Annex B2

Estimating the Operation and Support Costs of the Royal Netherlands Navy Landing Platform Dock Ships: an Ex Ante Analysis

NATO RTO Systems Analysis and Studies Task Group-076*

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1.0 INTRODUCTION

1.1 Background

SAS-076 set out to generate independent estimates of the Operation & Support (O&S) costs of the Netherland's Her Majesty Ship (HMS) Rotterdam Landing Platform Dock (LPD). This was an ex-ante analysis based on real organizational and operational data, followed-up with technical and economic data gathered from the Royal Netherlands Navy (RNLN). SAS-076 also generated an independent cost estimate (ICE) of the development and construction costs, labelled herein as acquisitions costs, for the LPD, which is described in Annex B1 of the SAS-076 report. The reader is referred to Annex B1 for technical data related to the HMS Rotterdam - the System of Interest (SoI) for this study.

For the selected systems, assumptions were made, technical data was gathered, and actual cost data was collected for the development, production and in-service phases. SAS-076 generated an independent cost estimate based on the SAS-054 guidelines [1] to estimate the O&S costs using 3 methods: *parametric, analogy* and *engineering "bottom-up"* methods. As expected, the latter was the most demanding in terms of resources and work-hours consumed.

The parametric and analogy method were used to develop an O&S cost estimate based on Cost Analysis Improvement Group (CAIG)[1] elements. This study was performed outside the SAS-076 by a group of researchers from the United States (U.S.) Naval Center for Cost Analysis (NCCA). The results of this study are attached to this report in Appendix 2. The engineering method estimates the O&S costs only for HMS Rotterdam, because logistic data was only available for this ship.

1.2 Objective

The objective of this report is to present the methods used, compare the results obtained, and describe the application of the engineering method for this study, as well as the benefits obtained and the difficulties encountered.

1.3 Scope

This report focuses mainly on the engineering method and how this should be used according to SAS-054 recommendations. As known, this method is not new in estimating costs, but remains a fundamental one.

1.4 Outline

Section 2 presents the methods used in this study; Section 3 presents the tools used to compute the O&S estimates; Section 4 defines the data and the assumptions; Section 5 describes the cost normalization; Section 6 presents the results of the analysis; Section 7 makes a comparison between the CAIG and the Generic Cost Breakdown Structure (GCBS) models; Section 8 provides the lessons learned;, and, Section 9 presents the conclusions. In the Appendices the CATLOC[2] model is described, the CAIG study is presented as well as the Cost Breakdown Structures used in both the CAIG and GCBS model.

[1] CAIG is now replaced by Cost Assessment and Program Evaluation (CAPE).
[2] Life cycle cost software from Systecon (http://www.systecon.co.uk/products/catloc/index.asp).

2.0 METHODOLOGY

The NATO RTO-TR-SAS-054 report recommended the use of more than one method. In this study, two independent O&S cost estimates were produced using 3 methods: *parametric, analogy* and *engineering "bottom-up"* methods.

2.1 Analogy Method

The analogy method compares a new system with one or more existing systems for which accurate cost and technical data are available. The historic system should be of similar size, complexity and scope.

2.2 Parametric Method

Parametric methods are based on various characteristics or measurable attributes of the system, hardware and software being estimated. It depends upon the existence of a causal relationship between system costs and these parameters. Such relationships, known as Cost Estimating Relationships (CERs), are typically estimated from historical data using statistical techniques. If such a relationship can be established, the CER will capture the relationship in mathematical terms, relating cost as the dependent variable to one or more independent variables.

2.3 Engineering "Bottom-up" Method

Engineering methods, as stipulated in the SAS-054 report, are the most detailed of all the techniques and the most costly to implement. This technique starts at the lowest level of definable work within the cost breakdown structure and builds up to a total cost. These types of estimates are used when detailed design data (Logistic Support Analysis Records) are available on the SoI.

Parametric and analogy methods were applied by experts from the U.S. Naval Centre for Cost Analysis and were based on U.S. ship data pulled from the U.S. Naval Visibility and Management of Operating and Support Costs (VAMOSC) management information system and averaged appropriately. These methods were applied on the U.S. Department of Defense (DoD) CAIG Cost Breakdown Structure (CBS). The cost obtained is the average annual O&S costs of a hull, not the specific O&S costs in a given year (see details in Appendix 2).

The Engineering bottom-up method was applied using data from the RNLN and was based on the CBS recommended in SAS-054, labelled herein as the GCBS. The results of applying this method can be found in Section 7. SAS-076 focused on the engineering method because it provided some key advantages:

- This type of method is a measure related to given requirements, and different requirements lead to different cost figures. It is also highlighting the critical aspects in the SoI design and its logistical organization, which also makes it a tool for project management and systems engineering.
- It provides a structured way of weighing significant technical and cost inputs.
- Even if the application of the method is expensive, its benefits may outweigh its cost[3].
- The application of the method shows the economical consequences of the technical system properties over time, which provides the means of evaluating the cost implication of a proposed system solution

[3] We should remember the saying credited to John Ruston: "It's unwise to pay too much, but it's foolish to spend too little" - this is the operating principle of the engineering method.

3.0 TOOLS

The tool used for the complete GCBS cost model was CATLOC. CATLOC is a tool that supports all the primary uses of Life Cycle Costing (LCC) presented in the NATO RTO-TR-SAS-054 report. Different uses of LCC typically require different LCC models, which can be implemented in CATLOC.

The most fundamental task in building an LCC model is to define the costs to be included in the model, and how to calculate them. LCC is broken-down in a cost breakdown structure, an LCC-tree, where it is expressed as the sum of sub costs or cost aggregates. These sub costs are recursively broken down, until at the lowest level the cost atoms are found. Cost atoms are costs that cannot be expressed as the sum of other costs; instead they are defined more explicitly in terms of parameters, constants and mathematical functions. Thus the only costs in CATLOC calculated through a formula are the cost atoms. The aggregated costs and the cost breakdown structure are used only to organize and group the cost atoms into logical groups. The purpose of grouping cost atoms into cost aggregates is to improve the possibilities for analyzing and understanding the calculated costs. For a given set of cost atoms there will exist many logical ways to group the cost atoms together. It will therefore be possible to create different cost breakdown structures, or cost views.

Based on the principles defined in NATO RTO-TR-058 (SAS-028) [2] and NATO RTO-TR-SAS-054 reports, a cost element (cost atom) shall be defined as follows: *a cost is due to the use of a Resource to perform an Activity for a Product over Time for a defined Customer*. This means that a cost atom shall be defined in five dimensions: Resource - Activity - Product - Time - Customer.

CATLOC allows the implementation of this principle. As a matter of fact, the tool offers functionalities that define cost atoms and parameters in five dimensions:

- MATERIAL (Product) e.g., systems and items in the material breakdown structure;
- TASK (Activity) e.g., corrective and preventive tasks performed on the technical system;
- RESOURCE e.g., resources required for operation and maintenance of the systems;
- STATION (Customer) e.g., stations where systems are operated and maintenance is performed; and,
- TIME e.g., the time periods of interest – “life’s length”.

The costs can be defined for a combination of the dimensions. A subset of the members in any dimension is called a domain. The five dimensions span a five dimensional space, and cost atoms and parameters are defined upon subsets of this five dimensional space. These subsets are called domains of definitions. The domain of definition for a cost atom or parameter is specified by giving a domain for the five dimensions. In each of the five dimensions, except the time dimension, it is possible to build a dimensional structure, i.e., define child objects and mother objects. The structure in the time dimension is implicitly defined by the order data is given in the time table.

The brief description above may not be easy to understand. For more details about the tool please refer to Systecon AB, Sweden, the developer and owner of this tool.

For the tools used in ex post testing parametric and analogy method see Appendix 2.

4.0 DATA AND ASSUMPTIONS

This chapter describes the data assumptions that were made in order to compute a cost estimate through an engineering approach. Most of the assumptions are based on information received from the RNLN, but in those instances where the data was not available an assumption was made to obtain a complete estimate.

Some of the parameters used in this Annex are described here. These are mainly the parameters connected to the general assumptions such as operational profile for the SoI and its maintenance organization. Parameters related to the reliability, maintainability and supportability of the system are also described here. These parameters were assumed to be found in an existing database. The rest of the parameters are presented in Appendix 1.

The abbreviations or designations used for all the parameters are at the discretion of the model designer. No standards exist. Because of the large number of abbreviations and their subjective character, an overview with all the acronyms used is not provided. The only references to the acronyms are found in this chapter, the following chapter, and Appendix 1.

4.1 Analogy and Parametric

For the analogy and parametric methods, the data captured represents initially 10 U.S. ships. Ultimately, 4 of them were dropped from the dataset because the dimensions of those classes were not analogous to the Rotterdam and Johan de Witt classes. One was dropped because there were only two years of data available for that class. Therefore, 5 ship classes were used in the final dataset.

Sources are the U.S. Naval VAMOSC management information system. VAMOSC collects and reports U.S. Navy and U.S. Marine Corps historical weapon system O&S costs. VAMOSC provides the direct O&S costs of weapon systems, some linked indirect costs (e.g., ship depot overhead), and related non-cost information such as flying hour metrics, steaming hours, age of aircraft, etc.

4.2 Engineering Bottom-up

For this assessment the O&S costs are estimated using both organizational and operational data as well as technical and economical data. Data was gathered by the RNLN and consists of the information described below. The level of confidence of the O&S cost is considered high when data was provided from national sources, and medium or low when provided from public available data.

However even data obtained from RNLN can be considered uncertain most of the time because the data that the group asked for was not provided and thus more calculations and/or approximations were done which inevitably induced more errors. Furthermore, the RNLN could not provide the group with all necessary data, mostly because of confidentiality reasons, which led to the use of publicly available data. In general, the results of the computation are considered to be of medium level of confidence. However, some cost atoms are considered to be of low level of confidence.

Each section below has a short description of the data and assumptions in qualitative and, whenever possible, in quantitative terms. Each section also includes a description of the parameters used in the cost model, and refers to a type of data or assumption. Some of the parameters and/or assumptions are only briefly described here. A more detailed explanation can be found in Appendix 1.

4.2.1 Organizational and Operational Data

Organizational and operational data and assumptions describe the operational profile, support organization of all stakeholders including the interfaces, and the administrative and logistic delay times according to national doctrines. It records also the requirements of the Nations in terms of measures of effectiveness. This section also describes data and assumptions related to the programme management organization, production organization, and test and trials organization.

4.2.1.1 Operational usage and types of missions

Operational usage defines the average operational time per system and year in hours. In the study it is assumed that the following operational profile is valid for the system's life cycle:

- War/crisis periods (when the system is assumed to be at sea) are defined in the model as **TOW** (average war/crisis operational time per system in hours per year).
- SAR missions (when the system is supposed to be at sea) are defined in the model as **TOS** (average SAR operational time per system in hours per year).
- Periods of time spent in foreign harbour, defined in the model as **TOH** (average operating time spent in harbour elsewhere in hours per year).
- Periods of time spent at home harbour, defined in the model as **TSB** (average operating time stand-by in hours per year).

These 4 types of operational time periods define the mission types and can be developed in more details if necessary. The first three periods above are considered as operational time and can be expressed as:

$$\mathrm{TO} = \mathrm{TOW} + \mathrm{TOS} + \mathrm{TOH}\ , \tag{1}$$

where **TO** is the average operational time per system per year, and is calculated as the sum of the other operational periods of time.

The model defines a period of time when the system is supposed to be at the contractor site for maintenance actions, **TSS** – average time stand-still in hours per year. This means that the sum of these periods of time and **TSB** (average operating time stand-by in hours per year) should be equal to the total number of hours per year, i.e.,

$$8760 = \mathrm{TO} + \mathrm{TSB} + \mathrm{TSS}\ . \tag{2}$$

All these periods of time have been deduced and computed from 10 years of Rotterdam class ship operational usage. In the model, which considers a 30 years life cycle for the system, an average value for the operational periods was computed for the missing data.

The input data from the RNLN was given for the time period between 2000 and 2009. The input parameters used are:

- **NSD** - the number of sailings days per year;
- **NDHH** - the number of days at home harbour, not including the time for major maintenance actions;
- **NDFH** - the number of days in foreign harbours or elsewhere (not at home harbour); and,
- **NHV** - the number of harbour visits elsewhere. The parameter NHV is not used in the model;

Using the input parameters, the periods of time defined above were calculated as follows:

$$\mathrm{TOW} = \mathrm{NSD} \times 24/2\ , \tag{3}$$

$$\mathrm{TOS} = \mathrm{NSD} \times 24/2\ , \tag{4}$$

$$\mathrm{TOH} = \mathrm{NDFH} \times 24\ , \tag{5}$$

$$\mathrm{TSB} = \mathrm{NDHH} \times 24\ , \tag{6}$$

$$\mathrm{TSS} = 8760 - \mathrm{TO} - \mathrm{TSB}\ . \tag{7}$$

The model defines with these periods of time two other parameters:

- **UTILF** - is a utilization factor describing the average fraction of operational time (TO) per calendar time.

$$\mathrm{UTILF} = \mathrm{TO}/8760\ . \tag{8}$$

- **UTILS** - is the utilization factor describing the average fraction operational time at sea per calendar time, calculated only over TOW and TOS

$$\mathrm{UTILS} = (\mathrm{TOW} + \mathrm{TOS})/8760\ . \tag{9}$$

The input values obtained from RNLN led to some uncertainties which still have not been resolved, i.e., it is unclear if NDFH includes only visits to foreign harbours or visits to the main contractor's docks. It is also unspecified if any major maintenance periods are included here. In the model, the assumption is that it does. This does not in any way affect the costs computation, at least not at the level of detail used in the model.

The operational profile is still very simple. In order to get all the benefits from the engineering method the definition of the operational profile and different types of missions should be described in much more detail.

4.2.1.2 Types of operators

According to the information received from RNLN, the manning profile is given in Table 1.

Assumptions used in Table 1 are:

Table 1: Rotterdam class ship manning profile

	Number of Accommodations	Number of Crew Members
Commander	1	1
Chief Officer	1	1
Officers	14	11
CPO's	28	22
Enlisted	84	78
Total	128	113

- The total number of 128 includes the reserves and equals the total number of accommodations on board the ship. The total of 113 is the actual number of crew members. It is considered that the number of persons included in the crew list, i.e., 113 will not change with the operational profile. The model considers the total number of persons including the reserves, i.e., 128.

- The costs related to the operating personnel on-board the ship is an average income per year, MIOP, i.e., 50.000 Euros,
- The model gives the possibility to implement more detailed costs related to the average yearly cost for personnel uniforms, accessories, shoes, special clothing, etc. through the parameter COPC, but the data was not available and this parameter is set to zero for the estimation.
- For the other types of personnel, the costs are captured at Maintenance Costs in association with either corrective maintenance actions or preventive maintenance actions.
- No increase in pay, inflation rate or present value factor is applied to the salaries.
- Because of the lack of data, other parameters such as operator tasks, i.e., categories of tasks necessary to operate the ship, or the quantity of personnel necessary to operate the ship, type of personnel and task, as well as the percentage of the working time dedicated to the operation of the ship per type of personnel and task category, were not included.
- According to RNLN there is a personnel cost associated to the helicopters operating from the ship. The data received from the RNLN is an average cost per year and is connected to the total personnel costs for the ship.

4.2.1.3 Consumables and all fluids

These assumptions reflect technical and economical data on fuel, oil and lubricants consumption, as well as other consumables, except repair parts. These consumables can be anything from office and personal computer supplies to water or other fluids, food and housekeeping materials.

4.2.1.3.1 Fuel

The input data from the RNLN contained the fuel consumption in litres per year for approximately 10 years. A conversion from cubic metres to metric ton was made. According to the Shell Oil Company, the density for maritime fuel-oil is between 840 – 990 $\mathrm{Kg/m^3}$, depending on the type of fuel. The average density chosen was 915 $\mathrm{Kg/m^3}$, leading to the following density coefficient used for conversion:

$$915/100 = 0.92\,. \tag{10}$$

This is an assumption, resting on the hope that some environmental considerations will be made when choosing the fuel.

The BWI (Bunkerworld Index) shows the actual price for different types of fuel in $/MT (metric ton). At the time of this study the prices varied between 600 and 960 $/MT. However, the average price in the last five years was between 370 and 670 $/MT, depending on the type of fuel. The average price used for the estimation is 370 euro/MT, using the present currency conversion from $ to euro, – parameter CLFS in the model.

Bunker Index (BIX) is the Average Global Bunker Price (AGBP) for all maritime gasoil port prices published on the Bunker Index website. More than 5 BIX were used to calculate the average price used in the model. The BIX is calculated by adding each individual daily fuel-type port assessment price and dividing by the number of prices. The statistics (the last five years prices) from the same source were used.

The fuel prices showed huge variations over the last few years; therefore the effect of this cost variation on the total LCC can be high, especially for yearly planning and budgeting. Due to the complexity of the

estimation of future fuel prices, and due to the time and resources limitations the group faced, it has not been possible to calculate the costs using future fuel price estimates. However the user of the SoI can use estimations of the fluctuation of the fuel prices from professional sources and adjust the training days at sea according to the budget, or buy the necessary quantity of fuel when the prices are lowest for future years according to the planned operational profile. A storage cost will eventually arise. Of course, this can be done in peace time. In war time or crisis, the cost of fuel is still important, but the shortage of fuel is more important and the budget will need to be adjusted accordingly.

These are usually the reasons that, when using the engineering LCC method, lead to the elimination of these variations in the fuel prices. In using the engineering method, one goal is to find the cost drivers which then can be reduced or affected by the user of the system himself.

The average consumption (expressed in the model by MFCH) for the given 10 years is 3461 m^3 or 3,461,000 litres per year. Assuming that the cost for fuel is in average 370 euro/MT, then the average cost for fuel consumption is much higher than the average value given by the RNLN for yearly petroleum, oil, and lubricant (POL) consumption. The model assumes that the cost for the fuel consumption is not included in this value and an additional cost is calculated.

4.2.1.3.2 Oil and lubricants

In some publications, the oil consumption is said to be 100 times smaller than the fuel consumption at nominal power, i.e., about 1%. Other assumptions are that for large ships the oil consumption is larger than 10% of fuel consumption. In lack of actual follow-up data, it has not been possible to find reliable information to make anything but a rough estimation for the oil consumption.

In the model, a formula is used which calculates the oil consumption as 15% of the fuel consumption. The propulsion systems for Rotterdam, both primary and secondary systems, are diesel generators and motors. According to information gathered from specialized literature, diesel generators and motors have a rate of lubricants consumption that may approach 5% of the fuel consumption. This is the assumption used in the model.

4.2.1.3.3 Food and water

Reasonable water consumption level per person is about 150 litres/day. There are 128 people on the ship and they spend about 200 days on-board on average which gives a total water consumption of 3,840,000 litres or 3,840 m^3 per year. In The Netherlands, the water price is on average 2.6 euro/m^3. This results in about 10,000 euro/year only for personnel needs. We estimate that the minimum needs for water are at least 3 times higher.

No increase rate has been applied to the prices although there has been a larger increase in the price of water in the Netherlands than in many European countries. Organisation for Economic Co-operation and Development (OECD)[4] average real increase (%/year) was 4.6 between 1990 and 1998.

4.2.1.3.4 Other consumables

In the model, other consumables, such as the electricity consumption and other operational materials could be calculated. As no input data was obtained, those elements had no impact on the O&S costs.

[4] www.oecd.org

4.2.1.3 Munitions and countermeasures

Data supplied by the RNLN included an average cost per year for use of munitions and countermeasures for training and missions. No other assumptions are made.

4.2.1.4 Support concept and organization

For maintenance tasks, the following general maintenance levels are distinguished:

- Organizational Level Maintenance (OLM)
- Intermediate Level Maintenance (ILM)
- Depot Level Maintenance (DLM)
- Contractor Level Maintenance (CLM)

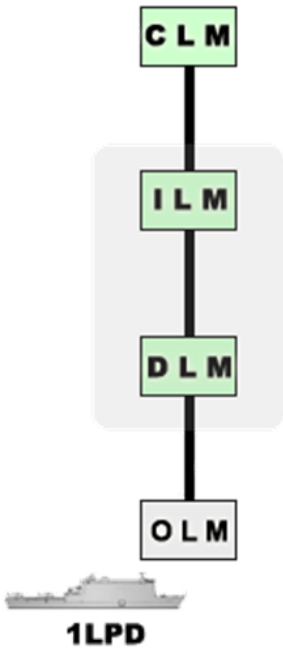

Figure 1: General maintenance levels

OLM - level

OLM-level consists of repairing failures by exchanging Line Replaceable Units (LRUs), preventive maintenance, corrective maintenance and condition monitoring. This is done by the crew of the ship, totally independent of any support from ashore. Basically the activities take place at sea or in the harbour. The maintenance personnel make use of tools, support equipment, spare parts and documentation on board the ship.

ILM/DLM - levels

Personnel employed at these levels are not specified in the model and subsequently no average income per year or month is specified either. The only cost taken into consideration here is the average man-hour cost, i.e., MHC, 65 euro/hr. However, the model gives the opportunity to specify the number of workers used for each preventive (PM) or corrective (CM) maintenance action on each part in the materiel structure, as well as the number of labour hours per each action.

Maintenance at ILM- and DLM-level is organised or done by the Marinebedrijf (Navy Maintenance Establishment, NME). The NME or third parties will do the complex and/or labour intensive maintenance tasks.

The crew of the ship can assist in the tasks at these levels (hours spent included in the maintenance capacity at OLM-level). Basically the NME will do their maintenance tasks during a scheduled maintenance period. Planned activities are done during the maintenance periods as captured in the yearly maintenance plan, as long as they are not part of a maintenance period during a mission. The NME will repair the failed or supposed to be failed mechanical and electronic LRUs, which then, after a check, will be added to the stock.

Statutory tasks, like yearly inspection and testing of pressurized containers and lifts, are always done by the NME. The same counts for calibration activities on Test and Support Equipment and tools.

For the activities at these levels, a larger set of tools or workshops ashore can be used. The electronic workshops will be equipped with the necessary tools, test equipment and test software, as far as it is considered.

The difference between these two levels is that activities at the ILM-level level are characterized by a short preparation time.

CLM - level

Contractor Level Maintenance is the maintenance that is done by industry. The contractor has specialized knowledge about the system and specialized equipment to perform the maintenance actions as efficiently as possible. Cost of contractor logistics support (CLS) captures the costs for using highly specialised personnel, and the costs of transportation related to these maintenance actions.

4.2.1.5 Logistic Support Elements

Data and assumptions for logistic support elements describe parts of the Integrated Logistic Support Elements (LSE) that are necessary for the costing study. These elements are: Documentation, Packaging, Handling, Storage & Transport, Facilities, Training and Training devices, data exchange and related information systems, and computer resource support.

4.2.1.5.1 Documentation update

No data was available from the RNLN if either investments in or updates of the documentation was needed to operate or to maintain the SoI.

The value of the investment costs for the documentation needed for a complex system like the Rotterdam LPD, can vary depending on how much experience the producer of such a system has, or how many systems are already produced. Assuming that the manufacturer of the system has such experience, but considering that only one system or very few have been produced and that The Rotterdam class might have been one of the first systems delivered to the customers, we can estimate the cost for initial documentation to around 8-10% of the total acquisition cost.

The yearly updates are on average 10 to 15% of the initial cost, but may be more depending on which technical modifications are carried out on the main system. Now included in this estimation is administration and transportation and any other costs connected with the documentation.

This is a very rough estimation, more so than should be accepted in a normal engineering estimation.

4.2.1.5.2 Continuous Training

By training, we mean the necessary courses to teach the personnel how to operate the system and how to maintain it. The type of parameters considered here are the training volume and types, as well as the cost per training type. Also considered is how many training devices are used and the cost for acquisition and maintenance of the devices. No data was made available from the RNLN

The assumption made here is that the yearly cost for training is comparable to the cost for documentation updates, or slightly lower. The value used is 10% lower than that for documentation updates. This simplified assumption excludes the initial cost for acquiring the necessary training devices or training documentation as well as the initial training events.

4.2.1.5.3 PHST (Packing, Handling, Storage, & Transporting)

Data obtained from the RNLN was:

- Materiel costs for handling of Government Owned Stores
- Man-Hour Costs for handling of Government Owned Stores

Initially, implemented in the cost model were parameters like: storage volume, percentage of storage areas used for the ship, storage costs or cost per m^3, as well as the frequency of transport per type of transport, and for each type of material to be transported: equipment spare parts, personnel, munitions and consumables. However, no data was available and these parameters were removed from the CBS.

N.B.: Other costs such as: costs for the support of the information systems (hardware/software); costs for embedded software and their support; costs for the use of the infrastructure at home or elsewhere (different types of fees) exist in the model. However, lack of data or other possibilities to estimate them have made their impact on the total outcome nil.

The assumptions made for training and documentation updates and for other similar assumptions are based on Swedish experience, and rely on data bases for similar costs for sea, air and land systems.

4.2.2 Technical Data

4.2.2.1 Life length of the system

Expected life length of the system is an input from the RNLN and is equal to 30 years. In CATLOC the built-in parameter, TIMEVAL, is taken into consideration in the TIME domain but is not explicitly used in any formulæ. More detailed information can be found in the description of the model.

4.2.2.2 System Breakdown Structure

This ICE used the generic CBS as defined in the SAS-054 Report. The cost elements that were estimated were defined iteratively. The list of the cost elements for this study as well as their definitions, are described in the next section. Furthermore the methodology defined in the SAS-028 Report with the generic resources, product and task dimensions were used; and for the definition of the generic System Breakdown Structure, ANEP-41 [3] was used. If necessary, these approaches were tailored according the specifics of the programme.

For the O&S costs (ex-ante estimate), even if not all the aggregates could be populated with input data, the costs were split into the generic System Breakdown Structure as follows:

- Group 000 General Guidance and Administration
- Group 100 Hull Structure
- Group 200 Propulsion Plant
- Group 300 Electric Plant
- Group 400 Command and Surveillance
- Group 500 Auxiliary System
- Group 600 Outfit and Furnishings
- Group 700 Armament
- Group 800 Integration/Engineering
- Group 900 Ship Assembly and Support Services

An example of the system breakdown structure and how this was used in the estimation is presented in Figure 2 as an Excel sheet, MtrlData, that includes the reliability data for each Item of the System Breakdown Structure. The structure can be adjusted by the system user.

Information from RNLN		System Materiel Data								
Basic Information							CM Replacements data			
MID	DESCR	SMID	TYPE	QTYPM	PRICE	FRT	LRE	MTTRP	NMTRP	CMRP
100	HULL STRUCTURE,	MAINSYS	ASSY	1	1	0	A	0	1	0
110	SHELL AND SUPPORTING STRUCTURE	100	SUBSYS	1	1	0	A	0	1	0
120	HULL STRUCTURAL BULKHEADS	100	SUBSYS	1	1	0	A	0	1	0
130	HULL DECKS	100	SUBSYS	1	1	0	A	0	1	0
140	HULL PLATFORMS AND FLATS	100	SUBSYS	1	1	0	A	0	1	0

Figure 2: Sample System Breakdown Structure

The values of the failure rates for the subsystems should be either the sum of the same parameter for the incorporated components of the subsystems or a "residual failure rate". To explain the term residual failure rate (RFRT), the following example is given: we assume that not all the components of a subsystem are listed in the input sheet, therefore the total failure rate for the subsystem can be greater than the sum of the failure rates for

its listed components. So that the Total FRT (TFRTsubsys) for a subsystem equals the sum of the failure rates for its listed components plus the residual failure rate:

$$\text{TFRTsubsys} = \text{FRTlisteditem} + \text{RFRT}. \tag{11}$$

If the values for the failure rates for a subsystem are zero, than the FRT listed will be used.

Figure 3 is a part of the Materiel Data sheet delivered to the RNLN to fill with follow-up data. The parameters seen in the columns are described below.

CM Repairs data								
CMRPC	ACMRP	CMTRP	LCM	MTTR	NMTR	CMCM	ACMC	CMCMC
0	0	0	A	0	1	0	0	0
0	0	0	A	0	1	0	0	0
0	0	0	A	0	1	0	0	0
0	0	0	A	0	1	0	0	0
0	0	0	A	0	1	0	0	0

Figure 3: Input failure rates

4.2.2.3 Maintenance and support

4.2.2.3.1 Basic Input

The parameters in this section are the basic parameters connected to the reliability, maintainability and supportability (RAMS) data. Most of these parameters are well known from RAMS analysis

- IID — Item Identifier – the item ID tag is used as a unique identifier per item. An ID tag is defined in the input table. The value should be entered as a character string. There is no maximal length but a maximum around 10-12 characters is recommended. Delimiter characters can cause trouble when exporting data to text format.
- DESCR — is a free text column used to describe an item, system, materiel position, station, failure mode, preventive maintenance task or resource more in detail.
- MID — Mother item or System Identifier. It specifies the ID-tag of the mother unit in the material hierarchy. The mother unit is either a system or another item.
- TYPE — The type determines whether an item is repairable, partially repairable or discardable and whether it is a primary or secondary item. It can also specify that it is an assembly or subsystem. The default value is LRU or SRU depending on whether the item is primary or not.
  - LRU — Repairable primary item replaced directly in the system. An LRU can be a part of a subsystem, assembly or can be a part of the main system.
  - SRU — Repairable secondary item replaced in an LRU, SRU, PRU or SPRU at LEVEL2 and 3.
  - DU — Discardable primary item replaced directly in the system. A DU can be a part of subsystem, assembly or can be a part of the main system.

- DP — Discardable secondary item replaced in an LRU, SRU, PRU or SPRU at LEVEL2 and 3.
- ASSY — An assembly is ignored in the logistics breakdown, but it is used here to gather the costs from its subsystems, on the level 2 of the CBS. An ASSY can only be part of the MAINSYSTEM, according with this model definition.
- SUBSYST — A subsystem is ignored in the logistics breakdown, but it is used here to gather the cost from its components, on the level 3 of the CBS.
- PRU — Partially repairable primary item replaced directly in the system. PRUs are still not used in the model. All PRU must be converted to LRUs.
- SPRU — Partially repairable secondary item replaceable in a LRU, SRU, PRU or SPRU at LEVEL2 or 3 SPRU are still not used in the model. All SPRU must be converted into SRUs.

- QTYPM — Quantity per Mother item; QTYPM contains the number of identical items per mother item in the breakdown structure. The mother item can either be the main system, a subsystem, an assembly or another (repairable) item. The given value must be an integer ≥ 1. Default value is 1.
- PRICE — The unit price is an input parameter given per item, per system, per resource or resource position. The value is mandatory per item but optional for systems and resources. The PRICE column is included in the input tables MtrlData and should be entered as a positive float number in $1000 \times$ euro. As the name unit price suggests, it is assumed that all prices are constant irrespective of item, system or resource quantities. The price used in the model do not includes storage costs. PRICE must not be specified for ASSY items. Any value specified for an ASSY is ignored with a warning.
- FRT — Failure Rate - the failure rate is an input parameter that contains the number of failures per million hours of operation. This value is mandatory per item and can also be given per system. It is given in the input table and should be entered as a floating-point value > 0. The entered value reflects the rate per each individual item/system. The rate per item is not strictly per failure but should include all replacements including those of type "no fault found", etc. The total sum of the sub item failure rates must not exceed the failure rate of the item/system itself. This will result in an error message during the calculation test. A total sub item failure rate less than the FRT of the item/system itself is allowed. The residual FRT in this case corresponds to failures that can be repaired without any sub item replacement. The FRT for systems is optional. If not entered this value is calculated as the sum of the item failure rates. FRT must not be specified for items having TYPE = ASSY or SUBSYST. Any value specified for an ASSY is ignored.

4.2.2.3.2 Corrective Maintenance (CM)

Corrective maintenance and the actions related to CM are usually associated with the FRT/Mean Time Between Failure (MTBF). The failure rates can be estimated for each important part of the main system. The engineering methodology tries to establish relationships between the system's failure rates and the costs generated by those failure rates. The model in CATLOC is trying to follow the methodology and gives the opportunity to the user to fill up the data available in different ways. In the model there are two actions considered to belong to the CM: replacement and repair actions.

4.2.2.3.3 Replacement data

The replacement data concerns only replacements due to corrective maintenance. Generally a replacement may be related to any replacement action performed at any level of maintenance. A replacement action can be a replacement of a repairable primary item (i.e., an LRU or DU) and in that case the replacement takes place at OLM or a replacement of a faulty repairable secondary item or discardable, which means that the replacement action takes place either at ILM or DLM or even at CLM.

Usually a replacement refers only to replacement actions regarding primary repairable items. This statement can lead to the impression that we search replacement data only at the OLM level. This is only partially true. In fact the model is not looking at all to the replacements at the OLM level performed by the personnel at OLM level since those actions are included in crew's maintenance capability and are already captured in the remuneration of the crew.

Due to the nature of the system, most certainly some replacements of important and/or expensive items can only be performed at ILM, DLM, or CLM, i.e., when the main system is in harbour. Even less expensive items, but difficult to replace, demanding extensive working time and/or a large number of workers can be interesting to follow. The data are the events when a replacement action is needed to be performed at the OLM level, but by personnel other than the crew.

The input parameters needed for the calculations are:

- LRE — is the STID where the replacement for a corrective maintenance action takes place.
- MTTRP — Mean time to replace [h].
- NMTRP — Number of personnel needed for replacement.
- CMRP — Average cost for materiel consumption at replacement [thousands of euros].
- CMTRP — Average cost for transportation due to replacements.
- ACMC — is an application factor (an optional column) given per item and is used as a factor on the FRT describing the average fraction of the failure rates which leads to replacements actions performed by external personnel. This mean that the CMTC cost will be applied here.
- ACMRP — is an application factor (an optional column) given per item and is used as a factor on the FRT describing the average fraction of the failure rates which leads to replacements actions performed by personnel from NME aboard, or at a foreign harbour. This mean that the transportation cost will be added here.
- CMRPC — is the average cost per item for external personnel including the costs for consumables.
- CMRPCC — InputParameters table - the average cost of consumables (for replacements action due to CM) consumption per year.
- MHCCMRP — average man hour cost for replacement actions performed by NME.
- TRCCMRP — an average cost value for transportation events per year due to CM actions.
- CMRPEX — is the average cost per year for external personnel including the cost for consumables.

If the LRE is at the OLM level and the replacement action is performed by the crew, then only CMRP should be entered. If the CMRP value is not known for each of the units replaced on board, then an average cost for materiel consumption at replacement per unit of time at the level OLM should be entered for the parameter CMRPCC.

As we assumed before, in case CM actions are necessary during the mission time, not all replacements at OLM can be performed by the crew. Such replacements are supposed to be performed by the Marinebedrijf (Navy Maintenance Establishment - NME) or by other external personnel or contractors hired for this purpose.

All of these actions are understood to be performed on board, but either when the ship is at home harbour or in a harbour elsewhere. If the replacement is performed by the NME personnel then at least parameters MTTRP and NMTRP above should be specified. In lack of data, an average man-hour cost for such actions should be entered for the parameter MHCCMRP. If the replacements are performed by external personnel or contractors (LRE = CLM) and the CMRPC is unknown per unit, then an average cost per year can be given to the parameter CMRPEX.

If the action takes place at a foreign harbour, then an average cost for transportation of the personnel as well as for the unit replaced (back and forth) can be specifically given in the column CMTRP, in the input sheet MtrlData or as a general value for the parameter TRCCMRP on the InputParameters sheet. The value in the InputParameters is an average value for transportation events per year valid for all the units, where the column CMTRP has a Y (yes) and not a numerical value.

The model is computing the average cost for replacements per year according to the formula:

$$\begin{aligned} = \; & QTYPM \times FRT \times UTILF \times 0.00876 \\ & \times ((CMRP + ACMC \times (CMTC - CMRP) \\ & + ACMRP \times (MHC2 \times NMTRP \times MTTRP + CMTRP)) \,, \end{aligned} \tag{12}$$

or

$$\begin{aligned} = \; & QTYPM \times FRT \times TO \times 0.000001 \\ & \times ((CMRP + ACMC \times (CMTC - CMRP) \\ & + ACMRP \times (MHC2 \times NMTRP \times MTTRP + CMTRP)) \,. \end{aligned} \tag{13}$$

The formula is calculated per year for each unit in the material breakdown structure. The results can then be aggregated at a subsystem level or for each assembly and finally for the entire main system.

The formula also takes into consideration the operational profile described above. The results can then be shown per unit/subsystem/assembly/system and year. Note that the formula above is similar, but not the same, to the one used in the model.

The results based on these parameters, give the user many possibilities to aggregate the input data. Not all of them are described or implemented in the model, but there is however some aggregates which were implemented more for descriptive reasons because no data could be delivered by the RNLN in the MtrlData sheet.

4.2.2.3.4 Repair data

Repair data refers to the repair actions performed at all levels of maintenance on LRU or SRU. The data does not include the repair actions performed during the scheduled maintenance periods. A repair action is mainly regarded here as a replacement of an SRU or DP in an LRU or other SRU, which already was removed

from the main system. Because of this characterization, there are similarities between replacement and repair input data. The following parameters are used:

- LCM — STID of repair action.
- MTTR — Mean time to repair MTTR [h]. It is the turnaround time, in hours by default, per repair action that does or does not require sub item replacement, i.e. all the repair actions triggered by the failure rate.
- NMTR — Average number of personnel required per repair action.
- CMCM — Average cost for material consumption (consumables) during a corrective maintenance task [thousands of Euros].
- CMCMC — Average cost for a repair action if performed by contractor /supplier on CLM [thousands of Euros].
- CMCMCC — InputParameters table -the average cost of consumables (for replacements action due to CM) consumption per year.
- MHCCMR — Average man hour cost for repair actions performed by NME.
- CMCMEX — Average cost per year for external personnel including the cost for consumables.

The description is similar to that presented for replacements: Focus here is on the repair actions performed by NME or the contractor. This means that LCM should be ILM, DLM or CLM. If the repair action is performed by NME, then both a cost for labour and materiel consumption will be computed. Each repair action can trigger a demand for spare parts in stock. However such demands are not captured in the model.

If the repair is performed by personnel of the NME, then at least parameters MTTR and NMTR above should be specified. In case there is a lack of data, an average man-hour cost for such actions should be entered for the parameter MHCCMR. If the CMCM value for all of the units repaired is unknown, an average cost for materiel consumption for repair actions performed by NME per suitable unit of time should be entered for the parameter CMCMCC.

If the repairs are performed by the contractor (LCM = CLM), no other value than the default value should be entered for MTTR and NMTR. Also if the CMCMC per unit is unknown, then an average cost per year can be entered for the parameter CMCMEX. CMCMC or CMCMEX should also include the transportation costs (back and forth) for the repaired unit.

On the FRT, no application factor, describing the average fraction of the failure rates which leads to repairs actions performed by the contractor, is used.

4.2.2.3.5 Preventive maintenance data

Major preventive maintenance (PM) periods on the main system are defined in the input data as a 3-years maintenance period and a 6-years maintenance period. These periods follow the calendar time during the system's life span as is shown in Figure 4 below. Cost data for these actions was acquired from the RNLN and implemented in the model.

Other types of PM can be decided by the contractor. These periods can refer to the whole system or only to subsystems or LRUs. Information on such PM periods can be entered in the input table MtrlData.

	1998	1999	2000
1	2001	2002	2002
1	2003	2004	2005
2	2006	2007	2009
2	2010	2011	2012
3	2013	2014	2015
3	2017	2018	2019
4	2020	2021	2022
4	2023	2024	2025
5	2026	2027	2028

Figure 4: Preventive maintenance periods

The PM actions include replacement and repair actions. But the model calculates the cost of a PM action as a whole; no differentiation is being made between replacements and repairs as in CM case. The parameters used are:

- LPM — STID for the PM task - should be B, C or D.
- NYPM — Number of PM actions per year.
- TPM — Preventive maintenance duration - gives the average number of labour hours for the PM task performed by one person.
- NMPM — Number of personnel necessary to perform the PM action within the required time frame (TPM).
- CMPM — The average cost for materiel consumption during PM task, costs for replacement of SRU/DP are not included [thousands of Euros].
- CPTC — Average cost for PM on LRU/SRU if performed by contractor/supplier. This also includes potential transportation costs to and from the contractor's site [thousands of Euros].

Many other costs may result from PM actions such as administrative costs or transportation costs. In order to keep the model fairly simple, but still useful for its purpose, the choice was made not to take into consideration such costs.

4.2.2.3.6 Support and test equipment

No data available. No assumptions made.

4.2.2.3.7 Spares Parts Consumption

A yearly cost for replenishment concerning the spare parts was supplied by the RNLN and implemented in the model.

4.2.2.3.8 Modifications and restorations

No data available. No assumptions made.

4.2.2.3.9 Industrial Logistic Support

No data available. No assumptions made.

4.2.3 Indirect Support

For the indirect support cost, the following data was obtained and implemented in the model:

- Materiel costs generated by Navy Command (Headquarters, Personnel & Operations).
- Man hour costs generated by Navy Command (Headquarters, Personnel & Operations).

5.0 COST NORMALIZATION

For the parametric and analogy methods, U.S. ship data was pulled from VAMOSC, with all costs in constant fiscal year (FY) 2009 U.S. Dollars. In order to deal with the high variability of O&S costs a two steps approach was undertaken:

- Data from VAMOSC was averaged on an annual basis between different hulls in each class;
- Then, the yearly data for each class of ship was averaged over the life of the hull, in all cases beginning in 1984 and ending when the ship was either decommissioned or the end of the sample period.

For the engineering estimation, the cost normalization follows the same principles as for the acquisition cost without the complexity related to different currencies. The costs gathered from the RNLN are expressed in FY 2005 euros, and they have been converted to FY 2008 euros using the annual average index for The Netherlands obtained from eurostat. No other inflation rates or other financial indices were applied for the rest of the life span of the SoI after 2008. The only variations of the yearly costs are triggered by real input data obtained from the RNLN regarding fuel consumption and PM costs.

6.0 RESULTS AND ANALYSIS

After normalizing the cost to FY 2008 and respecting the anonymity requested not to show explicitly the ship's O&S costs, the same fictitious notional common currency (abbreviated NCC) was used as in Annex B1 related to the Rotterdam acquisition costs. This was also done to be able to include the estimate for the acquisition cost in the model and to show the full results. The value used in the model is the actual Rotterdam acquisition cost.

Table 2 shows the values expressed in the same currency for the highest cost aggregates and for the total life cycle. The rest of the results are presented in percentage.

Usually an analysis made through an LCC engineering estimate comes with a lot of details on the distribution of the costs in the materiel dimension through the system breakdown structure or on the maintenance organization, for each and every site taken into consideration. The method will try to find parts of the system or parts of the organization that are generating the highest costs in order to find a solution to the problem.

Table 2: Total O&S costs

	Cost Aggregate	O&S Costs (Million NCC)
7.1	Operation	329.8
7.2	Supporting operations	24.0
7.3	Maintenance	321.0
7.4	Sustaining Support	21.6
7.5	PHST	204.5
7.6	Restoration	0
7.7	Indirect Support	182.0
Total O&S Costs		1082.9

At the same time, it shows where the resources are consumed and which tasks are the most demanding. The methodology goes hand in hand with RAMS methods based on both optimization and simulations.

Such an analysis cannot be performed here, mostly because of the lack of data. When data is missing, the result of an engineering estimate does not generate solutions, merely it raises more questions for further analysis.

However, it is useful to present the results and then to question them. The next task is then to either dig deeper in the records and find more data, or start a short term follow-up to see if data can be improved.

With a tool like CATLOC, an analyst can dissect the data in many ways and then present the results in a meaningful manner. In this study, it was not possible to do so, as the quality of the data was not sufficient. The results presented in the following charts are at a high level of the CBS, but they are sufficient to show some problems. Figure 5 shows the distribution between the O&S cost and the acquisitions cost. Percentage values are rounded to the nearest integer. At this level the results are not extraordinary.

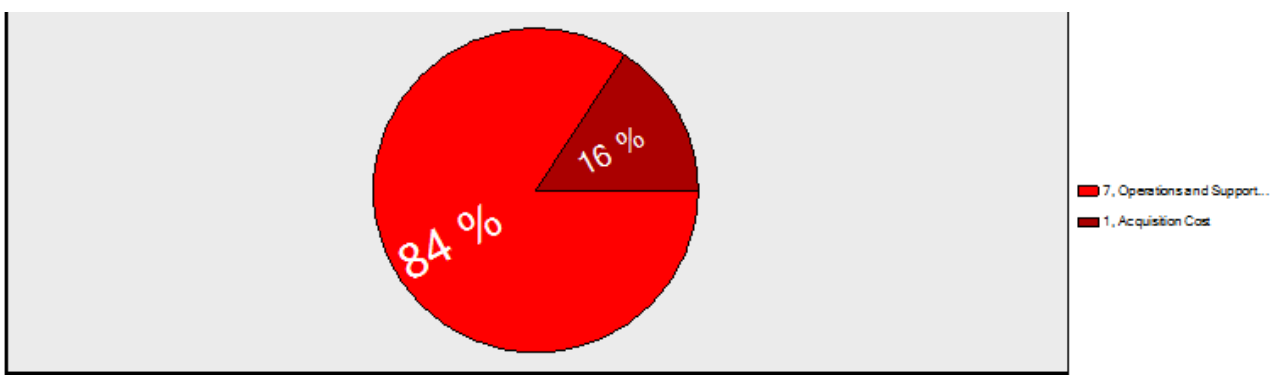

Figure 5: LCC showing O&S cost versus acquisition costs

Figure 6 shows the O&S costs in more detail. It can be noticed that the cost of Sustaining Support and Supporting Operations are relatively low to what could be expected, while the Indirect Support costs are relatively high. Additional analysis and data would be required to understand why the O&S costs are distributed over the CBS in these proportions.

Looking to the Operational costs (Figure 7), it is clear that the cost of personnel is too high when compared

to the cost for fuel, oil and other lubricants. Additional analysis and data would be required to understand these differences.

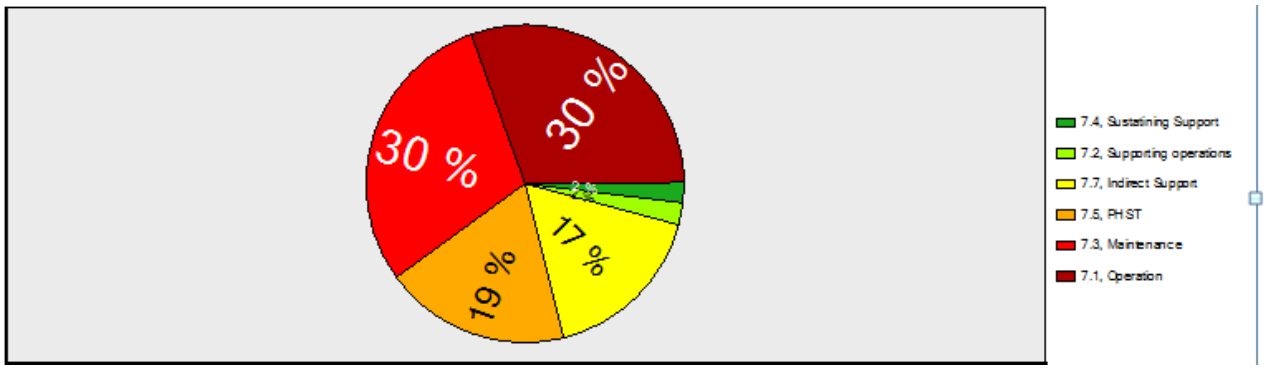

Figure 6: O&S cost distribution

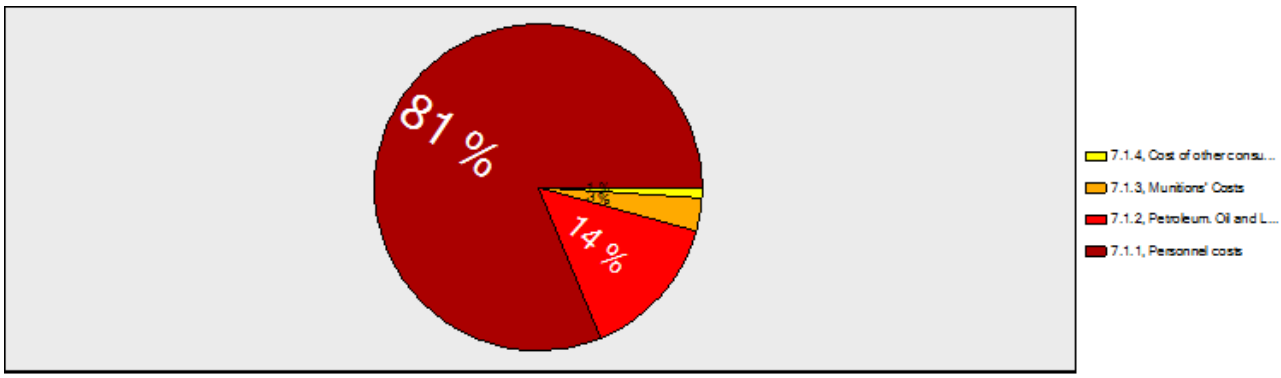

Figure 7: Distribution of operational costs

It can be noticed that the maintenance costs (Figure 8) of the two helicopters on the ship is almost as large as the ship's cost for Preventive Maintenance (PM) and Corrective Maintenance (CM) together. Furthermore, 7.3.3 (cost related to other operating systems) contains some uncertainties (e.g., whether the helicopters fuel cost is included or not). Given that the data was taken from the RNLN financial system, it was difficult to get additional information to clearly define the scope of this cost.

It is possible to breakdown the analysis further and to keep on asking questions, however, these questions should be asked directly to the user of the system.

Figure 9 shows the distribution of the PM costs (materiel and personnel) over time: 7.3.1.1 (the lower part of the bars) represents man-hour costs and 7.3.1.2 (the upper part of the bars) represents materiel costs. Figure 10 shows the distribution of cost over the types of resources used in operation.

Finally, this section presents the sensitivity of the estimate to changes in the parameter values. All parameters are increased by 100% and the impacts of that increase on the total O&S cost are shown in Figure 11. The parameters are ranked relatively to their impact on the O&S cost. It is noted that average yearly income of operators (MIOP), number of operators on-board (NOPT) and number of helicopters (NHALO) are

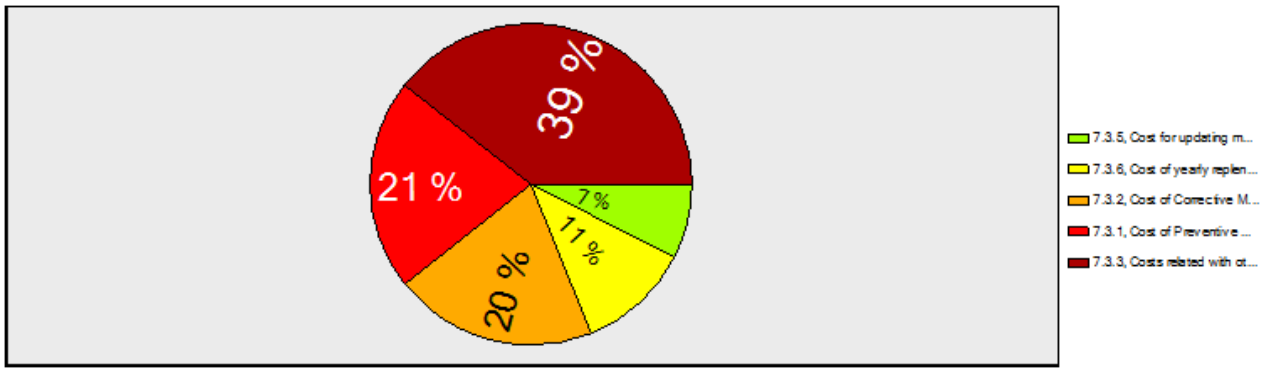

Figure 8: Distribution of maintenance costs

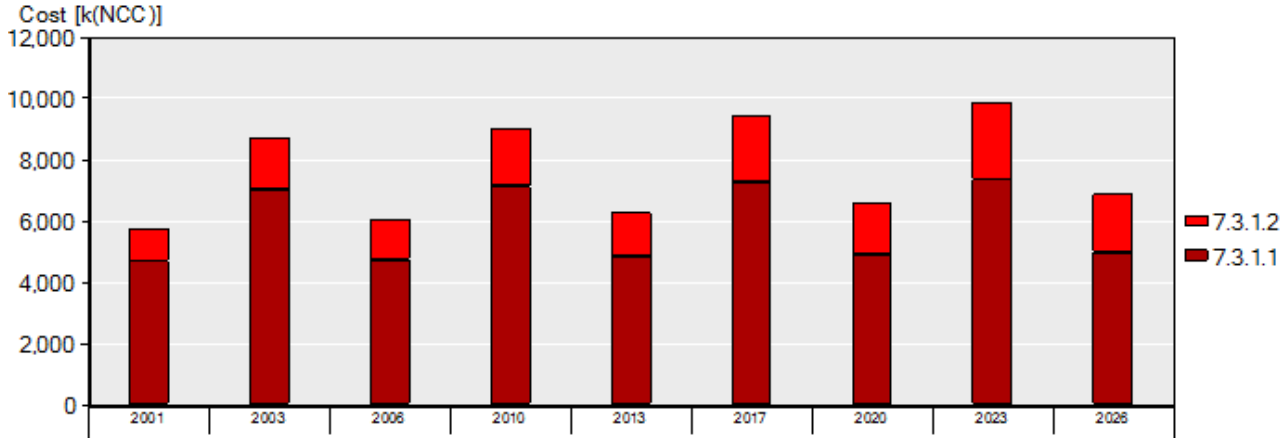

Figure 9: Preventive maintenance costs over time

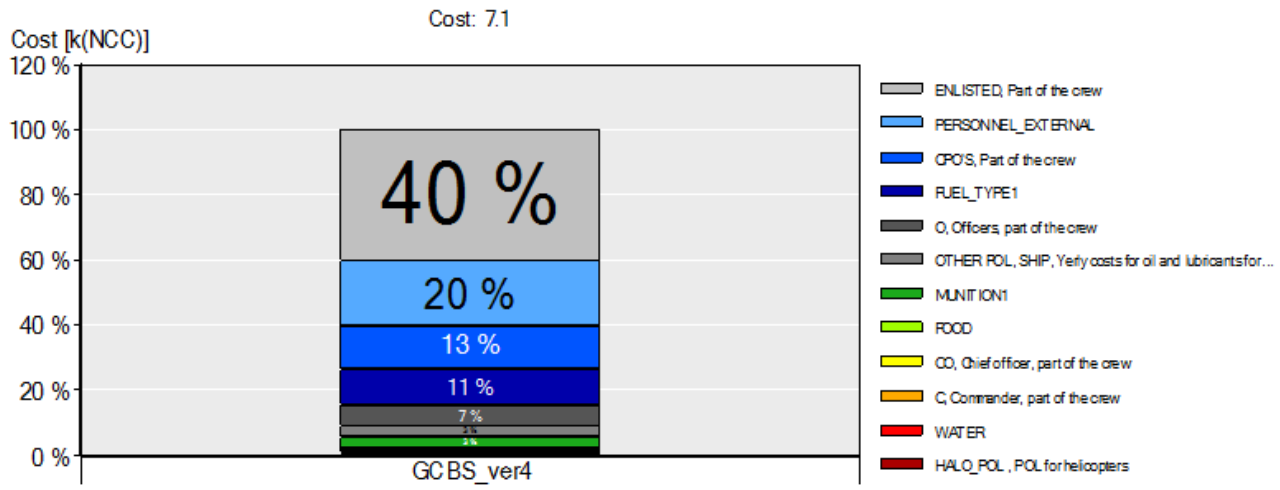

Figure 10: Distribution of cost over resource types

the three parameters that will influence total O&S cost the most, given an equally large percentage change, but the differences are not large.

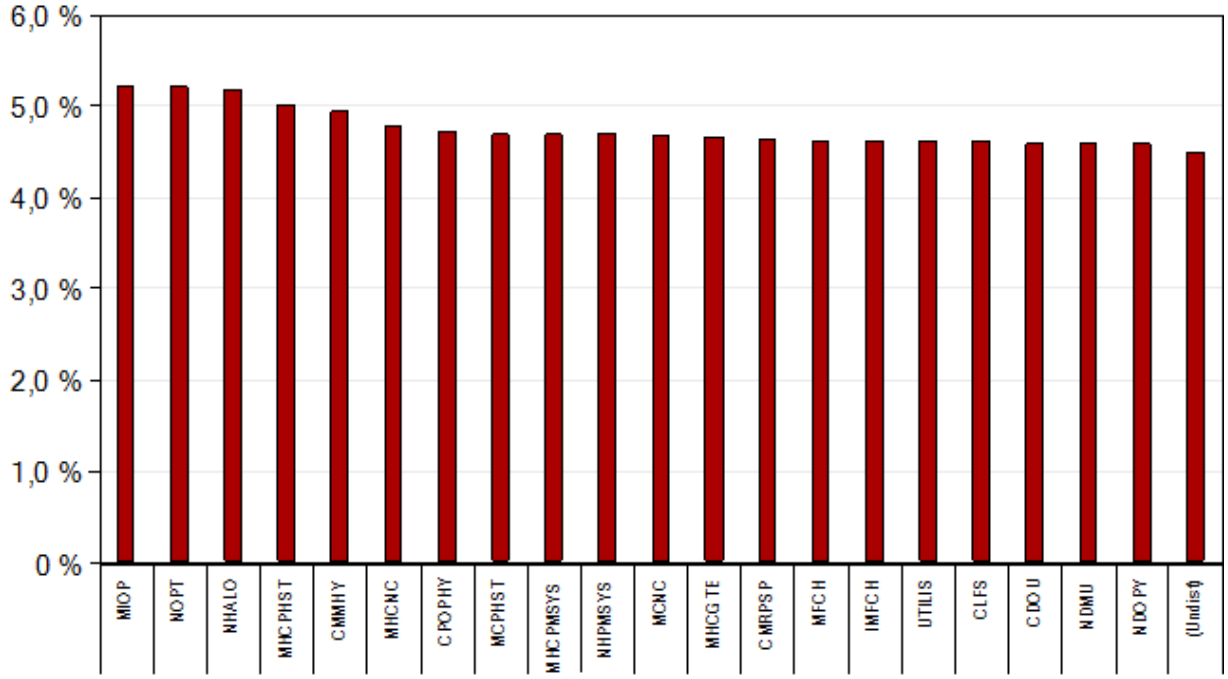

Figure 11: Sensitivity analysis over all parameters

The CM actions are usually a major cost driver for the O&S total cost. Because of the commercial sensitivity of data, the RNLN was not able to provide any data concerning CM. In general, it is considered that for large military systems, the acquisition cost stands for just under 30% of the total LCC and the O&S cost for the rest.

Usually maintenance, i.e., PM and CM actions stands for about just under 50% of the O&S cost. Frequently the costs for CM are not bigger than the costs for PM. Of course in the above figures both personnel and materiel cost are included.

7.0 COMPARING CAIG AND GCBS MODELS

The main objective of this section is to compare the top-down approach represented by the **CAIG model**, developed at the U.S. Naval Center for Cost Analysis, with the bottom-up approach represented by the **GCBS model**. The two cost models resulting from applying these approaches are presented in the appendices 1 and 2 of this report. However, in this section, a closer look is given to their set up.

The comparison has been made only for Rotterdam since the GCBS calculations have only been performed for this ship. No data was available for Johan de Witt.

The tasks have been mainly to work on the cost structures of the two models in order to make them comparable. The main tasks were:

- Implement the two cost structures in CATLOC with some restructuring of the GCBS model;
- Compare the results of the both approaches.

7.1 Analysing the Models

The basic structures of both models are shown in Figure 12:

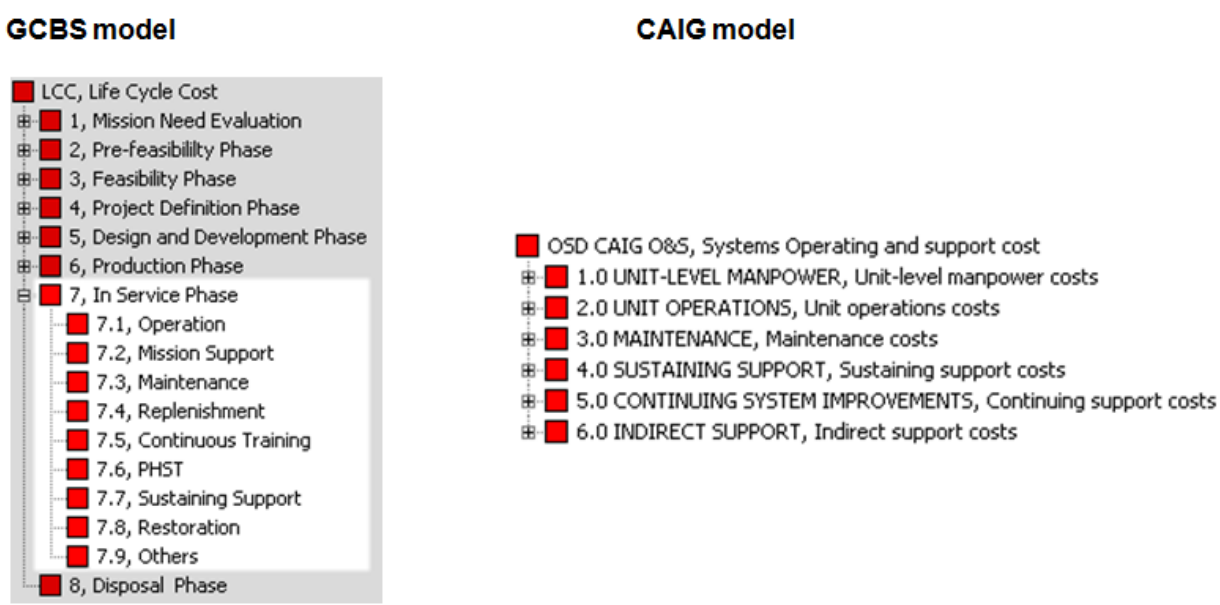

Figure 12: Structure of CAIG and GCBS models

In order to achieve the main objective of the analysis: to compare and evaluate the two cost estimating methods, the models needed to be implemented in CATLOC and to be made as comparable as possible. Given that the Cost Breakdown Structure of the GCBS model was more granular than the CAIG model, it was decided to restructure the former to make the comparison easier. The resulting model is called **GCBS-CAIG model** and

the Cost Breakdown Structure is presented in Appendix 3. During the GCBS model Cost Breakdown Structure restructuring, some assumptions were made. These assumptions are not specifically presented here but can be easily understood by comparing the GCBS-CAIG model (the transformed GCBS model) presented in Appendix 5 with the original model from Appendix 1. For example:

- Cost of test and support equipment and tools has been moved from Maintenance to Sustaining Support to match the CAIG model, even if its value is nil in the original GCBS model.
- Materiel and Man-hour costs for handling of Government Owned Stores have been moved to Sustaining Support too.

As for the implementation of the CAIG model in CATLOC, the initial intention was to implement the second Level of Cost Elements in the structure hierarchy (see Appendix 4) and then populate these costs. However, this was not achieved due to the lack of the definitions of these costs.

After the restructuring of the GCBS model Cost Breakdown Structure and the implementation of the CAIG model in CATLOC, the actual comparison can be done by mapping the cost elements in the GCBS-CAIG model to the relevant cost aggregate in the CAIG model for which an estimate exists (see Figure 13 for an example of the principle). This will allow for an assessment of the differences between the estimates. Big differences should trigger further investigations on the possible reasons for the deviation. In particular, to enable a fair comparison it was necessary to identify any costs that were present in the CAIG model but not in the GCBS model and vice versa.

7.2 Results

The final results are shown in Figure 14:

The total O&S costs computed exclude costs associated with CAIG cost work breakdown elements 5.0 (Continuing System Improvements) and 6.0 (Indirect Support). The main reason was that too much uncertainty existed to match some costs to these aggregates. Another reason is the total absence of CAIG 5.0 in the GCBS model and CAIG 6.0 in CAIG estimates.

7.3 Discussion

Due to the lack of data and information, no conclusions could be drawn on the accuracy of the models. Therefore, the observations made in this section are completely based on a qualitative analysis of the two models:

- Aggregate O&S costs in the GCBS-CAIG model are not directly comparable to the CAIG model. Although the CAIG model focuses on operations and support, it also includes, for instance, costs for continuous testing and development. In the GCBS, these costs belong to the aggregate “Production phase”, which is not part of the O&S. Furthermore, the CAIG model is not intended for crisis/war scenarios, while in the GCBS model (as implemented in CATLOC) a war/crisis scenario could easily be handled by considering it as a mission type.
- The “personnel costs”, which were considered to be overestimated in the CAIG model, are more than 30% higher in the GCBS model. However, the sum of CAIG elements 1.0 and 2.0 together seems to be close to the GCBS equivalent.

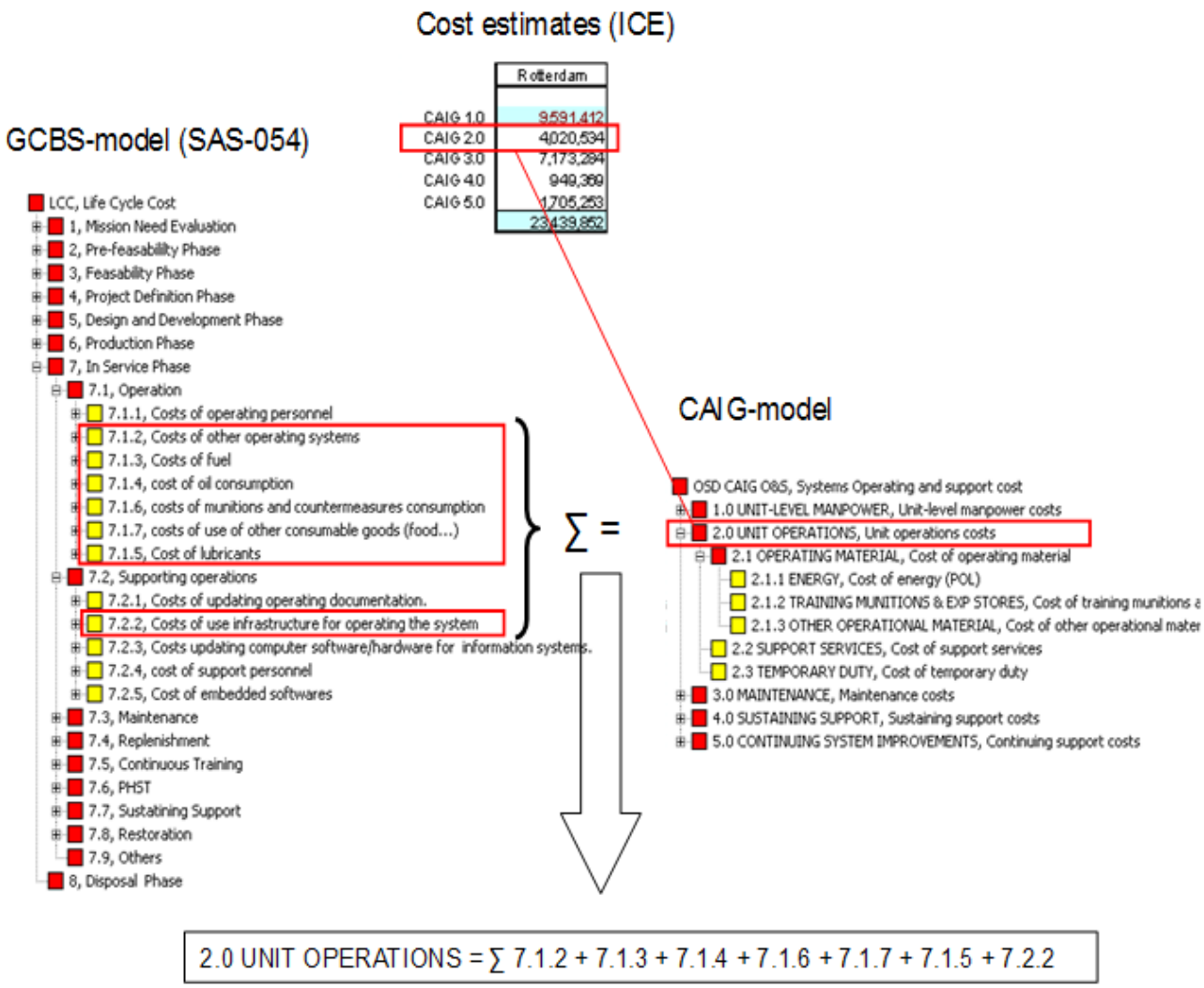

Figure 13: Example of the comparison method

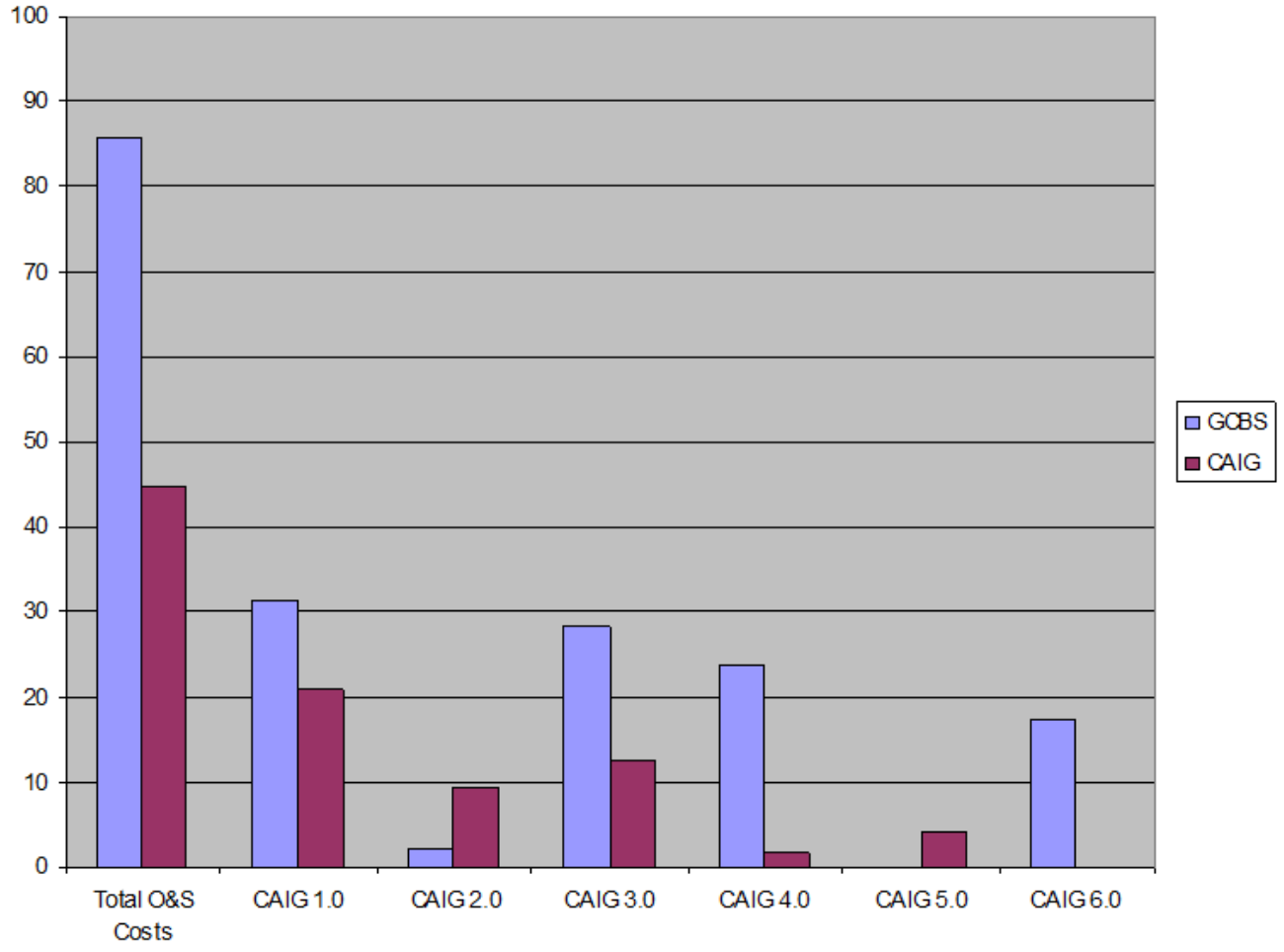

Figure 14: GCBS vs. CAIG

- The "maintenance costs" are more than twice as high in the GCBS model. If we consider only the PM costs, they still are higher. CAIG element 4.0 should be excluded from the comparison because there's obviously something wrong there.

Without more data it is not possible to draw any conclusions on which of the methods produces the most reliable cost estimate. Still, even if it has not been possible to do a numerical evaluation, it is clear that the GCBS model is more relevant than the CAIG model when it comes to understanding the origin of the costs.

If the only objective is to get the total sum of all costs, a thorough investigation may show that the two methods are more or less equivalent. If, on the other hand, the purpose of the cost analysis is to find cost drivers, identify opportunities for savings, or help decision-makers investment decisions, the bottom-up approach should be used.

8.0 LESSONS LEARNED

The section is divided into seven parts: the general management of the estimating process and the feedback of each topic of the cost estimating process; aims and cost boundary; data and assumptions; methods, models and tools; risk and uncertainty; analysis of the results; and presentation of results.

8.1 General Management of the Estimating Process

8.1.1 Initial Plan

SAS-076 started with a plan describing the activities and captured this in a Project Initiation Document (PID). Originally it was described as follows:

For the acquisition stage, a top-down approach would be adopted, using the information in the DADD and applying the parametric method. As a second estimating method, it was possible to apply the analogy method using public available data (Internet, NAO(UK) reports, etc.).

Initially the cost-estimating approach consisted of two iterations. The first iteration was to estimate high-level cost elements of the cost breakdown structure. This would result in many assumptions; these assumptions would need to be checked by the RNLN. It would then have been used to identify cost drivers. The second iteration was to go into more details for the costs drivers, if additional data was available.

The main milestones for the first iteration were:

- Milestone 1: Agreement on cost elements to be calculated - 16/01/2009.
- Milestone 2: Release of the data and assumptions list - 26/06/2009.
- Milestone 3: Release of first report - 22/01/2010.

The main Milestones for the second iteration were:

- Milestone 4: Agreement on new cost elements to be calculated - 22/01/2010.
- Milestone 5: Release of the updated data and assumptions list - 09/07/2010.
- Milestone 6: Release of second iteration report - 01/10/2010.

8.1.2 Actual Implementation of the Initial Plan

The following steps were actually followed after having established the PID:

- Agreement on the Cost Breakdown Structure (CBS): follow ANEP 41 (SWBS) and the CBS from SAS-054 report;
- Developed a Data and Assumptions Document Definition (DADD) based on the data found in public sources, participant's inputs and the RNLN;
- Investigated software tools to be used.
- Decision on methods to be use for O&S: analogy, parametric and engineering.

Since the O&S costs for a materiel system are in high extent dependent on both the use of the system as well as the systems reliability and maintenance, the group decided to apply a bottom-up/engineering method to estimate the O&S costs. The group proposed to use the type of estimating approach the Swedish Material Defence Administration has experience on. This approach was mainly applied to evaluate alternatives in acquisition, maintenance optimization, improvement of the in-service cost effectiveness, etc. Sweden also provided the necessary computer tools to support the O&S cost estimate. The analysis was dependent on the provision of the necessary input data by the RNLN. Since both the Rotterdam and the Johan de Witt have been used and maintained for quite some years, the availability of data was expected to be high.

8.1.3 Lessons Identified

- The group did not work continuously on this project, causing additional challenges in the estimates and in the management of some important issues.
- The SAS-076 group considered the estimating guideline and the tasks described in SAS-054 of the management process to be useful.
- The group tried to follow the SAS-054 guidelines as much as possible, however the group was restricted by the limited availability of resources and competence available in the group or available within the group members' professional network. This affected, to a certain extent, the work process. The conclusion was that the SAS-054 guidelines could be followed, however, it takes time and resources. Therefore, the resources and the budget required to do an estimate according to the SAS-054 guideline should be carefully planned before the actual work starts.

8.2 Definition of the Aims and Cost Boundary

8.2.1 The Team's Approach

The customer for the results of the study was the RNLN. As this estimate is also used to apply the guideline developed by SAS-054, NATO RTO can be considered as a secondary customer.

The aim was to practice the guidelines of SAS-054. The objective for the O&S costs estimation was to approximate the yearly in-service support costs and to sum them for a chosen life-time given the planned operational profile. This would result in finding the major cost drivers and eventually give the RNLN some opportunities to improve their maintenance plans.

For the O&S costs, the cost boundary changed during the cost estimating process, e.g., helicopters were first not included. The Rotterdam group included the costs for the helicopters as the RNLN informed the group that these costs were included in the data. Originally the disposal costs were included in the Cost Breakdown Structure, but the RNLN could not provide a strategy for the disposal of the ships, which resulted in the removal of these costs from the Cost Breakdown Structure.

8.2.2 Lessons Identified

- The aim and the objective of the study are fundamental for the way the cost analysis is conducted.
- For this ICE the generic Cost Breakdown Structure, as defined in the SAS-054 Report, was used and considered to be useful. The cost elements were estimated were defined iteratively.

8.3 Data and Assumptions

8.3.1 The Team's Approach

It was decided to use three approaches to estimate the O&S costs: parametric, analogy approach (CAIG estimate), and the engineering bottom-up approach.

A first estimate for the O&S costs was made using O&S cost data retrieved from VAMOSC (Visibility and Management of Operating & Support Costs) data base. The CBS followed OSD Cost Analysis Improvement Group (CAIG) Cost Element Structure, which provides a standardized system to prepare and submit O&S cost estimates. Analogous ships were selected on the basis of: dimensions, ship technical characteristics, and intended role/mission. Data was then averaged over the life-time of the ship, and the data points were used as a basis for the cost estimating relationships (CERs). Two estimating methods were used to compute the CAIG elements: a parametric approach – using only one parameter for each CAIG element, and an analogy method using LSD-49 Class averages. The outcome from both methodologies was then combined, leading to an initial cost estimate for the O&S costs.

The engineering approach to estimate the O&S cost is to a great extent based on the connection between Reliability, Availability, Maintainability and Supportability data (RAMS), and costs for spare parts, man-hours and other cost elements. The costs are computed in the cost atoms algorithms in the cost model. For this, it is important to have detailed knowledge of the technical and organizational data. Since the group could not obtain the required reliability data to estimate the costs for corrective maintenance (mainly failure rates), it was not possible to calculate the costs according to the engineering method. This is of great importance and had a severe impact on accuracy of the cost estimate since the Corrective Maintenance (CM) is often a major cost driver in the in-service phase of a system. As a result, a combination of CAIG data and Swedish experience with respect to the fraction of CM cost related to the total O&S cost was used instead. Naturally the purpose was to have a full estimate of the O&S cost, but data availability to apply the engineering method was insufficient

For this O&S estimate, the generic Cost Breakdown Structure, as defined in the SAS-054 Report, was used. The cost elements that were estimated were defined iteratively. The methodology defined in the SAS-028 Report with the generic Resources, Product and Task dimensions was used. Also, the definition of the generic System Breakdown Structure, ANEP41, was used. If necessary, these approaches were tailored according to the specifics of the program. For this assessment, the O&S costs were estimated using both organizational and operational data, as well as technical and financial data. Data was gathered by the RNLN. A more detailed description of the data can be found in the Section 4 and Appendix 1 of this Annex.

Regarding the cost normalization for the parametric and analogy methods used in CAIG estimate, the data was taken from the VAMOSC database with all costs in constant fiscal year (FY) or base year 2009 U.S. Dollars. In order to deal with the high variability in O&S costs, a two step approach was undertaken:

- Data from VAMOSC was averaged on an annual basis between different ships in each class;
- Then the yearly data for each class of ship was averaged over the life-time of the ships in all cases beginning in 1984 and ending when the ship was either decommissioned or at the end of the sample period.

The costs for the engineering method, provided by the RNLN in euros base year 2005, were normalized using the eurostat labour index and converted to euros base year 2008.

8.3.2 Lessons Identified

- Lessons learned related to the CAIG estimate:
  - Using a single parameter to estimate costs may not produce reliable estimates. For example CAIG elements 3 & 4 are computed on a more or less accurate relationship between displacement and maintenance/sustainment costs. The maintenance methods and schedules should also be taken into account here.
  - CER (cost estimating relationships) with FLD (Full load Displacement) only works when ships being compared have similar manning, operational and maintenance philosophies.
  - The best way to predict fuel consumption is to have specific data on steaming hours, fuel costs, engine efficiency and the units' usage portfolio.
  - System complexity, number of systems and many other factors can all have an impact on costs.
  - Databases like VAMOSC are very useful to estimate O&S costs.
- Lessons learned related to the engineering method:
  - Access to Follow-Up data from the In-Service phase was a necessary condition to be able to apply the engineering method for estimating O&S costs. If that condition could not be fulfilled, rough assumptions would have to be made. An alternative, not performed for the current estimation, was to use parametric COTS models to complete the estimate.
  - One has to bear in mind that the engineering method allows you not only to calculate the costs themselves, but also the costs related to the specific system and its operational profile and support organization. The engineering method allows the user to vary the above mentioned data and to calculate the costs for this variation. Thus, the engineering method allows the user to determine the cost efficiency of the system. This implies that the method is considered to be both expensive and vulnerable. The latter implies its dependence of accurate Follow-Up and RAMS data. This has been exemplified by the fact that the group was not able to gather all the necessary data.

8.4 Methods, Models and Tools

8.4.1 The Team's Approach

Three methods were used: an Engineering bottom-up, a parametric, and an analogy approach. However, it appeared that the engineering bottom-up was not applicable as such due to the lack of engineering data such as reliability of the items. The engineering method used was rather a mix of top-down and bottom-up methods.

The tools investigated were mainly commercial. It was not possible to acquire one of the tools, due to the very limited resources available. Therefore the group used tools that were already available in one or more nations and for which a temporary licence was given to the participating nations (CATLOC).

8.4.2 Lessons Identified

- The data available determined, to a very large extent, the choice of methods, from the start of the cost analysis process to the end of it. It was a continuous interaction between choices of methods, computer models and availability of data. For example, the methodologies were chosen assuming that certain data would be available, however, some data was not available and forced the team to adapt the methodology, or to gather the data from a different source.

- The SAS-054 report discusses the engineering method (bottom-up). The description of the engineering method is correct, however, reliability data should be mentioned explicitly. Suggestions include adapting the following sentence: "This type of estimate is used when detailed design data, such as reliability data on the system, is available".

- Furthermore, the engineering method is not the same as a bottom-up approach. Handbooks (including SAS-054) mix-up approaches (top-down and bottom-up), and methodologies (parametric, engineering). Top-down and bottom-up are dependent on the granularity of the Cost Breakdown Structure and the available data. What is missing in the SAS-054 report is the specification of the top-down and the bottom up approaches, before detailing the types of methodologies.

8.5 Risk and Uncertainty Analysis

8.5.1 The Team's Approach

Most data was received from the RNLN and was considered reasonably accurate. However, some parameters collected outside of the RNLN have uncertainties attached to them. These are: fuel price, labour cost escalation and the cost elements for which it was not possible to obtain data.

8.5.2 Lessons Identified

When applying an engineering method, it is inevitable that some data are uncertain. As a result, there is a need to adjust collected data to the LCC model for the analysis in question. The way to handle these uncertainties is to conduct a sensitivity analysis or to apply Monte Carlo simulation. For this study, this was not done.

8.6 Analysis of Results

8.6.1 The Team's Approach

The team showed the results for both the CAIG CBS and the GCBS. The engineering method (GCBS) allows showing detailed results and the distribution of costs among the cost aggregates and cost atoms. This way cost drivers can be identified and more detailed analysis on costs can be started. However, because of the lack of data, this type of analysis could not be performed.

8.6.2 Lessons Identified

Although sufficient data was not available to perform a detailed analysis on the costs, it was useful to present the results as detailed as possible. This way, areas can be identified for further detailed analysis. Furthermore, the CATLOC model proved to be very useful when applying the engineering method and provided very useful graphical outputs.

Another lesson is that showing the features of a model can be used as a catalyst for further data collection. Once customers are aware of what type of analysis is possible with a certain model, they are more than willing to gather more detailed data.

8.7 Presentation of the Results

8.7.1 The Team's Approach

Intermediate results were shown to the RNLN with the intention of persuading them to gather more data. This was done by explaining why the extra data was required and what was possible if data was to be provided. This was part of the "learning process" included in the methodology. Both the cost estimator and the operator of the system were learning from each other. The first one was learning what the user wants how the system was operated and structured and the second learns why it was necessary to capture costs, what the relation was between the RAMS data and the costs and finally how he could improve the effectiveness of his system.

8.7.2 Lessons Identified

- The SAS-076 task group did unintentionally assume that the data provided by the RNLN was coherent with the CBS, which was not the case. This could be regarded as a typical mistake of an international study group or an example of how input data determines the method. Therefore, during the acquisition phase of a system, the prerequisites for gathering data necessary to the future cost estimations should be established. This means that follow-up databases and input data structures should be implemented very early.

- Even if the group could not obtain the data necessary to properly apply the engineering method, and did not get the desired outcomes, the method worked. The learning process discussed above instigated a sharp reaction within the RNLN. They have already decided to improve the ways they collect data for future cost estimates.

9.0 CONCLUSIONS

The Rotterdam group managed to produce an estimate for the O&S costs based on the planned operational profile. Success depended on the availability of the right expertise, the right computer tools, and the right data sources. For the latter, especially for O&S cost estimation, open sources were helpful but any estimator cannot solely rely on them.

The engineering method used to estimate cost in a budgeting process, especially from a historical perspective, was not an optimal approach. Concerning budgeting and financing it is often required that all the costs should be presented, and for that more appropriate economical methods already exist. However, the engineering method is a very powerful tool, if not the only one, to identify and reduce cost drivers during the critical decision making in the systems lifetime.

The engineering method should concentrate on the objective of the analysis the user and the cost estimator would like to achieve. The boundaries for work, type of data, amount of data, the design of the CBS etc., differ according to the type of analysis. For example, not all the costs or RAMS parameters influence the analysis to be used. The engineering method is trying to minimize the need of input data taking into consideration only those costs and related parameters which influence the decision making process.

It is probably better to look at the engineering method as an on-going enterprise during the system life time, i.e., "from cradle to grave". Applied properly and consistently, the method not only implicitly leads to improvement of the system efficiency, but also gives the system operator after a period of time, access to a database similar to VAMOSC which will substantially improve the future Life Cycle Cost estimations.

The cost estimate resulting from this study should be considered as indicative. All the uncertainties related to the operating profiles during the system lifetime, the reliability, maintainability and supportability issues, the impacts of future technology, and the economical fluctuation on the market in general are reasons to believe that an accurate estimate of the life cycle costs is unfeasible. However, alternative solutions can usually be evaluated with higher degrees of consistency by certifying that the levels of uncertainty are similar for all considered alternatives. The engineering method may come closest to reality.

10.0 REFERENCES

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Appendix B2-1: CATLOC LCC MODEL DESCRIPTION

Figure 15 shows how the LCC-tree can be viewed in CATLOC.

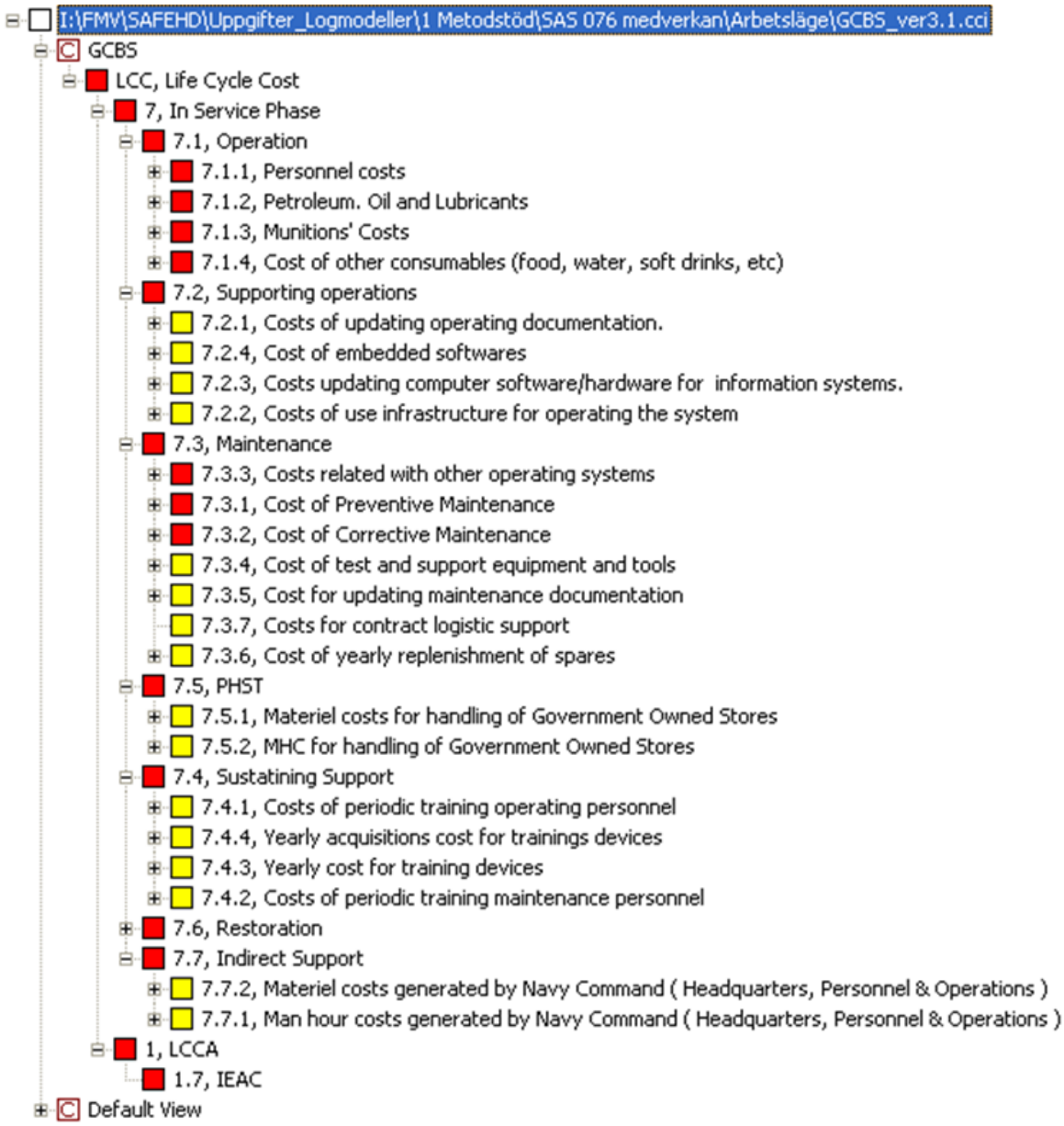

Figure 15: The LCC tree as listed in the CATLOC model

The CATLOC model shown in Table 3 below is based upon a template implementing a generic cost break-down structure (GCBS) proposed by the NATO RTO Task Group SAS-054. The generic hierarchy is described in section 10.3 and 12.1 of the SAS-054 final report. The template includes cost aggregates and a cost structure but no formulæ, cost atoms or domain dimensions.

The model was populated with cost atoms according to the initial assumptions made by SAS-076, and after that it was adjusted and tailored using the data obtained from the RNLN. Some cost aggregates, or cost atoms, have been kept in the model even if input data was not available. The main reason for this was to illustrate the benefits the engineering LCC methodology has if data was available. During a demonstration session these benefits were shown to the RNLN. The RNLN decided to have a closer look at the model and eventually decided to obtain the necessary data to perform a complete analysis.

The cost aggregates in Tables 3 – 5 comprise the sum of the cost aggregates or cost atoms from the next lower level. A cost atom is usually described by a parameter or a formula. For a better understanding of the model, first a "Level report" (Tables 3 – 5) is shown, representing the relation between cost aggregates and cost atoms. Then a "Tree report" (Tables 6–10) is shown, revealing the description of the parameters used in the formulæ. In both tables, the Title/Index column gives the name of the LCC tree node. In the Level report only, the cost aggregates have a formula (a sum) on the row below the description.

Table 3: The CATLOC model A1-1 Level reporting table (Levels 0–2)

Level	Title/Index	Description
LEVEL 0		
	LCC	Life Cycle Cost
		7 + 1
LEVEL 1		
	7	In Service Phase
		7.1 + 7.2 + 7.3 + 7.5 + 7.4 + 7.6 + 7.7
	1	LCCA
		1.7
LEVEL 2		
	7.1	Operation
		7.1.1 + 7.1.2 + 7.1.3 + 7.1.4
	7.2	Supporting operations
		7.2.1 + 7.2.2 + 7.2.3 + 7.2.4
	7.3	Maintenance
		7.3.1 + 7.3.2 + 7.3.3 + 7.3.5 + 7.3.4 + 7.3.6 + 7.3.7
	7.4	Sustaining Support
		7.4.1 + 7.4.2 + 7.4.3 + 7.4.4
	7.5	PHST
		7.5.2 + 7.5.1
	7.6	Restoration
		7.6.1
	7.7	Indirect Support
		7.7.1 + 7.7.2
	1.7	IEAC

Table 4: The CATLOC model A1-1 Level reporting table (Level 3)

Level	Title/Index	Description
LEVEL 3		
	7.1.1	Personnel costs 7.1.1.1 + 7.1.1.2
	7.1.2	Petroleum, Oil and Lubricants 7.1.2.1 + 7.1.2.2 + 7.1.2.3 + 7.1.2.4 + 7.1.2.5
	7.1.3	Munitions' Costs 7.1.3.1
	7.1.4	Cost of other consumables (food, water, soft drinks, etc) 7.1.4.1 + 7.1.4.2 + 7.1.4.3 + 7.1.4.4
	7.2.1	Costs of updating operating documentation
	7.2.2	Costs of use infrastructure for operating the system
	7.2.3	Costs updating computer software/hardware for information systems
	7.2.4	Cost of embedded software
	7.3.1	Cost of Preventive Maintenance 7.3.1.1 + 7.3.1.2 + 7.3.1.3 + 7.3.1.4 + 7.3.1.5
	7.3.2	Cost of Corrective Maintenance 7.3.2.1 + 7.3.2.2 + 7.3.2.3
	7.3.3	Costs related to other operating systems 7.3.3.1 + 7.3.3.2
	7.3.5	Cost for updating maintenance documentation
	7.3.4	Cost of test and support equipment and tools
	7.3.6	Cost of yearly replenishment of spares
	7.3.7	Costs for contract logistic support
	7.5.2	Man-Hour cost for handling of Government Owned Stores
	7.5.1	Materiel costs for handling of Government Owned Stores
	7.4.1	Costs of periodic training operating personnel
	7.4.2	Costs of periodic training maintenance personnel
	7.4.3	Yearly cost for training devices
	7.4.4	Yearly acquisitions cost for trainings devices
	7.6.1	Cost of recommended and mandatory modifications of the system
	7.7.1	Man hour costs generated by Navy Command (Headquarters, Personnel Operations)
	7.7.2	Materiel costs generated by Navy Command (Headquarters, Personnel & Operations)

Table 5: The CATLOC model A1-1 Level reporting table (Levels 4-5)

Level	Title/Index	Description
LEVEL 4		
	7.1.1.1	Costs of operating personnel
	7.1.1.2	Average personnel costs for operation of helicopters
	7.1.2.1	Cost of fuel
	7.1.2.2	Cost of oil consumption
	7.1.2.3	Cost of lubricants
	7.1.2.4	Yearly costs for POL, Ship
	7.1.2.5	Average POL costs due to maintenance of helicopter per year
	7.1.3.1	Costs of munitions and countermeasures consumption
	7.1.4.1	Average cost for food per year
	7.1.4.2	Average yearly cost for water consumption
	7.1.4.3	Average yearly cost for electricity consumption
	7.1.4.4	Average yearly cost of "other operational material"
	7.3.1.1	Annual man hour costs for major preventive maintenance action on main system
	7.3.1.2	Materiel costs for major preventive maintenance action on main system
	7.3.1.3	CHPMR, Annual man hour costs for PM actions on unit level
	7.3.1.4	CMPMT, Annual materiel costs for PM actions on unit level
	7.3.1.5	CPMTC, Annual costs for PM actions on unit level performed by contractor
	7.3.2.1	Average CM costs due to unit replacement actions 7.3.2.1.1+7.3.2.1.2+7.3.2.1.3+7.3.2.1.4+7.3.2.1.7+7.3.2.1.8 +7.3.2.1.5+7.3.2.1.6
	7.3.2.2	Average CM costs due to unit repair actions 7.3.2.2.1 + 7.3.2.2.2 + 7.3.2.2.3 + 7.3.2.2.4 + 7.3.2.2.5
	7.3.2.3	Average yearly CM cost , both material and man power
	7.3.3.1	Average man-hour cost for maintenance of helicopters (maintenance staff)
	7.3.3.2	Average materiel costs due to maintenance of helicopter per year
LEVEL 5		
	7.3.2.1.1	CHCMRP, Man hour costs for unit replacements due to CM during operational time onboard the ship performed by NME at OML level
	7.3.2.1.2	CMCMRP, Average cost for materiel consumption (consumables) due to CM replacement actions at OML performed by the crew
	7.3.2.1.3	CTCMRP, Average cost for transportation due to CM replacement action at OLM performed by NME personnel abroad
	7.3.2.1.4	CCMRPEX, Average cost for CM replacements at unit level performed by external personnel
	7.3.2.1.7	TRCCMRP, CMRp - Average transportation costs for replacements actions due to CM at OLM performed by personnel from NME per year - includes personnel and replaced unit transportation back and forth
	7.3.2.1.8	CMRPEX, CMRp - Average cost for replacement actions if performed by contractor / external man-power at OLM
	7.3.2.1.5	CMRPCC, CMRp - Average cost of consumables consumption for replacements due to CM at OLM per year
	7.3.2.1.6	MHCCMRP, CMRp - Average man-hour cots for replacements due to CM at OLM performed by personnel from NME per year
	7.3.2.2.1	CCMRNME, Average CM costs for repair actions at unit level performed by NME per year
	7.3.2.2.2	CMCMCT, Average CM costs for repair actions at unit level performed by contractor per year
	7.3.2.2.3	CMCMCC, CM - Average cost of consumables for repair actions due to CM per year
	7.3.2.2.4	MHCCMR, CM - Average man-hour cots for repair actions due to CM per year
	7.3.2.2.5	CMCMEX, CM - Average cost for repair actions due to CM per year performed by contractor

In Tables 6–10 in the Description column, the first row corresponds with the title of the node. The next row provides the formula used, if applicable. Then the parameter used is described. In some cases the parameter used is the result of a calculation. In this case the formula is shown below the parameter description. Finally the row before the next node is reserved for remarks. The sum for cost aggregates is no longer shown.

Table 6: The CATLOC model A1-2 Tree reporting table

Title/Index	Description
7	In Service Phase
7.1	Operation
7.1.1	Personnel costs
7.1.1.1	Costs of operating personnel
	NOPT*(MIOP+COPC)
	NTOPP - Number of different types of operational personnel. Not used explicitly in the model
	NOPT - Number of operators per type (manning profile)
	MIOP - Average yearly income of operators (salaries + benefits)
	COPC - Average yearly cost of on-board personnel uniforms, accessories, shoes, special
	clothing, etc
7.1.1.2	Average personnel costs for operation of helicopters
	NHALO*CPOPHY
	NHALO - Number of Helicopters on the ship
	CPOPHY - Average personnel costs for operation of helicopters
7.1.2	Petroleum, Oil and Lubricants
7.1.2.1	Cost of fuel
	CLFS*MFCH*UTILIS*8.760
	NFT - Number of types of fuel consumed per system per mission. The model allows 2 types of fuel
	MFCH - Average fuel consumption/operational hour/type of fuel in litres (l)
	IDFUEL - Unique identifier for fuel type
	IDMISSION - Unique identifier for mission type
	IMFCH - RNLN, input data , fuel consumption per year
	CLFS - Average cost for fuel per type of fuel in 1000*EUR/l
	RNLN input
7.1.2.2	Cost of oil consumption
	MOCH*CLOS*UTILIS*8.760
	NOT - Number of types of oil used per system per mission
	MOCH - Average oil consumption per operational hour per type of oil
	An analogous formula as for the fuel consumption is used for the oil consumption. However,
	since these cost atoms are not used, the formula and its parameters are not presented here.
	CLOS - Average cost for oil consumption per operational hour per type of oil used
	NOT is defined in CATLOC explicitly in the materiel domain, ALL_OIL_TYPES which contains
	for the moment 2 types of lubricants OIL1 & OIL2 No costs are calculated here, as the oil consumption is unknown
7.1.2.3	Cost of lubricants
	MLCH*CLGS*UTILIS*8760
	NLT - Number of types of lubricants used per system per mission
	MLCH - Average lubricant consumption per operational hour per type of lubricants
	Analogous formula as for fuel consumption is used for the lubricants consumption but since
	these cost atoms are not used, the formula and its parameters are not presented here.
	CLGS - Average cost for lubricants consumption per operational hour per type of lubricants
	NLT is defined in CATLOC explicitly in the materiel domain, ALL_LUBRICANT_TYPES which contains for the moment
	2 types of lubricants LUBRICANT1 & LUBRICANT2. No costs are calculated here, as the lubricant consumption is unknown.
7.1.2.4	Yearly costs for POL, Ship
	CPOLSH
	CPOLSH - Average cost for POL, ship
	In this case the formula is just an input parameter.
	RNLN input
7.1.2.5	Average POL costs due to maintenance of helicopter per year
	NHALO*CPOLHY
	CPOLHY - Average POL costs due to maintenance of helicopter per year
	RNLN input

Table 7: The CATLOC model A1-2 Tree reporting table (Cont'd)

Title/Index	Description
7.1.3	Ammunition Costs
7.1.3.1	Costs of ammunition and countermeasures consumption
	MMCY*CMUY
	MMCY - Average units of ammunition type i consumed per year
	CMUY - Average cost per unit of munitions type i
	More than one type of ammunition can be defined (RNLN input)
7.1.4	Cost of other consumables (food, water, soft drinks, etc)
7.1.4.1	Average cost for food per year
	NMOB*CFOB*UTILF*365
	NMOB - Number of man on-board the ship
	CFOB - Average cost of food per person per day
	Assumed cost, see section 4
7.1.4.2	Average yearly cost for water consumption
	CWCU*MWCY
	CWCU - Average cost per water unit
	MWCY - Average water consumption per year
	Assumed cost. See section 4
7.1.4.3	Average yearly cost for electricity consumption
	CECU*MECY
	CECU - Electricity cost per kWh
	MECY - Average electricity consumption per year
	No data available, not used.
7.1.4.4	Average yearly cost of "other operational material" CCOE
	CCOE - Yearly cost of "other operational material" No data available, not used.
7.2	Supporting operations
7.2.1	Costs of updating operating documentation.
	NDOU*NDOPY*CDOU
	CDOU - Cost per operating documentation update of type i per year
	NDOU - Number of operating documentation updates for each type per year.
	NDOPY - Number of operating documentation updates of type i per year
	Only CDOU has an assumed input defined in section 4 representing the total cost per year for documentation updates.
7.2.2	Costs of use infrastructure for operating the system
	NDFH*CDFH
	NDFH - Period in harbours per year
	CDFH - Average fee in harbour per day
	Not enough data available, not used
7.2.3	Costs updating computer software/hardware for information systems.
	No data available, not used
7.2.4	Cost of embedded software
	No data available, not used
7.3	Maintenance
7.3.1	Cost of Preventive Maintenance
7.3.1.1	Annual man hour costs for major preventive maintenance actions on main system
	MHCPMSYS*NHPMSYS
	MHCPMSYS - Man hour costs for major preventive maintenance actions on main system
	NHPMSYS - Number of labour hours for major preventive maintenance actions on main system RNLN input
	RNLN input
7.3.1.2	Materiel costs for major preventive maintenance actions on main system
	MCPMSYS
	RNLN input

Table 8: The CATLOC model A1-2 Tree reporting table (Cont'd)

Title/Index	Description
7.3.1.3	Annual man hour costs for PM actions at unit level. **CHPMR** NYPM*QTYPM*TPM*NMPM*MHC The formula mentioned above is just to illustrate how this cost atom may be computed. The formula does not work in the model as the parameters should be defined as vectors or arrays over predefined domains. See section 4 for definition of the parameters. Kept in the model for demonstration reasons.
7.3.1.4	**CMPMT** NYPM*QTYPM*CMPM Annual materiel costs for PM actions at unit level. See 7.3.1.3.
7.3.1.5	Annual costs for PM actions at unit level performed by contractor **CPMTC** IF(LPM=1,NYPM*QTYPM*CPTC,0) See 7.3.1.3.
7.3.2	Cost of Corrective Maintenance
7.3.2.1	Average CM costs due to unit replacement actions
7.3.2.1.1	Man hour costs for unit replacements due to CM during operational time onboard the ship performed by NME at Organisational level. **CHCMRP** MHC*QTYPM*FRT*ACMRP*NMTRP*MTTRP The formula mentioned above is just to illustrate how this cost atom may be computed. The formula does not work in the model as the parameters should be defined as vectors or arrays over predefined domains. See section 4 for definition of the parameters. Kept in the model for demonstration reasons.
7.3.2.1.2	Average cost for materiel consumption (consumables) due to CM replacement actions at Organizational level performed by the crew. **CMCMRP** UTILF*0.00876*QTYPM*FRT*(1-ACMC)*CMRP It Is the aggregate value for all the parts which has a value for CMRP and where LRE is OLM The same comments as above.
7.3.2.1.3	Average cost for transportation due to CM replacement action at OLM performed by NME personnel abroad **CTCMRP** QTYPM*FRT*UTILF*0.00876*ACMRP*CMTRP The same comments as above.
7.3.2.1.4	Average cost for CM replacements at unit level performed by external personnel **CCMRPEX** QTYPM*FRT*UTILF*0.00876*ACMC*CMRPC These costs should include both man power costs and material consumption costs The same comments as above.
7.3.2.1.7	Average transportation costs for replacements actions due to CM at OLM performed by personnel from NME per year - includes personnel and replaced unit transportation back and forth **TRCCMRP** Should be an input from the user. Kept in the model for demonstration reasons
7.3.2.1.8	Average cost for replacement actions if performed by contractor / external man-power at OLM **CMRPEX** Should be an input from the user. Kept in the model for demonstration reasons
7.3.2.1.5	Average cost of consumables consumption for replacements due to CM at OLM per year **CMRPCC** Should be an input from the user. Kept in the model for demonstration reasons
7.3.2.1.6	Average man-hour cots for replacements due to CM at OLM performed by personnel from NME per year **MHCCMRP** Should be an input from the user. Kept in the model for demonstration reasons
7.3.2.2	Average CM costs due to unit repair actions

Table 9: The CATLOC model A1-2 Tree reporting table (Cont'd)

Title/Index	Description
7.3.2.2.1	Average CM costs for repair actions at unit level performed by NME per year **CCMRNME** 0.00876*UTILF*QTYPM*FRT*(MHC*NMTR*MTTR+CMCM) The above formula is just to illustrate how this cost atom may be computed. The formula does not work in the model as it is because the parameters should be defined as vectors or arrays over predefined domains. Se Ch.4 for parameters definitions. Kept in the model for demonstration reasons
7.3.2.2.2	Average CM costs for repair actions at unit level performed by contractor per year **CMCMCT** QTYPM*FRT*UTILF*0.00876*CMCMC The same comments as above.
7.3.2.2.3	CM - Average cost of consumables for repair actions due to CM per year **CMCMCC** Should be an input from the user. Kept in the model for demonstration reasons
7.3.2.2.4	CM - Average man-hour cots for repair actions due to CM per year **MHCCMR** Should be an input from the user. Kept in the model for demonstration reasons
7.3.2.2.5	CM - Average cost for repair actions due to CM per year performed by contractor **CMCMEX** Should be an input from the user. Kept in the model for demonstration reasons
7.3.2.3	Average yearly CM cost, both material and man power **AYCMC** Average yearly cost for CM actions This cost is calculated as a result of the assumption made in Ch. 4
7.3.3	Costs related with other operating systems
7.3.3.1	Average man-hour cost for maintenance of helicopters (maintenance staff) NHALO*MHCOPH **MHCOPH** - Average man-hour cost for maintenance of helicopters (maintenance staff) Input data from RNLN
7.3.3.2	Average materiel costs due to maintenance of helicopter per year NHALO*CMMHY **CMMHY** - Average materiel costs due to maintenance of helicopter per year Input data from RNLN
7.3.5	Cost for updating maintenance documentation NDMU*NDMY*CDMU **NDMU** - Number of maint. documentations updates for each type per year NDMY - Number of maint. documentations updates of type i per year CDMU - Cost for one maint. documentation update of type i per year No data available. Not used
7.3.4	Cost of test and support equipment and tools CTSEQ+CITSEQ **CITSEQ** - Yearly investment cost for test/support equipment **CTSEQ** - Yearly support cost for test/support equipment No data available. Not used
7.3.6	Cost of yearly replenishment of spares **CMRPSP**
7.3.7	Costs for contract logistic support No data available. Not used
7.5	PHST
7.5.2	MHC for handling of Government Owned Stores **MHCPHST**
7.5.1	Materiel costs for handling of Government Owned Stores **MCPHST**
7.4	Sustaining Support

Table 10: The CATLOC model A1-2 Tree reporting table (Cont'd)

Title/Index	Description
7.4.1	Costs of periodic training operating personnel
	NTC_OP*NTP_OP*CTC_OP+CTOPCY
	CTC_OP - Cost for one op. training course of type i per attendee including the necessary documentation
	CTOPCY - Annual cost for training material (consumables) for operating personnel [cost/year]
	NTC_OP - Number of op. training courses for each type per year
	NTP_OP - Number of attendees per op. training course of type i No data available. Not used
7.4.2	Costs of periodic training maintenance personnel
	NTC_MAINT*NTP_MAIN*CTC_MAINT+CTMCY
	CTC_MAINT - Cost for one maint. training course of type i per attendee including the necessary documentation
	CTMCY - Annual cost for training material (consumables) for maintenance personnel [cost/year]
	NTC_MAINT - Number of maint. training courses for each type per year
	NTP_MAIN - Number of attendees per maint. training course of type i No data available. Not used
7.4.3	Yearly cost for training devices
	CTD*SUM(NTD,ALL_TRAININGS)
	NTD - Number of training devices of type k used for training courses /year
	CTD - Average cost for using a device of type k once
	No data available. Not used
7.4.4	Yearly acquisitions cost for trainings devices
	CATD*NTDA
	CATD - Annual investments in training devices of type k
	NTDA - Number of training devices acquired per year No data available. Not used
7.6	Restoration
7.6.1	Cost of recommended and mandatory modifications of the system
	No data available. Not used
7.7	Indirect Support
7.7.1	Man hour costs generated by Navy Command (Headquarters, Personnel & Operations)
	MHCNC
7.7.2	Materiel costs generated by Navy Command (Headquarters, Personnel & Operations)
	MCNC
1	LCCA
	Life Cycle Cost Aq.
1.7	**IEAC**
	Assigned for independent estimated acquisition cost

Appendix B2-2: EX ANTE TESTING – CAIG

PURPOSE

The purpose of this study was to develop a cost estimating relationship methodology that could be used to estimate the Operating and Support (O&S) cost for the Dutch Navy Landing Platform Dock (LPD) Rotterdam (L-800) and Johan de Witt (L-801) ships[5]. The basis for the methodology was the use of the U.S. Naval Visibility and Management of Operating and Support Costs (VAMOSC) [5] management information system. VAMOSC collects and reports U.S. Navy and U.S. Marine Corps historical weapon system O&S costs. VAMOSC provides the direct O&S costs of weapon systems, some linked indirect costs (e.g., ship depot overhead), and related non-cost information such as flying hour metrics, steaming hours, age of aircraft, etc.

DATA

General data specifications for the L800 and L801 were provided by Study Director Dr. Brian Flynn. The information was verified to be accurate via Jane's and open-source information from the internet. U.S. ship data was pulled from VAMOSC, with all costs in constant fiscal year (FY) 2009 dollars. Additional information was taken from the Naval Vessel Registry [6], which is the official inventory of U.S. ships and service craft from the time of vessel authorization through its life cycle and disposal. Initially, O&S data was pulled for the following ships: LCC-19, LHD-1, LPD-1, LPD-4, LPD-17, LPH-2, LSD-36, LSD-41, LSD-49 and LST-1179. Ultimately, LCC-19, LHD-1, LPH-2 and LST-1179 were dropped from the data set because the dimensions of these classes were not analogous to the L800 and L801. LPD-17 was dropped because there were only 2-years of data available for that class. Therefore, the ships classes used in the final dataset were:

LPD – 1 LPD – 4 LSD – 36 LSD – 41 LSD – 49 .

To deal with the high variability of O&S costs between hulls, classes and years, two steps were taken. First, data was averaged on an annual basis between the different hulls in each class. This was done so as to provide a better estimate of the annual O&S costs for each class. Although some ships of a class may experience abnormal costs from year to year, when averaged together this volatility should be mitigated. The yearly data for each class of ship was then averaged over the life of the hull, in all cases beginning in 1984 and ending when the ship was either decommissioned or the end of the sample period (2008) was reached. Again, this was done to deal with the high variability of O&S costs. It is noted that the presented methodology can be used to estimate the average annual O&S costs of a hull, not the specific O&S costs in a given year.

PARAMETRIC COST ESTIMATING RELATIONSHIP METHODOLOGY

The parametric method is based on various characteristics or measurable attributes of the system, hardware and software being estimated. It depends upon the existence of a causal relationship between system costs and these attributes. Such relationships, known as CERs (cost estimating relationships) are typically estimated from historical data using statistical techniques.

[5]This appendix is an exact copy of the report: Methodology for Approximating Annual Operating Support Cost of Amphibious Ships - Dutch Navy Landing Platform Dock Rotterdam (L800) and Johan de Witt (L801) by Michael Mender and John Murray of the U.S. Naval Center for Cost Analysis [4].

The methodology behind the creation of the CERs for each Cost Analysis Improvement Group (CAIG) cost element was as follows.

- First, analogous ships to Rotterdam and Johann de Witt were selected and their data pulled from VAMOSC.
- The work breakdown structures (WBS) for each element were analysed so as to identify likely cost drivers for each element.
- Possible drivers were then analysed via scatter plots to evaluate the relationship between the probable drivers and their respective CAIG elements.
- If a correlation was revealed, regression calculations were run via the Excel module 'CoStat', to quantify the relationship and allow non-arbitrary comparisons of cost drivers.

Although other functional forms were evaluated, all of the final CERs used standard linear regression models with one variable.

The equation therefore takes the form:

$$Y = B_0 + B_1 X_1 \,, \tag{14}$$

where Y is the CAIG element being estimated (the dependent variable), B_0: is a constant term, X_1: is the identified cost driver, and B_1: is the coefficient attached to that cost driver.

CAIG 1.0 (Unit Manpower)

This CAIG element is driven by the number of personnel (billets) assigned to a ship, and personnel rates associated with each billet [7]. Billets per ship were originally identified as the main cost driver to be used in the CER, but further analysis of the data revealed that due to substantially different manning requirements between the U.S. and Dutch hulls, a regression based upon the number of billets was not feasible. The problem being that all U.S. ships that are of a similar size and function to the L-800CL had approximately 300 billets. With all the data points clustered around one number; no correlation existed to base a CER. As a result, full load displacement was selected, however, displacement only works when the ships for which the estimate is being prepared have similar manning requirements to U.S. ships. As the L-800/L-801CL don't have similar manning requirements, the recommendation was that CAIG 1.0 should be estimated using the analogous method presented later in this report.

CAIG 2.0 (Unit Operations Cost)

This CAIG element is largely driven by fuel costs. Ships that consume more fuel experience higher CAIG 2.0 costs than ships that use less fuel. The decision was made to develop a CER around annual fuel consumption. As this piece of data was not available for the L-800/L-801CL class of ships, an intermediate equation using full load displacement and a dummy variable for engine type was used to estimate annual fuel consumption. Please note that this implicitly assumes that the RNLN has a similar usage portfolio when compared to the USN, additionally it assumes that the RNLN experiences comparable engine efficiency and fuel costs.

CAIG 3.0 (Maintenance Costs)

This CAIG element was found to be largely driven by full load displacement (FLD). Larger ships cost more to maintain, therefore, a simple regression linking full load displacement to CAIG 3.0 was used to estimate the maintenance costs of the L-800 and L-801.

CAIG 4.0 (Sustainment Costs)

This CAIG element was found to be similar to CAIG 3.0. A major cost driver is FLD, and a correlation was found to exist between an increase in full load displacement and larger sustainment costs.

CAIG 5.0 (Continuing Systems Improvements)

This CAIG element is notoriously difficult to estimate. Upgrades and systems improvements can vary wildly between hulls in a class, between years for individual hulls, and are also heavily influenced by policy and other non-quantifiable factors. A variety of methods and theories were evaluated, with the following being the only one that showed any promise. It was hypothesized that ships with higher annual fuel consumption may also have higher annual CAIG 5.0 related costs. The reason we might expect to see this is that ships that consume more fuel, probably have a higher OPTEMPO and may receive higher priority for upgrades as a result. Keeping in mind that upgrades are influenced by policy and other factors, it is likely that the actual CAIG 5.0 costs for the RNLN (or any navy other than the USN) will differ significantly.

MONTE CARLO SIMULATION FOR PREDICTION INTERVALS

Once the CERs for each individual CAIG element were established, the combined information was assembled into an estimate through the use of CoStat and Crystal Ball. CoStat can be programmed to automatically generate prediction intervals when a regression is run. By setting the prediction intervals such that they were one standard deviation from the mean, the standard deviation of each estimate was easily computed via simple math. This information was then fed into Crystal Ball. Crystal Ball allows analysts to run Monte Carlo simulations, which allow for the generation of prediction intervals for the combined estimate. This is done by using the mean estimate and standard deviation for each CAIG element to create a normal distribution for that element. The combined estimate was then set equal to the sum of the most probable values of each of the elements. Crystal Ball then runs a simulation, during which random numbers are generated according to the probabilities associated with the normal distributions for each element. After 200,000 iterations, a histogram of the results reveals the most likely values of the combined estimate.

ANALOGOUS COST ESTIMATING METHODOLOGY

First, of all the classes in the available dataset, the most analogous based on its similarities in dimensions to the Rotterdam and Johan de Witt was selected. Then the analogous ratio or multiplier defined for each cost element e will be:

$$R_e = A_e / P_e^1 \ , \tag{15}$$

where A_e is the historical average analogous system cost corresponding to the CAIG cost element e being estimated (the dependent variable), and P_e^1 is the value of the analogous ship parameter on which the analogy will be made for the CAIG cost element e being estimated.

The estimated cost for the cost element e is:

$$Y_e = R_e \times P_e^0 \ , \tag{16}$$

where P_e^0 is the value of the estimated ship parameter on which the analogy will be made for the CAIG cost element e being estimated.

Of the five classes in the dataset, the LSD-49 Class was the most analogous based on its similarities in dimensions to the L-801 but is slightly larger than L-800.

Table 11: Ship parameters

Ship Name	Rotterdam	Johan de Witt	Harpers Ferry
Nation	Netherlands	Netherlands	United States
Number	L800	L801	LSD 49
Type	LPD	LPD	Landing Ship Dock
Dimensions			
Length(m)	162.2	176.35	185.9
Beam(m)	25	25	25.6
Draught(m)	5.9	5.9	6.3
Displacement(tonnes)			
Light	?	?	11604
Full Load	12750	16680	16601
Crew Complement			
Officers	13	17	30
Crew	100	129	309

Additionally, the LSD-49CL is the newest U.S. amphibious ships among the VAMOSC dataset, and it has a similar power train (Diesel Electric) to the L-800 and L-801. The class consists of the following hulls:

$$\textbf{LSD} - \textbf{49} \qquad \textbf{LSD} - \textbf{50} \qquad \textbf{LSD} - \textbf{51} \qquad \textbf{LSD} - \textbf{52} \ .$$

With the exception of CAIG 1.0 elements, the methodology for developing the analogous cost estimate was based on each Dutch LPD's weight relative to the LSD-49CL. For CAIG elements 2.0 – 5.0, the equation takes the form:

$$Y = A_0 \times (FLD_0/FLD_1) \ , \tag{17}$$

where Y is the CAIG element being estimated (the dependent variable), A_0 is the historical average LSD-49 class cost in CY09$ corresponding to the CAIG element being estimated, FLD_0 is the L-800 or L-801 full load displacement (tonnes), and, FLD_1 is the LSD-49CL average full load displacement (tonnes).

2-5.1 CAIG 1.0 (Unit Manpower)

The L-800 and L-801 do not have similar manning requirements. The recommendation for estimating CAIG 1.0 is to multiply the estimated number of billets with the expected personnel rates. Personnel rates were obtained by averaging the annual cost per billet for officers (O-5 to WO-2) and for enlisted (E-9 to E-1) into a composite

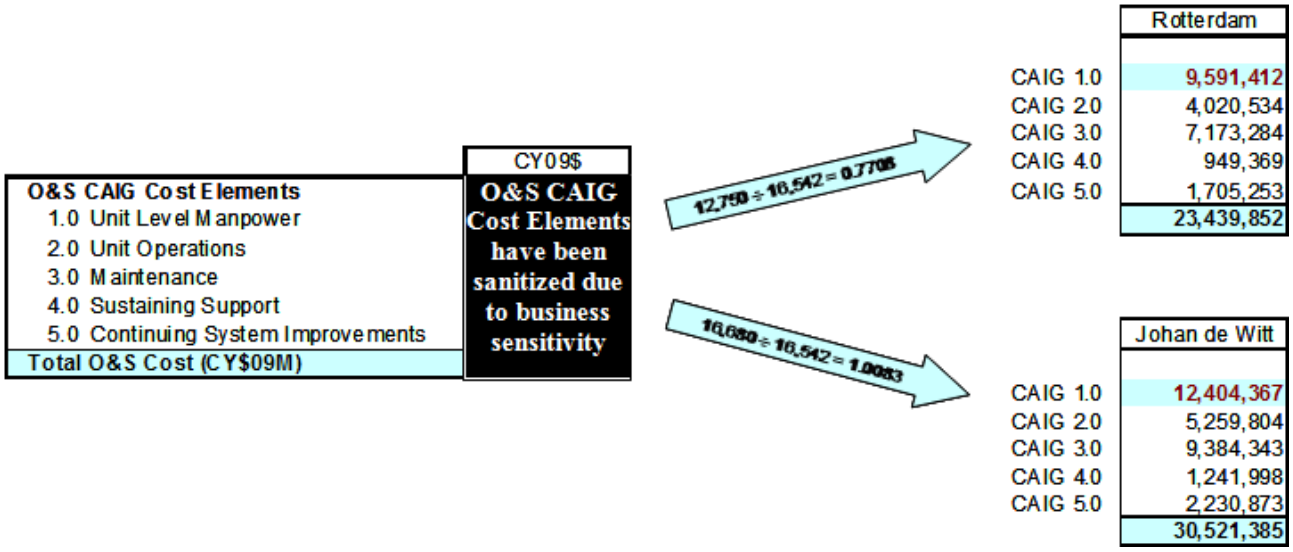

Figure 16: VAMOSC O&S cost estimate results for HMS Rotterdam and Johan de Witt

officer rate and an enlisted composite rate. These two numbers were then multiplied by the number of officer billets and enlisted billets per ship, as a means of estimating the annual unit manpower costs per ship.

Due to the significantly smaller number of billets of the RNLN ships, there will be a significant difference in CAIG 1.0 between USN and RNLN ships. The method presented in this section was designed to capture that difference as it includes the number of billets per ship, and the only assumption is that the RNLN experiences similar personnel costs.

Appendix B2-3: COST BREAKDOWN STRUCTURE FOR THE GCBS-CAIG MODEL

- I:\FMV\SAFEHD\Uppgifter_Logmodeller\1 Metodstöd\SAS 076 medverkan\Arbetsläge\GCBS_ver5.cci
  - GCBS
    - O&S GCBS-CAIG, Operational and Support Costs
      - 1, Operation
        - 7.1.1, Personnel costs
        - 7.1.2, Petroleum. Oil and Lubricants
          - 7.1.2.1, Cost of fuel
          - 7.1.2.2, Cost of oil consumption
          - 7.1.2.3, Cost of lubricants
          - 7.1.2.4, Yearly costs for POL, Ship
          - 7.1.2.5, Average POL costs due to maintenance of helicopter per year
        - 7.1.3, Munitions' Costs
          - 7.1.3.1, Costs of munitions and countermeasures consumption
        - 7.1.4, Cost of other consumables (food, water, soft drinks, etc)
          - 7.1.4.1, Average cost for food per year
          - 7.1.4.2, Average yearly cost for water consumption
          - 7.1.4.3, Average yearly cost for electricity consumption
          - 7.1.4.4, Average yearly cost of "other operational material"
      - 2, Supporting operations
        - 7.2.1, Costs of updating operating documentation.
        - 7.2.2, Costs of use infrastructure for operating the system
        - 7.2.3, Costs updating computer software/hardware for information systems.
        - 7.2.4, Cost of embedded softwares
      - 3, Maintenance
        - 7.3.1, Cost of Preventive Maintenance
          - 7.3.1.1, Annual man hour costs for major preventive maintenance action on main system
          - 7.3.1.2, Materiel costs for major preventive maintenance action on main system
        - 7.3.2, Cost of Corrective Maintenance
          - 7.3.2.1, Average CM costs due to unit replacement actions
          - 7.3.2.2, Average CM costs due to unit repair actions
          - 7.3.2.3, Average yearly CM cost , both material and man power
        - 7.3.3, Costs related with other operating systems
          - 7.3.3.1, Average man-hour cost for maintenance of helicopters (maintenance staff)
          - 7.3.3.2, Average materiel costs due to maintenance of helicopter per year
        - 7.3.6, Cost of yearly replenishment of spares
        - 7.3.7, Costs for contract logistic support
      - 4, Sustatining Support
        - 7.4.1, Costs of periodic training operating personnel
        - 7.4.2, Costs of periodic training maintenance personnel
        - 7.4.3, Cost of test and support equipment and tools
        - 7.4.4, Cost for updating maintenance documentation
        - 7.4.5, Materiel costs for handling of Government Owned Stores
        - 7.4.6, MHC for handling of Government Owned Stores
      - 5, Restoration
        - 7.5.1, Cost of recommended and mandatory modifications of the system
      - 6, Indirect Support
        - 7.6.1, Man hour costs generated by Navy Command (Headquarters, Personnel & Operations)
        - 7.6.2, Materiel costs generated by Navy Command (Headquarters, Personnel & Operations)
        - 7.6.3, General Training and Education
  - Default View

Figure 17: Cost Breakdown Structure for the GCBS-CAIG model

Appendix B2-4: COST BREAKDOWN STRUCTURE FOR THE CAIG MODEL

- I:\FMV\SAFEHD\Uppgifter_Logmodeller\1 Metodstöd\SAS 076 medverkan\Systecon\Leverans\CAIG model - no values.cci
  - CES
    - OSD CAIG O&S, Systems Operating and support cost
      - 1.0 UNIT-LEVEL MANPOWER, Unit-level manpower costs
        - 1.1 OPERATIONS MANPOWER, Cost of operations manpower
        - 1.2 UNIT-LEVEL MAINTENANCE MANPOWER, Cost of unit-level maintenance manpower
        - 1.3 OTHER UNIT-LEVEL MANPOWER, Cost of other unit-level manpower
      - 2.0 UNIT OPERATIONS, Unit operations costs
        - 2.1 OPERATING MATERIAL, Cost of operating material
          - 2.1.1 ENERGY, Cost of energy (POL)
          - 2.1.2 TRAINING MUNITIONS & EXP STORES, Cost of training munitions and expendable stores
          - 2.1.3 OTHER OPERATIONAL MATERIAL, Cost of other operational material
        - 2.2 SUPPORT SERVICES, Cost of support services
        - 2.3 TEMPORARY DUTY, Cost of temporary duty
      - 3.0 MAINTENANCE, Maintenance costs
        - 3.1 ORG MAINTENANCE AND SUPPORT, Cost of org maintenance
          - 3.1.1 ORG LEVEL CONSUMABLES, Cost of org level consumables
          - 3.1.2 ORG LEVEL REPAIR PARTS, Cost of org level repair parts (DU)
          - 3.1.3 ORG LEVEL DLR:S, Cost of org depot level reparables (LRU)
          - 3.1.4 CONTRACT MAINTENANCE SERVICES, Cost of contract maintenance services
          - 3.1.5 OTHER UNIT MAINTENANCE, Cost of other unit maintenance
        - 3.2 INTERMEDIATE MAINT AND SUPPORT, Cost of intermediate maint and support
          - 3.2.1 INTERM LEVEL CONSUMABLES, Cost of intermediate level consumables
          - 3.2.2 INTERM LEVEL REPAIR PARTS, Cost of intermediate level repair parts (DU)
          - 3.2.3 INTERM LEVEL DLR:S, Cost of intermediate depot level reparables (LRU)
          - 3.2.4 GOVERNMENT LABOR, Cost of manpower performing intermediate maintenance
          - 3.2.5 CONTRACTOR MAINTENANCE, Cost of contractor maint at intermediate level
          - 3.2.6 OTHER INTERMEDIATE MAINTENANCE, Cost of other intermediate maintenance
      - 4.0 SUSTAINING SUPPORT, Sustaining support costs
        - 4.1 SYSTEM SPECIFIC TRAINING, Cost of system specific training
          - 4.1.1 SYSTEM SPECIFIC OPERATOR TRAINING, Cost of system specific operator training
          - 4.1.2 SYSTEM SPECIFIC NON-OPERATOR TRAINING, Cost of system specific non-operator training
        - 4.2 SUPPORT EQUIPMENT REPLACEMENT, Cost of support equipment replacement
        - 4.3 OPERATING EQUIPMENT REPLACEMENT, Cost of operating equipment replacement
        - 4.4 SUSTAINING ENGINEERING AND PROGRAM MGMT, Cost of sustaining engineering and program mgmt
        - 4.5 OTHER SUSTAINING SUPPORT, Cost of other sustaining support
      - 5.0 CONTINUING SYSTEM IMPROVEMENTS, Continuing support costs
        - 5.2 SOFTWARE MAINTENANCE AND MODIFICATIONS, Cost of sw maintenance and modifications
          - 5.2.1 CORRECTIONS OF DEFICIENCIES, Cost of deficiencies
          - 5.2.2 SOFTWARE ENHANCEMENTS, Cost of software enhancements
        - 5.1 HARDWARE MODIFICATIONS OR MODERNIZATIONS, Cost of hw modifications or mondernization
      - 6.0 INDIRECT SUPPORT, Indirect support costs
        - 6.2 PERSONNEL SUPPORT, Cost of personnel support
          - 6.2.1 PERSONNEL ADMINISTRATION, Cost of personnel administration
            - 6.2.1.1 PERSONNEL ACQUISITION, Cost of personnel acquisition
            - 6.2.1.2 PERSONNEL NOT AVAILABLE FOR DUTY, Cost of personnel not available for duty
          - 6.2.2 PERSONNEL BENEFITS, Cost of personnel benefits
            - 6.2.2.1 FAMILY HOUSING, Cost of familiy housing
            - 6.2.2.2 DEPENDENT SUPPORT, Cost of dependent support
            - 6.2.2.3 COMMISSARIES AND EXCHANGES, Cost of commissaries and exchanges
          - 6.2.3 MEDICAL SUPPORT, Cost of medical support
        - 6.1 INSTALLATION SUPPORT, Cost of installation support
        - 6.3 GENERAL TRAINING AND EDUCATION, Cost of general training and education
  - Default View
    - All cost atoms

Figure 18: Cost breakdown structure for the CAIG model

Second-Level Cost Estimating Structure

1. Unit-Level Manpower
   - 1.1 Operations
   - 1.2 Unit-Level Maintenance
   - 1. 3 Other Unit-Level
2. Unit Operations
   - 2.1 Operating Material
   - 2.2 Support Services
   - 2.3 Temporary Duty
3. Maintenance
   - 3.1 Organizational Maintenance
   - 3.2 Intermediate Maintenance
   - 3.3 Depot Maintenance
4. Sustaining Support
   - 4.1 System Specific Training
   - 4.2 Support Equipment Replacement
   - 4.3 Sustaining Engineering and Program Management
   - 4.4 Other Sustaining Support
5. Continuing System Improvements
   - 5.1 Hardware Modifications or Modernization
   - 5.2 Software Maintenance and Modifications
6. Indirect Support
   - 6.1 Installation Support
   - 6.2 Personnel Support
     - 6.2.1 Personnel Administration (Personnel Acquisition , Individuals Overhead Accounts)
     - 6.2.2 Personnel Benefits (Family Housing, Commissaries, Child & Family Support, DoD Schools)
     - 6.2.3 Medical Support
   - 6.3 General Training and Education
     - 6.3.1 Basic & Initial Skill Training
     - 6.3.2 Educational Activities

Figure 19: Second-level cost estimating structure

Source: Office of the Secretary of Defense Cost Analysis Improvement Group (CAIG) [8].

Appendix B2-5: TREE REPORT TABLE FOR GCBS-CAIG MODEL

Table 12: Tree Report Table for GCBS-CAIG Model (Cont'd on next page)

Title/Index	Description
1	Operation
7.1.1	Personnel costs
7.1.1.1	Costs of operating personnel
7.1.1.2	Average personnel costs for operation of helicopters
7.1.2	Petroleum. Oil and Lubricants
7.1.2.1	Cost of fuel
7.1.2.2	Cost of oil consumption
7.1.2.3	Cost of lubricants
7.1.2.4	Yearly costs for POL, Ship
7.1.2.5	Average POL costs due to maintenance of helicopter per year
7.1.3	Munitions' Costs
7.1.3.1	Costs of munitions and countermeasures consumption
7.1.4	Cost of other consumables (food, water, soft drinks, etc)
7.1.4.1	Average cost for food per year
7.1.4.2	Average yearly cost for water consumption
7.1.4.3	Average yearly cost for electricity consumption
7.1.4.4	Average yearly cost of "other operational material"
2	Supporting operations
7.2.1	Costs of updating operating documentation.
7.2.2	Costs of use infrastructure for operating the system
7.2.3	Costs updating computer software/hardware for information systems.
7.2.4	Cost of embedded software
3	Maintenance
7.3.1	Cost of Preventive Maintenance
7.3.1.1	Annual man hour costs for major preventive maintenance action on main system
7.3.1.2	Materiel costs for major preventive maintenance action on main system
7.3.2	Cost of Corrective Maintenance
7.3.2.3	Average yearly CM cost , both material and man power
7.3.2.1	Average CM costs due to unit replacement actions
7.3.2.2	Average CM costs due to unit repair actions
7.3.3	Costs related with other operating systems
7.3.3.1	Average man-hour cost for maintenance of helicopters (maintenance staff)
7.3.3.2	Average materiel costs due to maintenance of helicopter per year
7.3.6	Cost of yearly replenishment of spares
7.3.7	Costs for contract logistic support

Table 13: Tree Report Table for GCBS-CAIG Model (Cont'd)

Title/Index	Description
4	Sustaining Support
7.4.1	Costs of periodic training operating personnel
7.4.2	Costs of periodic training maintenance personnel
7.4.3	Cost of test and support equipment and tools
7.4.5	Materiel costs for handling of Government Owned Stores
7.4.6	MHC for handling of Government Owned Stores
7.4.4	Cost for updating maintenance documentation
5	Restoration
7.5.1	Cost of recommended and mandatory modifications of the system
6	Indirect Support
7.6.1	Man hour costs generated by Navy Command (Headquarters, Personnel & Operations)
7.6.2	Materiel costs generated by Navy Command (Headquarters, Personnel & Operations)
7.6.3	General Training and Education