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Alternate Marine System Materials Study – Phase II

Engineering Cost Analysis Tools

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Contract Number: W7707-063506-001-HAL

Contract Scientific Authority: Dr. Yueping Wang, 902-427-3035

Defence R&D Canada – Atlantic

Contract Report

DRDC Atlantic CR 2008-106

June 2008

Canada

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Abstract

A literature review was conducted on commonly used engineering cost analysis tools to identify one that is suitable for conducting through-life cost analysis studies on marine system materials. The report will comment on how cost analysis can and has been used in performance based procurement specifications and make recommendations on the most appropriate method for developing performance based specifications for marine systems which incorporate through life cost models.

This work required two main streams of investigation; the first to identify the cost model best suited for comparing life cycle costs of marine systems constructed from different materials, and the second to review Performance Based Specifications and Contracting methodologies and recommend how the life cycle cost model could be used to support them. No costing tools specific to marine systems were found, however a generic software package was identified and recommended to conduct costing analysis and to build a cost estimating model. A way forward was proposed to develop a cost analysis tool to support marine system material selection.

Résumé

Une analyse documentaire a été menée relativement aux outils utilisés généralement pour analyser les coûts de conception et ce afin de dégager un qui soit utile pour mener des études de coût du cycle de vie visant les matériaux des systèmes marins. Le rapport présentera des commentaires sur la façon dont l’analyse des coûts peut et a été utilisé dans des spécifications d’achats basées sur la performance et formulera des recommandations sur la méthode appropriée pour élaborer des spécifications basées sur la performance pour les systèmes marins, méthode qui inclura des modèles de coût du cycle de vie.

Ce travail exigeait deux volets principaux, le premier visant à déterminer le modèle de coût qui convient le mieux pour comparer les coûts du cycle de vie de systèmes marins construits avec différents matériaux et le deuxième, servant à examiner les spécifications basées sur la performance et les méthodes de réalisation, d’une part, et à recommander la manière d’utiliser le modèle de coût du cycle de vie pour les appuyer, d’autre part. Aucun outil d’établissement de coût spécifique des systèmes marins n’a été trouvé. Toutefois, un progiciel générique a été cerné et recommandé pour faire une analyse de coût et construire un modèle d’estimation de coût. Un plan d’avenir a été proposé pour mettre au point un outil d’analyse de coût en vue d’appuyer la sélection des matériaux pour les systèmes marins.

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Executive summary

Alternate Marine System Materials Study – Phase II *Engineering Cost Analysis Tools*

Richard Atwood, Mladen Pejcic and L. N. Pussegoda, 2008, DRDC Atlantic CR 2008-106; Defence R&D Canada – Atlantic

Introduction or background: The report provides the results of a literature review of engineering cost analysis tools with a potential application to marine systems and how those models may be used to support performance based specifications. Performance based specifications are design requirements that describe the capability to be provided by a system, rather than describe how the system is to be constructed. Life cycle cost models are used to either select between options or to reward a contractor for providing superior product or services.

Results: The literature review indicates that there are no existing life cycle costing models capable of comparing the cost performance of marine systems constructed of various materials. Most costing tools predict the construction and acquisition cost of ships without considering the through life costs. These tools are also designed to predict the cost of ship construction in a specific market, generally the US. The review has also identified and recommended one generic software package to conduct costing analysis and to build a cost estimating model on marine system materials cost analysis.

Significance: Although no available tools were identified, a software package which could be used to construct LCC models for marine systems was identified. This package, Isograph Availability Workbench, provides the data structure, storage and calculating engine capabilities for cost models. Research will be required to identify the formulas linking performance and cost to material characteristics. Although research is required to populate the software with cost estimating relationships, it allows models to be created that link performance to Canadian cost structures, something which cannot be guaranteed with off the shelf models.

Future plans: The report recommends that DND:

1. Adopt a standard commercial software package capable of linking reliability and life cycle cost calculations. The Isograph Availability Workbench package is the recommended solution.
2. Conduct research to establish a reliability baseline for existing ships' systems and equipment.
3. Conduct research to establish a cost baseline for the existing ships' systems and equipment.
4. Conduct research into how material parameters affect the LCC through changes in reliability and maintainability.
5. Work with industry to develop an understanding of how Canadian shipyards price their work.
6. Develop cost estimating relationships between the reliability and the cost of the systems.
7. Create formulas linking material characteristics and system performance.
8. Develop performance based specifications for ships' systems and equipment using LCC as a selection criterion or to provide incentives for superior performance of contractors.

Sommaire

Étude de matériaux de remplacement pour les systèmes marins – *Phase II Outils d'analyse du coût de conception*

Richard Atwood; Mladen Pejcic; L. N. Pussegoda, 2008, DRDC Atlantic CR 2008-106; R & D pour la défense Canada – Atlantic

Introduction ou contexte : Le rapport fournit les résultats d'une analyse documentaire d'outils d'analyse du coût de conception avec application potentielle aux systèmes marins et expose comment ces modèles d'outils peuvent être utilisés pour appuyer les spécifications basées sur la performance. Les spécifications basées sur la performance sont des exigences nominales qui décrivent la capacité à fournir par le système plutôt que la façon dont le système doit être construit. Le modèles de coût du cycle de vie servent soit à choisir parmi les options ou à récompenser un entrepreneur pour prestation supérieure de produits ou de services.

Résultats : L'analyse documentaire montre qu'il n'y a pas de modèles d'établissement du coût du cycle de vie capables de comparer la tenue des coûts des systèmes marins construits avec des matériaux variés. La plupart des outils d'établissement de coût prévoient le coût de construction et d'acquisition des navires sans tenir compte des coûts du cycle de vie. Ces outils sont aussi conçus pour prévoir le coût de construction des navires dans un marché particulier, généralement étatsunien. L'analyse a aussi dégagé et recommandé un progiciel pour effectuer des analyses d'établissement de coût et construire un modèle d'établissement de coût concernant l'analyse de coût des matériaux des systèmes marins.

Portée : Bien qu'aucun outil disponible n'ait été trouvé, un progiciel a été découvert, qui pourrait servir à la construction de modèles de coûts du cycle de vie des systèmes marins. Ce progiciel, Isograph Availability Workbench, fournit les capacités requises pour les modèles de coût quant à la structure, le stockage et les moteurs de calcul des données. Il faudra mener des recherches pour déterminer les formules reliant la performance et le coût aux caractéristiques des matériaux. Malgré qu'il soit nécessaire d'effectuer des recherches pour charger le logiciel avec des relations estimatives de coût, celui-ci permet de construire des modèles qui relient la performance aux structures de coûts canadiennes, ce que les modèles commerciaux ne peuvent pas garantir.

Futures recherches : Le rapport recommande au MDN de :

1. adopter un progiciel commercial standard capable de relier la fiabilité aux calculs du coût du cycle de vie. Le progiciel Isograph Availability Workbench est la solution recommandée.
2. effectuer des recherches pour établir une fiabilité de référence pour pour les systèmes et les équipements existants des navires.
3. effectuer des recherches pour établir des coûts de référence pour les systèmes et les équipements existants des navires.
4. effectuer des recherches pour déterminer comment les paramètres des matériaux influent sur le CCV au gré des changements de la fiabilité et de la maintenabilité.
5. travailler avec l'industrie pour mieux comprendre la façon dont les chantiers navals canadiens établissent le prix de leurs travaux.
6. formuler des relations d'estimations de coût entre la fiabilité et le coût des systèmes.

7. créer des formules reliant les caractéristiques des matériaux à la performance des systèmes.
8. établir, pour les systèmes et les équipements des navires, des spécifications basées sur la performance en se servant du CCV comme critère de sélection ou pour inciter les entrepreneurs à fournir un rendement supérieur.

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1 Introduction

The purpose of this investigation was to conduct a literature review on commonly used engineering cost analysis tools and identify one that is suitable for conducting through-life cost analysis studies on marine system materials. The report will comment on how cost analysis can and has been used in performance based procurement specifications and make recommendations on the most appropriate method for developing performance based specifications which incorporate through life cost models.

This work required two main streams of investigation; the first to identify the cost model best suited for comparing life cycle costs of marine systems constructed from different materials, and the second to review Performance Based Specifications and Contracting methodologies and recommend how the life cycle cost model could be used to support them.

Due to the extensive number of documents reviewed for this report, not all are referenced in the text. The bibliography lists these sources which provided background and additional information to support that provided in the references.

2 Life Cycle Cost

2.1 Definitions

Life Cycle Costs (LCC) are the total costs for a system from conception through use to disposal.

Life Cycle Cost Analysis (LCCA) is an economic analysis which systematically investigates alternative methods of satisfying an objective by identifying and comparing the costs and benefits of the alternatives. This allows decisions to be made based on evidence and recorded data.

2.2 Description

As noted above in the definitions the LCC is a calculated figure that represents the total cost of a system over its entire life cycle. Since the LCC is usually calculated at the start of a system's life, most of the costs are not known but must be estimated. How these costs are estimated is a subject of this report.

The LCC for a naval ship is typically broken down into recurring and non-recurring costs. Non-recurring costs are those costs dealing with the design and construction of the ship, as well as the initial fleet introduction package. The recurring costs include the operating and support costs as well as the costs of managing the system over its life. [1]

2.3 LCC Elements

The life cycle costs are broken into four elements: research and development (R&D), investment, operations and support (O&S) and disposal at the end of system life.

2.3.1 Research and Development Cost

The costs of all R&D phases—concept and technology development, system development and demonstration—are included in this cost element. There are many types of R&D costs: prototypes, engineering development, equipment, test hardware, contractor system test and evaluation, and government support to the test program. Engineering costs for environmental safety, supportability, reliability, and maintainability efforts are also included, as are support equipment, training, and data supporting R&D efforts.

2.3.2 Investment Cost

The investment cost for production, and deployment includes the cost of procuring the prime mission equipment and its support. This includes training, data, initial spares, war reserve spares, pre-planned product improvement (P3I) program items, and facility construction. Facilities cost is the cost of acquisition, construction, or modification of facilities necessary to accommodate an alternative. The cost of all related procurement, such as modifications to existing equipment, is also included.

2.3.3 Operating and Support Cost

O&S costs are those program costs necessary to operate, maintain, and support system capability. This cost element includes all direct and indirect elements of a program and encompasses costs for personnel, consumable and repairable materiel, all levels of maintenance, facilities, and sustaining investment.

2.3.4 Disposal Cost

Disposal cost is the cost of getting rid of excess or surplus property or materiel from the inventory. It may include costs of detoxification, redistribution, transfer, donation, sales, salvage, or destruction. It may also reflect the costs of hazardous waste disposition (including long-term storage) and environmental cleanup. Disposal costs may occur during any phase of the acquisition cycle.

2.4 Cost Types

Each of these elements is made up of different types of costs; fixed, variable, semi fixed, direct, indirect, and sunk. The behaviour of these cost types may differ based on the level of system use. Therefore system use must be considered when calculating the LCC. The variability also leads to sensitivity analysis of the LCC in order to determine what system use patterns have on the total cost.

2.4.1 Fixed Cost

Fixed cost remains the same even if output varies, e.g. rent on a building will not change regardless whether any product is generated.

2.4.2 Variable Cost

Variable cost varies with changes in output, e.g. the cost of steel as more vessels are built.

2.4.3 Semi-fixed Cost

Semi-fixed cost has both fixed and variable behaviour, e.g. the electricity for a shipyard will have a minimal level to sustain lights and heat but will increase as more tools are used to increase production.

2.4.4 Direct Cost

Direct costs can be directly associated with a specific item, e.g. the costs of labour to weld steel for a specific ship.

2.4.5 Indirect Cost

Indirect costs are associated with more than one item and are often difficult to break out against a specific product, e.g. the cost of human resources or pay office personnel for a shipyard. These are generally spread across all personnel and are represented by overhead on labour rates.

2.4.6 Sunk Cost

Sunk costs are unrecoverable past expenditures. These should not normally be taken into account when determining whether to continue a project or abandon it, because they cannot be recovered either way, e.g. money expended on research for a new ship type should not be considered when trying to decide whether or not to build the ship if an alternative design is more cost effective.

2.5 Cost Estimating Methodologies

There are three structured cost estimating methodologies available to the analyst. These include the engineering build-up (or bottom-up technique), the parametric estimating technique, and the analogy technique. Informal approaches like expert opinion can also be used when the formal techniques are not practical. [2, 3, 4, 5]

2.5.1 Engineering Cost Method

The Engineering Cost Method builds up costs at a detailed task level. Costs can be estimated for basic tasks like engineering design, tooling, fabrication of parts, manufacturing engineering, and quality control. The cost of materials may also be estimated. Although this is considered to be the most accurate method, the disadvantages of this approach are its time-consuming nature and the need for detailed, actual cost data.

It is used where there is detailed and accurate capital and operational cost data for the asset under study. It involves the direct estimation of a particular cost element by examining the asset component-by-component.

2.5.2 Parametric Cost Method

The Parametric Cost Method is normally appropriate at the early stages of a program when there is limited program and technical definition. It involves collecting relevant historical data at an aggregated level of detail and relating it to the area to be estimated through generally simple mathematical equations—known as cost estimating relationships (CER). CER relate cost to one or more variables (e.g., volume, weight, or power). Usually, less detail is required for this approach than for other methods. Since CER are based on actual program cost history, they reflect the impacts of system growth, schedule changes, and engineering changes. When costs are captured at a very high level, however, visibility into more detailed levels is lost.

The use of a factor or ratio relating the cost of one entity to another is also considered a form of parametric estimating (for example, training costs might be estimated as 20% of production costs). Factors and ratios allow the estimator to capture a large part of an estimate with limited descriptions of both the historical database used to develop the factor and the program to be estimated. This method is often used for training, data, peculiar support equipment, and systems engineering and program management.

Compared to the Engineering Cost Method, the Parametric Cost Method is more subjective; making it faster and cheaper, and allowing it to be used earlier in development cycle. It is employed where actual or historical detailed asset component data is limited to known parameters. This available data from existing cost analyses is used to develop a mathematical regression or progression formula that can be solved for the cost estimate required

2.5.3 Analogous Cost Method

The Analogous Cost Method uses actual costs from similar programs and adjusts for the new program's complexity and technical or physical differences to derive the estimate. This method is normally used early in a program cycle when there is insufficient actual cost data to use as a basis for a detailed approach.

It is based on the premise that analogies “always” exist; however gathering cost data from previous projects can be a problem. Engineering assessments are necessary to ensure the best analogy has been selected and proper adjustments are made. These engineering judgments are the mainstay of the approach and can also be a limiting factor.

This method provides the same level of detail as the Engineering Cost Method but draws on historical data from components of other assets having analogous size, technology, use patterns and operational characteristics. The data is used in a variety of means from simple analogy to complex parametric models. In both speed and accuracy it lies between the Engineering and Parametric methods.

3 Life Cycle Cost Analysis

3.1 Description

Life Cycle Cost Analysis is used to compare alternatives and select the most cost effective solution. The alternatives may differ in materials, technologies or processes. The LCCA estimates the LCC of each alternative which are then compared to the effectiveness of each alternative to identify the solution that represents the best value. The results of the analysis can be used for making decision about purchasing a product, optimizing design, scheduling maintenance or in planning upgrades. [6]

LCCA can include many kinds of analysis, e.g., reliability-availability-maintainability analysis, economic analysis, risk analysis, and so on. It provides a more cost effective basis for comparing and selecting material options than the traditional method of judgments based on comparing acquisition costs alone. The LCCA does not include sunk costs (money already spent) that do not affect the decision. Sunk costs may be of interest to decision makers, however, and should be identified separately.

3.2 Uses of LCCA

The primary uses of LCCA are:

- Assess a project's budget and economic viability
- Select among competing contractors
- Compare alternative strategies
- Compare logistics concepts
- Evaluate and compare design alternatives
- Cost monitoring of active programmes
- Long term financial planning
- Identification of O&S cost drivers
- Identification of cost effective improvements
- Decisions about replacement of ageing equipment

All of the above uses reduce to comparison of alternatives to select the most cost effective. This holds true whether the choice is between proceeding with a project or foregoing the capability, supporting the system with contractors or in-house employees, choosing between competing technologies or selecting which upgrades will be done to systems in use.

The Australian Stainless Steel Development Agency describes the use of LCCA in support of material selection in the following excerpt from their web site. "*In circumstances where stainless steel is being considered or introduced into new fields of applications, comparisons are often made with materials of a lower initial cost such as coated carbon steel or plastics. Here the reasoning should progress well beyond the simple initial cost comparison and take account of the* *long term cost assessments associated with maintenance replacement and operating stoppages."* [7]

3.3 LCCA Methodology

LCCA allows alternatives to be compared to a baseline system using relative estimated costs. The LCCA methodology is initially outlined in the study plan and updated as the analysis proceeds. While the LCC analysis of all alternatives must be based on the same work breakdown, the level of alternative description available to the cost analyst—and thus the fidelity of the estimate—will vary depending on the detail of system definition and its technological maturity.

3.4 Ground Rules and Assumptions

As part of the cost analysis, the plan should identify general rules and assumptions underlying the analysis as well as those specific to particular cost elements or life cycle phases (e.g., an assumption that no additional personnel are required to employ any alternative). At a minimum, a preliminary list of ground rules and assumptions should address the following:

- Cost basis of the estimate (specified Budget Year $)
- Specific inflation indices used
- Definition of sunk costs (date separating costs expended or contractually committed from those to be included in the LCC estimate)
- Schedule issues, including major milestones and significant events (operational dates, production schedules and quantities, etc.)
- Basing, logistics, and maintenance concepts
- Business intelligence support requirements
- Environmental cost considerations
- Personnel requirements and constraints
- Affordability constraints

3.5 Work Breakdown Structure

The LCC methodology is generally based on a Work Breakdown Structure (WBS). A WBS is a product-oriented (as opposed to functionally-oriented) tree composed of hardware, software, services, data and facilities that define the product to be developed and produced. Once the WBS has been created, costs are collected for each WBS element and the LCC estimates developed for each alternative.

Estimates can be done by cost element, and as the WBS develops, some elements may be best estimated using different approaches. Some could be estimated using expert opinion, some could be analogy, some could be parametric, some could be detailed, and some could be items where costs are known and estimation is not necessary.

3.6 Cost Risk and Uncertainty

Because a cost estimate is a prediction of the future, there is a significant probability that actual costs will differ from the costs developed in the estimate; risk and uncertainty analyses address this concern. Most cost estimates are a composite of both risk (known-unknowns) and uncertainty (unknown-unknowns). However, "risk" is often used generically to address both types of unknowns.

Risk stems from three primary sources: configuration changes, technical and schedule problems, and cost estimating error. Technical and schedule risk and cost estimating error can be accounted for in the risk analysis, but major configuration changes may require a new estimate rather than trying to compensate by applying a risk approach.

Several approaches are available to treat risk in an estimate; they range from very subjective to those with detailed statistics. Whatever risk methodology is employed, it should be described in the study plan. The results of the risk analysis should be included in the final cost estimates as a cost range rather than as a discrete point estimate.

3.7 Cost Documentation

A complete set of cost documentation is an essential part of the cost analysis. Without an explanation of the data sources and methodology used for each element of the estimates, the costs cannot be replicated and lack credibility.

Cost models incorporating the three methodologies outlined in Section 2.5 are available to help the cost analyst derive the LCC estimates. Wherever any of these models is used, the models and data should be identified and described in the study plan.

3.8 Preferred Methodology

As noted in section 3.6, cost estimation is a prediction of the future with significant uncertainties. These uncertainties must be addressed and accounted for in the LCCA. This requires the ability to calculate costs based on a distribution of possible material performances. This has generally not been an area of research for marine cost models; however the management of road and transportation infrastructure has many features that are comparable to a naval vessel. The use of the assets is variable with changes in use based on many different factors such as season, weather and the economic climate. The assets can use various materials with differing performance and for the most part they are not revenue generating and therefore pay-back periods or profit cannot be used as a basis of comparison. [8, 9, 10]

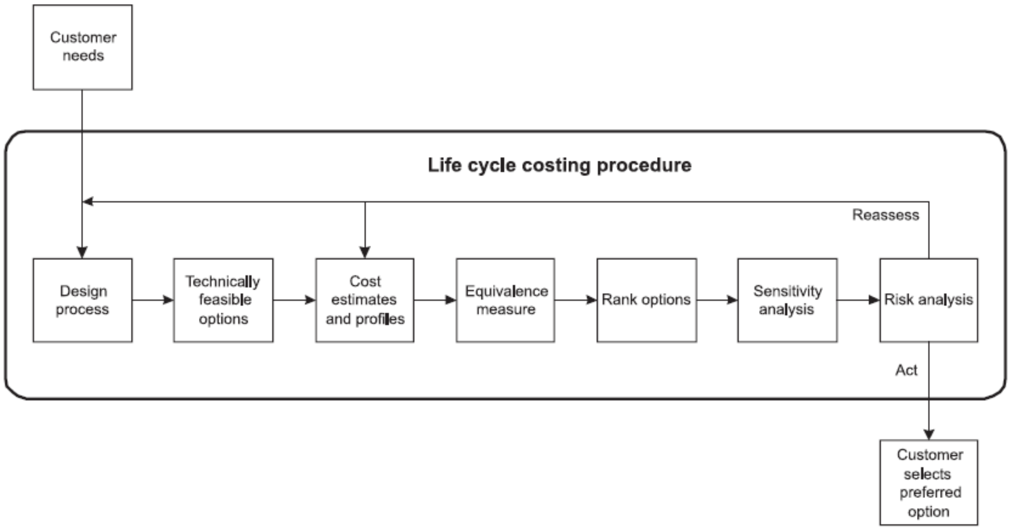

Figure 1 State-of-the-art life cycle costing method

Figure 1 from Christensen et al illustrates the state of the art in producing cost estimates for road construction. The design process produces the engineering data and technically feasible options are selected. The LCC of the various options are calculated and reduced to a common base line (e.g. net present value). Sensitivity analysis is conducted by calculating the LCC across a range for each of the variables. The options are then subject to a risk analysis which attempts to identify the possible events that will cause the LCCA to be significantly inaccurate. The final selection is made with knowledge of the costs, benefits and risks for each option.

This methodology requires a model that can calculate an LCC with distributed variables using Monte Carlo techniques to produce a distributed series of cost estimates.

4 Cost Models

4.1 Definition

The NATO Task Group on Life Cycle Costing (SAS-054) defines a cost model as:

"A Cost Model: is a set of mathematical and/or statistical relationships arranged in a systematic sequence to formulate a cost methodology in which outputs, namely cost estimates, are derived from inputs. These inputs comprise a series of equations, ground rules, assumptions, relationships, constants, and variables, which describe and define the situation or condition being studied. Cost models can vary from a simple one- formula model to an extremely complex model that involves hundreds or even thousands of calculations. A cost model is therefore an abstraction of reality, which can be the whole or part of a life cycle cost." [11]

4.2 Types of Models

The NATO Task Group (SAS-054) work has identified four types of cost models.

4.2.1 Estimation Models

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

Estimation models are all types of models dealing directly with the estimation and calculation of cost. The estimation of cost can, in turn, be supported by some other type of method, but in the case of the estimation model the main objective is to come to some sort of conclusion as to the level of cost for a system or sub-system.

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

4.2.2 Decision Support Models

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

4.2.3 Simulation Models

This category contains all the models based on simulations which step through time and perform calculations for that point in time which will change the state of the system in some way. The end state at one point in time is the start state for the next. This includes models using system dynamics and discrete event simulation as well as Monte Carlo techniques.

4.2.4 Optimisation Models

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

4.3 Purpose of Model

When selecting a model the analyst must consider its purpose and how it is to be used. The understood purpose for this work is to identify a cost model that will support the selection of alternate materials for the construction of sea water containing systems and that could be used to identify construction and maintenance costs to support performance based contracting for the in-service support of ships or facilities using the materials.

4.4 Cost Models and Data

LCCA is a tool designed to assist selection between options. However the models, especially for ship construction and maintenance are often complex and based on great levels of detail that may not reflect the actual level of knowledge. This could explain the reluctance to share cost models or place them on the open market.

"Cost models by their nature involve significant proprietary and sensitive data. Even within the Navy, organizations like NAVSEA 017 have resisted providing their models to the engineers. A practical and accepted cost model is required. This model must be sensitive to important producibility characteristics, but with a level of detail appropriate for concept exploration" [12]

Any model should satisfy the following ten rules.

1. The model should be useful to the acquisition management process as well as the review process
2. The model should be sensitive to management control factors, design changes and varied operational and logistics support scenarios
3. All significant cost drivers that are relevance to the issue under consideration should be incorporated into the model as clearly as possible
4. The development, alteration, updating and operation of the model should be as inexpensive as possible
5. The model should be sensitive to design parameters or acquisition characteristics that affect the cost of investment alternatives
6. Valid relevant input should be readily available

7. The model should be flexible and capable of accommodating the growing complexity of an acquisition; and should allow for adjustments of inflation, discounting and learning curve factors
8. The model should be separated into interactive modules for easier modification
9. Inputs and outputs should be expressed in terms that are familiar to users and that can be verified to ensure credibility
10. Outputs should be reliable i.e. results should be repeatable.

4.5 Available Software

Research by the NATO Task Group on Life Cycle Costing (SAS-054) indicates that a wide variety of cost estimating tools are in use within the militaries of the NATO countries. A limited survey of 11 participating nations identified 62 different software tools. This does not include the US which could only state “hundreds” were used in the different services and departments at various stages of projects. Table 1 lists some of the models used in the LCC processes of the various nations surveyed. [13]

Many of the commercial tools are not actually LCC estimating tools but are used to predict reliability or material consumptions and thus their output is used to build up expenditures over the life of the system. Other “in-house” tools predict costs based on levels of activity. These tools are not available for review and are not considered further in this report.

Table 1 Software Used in Cost Modelling

Software	Description
@Risk	Risk Analysis Tool
ACES	Advanced Cost Estimating Systems
A-Credit	Automated Cost Resource Evaluation And Data Integration Tool
ALCAM	Aircraft Life Cycle Cost Analysis Model
ARENA	Standard Edition 8.0 (Including Optquest Feature)
ARM	Active Risk Manager
Arrisca	Risk Management And Analysis Tool (Cost & Schedule)
ASTOR	Air Force Simulation Of Tactics And Operational Resources
BAM	Budget Allocation Model
Bestfit	Distribution Fitting Software
BESTSEL	Prioritization Tool Based On Optimization
CALS – ILS	Continuous Acquisition Lifetime Support - Integrated Logistic Support Module
CARA	Fault Tree Modelling
CATLOC	System Model For Life Cycle Cost (LCC) Calculation And Analysis
CGT	Compensated Gross Tonnage (Ships)
COCOMO	Software Estimating Tool

Software	Description
COCOMO II	Software Estimating Tool
COST+	Proprietary Software
CostXpert	Software Cost Estimating Tool
Crystal Ball	Risk Analysis Tool
Easy Risk Manager	Risk Management Software
EXCAM	Exercises Cost Effectiveness Analysis Model
Expert Choice	Advanced Decision Support Software
Extend	Simulation Software
Extended Large-Scale LP	Optimisation Software For Excel
Extended What's Best 7.0	Optimisation Software For Excel
FACET	Proprietary Cost Estimating Models
FLYT2	Air Force Model, Availability Of Aircraft And Pilots
FMSCAM	Foreign Military Students Cost Analysis Model
GVCAM	Ground Vehicle Cost Analysis Model
JMP	Statistical Data Presentation
KOSTMOD	Force Structure Cost M LCC Database
LCC Analyzer	Activity Based Costing Model
Lingo 8.0	Optimisation Software
MACE	Multiple Attribute Choice Elucidation (Cost Is Just One Element)
MACRO	Method For Assessing Cost Of Exploiting Research Output)
MELICCA	Cost Collection Tool
Metify	Activity Based Costing/Management (ABC/M)
MOPSOS	Armoured Vehicle Cost Software
NIMROD	Equation Solver
OATS & COO System	Options And Affordability Tools Set & Cost Of Ownership System
OPUS	Modelling And Spares Optimisation
Orbit RCM	Maintenance Planning Software
P3M	Pre-Payment For Projects Model Activity Based Costing
PERT Master	Schedule Risk Management And Analysis Tool
Predict Risk Controller	Schedule Risk Management And Analysis Tool
Premium Solver Platform	Optimisation Software For Excel
PRICE	Parametric Review Of Information For Costing And Evaluation
SCOPE	Cost Estimating Tool For Ships
SEER	Parametric Cost Estimating Models
SIMLOX	Discrete Event Monte Carlo Simulation Model
SPRUCE	Ship Platform Risk Based Unit Cost Estimates
SPSS	Data Mining Software

Software	Description
SSCM	Software Support Cost Model
TDRM	Top Down Risk Model
winRAMA	Risk Analysis Software

4.6 Marine/Shipbuilding Models

After a review of LCC models and methodologies it has become apparent that most of the existing marine models are concerned with estimating the construction costs of vessels based on preliminary design information. This is particularly true of the work conducted by the US Navy, which is primarily interested in controlling the costs with series production of ships based on multiple contracts across two or more shipyards. [14, 15, 16, 17]

A almost unique exception to this statement is the book *"Guide To Ship Repair Estimates (In Man-Hours)"* [18] While not a model per se, this book is written as an aid in estimating the cost of repairing a small to medium sized commercial cargo ship or fishing vessel. Since the work is estimated in man-hours, multiplying by the hourly rate allows it to be used in various countries and accounts for monetary fluctuations. The drawback is that being based on commercial vessels it does not account for the greater complexity and equipment density found in most warships.

The end result is that there is no available "off-the-shelf" model for calculating the LCC of a naval vessel and a new model must be built in order to support the use of LCCA in Canadian naval ship design. The development of this model will not require starting from scratch as there are several software packages which provide the calculating engines and database structures for creating LCC models for specific designs.

5 LCC Software Tools

A review of dedicated LCC software has identified 4 commercial packages; Availability Workbench and LCCWare from Isograph Software, Relex LCC from Relex Software and D-LCC, from Advanced Logistics Developments.

Other software was also investigated but was found to be written for the US government processes (AceIT), controlled by consulting companies (SAMO) or were simple programs written by non-software companies (various examples from universities). These were relegated from consideration as the task required the selection of a model that could be used for *"conducting through-life cost comparison study on marine system materials."* The cost analysis tool needs to be flexible and supported by software experts that will allow the researchers to concentrate on creating the model and analysing data rather than getting the software to run properly.

5.1 LCCWare

LCCWare is a life cycle cost analysis package developed by Isograph Software. According to their website, their software packages are used at over 7000 sites worldwide, in any industry where "Reliability, Availability, and Safety are paramount." When used as a standalone package, LCCWare "…allows the user to define the cost elements throughout the system lifetime…" Life cycle costs are represented by what Isograph calls a "cost breakdown structure", which is composed of nodes in a tree structure, analogous to the Windows Explorer file system. In order to determine the value of each node, "cost functions" are used. These cost functions are written in a Visual Basic compatible language, and strongly resemble MS Excel equations. In addition, the user can create global and local variables, which can be either constant or time-dependent. LCCWare also features a sensitivity analysis module, allowing the user to "examine effect of variations in global and local variables." It also features what Isograph calls "part trees," which provides the ability to assign "costs associated with a frequently used piece of equipment to a cost function." Projects generated by LCCWare can also be protected by four levels of user security; administrative, design, modify, or read. Reports produced by LCCWare are able to interface with MS Office products, and the program also has "extensive import and export facilities."

5.2 Availability Workbench

Availability Workbench integrates updated versions of the AvSim+ (Availability Simulation Software) and RCMCost (Reliability Centered Maintenance) products with a new life cycle cost analysis module and a Weibull failure data analysis module. This provides a fully integrated environment for calculating life cycle costs based on system availability predictions. These are in turn based on historical data to develop the reliability data. These costs are added to the maintenance costs calculated from programs developed using RCM logic. The availability figures take into account complex dependencies on spares and other resources which can help calculate the LCC based on a performance specification.

Both of the above packages can be combined with another package, Reliability Workbench, allowing for reliability prediction, failure modes effects and criticality (FMECA) studies, reliability block diagrams, fault trees, event trees, and Markov Analysis to be included in the software.

Both of the above are available from:

Isograph Inc
8001 Irvine Center Drive
Suite 1430
Irvine, CA 92618
Tel: 949 502 5689
Fax: 949 502 5933
sales@isograph.com

5.3 Relex LCC

Relex LCC appears quite similar to Isograph's LCCWare, but has a more intuitive interface. Like LCCWare, Relex LCC uses a "file tree" based cost breakdown structure (CBS), and allows the user to input equations to represent variables, in a format familiar to Excel users. According to Relex's technical highlights, their software supports calculations for cost, net present value (NPV), cost percentages, NPV percentages and sensitivity analysis. It allows the user to implement constant values, such as days of operation, unit price, salaries, transportation, and electricity; values which vary by alternative, such as inspection testing, manufacturing costs, material costs, operating costs, Quality Ananlysis, and salvage value; as well as values which vary over time, such as battery replacement, financing, taxes, and gas prices. After analysis, the software can output total system cost, cost per assembly, percentage costs, sensitivity results, or NPV results. Relex can import/export MS Excel, Access, and Text data, and generate reports in Word, Excel, PDF, RTF, or HTML formats. It also supports several databases, such as MS SQL Server, Oracle, and MS Jet Engine.

Relex also offers their LCC package as part of a software suite, known as Relex Reliability Studio. This suite includes several programs, including Fault Tree/Event Tree, FMEA/FMECA, FRACAS (Failure Reporting, Analysis, and Corrective Action Systems), Human Factors Risk Analysis, Life Cycle Cost, Maintainability Prediction, Markov Analysis, Optimization and Simulation, Reliability Block Diagram, Reliability Prediction, and Weibull failure analysis.

In addition, Relex notes that it also makes available services in:
- Software module training
- Theory training
- Professional consulting services
- Web-based training
- Expert technical support
- Online customer support

The above software is available from:

Relex Software Corporation
540 Pellis Road
Greenburg, PA 15601
Phone: 724-836-8800

Fax: 724-836-8844
http://www.relex.com/index.asp

5.4 D-LCC

Decision by Life Cycle Cost, otherwise known as D-LCC, is a program developed by Advanced Logistics Developments (http://www.aldservice.com/Default.asp). This program is very similar to LCCWare in that it allows the user to create both Cost Breakdown Structures and Part Breakdown Structures. This software performs bottom-up cost analysis and net present cost analysis. A product tree can be incorporated to allow for the calculation of any required cost elements (ALD’s example is “spare parts cost for each Level of Repair”) across all product tree items. D-LCC is able to calculate net present cost, perform cost profile and/or sensitivity analysis, complete cost-effectiveness evaluations and cost item analysis, as well as optimal repair level analysis.

D-LCC provides graphical representations of cost breakdown structures, “spreadsheet-like, easy to modify cost models for each CBS element”, as well as a “powerful expression builder” and global variables. The software is data-compatible with other Reliability, Maintainability and Logistics Analysis software packages from ALD, such as RAM Commander.

ALD can be contacted at support@ald.co.il

5.5 Comparison

Trial versions of the software packages were downloaded and tested on a PC platform running Windows 2000 Professional. The D-LCC model would not download correctly which was considered as indicative of the age of the software and level of support given to it by the company. The inability of the software to run and poor customer support caused the reviewer to drop it from consideration.

The remaining three packages were compared with the following results:

5.5.1 LCCWare

The LCCWare front end was a MS Access® application with the inherent issues of presentation, many separate pages, linked tables and the requirement to enter most equations in Excel® syntax. The GUI appeared slightly dated and the help files were written in technical English and occasionally difficult to understand. From this reviewers perspective the package appeared dated and of questionable benefit compared to Excel® spreadsheets or Access® applications prepared for specific LCC studies. This package is not recommended as a standalone application.

5.5.2 Availability Workbench

The Availability Workbench had a more modern GUI and appearance than LCCWare and was easy to use. Models could be built intuitively with information obtained from records, other software spreadsheets or calculated from the Weibull module. This reviewer has used earlier versions of the company’s Reliability Workbench, which he was able to use and produce useful results without specific training in the software. The integrated software capabilities worked well for LCC definition and were considered acceptable for constructing LCC models for marine systems.

5.5.3 Relex Reliability Studio

The Relex software was in a recent version with a well presented and current front end. The Relex model was easier to construct than the LCCWare model with a very intuitive presentation and linking of pages. The ability to navigate between different functions was easy to understand after the demonstration package. The Reliability Studio also has the ability to link many modules to expand the capabilities of the software to match the task at hand.

5.6 Costs

The companies were not willing to quote prices without details of the customer and the number of licences required. They were willing to quote single license budgetary prices which are provided below.

LCCWare	$ 5,500 USD
Availability Workbench	$ 16,000 USD
Relex	$ 11,295 USD

5.7 Recommendation

Based on the foregoing review of the four software packages either the Isograph Availability Workbench or the Relex Reliability Studio with the following modules; Reliability Block Diagram and Life Cycle Costing, were considered acceptable packages to support LCC modelling of marine systems. The Availability Workbench from Isograph was considered slightly superior as it has the ability to develop maintenance programs using a reliability centred maintenance process and determine the costs for the maintenance.

6 Performance Based Specification

6.1 Definition

A performance specification is a statement of requirements in terms of desired results and the criteria for verifying compliance, without stating methods for achieving the desired results. A performance specification defines:

- the functional requirements for the item,
- the environment in which it must operate, and
- the interface and interchangeability requirements.

6.2 Performance Based Contracting

Performance Based Contracting (PBC) uses Performance Based Specifications to define the work through outcomes rather than the actual tasks to be completed. The outcomes are the results the customer desires without prescribing the manner in which those tasks are to be achieved. Incentives may also be used to reward contractors that exceed the most important outcomes. This makes the contractor accountable for the final outcomes whilst motivating it with incentives for providing higher levels of performance.

The State of Washington defines it as:

"A performance-based [contract] describes and communicates measurable Outcomes rather than a direct performance process (i.e. it instructs service providers on what needs to be done, not how it needs to be done.) Service requirements are defined in terms of performance objectives, and a service provider is allowed the latitude to determine how to meet those objectives…

If incentives are used, this can further motivate a service provider to deliver the best performance possible." [19]

The US Federal Acquisition Regulation (FAR) 2.101 defines Performance-Based Acquisition as "*an acquisition structured around the results to be achieved as opposed to the manner by which the work is to be performed.*"

6.3 Advantages

Performance based specifications offer some advantages over traditional contracting specifications. Contractors are encouraged to be innovative and are provided with incentive to offer the most competitive solution rather than the lowest unit cost for a specified solution. The owner's interests are protected by a rigorous testing program to verify performance rather than using prescriptive construction specifications.

This system encourages innovation and is well suited to rapidly changing technologies.
There are difficulties and limitations with performance specifications. Although the customer does not directly assume the risk of performance, the end result is dependent upon a clear and concise expression of required performance and the level of testing and monitoring to assure performance and provide quality assurance.

6.4 Characteristics

A performance based contract is characterised by measurable requirements with clearly defined standards of performance.

FAR 37.601(b) states "*Performance-based contracts for services shall include:*

- *A performance work statement (PWS);*
- *Measurable performance standards (i.e., in terms of quality, timeliness, quantity, etc.) and the method of assessing contractor performance against performance standards; and*
- *Performance incentives where appropriate.*"

PBC emphasises that all aspects of an acquisition be structured around the purpose of the work to be performed as opposed to the manner in which the work is to be performed. It is designed to ensure that contractors are given freedom to determine how to meet the customer's objectives that appropriate performance quality levels are achieved, and that payment is made only for services that meet these levels. Table 2 provides a short synopsis of the differences between traditional and performance based requirements.

Table 2 Comparing Requirements

Area of Comparison	**Performance Based Requirements**	**Traditional Requirements**
Purpose	Describe functions product is to perform and level of performance	Describe how product is to be designed and manufactured
Key Criteria	Describe means for verifying performance	Describe means of ensuring specified processes are followed
Design Latitude Given to Contractor	Allow contractor to determine best ways to achieve results	Force the contractor to use prescribed methods and approaches
Responsibility	Responsibility for results clearly belongs to contractor	Responsibility for results shared by customer and contractor

In general, performance requirements should have the following characteristics:

- Requirements should be quantitative rather than qualitative.
- Requirements should be verifiable.
- Performance requirements should describe interfaces in sufficient detail to allow exchange with parts of a different design.
- Requirements should be material and process independent.
- The specification must enable the customer and contractor to measure compliance with the specification requirements.

7 LCC Model to Support Performance Based Contracting

7.1 Background

Performance based contracts are broken into those for services and those for goods. Both of these can use Life Cycle Cost techniques to measure the performance of the contractor and the incentive due for superior performance.

For service contract cost data is generally used in a reactive format with service being rewarded or penalised based on the amount of money they have saved or cost the client compared to an agreed baseline. This baseline is usually centred on costs associated with loss of service or additional costs to maintain the level of service required.

Contracts for the delivery of goods generally reward the contractor for providing material with properties superior to a set baseline, where the properties can be linked to the life cycle cost by a cost estimating ratio (CER). A CER is a mathematical relationship between physical attributes and cost. Examples might be engine horsepower per dollar or cost per kilogram of electronic equipment. Most commonly the CER is linked to the life of the material which allows the customer to calculate the repair and replacement rate, thus the cost of maintaining the asset.

In both cases the contractor is rewarded for producing high quality work that will reduce the LCC from a specified baseline. Conversely they are penalised for providing lower quality materials or workmanship.

7.2 LCC Data Requirements

For both services and goods a baseline LCC must be identified as a performance specification. In order to reward the contractor for superior performance it must be possible to calculate the change from the baseline. For service contracts where the incentives are usually paid in arrears of the performance this is easy to do. When materials are provided, an LCC must be calculated, showing the change caused by the provision of superior material.

In order for the LCC to be valid it must be supported by verifiable and repeatable data. This means CER must be developed for each of the measured properties of the material and it must allow for variability between the properties that affect the LCC. [20]

The nature of the PBC will define the requirements for the LCC model. For the purposes of this report the PBC is concerned with the acquisition of the most cost effective design of marine systems for current and future Canadian Naval Vessels. The model must therefore consider the design and construction costs of the vessel as well as the through life maintenance costs. The first element is relatively easy to calculate as material costs are readily available from suppliers along with lead times and other information. The construction costs can be more difficult to estimate as novel materials may require different construction and fabrication techniques which could result in a substantial learning curve for the manufacturers.

The final data elements are the repair and refurbishment costs for the different materials. These are directly related to the environment, operation and maintenance program for the system. All of these factors will result in different deterioration rates of the material, so CER have to be developed, based on thorough research, relating the material properties to the deterioration to the maintenance costs of the system.

As noted in Section 4.4 above, obtaining the data can be very difficult, even within a single national agency. When the different assumptions and national operating profiles are added in, the utility of obtaining an existing LCC model and cost database must be questioned. The cost data must be developed internally to reflect the Canadian Navy operational profile, maintenance program and skill level of its maintainers. This information should be available in the navy's maintenance data and the corporate knowledge of the maintainers.

A research program should be launched to review all system performance and cost data, both from the navy and PWGSC, to develop the CER to support the use of Performance Based Specifications.

7.3 Use of LCC Model

As noted in section 7.1, the LCC is used one of two ways in a Performance Based Specifications; either to reward a contractor for providing a superior service or product, or to select between alternatives.

Using an LCC model to select between competing designs would fit closer into the performance based specification acquisition. The specification would require the lowest LCC for a stated ship performance. The model would have to be provided to all competitors and a subject matter expert would have to develop and manage the analysis for the navy. In order to prevent "gaming" of the model or use of questionable reliability or cost data, the navy could also insist the winning contractor must provide a lengthy period of support (e.g. not less than 5 years from delivery) at a price based on the LCC submitted with the bid.

To establish the baseline for an in-service support contract, the LCC is calculated using an agreed model to establish a baseline. The contractor would be rewarded for lower support costs, higher availability or higher reliability of the ship and its systems. Given the widely varying operational profiles of the navy ships, the contractor would probably demand a two stage price, e.g. a fixed element for maintaining the capability to support the ships including engineering, administrative and supervisory staff and workshop facilities and a variable element for the direct labour and material costs. The LCC incentives would be attached to the second element of this formula.

In order to use the LCC as part of a performance based specification it must be possible to link design features or material parameters to LCC. This can be done using the following process:

1. Construct a reliability block diagram of the system.

2. Insert reliability figures based on testing, in-service experience or use of analogous equipment.

3. Conduct a maintenance analysis to determine the appropriate maintenance program and its cost.

4. Conduct availability analysis to calculate the system performance and to create a CER linking the material characteristics of step 2 to the cost and system performance.

5. When a change is proposed DND would have to calculate new system performance figures and life cycle costs based on material specifications or system design.

6. Complete an LCCA to select the preferred option or calculate the incentive payment to the contractor.

This process would be well supported by the capabilities of the Availability Workbench software. The availability module calculates the corrective maintenance activities, the RCM calculates the preventive maintenance activities and costs, the Weibull module calculates the performance of the current equipment and the LCC module provides the total costs of building and maintaining the system.

8 Recommendation

Task 4 of the SOW requires BMT to *"…make recommendations on the most appropriate method for developing ship performance based specifications which incorporate through life cost models.*"

Since the navy has limited experience with performance based specifications, their creation requires careful consideration of what the work is designed to achieve and the function of the LCC model in the specification. If the objective is to improve the cost effectiveness of the Canadian naval ships the following process is recommended:

1. Analyse the reliability and cost performance for current marine system equipment in Canadian naval vessels.

2. Conduct research into maintainability issues with current designs.

3. Use the current levels of performance to develop new performance standards for marine systems.

4. Use the process in section 7.3 to calculate improvements in LCC caused by design changes for current ships or to calculate the value of new materials/features in proposed designs.

5. Use the LCC figures in a cost benefit analysis to select the optimal solution presented or determine the incentive payment as applicable to the situation.

It is recommended that DND:

- Adopt a standard commercial software package capable of linking reliability and life cycle cost calculations. The Isograph Availability Workbench package is the recommended solution.

- Conduct research to establish a reliability baseline for existing ships' systems and equipment.

- Conduct research to establish a cost baseline for the existing ships' systems and equipment.

- Conduct research into how material parameters affect the LCC through changes in reliability and maintainability.

- Work with industry to develop an understanding of how Canadian shipyards price their work.

- Develop cost estimating relationships between the reliability and the cost of the systems.

- Create cost estimating relationships between material characteristics and system performance.

- Develop performance based specifications for ships' systems and equipment using LCC as a selection criterion or to provide incentives for superior performance of contractors.

9 Summary

The documents listed in the references and bibliography have been reviewed to identify engineering cost analysis tools which could be used to identify the life cycle costs of a marine system. No specific costing tools applicable to marine systems were identified; however a process using a commercial software package and data from DND and PWGSC was suggested.

The second half of the project was the application of the costing tool to performance based contracting. A literature review of performance based contracting was completed and the essential features of the process noted. A process to adopt the costing tool to develop performance based contracts for DND marine systems was proposed along with recommendations for future research and development.

References

[1] Tedesco, Mathew, An Approach to Standardization of Naval Equipment and Components, Massachusetts Institute of technology, January 1994

[2] TAM04-10, Total Asset Management; Life Cycle Costing Guideline September 2004 New South Wales Government

[3] Suwondo, Edy; LCC-OPS; Life Cycle Cost Application In Aircraft Operations; Copyright © 2007 by Edy Suwondo

[4] RTO-MP-096 NATO AC/323(SAS-036)TP/27; RTO Meeting Proceedings 96 Cost Structure and Life Cycle Cost (LCC) for Military Systems

[5] Smit et al, Methods and Models for Life Cycle Costing (RTO-TR-SAS-054), Final Report. June 2007

[6] Kawauchi, Yoshio; Rausand, Marvin; Life Cycle Cost (LCC) analysis in oil and chemical process industries; June, 1999

[7] ASSDA Life Cycle Costing Paper Downloaded 11/10/07 from www.assda.asn.au/asp/index.asp?pgid=17981

[8] Life-Cycle Cost Analysis Primer; Federal Highway Administration, Office of Asset Management U.S. Department of Transportation,; August 2002

[9] Christensen, Paul N., Sparks, Gordon A., and Kostuk, Kent J.; A method-based survey of life cycle costing literature pertinent to infrastructure design and renewal, Can. J. Civ. Eng. Vol. 32, 2005

[10] Piyatrapoomi, N.; Kuma,r A.; Robertson, N.; Weligamage, J.; Review of the Literature: Maintenance and Rehabilitation Costs for Roads (Risk- based Analysis); Queensland Department of Main Roads, Project: 2003-029-C; Report: 2003-029-C/001; September 2004

[11] Smit et al

[12] Demko, D; Tools for Multi-Objective and Multi-Disciplinary Optimization in Naval Ship Design, Thesis Virginia Polytechnic Institute May 2005

[13] Smit et al

[14] Moyst, H.; Das, B.; Factors Affecting Ship Design And Construction Lead Time And Cost, Journal of Ship Production Vol 21, No 3, Aug 2005

[15] Liker, J.; Lamb, T.; What Is Lean Ship Construction And Repair?, Journal of ship production Vol 18, No 3 Aug 2002

[16] Ennis, K.J.; Dougherty, J.J.; Lamb, T.; Greenwell, C.R.; Zimmerman, R.; Product-Oriented Design and Construction Cost Model; Ship Production Symposium, San Diego, California , 1998, vol. 14, no1, pp. 41-58

[17] Carreyette, J. Preliminary Ship Cost Estimation, The Naval Architect, RINA 1977

[18] Butler, Don Guide To Ship Repair Estimates (In Man-Hours), , Butterworth and Heinemann, 2000

[19] NECCC Performance-Based Procurement Work Group Developments in Performance-Based Procurement for Technology; Prepared by the, 2004

[20] Whiteley, Leanne; Tighe, Susan; Incorporating Variability into Pavement Performance Models and Life Cycle Cost Analysis for Performance-Based Specification Pay Factors; University of Waterloo; July 8, 2005

Bibliography

1. A Guide To Best Practices For Performance-Based Service Contracting, Office of Federal Procurement Policy (OFPP), Office of Management and Budget (OMB), Executive Office of the President, FINAL EDITION, OCTOBER 1998

2. ASSDA Life Cycle Costing Paper Downloaded 11/10/07 from www.assda.asn.au/asp/index.asp?pgid=17981

3. Ausink John, Camm Frank, Cannon Charles, Performance Based Contracting in the Air Force, A report on Experiences in the Field; 2001

4. Barringer H. Paul, P.E.; Life Cycle Cost Issues; Barringer & Associates, Inc. Downloaded 11/10/07 Last revised 09/25/2006

5. Brindle, Kari Elizabeth; The Relationship Between Life-Cycle Costing And Performance: An Exploratory Analysis; Thesis Submitted to the Faculty of the Graduate School of Vanderbilt University in partial fulfillment of the requirements for the degree of Master Of Science in Management of Technology, May, 2005

6. Butler, Don Guide To Ship Repair Estimates (In Man-Hours), , Butterworth and Heinemann, 2000

7. Carreyette, J. Preliminary Ship Cost Estimation, The Naval Architect, RINA 1977

8. Christensen, Paul N., Sparks, Gordon A., and Kostuk, Kent J.; A method-based survey of life cycle costing literature pertinent to infrastructure design and renewal, Can. J. Civ. Eng. Vol. 32, 2005

9. Connell, Kathleen; Andal, Dean; Brown, Craig L; Performance Based Procurement - Another Model for California; Developed by California Franchise Tax Board; Presented at Harvard University, John F. Kennedy School of Government; Revised March 1998,.,

10. Copper Development Association, Transformer Life-Cycle Cost (Total Owning Cost), http://64.90.169.191/applications/electrical/energy/trans_life_cycle.html

11. Criscimagna, Ned H. Performance-Based Requirements (PBRs) Selected Topics in Assurance Related Technologies; START 99-2, PBR;

12. Crow, Kenneth; Achieving Target Cost / Design-To-Cost Objectives; DRM Associates, © 2000 DRM Associates

13. Curran, Sully; Sewer-Main Collection Pipe Joint Infiltration Testing and Life Cycle Cost Analysis, P. E. Executive Director, Fiberglass Tank & Pipe Institute

14. Daly, Donna; Tucker-Tatlow Jennifer, Gibson Carrie Innovations in Performance-Based Contracting; A Report Commissioned by: The Southern Area Consortium of Human Services (SACHS); Prepared by: ,; September 2004

15. Demko, D; Tools for Multi-Objective and Multi-Disciplinary Optimization in Naval Ship Design, Thesis Virginia Polytechnic Institute May 2005

16. Ennis, K.J.; Dougherty, J.J.; Lamb, T.; Greenwell, C.R.; Zimmerman, R.; Product-Oriented Design and Construction Cost Model; Ship Production Symposium, San Diego, California , 1998, vol. 14, no1, pp. 41-58

17. Gratsos, G A; Zachariadis, P; Life Cycle Cost Of Maintaining The Effectiveness Of A Ship's Structure And Environmental Impact Of Ship Design Parameters;

18. Habash, Nicholas; An Interactive Life Cycle Cost Forecasting Tool, Thesis Air Force Inst Of Tech Wright-Patterson AFB School Of Engineering

19. Ennis K.; Doughery, J.; Lamb, T.; Greenwell, C.; Zimmerman, R.; Product Oriented Design And Construction Model; Journal of Ship production Vol 14 No 1 Feb 1998

20. Kashiwagi, Dean; Savicky, John; Sullivan, Kenneth; Kovel, Jacob; Greenwood, David; Egbu, Charles; Is Performance-Based Procurement A Solution to Construction Performance? Published In: 11th Joint Symposium: Combining Forces –Advancing Facilities Management and Construction through Innovation, Helsinki, Finland, 172-182 (June 13, 2005).

21. Kawauchi, Yoshio; Rausand, Marvin; Life Cycle Cost (LCC) analysis in oil and chemical process industries; June, 1999

22. Life-Cycle Cost Analysis Primer; Federal Highway Administration, Office of Asset Management U.S. Department of Transportation,; August 2002

23. Liker, J.; Lamb, T.; What Is Lean Ship Construction And Repair?, Journal of ship production Vol 18, No 3 Aug 2002

24. Lu, Mingshan; Ma, Ching-to Albert; Yuan, Lasheng; Risk selection and matching in performance based contracting; May 2000, July 2001

25. Moyst, H.; Das, B.; Factors Affecting Ship Design And Construction Lead Time And Cost, Journal of Ship Production Vol 21, No 3, Aug 2005

26. NECCC Performance-Based Procurement Work Group Developments in Performance-Based Procurement for Technology; Prepared by the, 2004

27. NORSOK standard O-CR-001, Life cycle cost for systems and equipment;; Rev. 1, April 1996

28. Office of Government Commerce, Life Cycle Costing, www.ogc.gov.uk/implementing_plans_introduction_ life_cycle_ costing_.asp, Downloaded 11/10/07

29. Pedersen, Lars Erik; Life Cycle Cost Assessment of Maritime Command and Control Systems; Norwegian Defence Research Establishment (FFI)

30. Pillay, A.; Wang, J.; Wall, A.; Optimal Inspection Period for Fishing Vessel Equipment: A Cost and Downtime Model Using Delay Time Analysis, Marine Technology Vol. 38 No. 2 April 2001

31. Piyatrapoomi, N.; Kuma,r A.; Robertson, N.; Weligamage, J.; Review of the Literature: Maintenance and Rehabilitation Costs for Roads (Risk- based Analysis); Queensland Department of Main Roads, Project: 2003-029-C; Report: 2003-029-C/001; September 2004

32. Plant Maintenance Resource Center – Availability/Reliability/Life Cycle Cost Modelling Software Directory, www.plant-maintenance.com/maintenance_ software_availability. shtml

33. Proposed Investment Strategy to Address the First Marine International Benchmarking Study Findings; Submitted to DUSD (Industrial Policy) on March 31, 2005 by the Executive Control Board of the National Shipbuilding Research Program (updated August 1, 2005)

34. Reliasoft, Life Cycle Cost Analysis, Reliability HotWire http://www.weibull.com/hotwire/issue47/hottopics47.htm, Downloaded 11/10/07

35. RTO-MP-096 NATO AC/323(SAS-036)TP/27; RTO Meeting Proceedings 96 Cost Structure and Life Cycle Cost (LCC) for Military Systems

36. Smit et al, Methods and Models for Life Cycle Costing (RTO-TR-SAS-054), Final Report. June 2007

37. Spain, T. Kenneth; Pay Now or Pay Later: Life-Cycle Cost and Payback Analysis Techniques, 9 November 2000

38. Stankevich, Natalya; Qureshi, Navaid; Queiroz, Cesar; Performance-based Contracting for Preservation and Improvement of Road Assets; ; The World Bank, Transport Note No. TN-27 September 2005

39. Suwondo, Edy; LCC-OPS; Life Cycle Cost Application In Aircraft Operations; Copyright © 2007 by Edy Suwondo

40. TAM04-10, Total Asset Management; Life Cycle Costing Guideline September 2004 New South Wales Government

41. Tedesco, Mathew, An Approach to Standardization of Naval Equipment and Components, Massachusetts Institute of technology, January 1994

42. USACERL Technical Report 99/28, Engineering Life-Cycle Cost Comparison Study of Barrier Fencing Systems; US Army Corps of Engineers, Construction Engineering research Laboratories, Feb 1999

43. Vipulanandan, C.; Pasari, G.; Life Cycle Cost Model For A Wastewater System With Infiltration, 1998, http://cigmat.cive.uh.edu/content/conf_exhib/02_present/11.html

44. Walthers, Kevin; Value Based Procurement at DFCM, , Division of Facilities Construction and Management, State of Utah, 17June 2003

45. White, David; Hill, James; Copsey, Thomas; A Roadmap for Performance-Based Ship Systems Engineering; Naval Sea Systems Command, 21 March 2000

List of symbols/abbreviations/acronyms/initialisms

Acronym	Definition
CER	Cost Estimating Ratio
DND	Department of National Defence
FAR	Federal Acquisition Regulations
FMEA	Failure Modes Effects Analysis
FMECA	Failure Modes Effects And Criticality Analysis
GUI	Graphic User Interface
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
NATO	North Atlantic Treaty Organisation
NAVSEA	Naval Sea Systems Command
NPV	Net Present Value
O&S	Operation And Support
P3I	Pre-Planned Product Improvement
PBC	Performance Based Contracting
PBS	Performance Based Specification
PWGSC	Public Works And Government Services Canada
PWS	Performance Work Statement
R&D	Research And Development
WBS	Work Breakdown Structure
CBS	Cost Breakdown Structure (CBS)

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A literature review was conducted on commonly used engineering cost analysis tools to identify one that is suitable for conducting through-life cost analysis studies on marine system materials. The report will comment on how cost analysis can and has been used in performance based procurement specifications and make recommendations on the most appropriate method for developing performance based specifications for marine systems which incorporate through life cost models.

This work required two main streams of investigation; the first to identify the cost model best suited for comparing life cycle costs of marine systems constructed from different materials, and the second to review Performance Based Specifications and Contracting methodologies and recommend how the life cycle cost model could be used to support them. No costing tools specific to marine systems were found, however a generic software package was identified to conduct costing analysis and to build a cost estimating model. A way forward was proposed to develop a cost analysis tool to support marine system material selection.

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Marine system, copper alloy, seawater, corrosion, cost analysis tool

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