements related to the system of interest are identified, defined and will be considered. This may be defined as an organised list of all cost items related to the life cycle of a system or programme.

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Definition

A CBS must satisfy the following requirements:

- Easy to develop, use and update;
- Sufficiently comprehensive to include all relevant cost items;
- Clear in terms of cost definitions;
- Flexible in order to be adapted to different systems;
- Comparable to other cost breakdown structures enabling decision makers to make option analyses.

A LCC-analysis 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, such as unit, service branch, nation (multinational programme) and public or 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. In the NATO RTO SAS-028 report (Ref. 9) is suggested to break the cost down by “resource” used by an “activity” applied to a “product”, where a product tree defines all relevant product elements during the life of a system., an activity list defines all possible activities

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performed during the life of a system and the resource list defines all possible resources used by the activities.

The list of all cost elements is then obtained by combining the product tree, the activity list and the resource list. This is illustrated in Figure 3.

Figure 3: Cost Breakdown Structure

The NATO generic cost breakdown structure developed by NATO RTO SAS-028 (Ref. 9) has been reviewed by nations and organisations participating in a succeeding task group NATO RTO SAS-054. This Task Group recommended in their report (Ref. 17) some enhancements to the NATO generic cost breakdown structure based on recent experience in implementing it in multi-national programmes.

It has been found that, so far, most nations have not adopted the generic cost breakdown structure reported by NAT RTO SAS-028 (Ref. 9) as their national life cycle cost breakdown structure. However, the NATO generic cost breakdown structure has been applied on specific multi-national programmes and some enhancements are recommended.

For instance, the structure does not allow the identification of the life cycle cost results over the time phasing for national financial and programme contributions. Therefore, it is recommended to include two dimensions in addition to the Activity, Product and Resource dimensions. These additional dimensions are Time phasing and National contribution.

Furthermore, the coding of the Generic Cost Breakdown is complex for non-experts. So it is recommended to adopt a Generic Hierarchy for the GCBS as provided in Figure 4. This gives an instant overview of a CBS, based on stages and activities. For

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

Figure 4: CBS Generic hierarchy

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5.6. Data collection

In terms of time, effort, and resources consumed, collection of data is a major part of a life cycle cost study. 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 therefore determine the usefulness of the results that can be achieved.

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. Unfortunately, because uncertainty, risks, and opportunities decrease as the life cycle progresses, the need for data is greatest at the earliest stages. This means that more time and resources should be allocated to the data collection effort during the earlier stages of the life cycle in order to develop an acceptable and auditable life cycle cost estimate. In the early stages the system itself is non-existent, so data will have to come from comparable systems and programmes, using the method of analogy. It is also possible to use expert opinions to gather data.

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Figure 5 illustrates the relationship between data maturity and level of assumptions to be applied.

Figure 5: Relation level of data maturity and level of assumptions

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Data Sources

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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, while 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.

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Data Normalisation

As mentioned before data for life cycle costing originates from a variety of sources and therefore there is generally a lack of uniformity in the data and 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

The NATO RTO SAS-054 task group has recommended that investments should be made to increase the accuracy, visibility, and availability of cost, programmatic,

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technical, and performance data within the NATO/Partnership for Peace(PfP) cost analysis community, resulting in improved data exchange standards or even the development of a NATO costing database.

These improvements would not only improve the quality of the life cycle cost estimate, but also reduce the time schedule and the effort needed to conduct the life cycle cost estimate.

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5.7. Methods to estimate costs

There are many methods available to conduct life cycle cost estimates. It is important to understand the applicability and boundaries of each method in order to use them appropriately.

The NATO RTO SAS-054 task group has captured all the key estimating methods and provided examples to demonstrate their applicability. For consistency, both the methods and models have been categorised as Optimisation, Simulation, Estimation and Decision Support. The findings confirmed that almost all nations used a similar process to develop life cycle cost estimates; that the quality of the available data nearly always determined the method to be employed; and, in addition, that the type of study also influenced the process and the selection of the appropriate method.

Figure 6 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 (Ref. 17).

Figure 6: Cost Estimating Methods

Furthermore, the NATO RTO SAS-054 task group recommends that Life cycle cost estimates should be fully documented. All assumptions and data related to the study should be captured in an Master Data and Assumptions List (MDAL) or Cost

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Analysis Requirements Document (CARD) or similar document.

This way a cost analyst is able to re-create the complete estimate working from the documentation alone.

Decisions such as budget setting and options analysis studies are often conducted when data to support cost forecasting and life cycle costing is very sparse. It is therefore essential that experienced personnel is used to conduct the life cycle cost estimates to support the decision process at these key stages.

Affordability plays an important part in programme decisions throughout the life cycle. Even before a programme is formally approved for initiation, affordability plays a key role in the identification of capability needs. This aspect is part of the process which balances cost versus performance and in establishing key performance parameters. Although this is not common practice in all nations the assessment of affordability is recommended to be conducted by all nations.

The use of two or more independent methods to develop the life cycle cost estimates for each cost breakdown structure element.will improve the confidence in the results and help to validate the outputs. It is accepted that this may be tempered by the constraints imposed by a financial threshold or by a simple consideration of what the estimate will be used for (e.g., rough cost for initial views or detailed costs for decision making). So, the use of alternative methods should always be evaluated from a cost-benefit point of view.

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5.8. Models to estimate costs

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

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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.

There are many models available to conduct a LCC-analysis. It is important to understand the applicability and boundaries of each model in order to use them appropriately.

The NATO RTO SAS-054 report (Ref. 7) showed that in developing life cycle cost estimates all the nations have in-house developed models that are based on a defined CBS. Data for these models is estimated either by empiric methods or parametric formulae. Besides the widely known statistical regression methods, it is also possible to derive the parametric formulae using machine learning methods. The findings of the NATO RTO SAS-054 task group confirmed that many life cycle cost models are in use and these are identified within the report. It is important to ensure that the life cycle costing activities are conducted in a cost-effective manner and balanced with what is realistically achievable at a specific stage in the programme.

NATO RTO SAS-054 task group recommends that every model used for life cycle costing is subject to verification and validation. Generally speaking, the use of more than one model to produce a life cycle cost estimate is considered good practice. This would provide verification of the life cycle cost estimate. However, the use of multiple models should always be balanced with the knowledge and understanding of how the estimate will be used. It is also essential that all life cycle cost models implemented through spreadsheets or more advanced programming techniques be validated by using recognised testing processes. This will increase confidence that

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the model is fit for purpose and that the input data and results can be assessed through a clear audit trail and mathematical reasoning of any cost estimating relationships.

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5.9. *Uncertainty and Risk*

Life cycle cost estimates of any new system of interest will inevitably contain uncertainty and risk. Uncertainty is the variance associated with the data and assumptions, while risk is the consideration of potential adverse events. Risk can be further decomposed in the probability of occurrence of an unfavourable event and the consequences of that event.

Estimates are often made when information and data is sparse. Estimates, in turn, are based on historical samples of data that are almost always messy, of limited size, and difficult and costly to obtain. And no matter what estimation tool or method is used, historical observations never perfectly fit a smooth line or surface but instead fall above and below an estimated value. For all of these reasons, a life cycle cost estimate, when expressed as a single number, is merely one outcome or observation in a probability distribution of costs. To better support the decision making process it is recommended that three point estimating is always undertaken. There is a wide variety of methods and models available for conducting risk and uncertainty analysis of life cycle cost estimates of weapons systems. Each, if used properly, can give scientifically sound results and provide a better yardstick for an accurate life cycle cost estimate.

In general cost data is necessarily limited and accurate cost estimating is a significant challenge. Given this environment of limited data and substantial uncertainty associated with predicting the future, for best decision support it is imperative that analysts quantify the uncertainty of their estimates (Ref. 18).

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Risk and uncertainty analysis should be conducted following the principle for estimating risk and uncertainty as given in figure 7. 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.

Figure 7: Principles of estimating risk and uncertainty

Furthermore, risk and uncertainty analysis should be conducted at the same time as the life cycle cost estimate. And to better support senior leadership, risk and uncertainty results should to be presented at the same time as the point estimate. This will present the decision maker with a comprehensive true view of the programme's likely eventual costs.

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5.10. 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. 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 in Figure 8 and 9. 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.

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Figure 8: Example of a Baseline Life Cycle Cost Spend Profile

Figure 9: Example of a Life Cycle Cost Allocation[1]

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.

Figures 8 and 9 represent single point estimates with no consideration to the presentation of uncertainty and risk. Figure 10 presents a recommended approach for communicating results of a life cycle cost estimate to senior decision makers (see Ref. 18). 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.

Figure 10: 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.

[1] The cost allocation percentage shown in this example should not be considered as being representative of all life cycle cost estimates.

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5.11. *Multi-National aspects*

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Multi-national programmes involve at least two nations who have agreed upon the main principles of co-operation in a Memorandum of Understanding, or an equivalent arrangement, for one or several phases of the entire lifetime of that programme.

Life cycle cost studies for multi-national programmes follow the same principles as national life cycle cost requirements. However, there are some specifics that have to be taken into account in terms of organisation, currency issues, studies, model(s) and presentation of the life cycle cost results.

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 programmes is the definition of a common LCC framework. This framework is determined by the costing boundary and the tools that will be employed to populate the framework. A common framework will provide consistency, comprehensiveness, traceability and audit. All are essential to achieve life cycle cost estimates in a timely and responsive manner.

6. Applying the NATO LCC framework

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The next step in developing a framework for generating realistic and consistent life cycle cost estimates is to demonstrate the proof of concept (methods and models) by using a practical application of the guideline.

In a new Task Group (NATO RTO SAS-076) an independent cost estimate is currently conducted on three systems to demonstrate proof of concept. This Task Group started in 2008 and expects to produce the final report late 2011.

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Independent cost estimates are developed for the following systems:

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- Landing Platform Docks (LPDs) for the Royal Netherlands Navy
- NATO Alliance Ground Surveillance System (AGS)
- Canada's Light Armored Vehicle III

The results of these ICEs will provide invaluable feedback on the accuracy and completeness of the guideline will be used to improve the guideline and the code of practice.

6.1. *Netherlands LPDs*

For the Netherlands LPDs (HMS Rotterdam and HMS Johan de Witt) an independent cost estimate is produced, based on the NATO RTO SAS-054 guidelines. Historical data from 64 ships in 17 classes from 7 nations is gathered and the development and production cost will be estimated by using these data. From the Royal Netherlands Navy LPD programme office actual costs are obtained. During the study, risks and uncertainty will be analyzed, and costs generated over the life cycle. Finally, after the ICE is completed, the task group will compare the results of the ICE with the actual acquisition cost of the weapon system under study. Differences between actual costs and estimates will be calculated and analyzed.

Furthermore a cost estimate will be produced for the Operation and Support (O&S) costs using the operational profile of the ships and descriptive parameters. This estimate will be compared with actual budgets and budget forecasts for the Netherlands LPDs.

6.2. *NATO AGS*

To support NATO and national decision making for the NATO AGS an estimate will be produced for the development and production costs of the Global Hawk using technical parameters of the system. These results will be compared with cost information in General Accounting Office report related to Unmanned Aerial

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Vehicles. In order to estimate the costs of the sensor and the associated ground stations a parametric model will be used.

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6.3. *Canada LAV III*

For the Canadian LAV a cost estimate will be produced by gathering Canadian program actual cash flows and acquisition numbers per year. These actual costs will be compared with estimated concept stage and development stage total costs. The actual costs will also be compared with historical calculated acquisition cost per year. Operations and Support costs will be calculated using average usage per year.

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7. Conclusions

This paper presents the findings to date of NATO RTO SAS studies to develop a framework for Life Cycle Cost analysis in a multi national environment. The first step in this framework was to develop the generic life cycle cost breakdown structure under NATO RTO SAS-028. The next step was to define methods and models within this framework and to develop a guideline for Life Cycle Costing which is the subject of NATO RTO SAS-054. The succeeding working group NATO RTO SAS-069 summarized the previous work in a Code of Practice for Life Cycle Costing (Ref. 13). The paper concludes by presenting the next step in the NATO cost improvement process, i.e. to exercise the guideline for example programmes. In this new working group (NATO RTO SAS-076) an independent cost estimate is conducted on three systems to demonstrate proof of concept. The results of these independent cost estimates will be used to improve the guideline and the code of practice.

Acknowledgements
The author, who has participated in the abovementioned RTO working groups and has been the chairman of a number of these working groups, would like to thank the participating nations and, in particular all the participants in the working groups for their valuable contribution. A special thank to NATO RTO, who gave me the opportunity to present the results of these working groups to a broader audience.

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A NATO Framework for Life Cycle Costing

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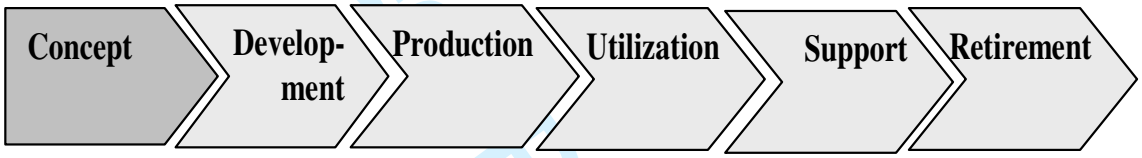


Figure 1. Life Cycle Stages

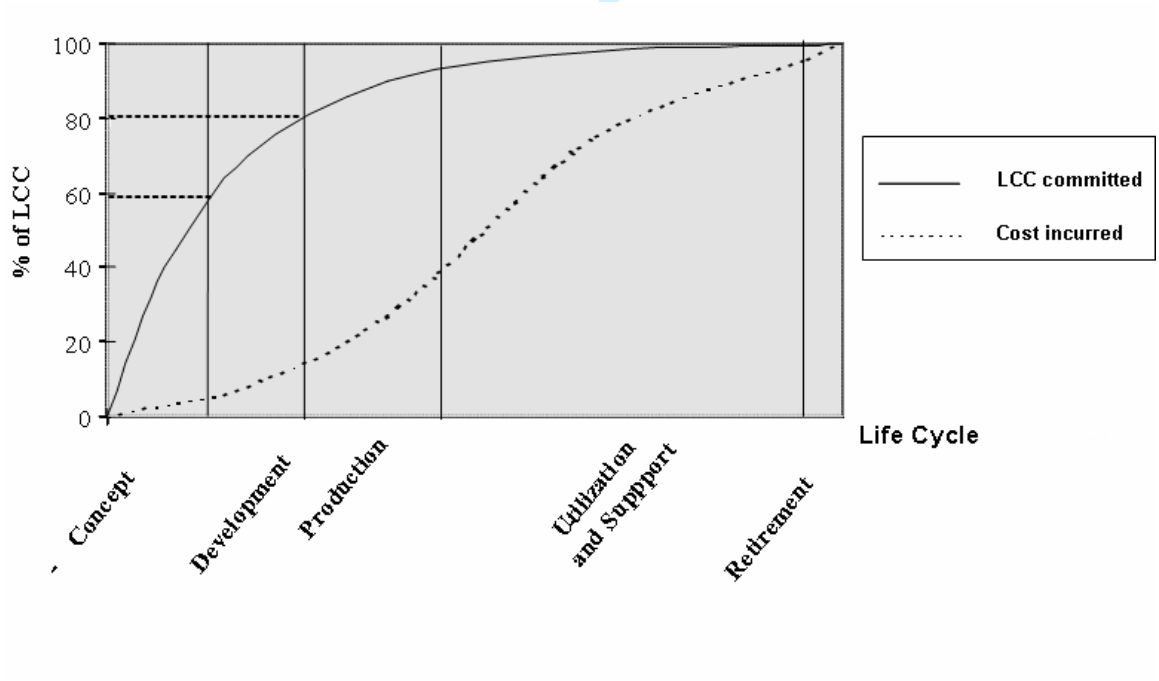
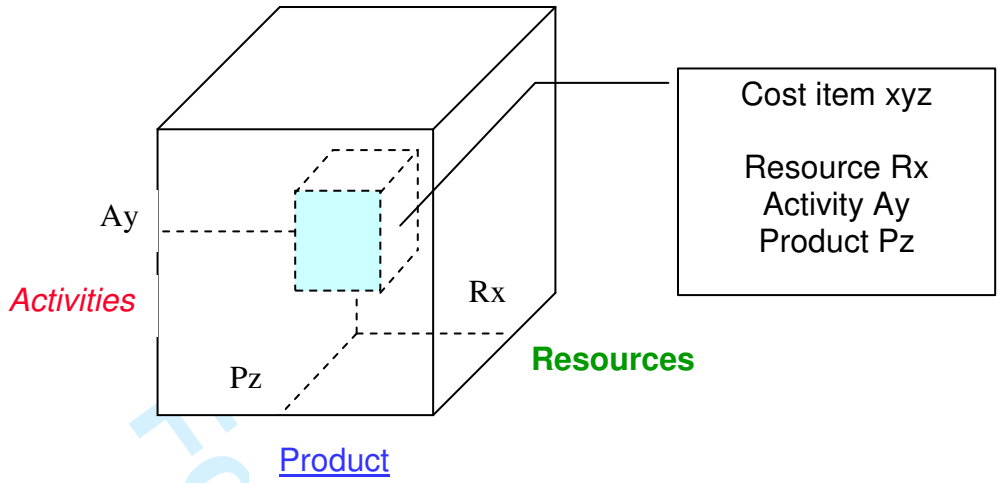


Figure 2: Traditional LCC committed versus incurred cost curve



Cost of **consumables** for the *maintenance* of an aircraft

Cost of **personnel** for the *development* of a software

Figure 3: Cost Breakdown Structure

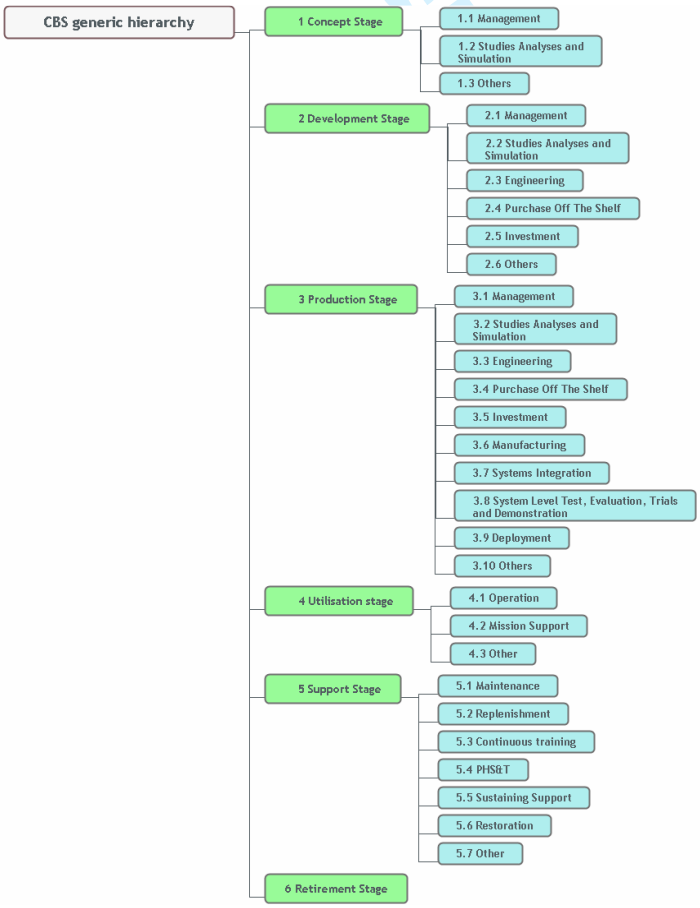


Figure 4: CBS Generic hierarchy

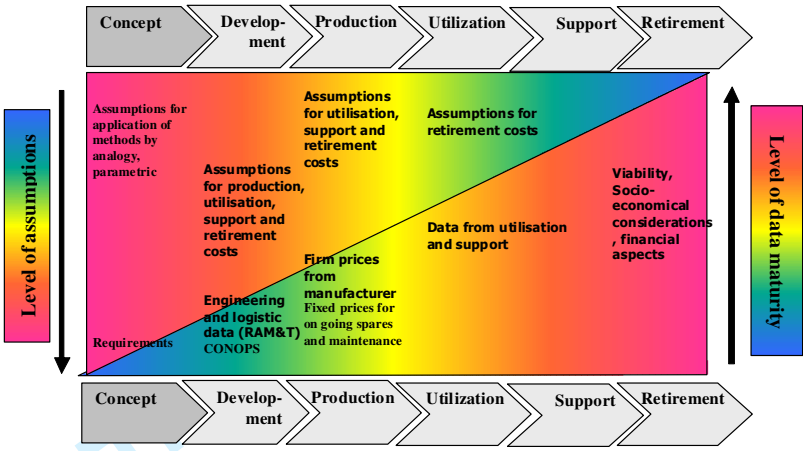


Figure 5: Relation level of data maturity and level of assumptions

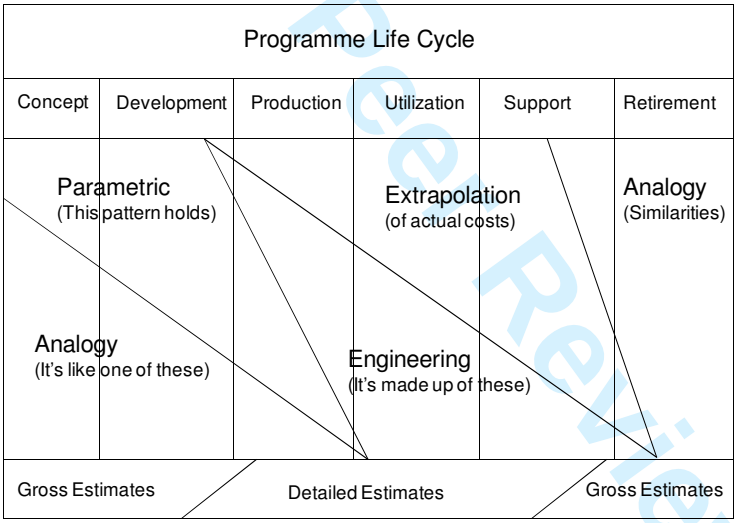


Figure 6: Cost Estimating Methods

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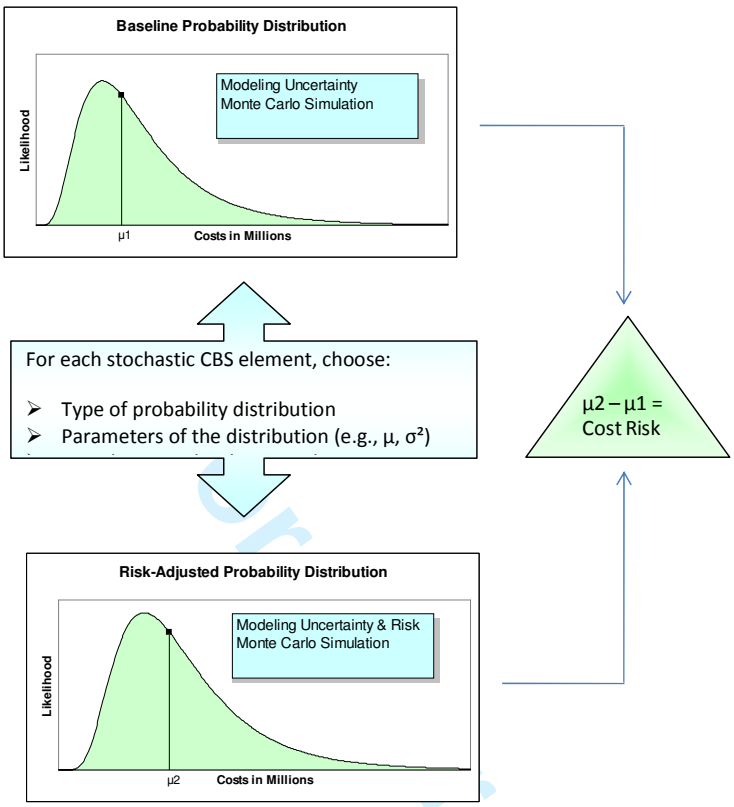
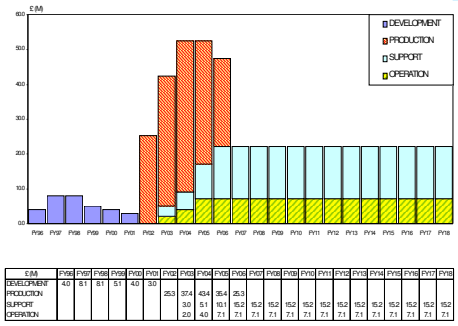


Figure 7: Principles of estimating risk and uncertainty



£M	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
DEVELOPMENT	4.0	8.1	8.1	5.1	4.0	3.0							
PRODUCTION							25.3	37.4	43.4	35.4	25.3		
SUPPORT								3.0	5.1	10.1	15.2	15.2	15.2
OPERATION								2.0	4.0	7.1	7.1	7.1	7.1
											15.2	15.2	15.2
											7.1	7.1	7.1

Figure 8: Example of a Baseline Life Cycle Cost Spend Profile

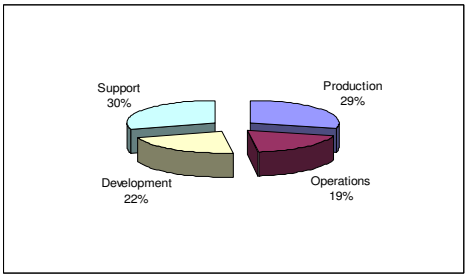


Figure 9: Example of a Life Cycle Cost Allocation

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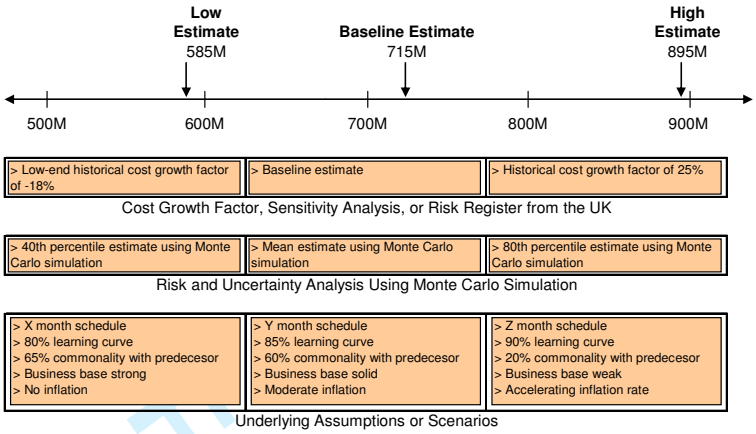


Figure 10: Recommended Presentation of Cost Estimating Risk Analysis

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