NATO Independent Cost Estimating and the Role of Life Cycle Cost Analysis in Managing the Defence Enterprise

Systems Analysis and Studies (SAS) Task Group-076

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1.0 INTRODUCTION

1.1 Background

Life-cycle cost estimates of defense acquisition programs are inherently uncertain. Estimates are often required when only 5% of a program's total cost is known. Years of system development and production, and decades of operating and support costs, need to be estimated. Estimates, in turn, are based on historical samples of data that are almost always messy, of limited size, and difficult and costly to obtain. Herculean efforts are commonly required to squeeze usable information from a limited, inconsistent set of data. And no matter what estimation tool or method is used, historical observations never perfectly fit a smooth line or surface but instead fall above and below an estimated value. To complicate matters, the weapon system or automated information system under study is often of sketchy design. Only limited programmatic information may be available on such key parameters as schedule, quantity of units to be bought, performance, requirements, acquisition strategy, and future evolutionary increments. Further, key characteristics of the system may actually change as the system proceeds through development and even production. Increases in system weight, complexity, and lines of code are commonplace.

For all of these reasons, a life-cycle cost estimate, when expressed as a single number, is merely one outcome or observation in a probability distribution of costs. That is, the estimate is stochastic rather than deterministic, with uncertainty and risk determining the shape and variance of the distribution.

Given the difficult job of producing credible, cradle-to-grave cost estimates in a highly stochastic acquisition and estimating environment, SAS-054 has developed a guideline to conduct a life-cycle cost analysis in a multi-national environment. SAS-076 then sought to establish a new mode of cooperative working within the international cost-estimating community. Hitherto, nations have often developed, by themselves, life-cycle cost estimates for acquisition programs of mutual or collaborative interest.

The vision of SAS-076 is that by working together in the cost-estimation process, NATO and PfP nations will all hopefully benefit from a cross-fertilization of ideas, data, experiences, perspectives in multi-national projects.

1.2 Provenance and Approval

The NATO Research & Technology Organization (RTO) System Analysis and Studies (SAS) Task Group SAS-054 (Methods and Models for Life Cycle Costing) published guidelines for conducting life cycle costing analysis within the NATO nations [1]. Their comprehensive report provided an extensive review of cost forecasting methods and models, including the two most critical elements for any viable forecasting analysis: data collection and the measurement of uncertainty and risk. One of the key recommendations of the study "... would be to demonstrate the proof of concept (methods and models) described in the report by using a practical application of the guideline".

At its October 2006 Panel Business Meeting (PBM), the Systems Analysis and Studies (SAS) Panel established an Exploratory Team (ET.AY) to propose new life cycle cost estimating activities as a follow-on to SAS-054[1]. The Exploratory Team was established to determine the feasibility of conducting an independent cost estimate (ICE) of a major weapon system acquisition programme of current international interest. Candidate systems discussed by the team members included NATO AGS, NATO's multi-mission aircraft, A400M, the European multi-mission frigate, FREMM, amongst others. Within a year of establishment, the team found just how hard it was to get approval from national consortia to develop an ICE for a major acquisition programme.

[1] SAS-054, in turn, built on the work of SAS-028 which had developed a generic cost breakdown structure.

Rejection notes were received confirming that no approval could be given involving a study on FREMM and A400M. However, approval was received for the team to conduct an ICE on the NATO AGS programme, and eventually, for the Royal Netherlands Navy Landing Platform Dock Rotterdam class amphibious warfare vessel and the Canadian LAV III, light armoured vehicle.

The Exploratory Team recommended a third and logical phase that would build upon the efforts of SAS-028 and SAS-054:

- Implement best life cycle costing practices, as defined in the work of SAS-054, by rigorously applying them to generate a sound, reliable independent cost estimate (ICE) of a major weapon system acquisition programme of current, international interest. This will demonstrate proof of concept of the guidelines.
- Identify best practices in capability portfolio analysis, with an emphasis on the role of cost analysis in the process.

NATO's Research and Technology Board (RTB) approved these recommendations in the Spring of 2008 and stood-up SAS-076 to implement them. In June 2008, the first meeting of SAS 076, *NATO Independent Cost Estimating and its Role in Capability Portfolio Analysis*, was held in Rome, Italy.

1.3 Objectives

Study objectives were defined as follows:

- Independent Cost Estimates (ICEs)
  - Choose one or more existing systems for which there is a CARD (Cost Analysis Requirements Description - used in the U.S.) or an MDAL (Master Data and Assumptions List - used in the U.K.) and for which actual cost data exist for development, production and in-service.
  - Generate an independent cost estimate based on the SAS-054 guidelines for best practice, using the CARD or MDAL as it existed at the start of the acquisition program.
  - Analyze risks and uncertainties.
  - Generate costs over the life cycle.
  - Obtain information on the actual cost of the weapon system under study, if available. Tally and analyze differences between actuals and estimates, thus providing invaluable feedback on the accuracy and completeness of the guidelines.
  - Provide a complete, documented analysis for both ex-post and ex-ante cost estimation to decision makers.

  Through these activities, the cost estimating concepts of the guideline developed in the SAS-054 study activity were to be demonstrated and validated, including the methods, models and processes.

- Role of Cost Analysis in Managing the Defense Enterprise

  Most defense establishments are quite adept at measuring the cost and the value of a specific program to fulfill a specified mission. Trade-offs are conducted. Analyses of alternatives are studied. Sometimes, gap analysis is done. But are comparisons made program versus program with an emphasis on the best way of meeting national and coalition objectives? Portfolio analysis is a promising method to improve defense business practices by analyzing a group of systems as a whole rather than focusing on acquisition programs one at a time.

  Specific objectives of SAS-076 were to:

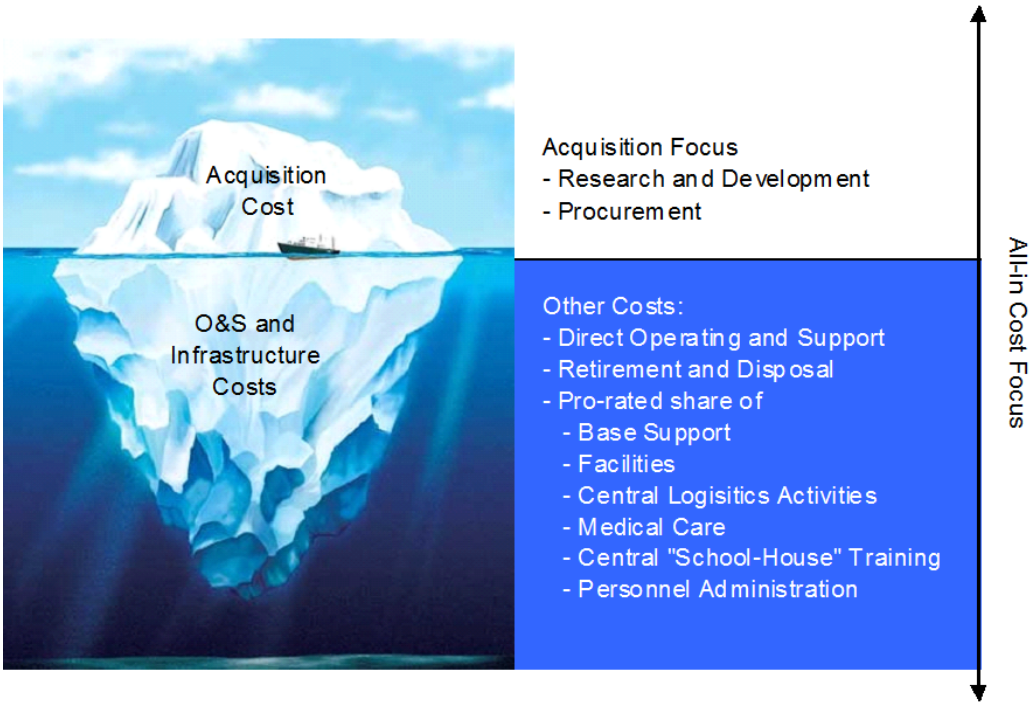

Figure 1: The life cycle cost iceberg

– Identify commonalities and differences among NATO and PfP nations in executing capability portfolio analysis, especially with respect to the use of life-cycle cost analysis.

– Recommend best practices regarding the analysis of risks and uncertainties of costs, capabilities, and requirements, thus engendering more informed decision-making on the allocation of scarce defense resources.

1.4 Scope

ICEs were generated for these acquisition programs:

- NATO Alliance Ground Surveillance System (AGS)
- Royal Netherlands Navy Landing Platform Dock (LPD): HMS Rotterdam and HMS Johan de Witt

Within the domain of total ownership costs shown in Figure 1, the primary focus of the ICEs was estimation of acquisition costs, and, in some cases, operating and support costs. Infrastructure costs were beyond the scope of this effort. Details on the AGS ICE are presented in Annex A. Details on the Netherlands LPD ICEs are presented in Annex B1 and B2.

The effort in capability portfolio analysis was expanded to include an investigation of the role played by life-cycle cost analysis in managing the entire defense enterprise, as shown in Figure 2 [2]. Details are presented in Annex C.

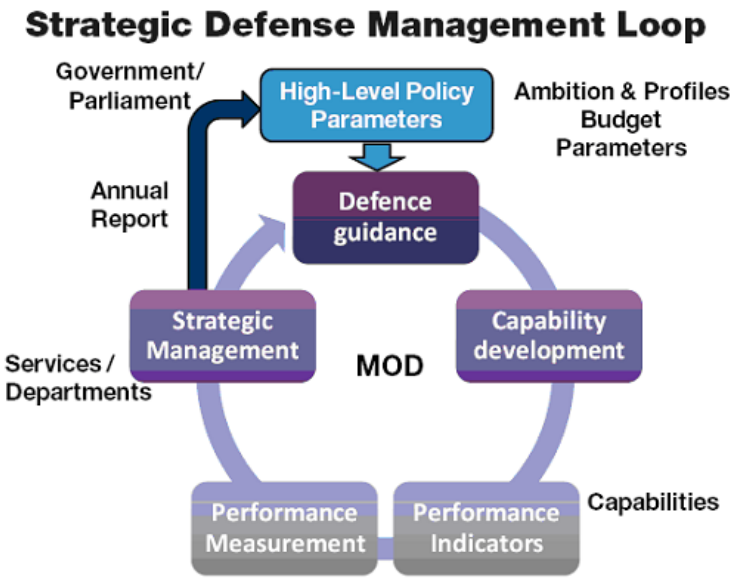

Figure 2: The strategic defense management loop

2.0 APPROACH

2.1 Independent Cost Estimates

SAS-076 used the six major steps of Figure 3 to generate scientifically-sound cost estimates for multiple acquisition programs under consideration.

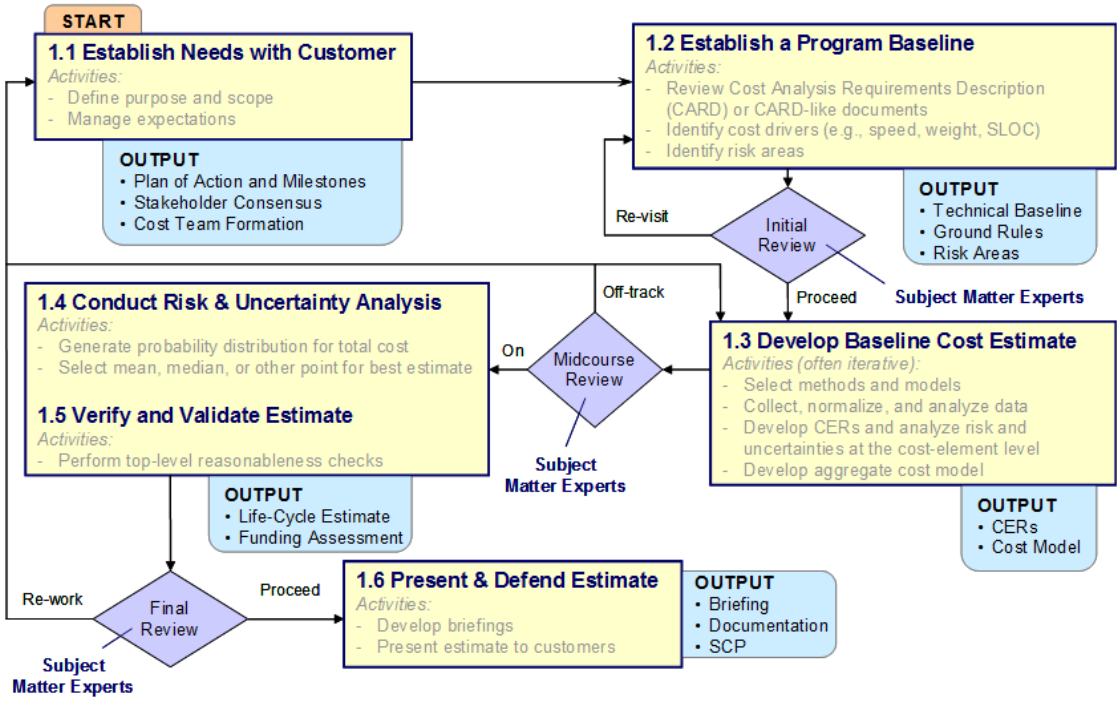

Figure 3: Methodology for the development of independent cost estimates

More specifically, for each program, SAS-076:

- Established Needs with the Customer.
  - Defined and managed expectations among stakeholders on cost-analysis activities, events and products throughout the life of the estimate.
- Established a Program Baseline.
  - Defined the program to include all technical and programmatic information required to generate the cost estimate.
- Developed the Baseline Cost Estimate.
  - Generated an estimate by collecting data, selecting methods, building models, and analyzing risks and uncertainties.
- Conducted Risk and Uncertainty Analysis.

  - Used an acceptable statistical technique to develop a probability distribution for the estimate.

- Verified and Validated the Cost Estimate.
  - Assessed critically the inputs, outputs, and methodology of the cost estimate using peer reviews and cross-checks.

- Presented and Defended the Estimate.
  - Finished documenting the estimate to produce an audit trail of source data, methods, and results, and present the estimate to principal decision makers in a cogent, understandable, and informative fashion.

Since a “second set of eyes” is of paramount importance in the discipline of defense cost analysis, subject matter experts provided guidance and feedback at critical review points.

2.2 Role of Life-Cycle Cost Analysis in Managing the Defense Enterprise

SAS-076 developed the following templates to ensure a common denominator of responses from NATO and PfP nations:

- Strategic Framework
  - Captures national practices in defining, managing, and implementing national security strategy

- Needs and Solutions
  - Defines the process for identifying military needs and developing and acquiring solutions

- Lexicon and Taxonomy
  - Captures national definitions of "defense capability" and defines methods that might be employed in grouping capabilities

- Role of Life-Cycle Cost Analysis
  - Captures the degree to which life-cycle cost analysis plays a role in planning, acquisition, and budgeting processes in each nation.

3.0 SUMMARY OF RESULTS

3.1 ICE on NATO Alliance Ground Surveillance System (AGS)

The SAS-076 Task Group focused its work on generating an independent cost estimate (ICE) on the acquisition phase of the program. This phase represents over 80% of the cost of the contract to be awarded to Northrop Grumman. The ICE, in turn, was based on:

- Historical costs of Global Hawk production (Blocks 30 and 40),

- An analogy for the new radar (Multi-Platform Radar Technology Improvement Program), based on the AESA radar on the F/A-18 E/F aircraft,

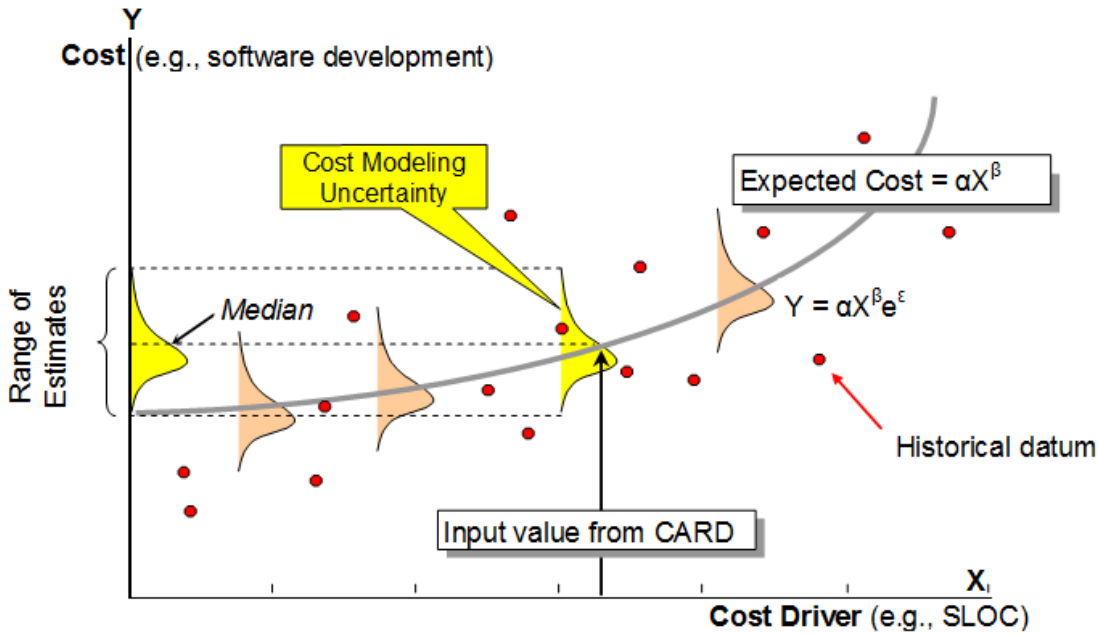

Figure 4: Estimating the cost for software development (example)

- Cost Estimating Relationships (CERs) for software development, as illustrated in Figure 4.

Operating and support costs for the in-service portion of the program were not formally proffered although one national participant in the group did some rough-order-of-magnitude estimates.

The Task Group conducted risk and uncertainty analysis for the acquisition program using benchmark coefficients of variation (CV) coupled with a point estimate to generate a cumulative probability distribution, or *S*-curve, as shown in Figure 5.

Results of the analysis were completely documented with the ICE delivered to the NATO AGS Management Agency (NAGSMA).

3.2 ICE on Royal Netherlands Navy LPDs

The full ICE was completed by estimating development and construction cost as an ex post exercise and O&S cost as an ex ante exercise. The SAS-076 Task Group used a novel application of known data mining algorithms to the problem of estimating the cost of development and construction for the Netherlands' LPDs. In a blind, ex post exercise, the Task Group set out to estimate the costs of these vessels and to then compare the estimates to actual costs (the Netherlands Royal Navy withheld the actual ship costs until the exercise was completed).

3.2.1 Acquisition ICE

Technical and cost data for ships similar to the HMS Rotterdam LPD was gathered. A database of 59 ships in 18 classes from 7 nations was compiled, spanning years (commissioned) from 1954 to 2010. For each ship, over a hundred descriptive and technical ship attributes were obtained, encompassing dimensions, performance, power generation, lift capacity, armament & countermeasures, sensors, combat & weapon control systems, etc.

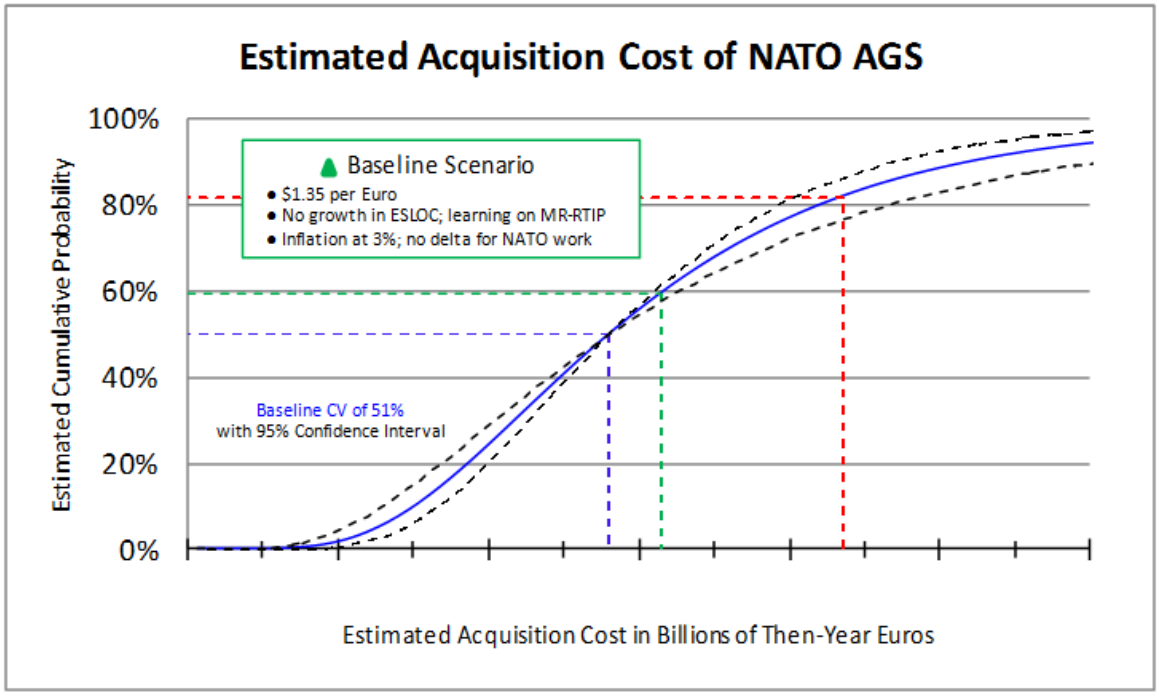

Figure 5: Estimated acquisition cost of NATO AGS

Ship development and production cost data was expressed in various currencies and a normalization procedure was required. Two cost estimating approaches were taken: parametric analysis and costing by analogy.

Parametric approach

Traditional ship building cost estimating relationships (CERs) are often mathematically simple or involve linear regression analysis (of historical systems or subsystems) on a single parameter. This is often insufficient - other cost driving factors must be incorporated to develop estimates of sufficient quality at the preliminary design phase. A parametric approach for ship cost estimation that incorporates a multitude of cost driving factors, while remaining a top-down approach applicable in early design phases of the procurement cycle was used. The M5 Model Tree Algorithm combines features of decision trees with linear regression models to both classify similar ships and build piece-wise multivariate linear regression models. Figure 6 depicts the M5 model tree applied to the NATO RTO SAS 076 ship data set.

Costing by Analogy

Cost estimation by analogy is typically accomplished by forecasting the cost of a new system based on the historical cost of similar or analogous system. There must be a reasonable correlation between the new and historical system. Subjectively chosen complexity factors are often used to adjust the analogous system's cost to produce an estimate. The credibility of the estimate for the new system may be undermined if the adjustment factors are not substantiated - this is a key disadvantage of the traditional analogy method. Hierarchical cluster analysis was used for a novel cost estimation by analogy approach void of the subjectivity inherent (of the tra-

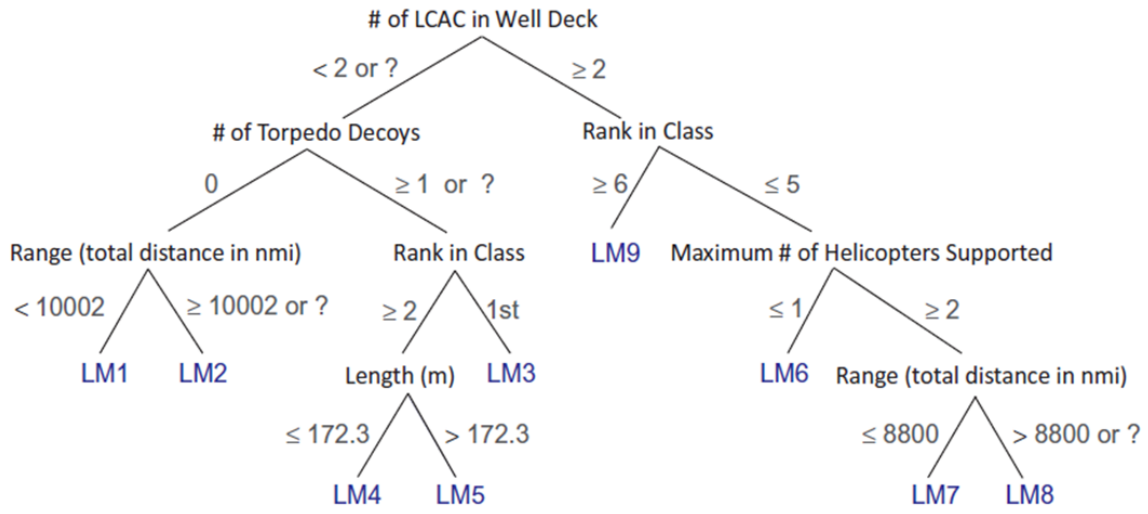

Figure 6: M5 model tree applied to the NATO RTO SAS 076 ship data set

ditional approach) in quantifying the cost of the technical and other differences between the historical system and the new system. The approach also considers multiple analogous systems rather than just one. Figure 7 illustrating the arrangement of the clusters produced by the hierarchical clustering of ships.

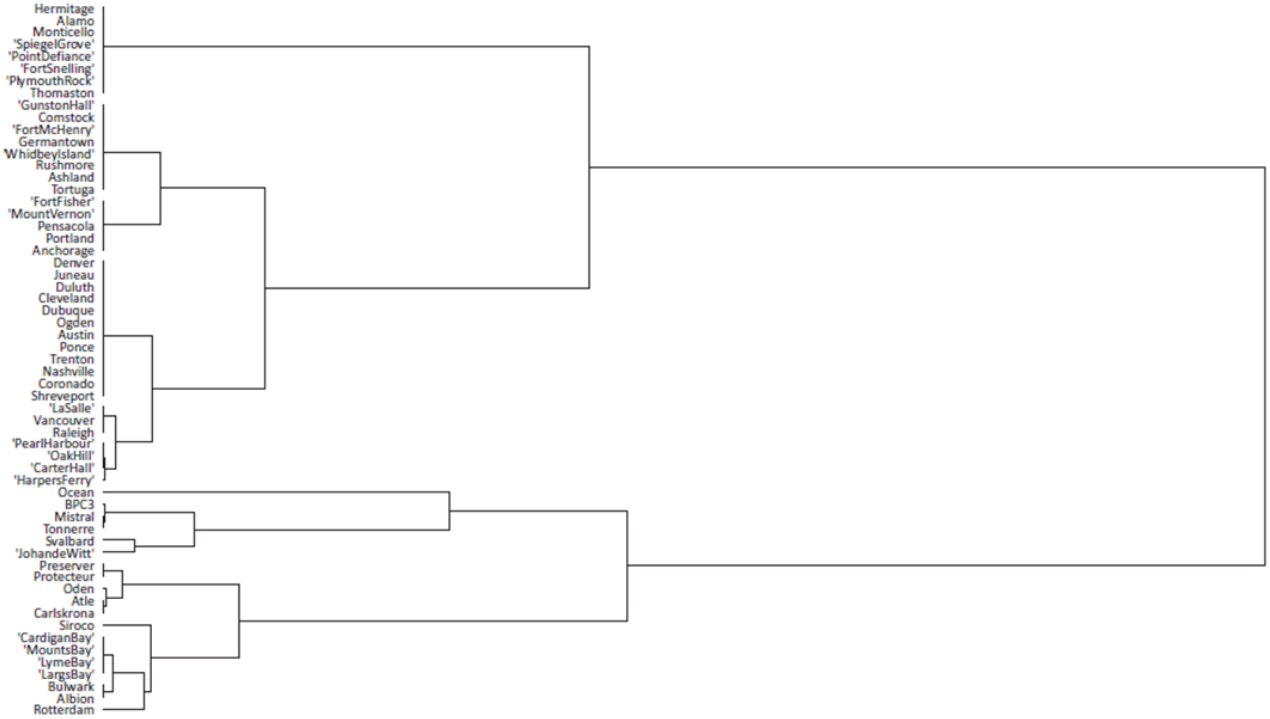

Figure 7: Dendrogram illustrating the arrangement of the clusters produced by the hierarchical clustering of ships

Results

The Royal Netherlands Navy revealed the actual development and production costs of HMS Rotterdam and Johan de Witt LPDs to the Task Group once the cost estimates were established. Figures 8 and 9 illustrate where the actual costs (thick vertical lines) fall with respect to the log-normal probability density and cumulative distribution functions for the M5 model tree and hierarchical cluster cost estimates for HMS Rotterdam LPD and Johan de Witt LPD (cost figures normalized to a fictitious notional common currency).

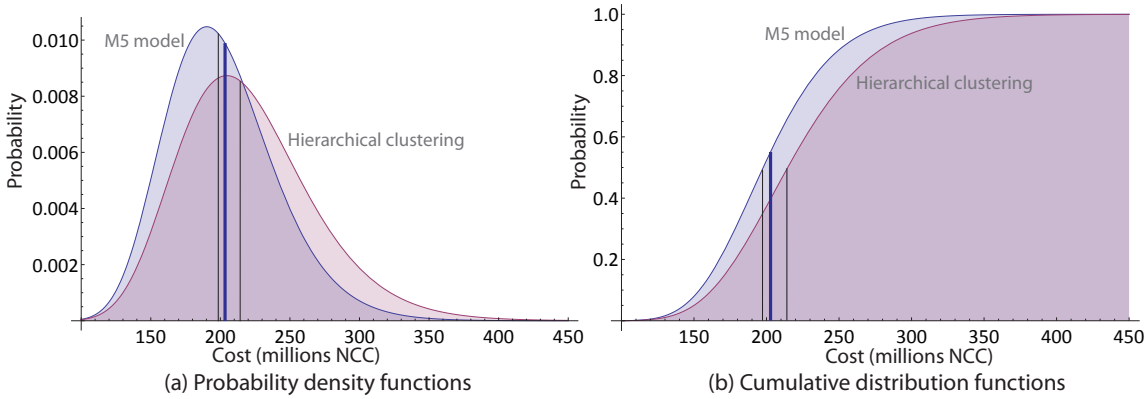

Figure 8: Probability density function (a) and cumulative distribution function (b) of the M5 model tree (blue) and hierarchical clustering (red) estimates of HMS Rotterdam LPD cost

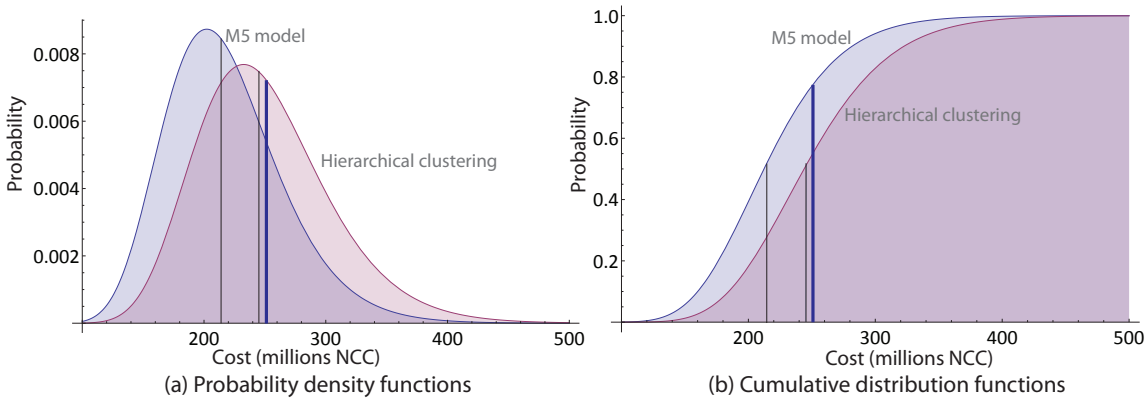

Figure 9: Probability density function (a) and cumulative distribution function (b) of the M5 model tree (blue) and hierarchical clustering (red) estimates of HMS Johan de Witt LPD cost

3.2.2 Operational & Support ICE

The ICE for operational & support (O&S) costs of the HMS Rotterdam LPD ship was an ex-ante exercise based on real organizational, operational, technical, and economic data gathered from the Royal Netherlands Navy (RNLN).

Methods

The ICE was based on three methods: parametric, analogy and engineering "bottom-up" methods. The parametric and analogy methods were applied by experts from the United States Naval Centre for Cost Analysis (NCCA) 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. These methods were applied on the U.S. Department of Defense defined Cost Analysis Improvement Group (CAIG) Cost Breakdown Structure (CBS). The SAS-076 task group applied the engineering, bottom-up method using data from the RNLN and the CBS recommended in SAS-054. The most important reason for applying this detailed method is that it highlights the critical elements of the Rotterdam LPD and the logistical organization and that it shows the economical consequences of the technical system characteristics over time, allowing to evaluate the implication in costs for possible system solutions.

Results

Besides the effort performed by NCCA based on the VAMOSC data, SAS-076 managed to produce an estimate for the O&S costs based on the planned operational profile. The data provided by the RNLN, however, was not sufficient to produce a reliable cost estimate. Nevertheless, using open source data SAS-076 was able to produce an estimate for the O&S costs. Dividing the HMS Rotterdam ship's life cycle cost into acquisition (development and production) costs and O&S costs, SAS-076 estimated that cost of 0&S over 30 years of service represents 84% of the total life cycle cost.

3.3 Role of Life-Cycle Cost Analysis in Managing the Defense Enterprise

After an extensive literature review, the SAS-076 Task Group conducted a Capability Portfolio Analysis conference in Paris, France, in an effort to learn more about the application of the discipline in the international defense establishment. The group found that many existing models and processes within NATO fall short of the ideal goal of addressing all strategic requirements and the capabilities and costs of all components of the portfolio, large and small alike.

One exception was the Strategy-to-Tasks Model (STAM) of United States Special Operations Command (USSOCOM), headquartered at MacDill Air Force Base in Florida. USSOCOM is the combatant command for the worldwide use of Special Forces such as Navy Seals and Delta Operators. STAM does a good job of matching budget to strategy. And it uses impressive methodology in evaluating the warfighting value of assets in the USSOCOM portfolio. However, USSOCOM, unlike most ministries of defense within the Alliance, is not in the business of acquiring multi-billion dollar weapons systems since these are resourced through the Services in the U.S. DoD.

In a capability portfolio analysis pilot effort in the U.S., risk-reward bubble diagrams, such as shown in Figure 10, proved useful.

For the templates, the responses obtained from the sample of nations summarizes as below:

- Strategic Framework
  - All nations in the sample state general goals or ambitions in a national security document. Some nations offer more detail than others. All nations have processes and products that translate high-level objectives into more concrete policy parameters needed to build military forces. Most nations in the sample and many others within NATO engage in capability-based planning.
- Needs and Solutions

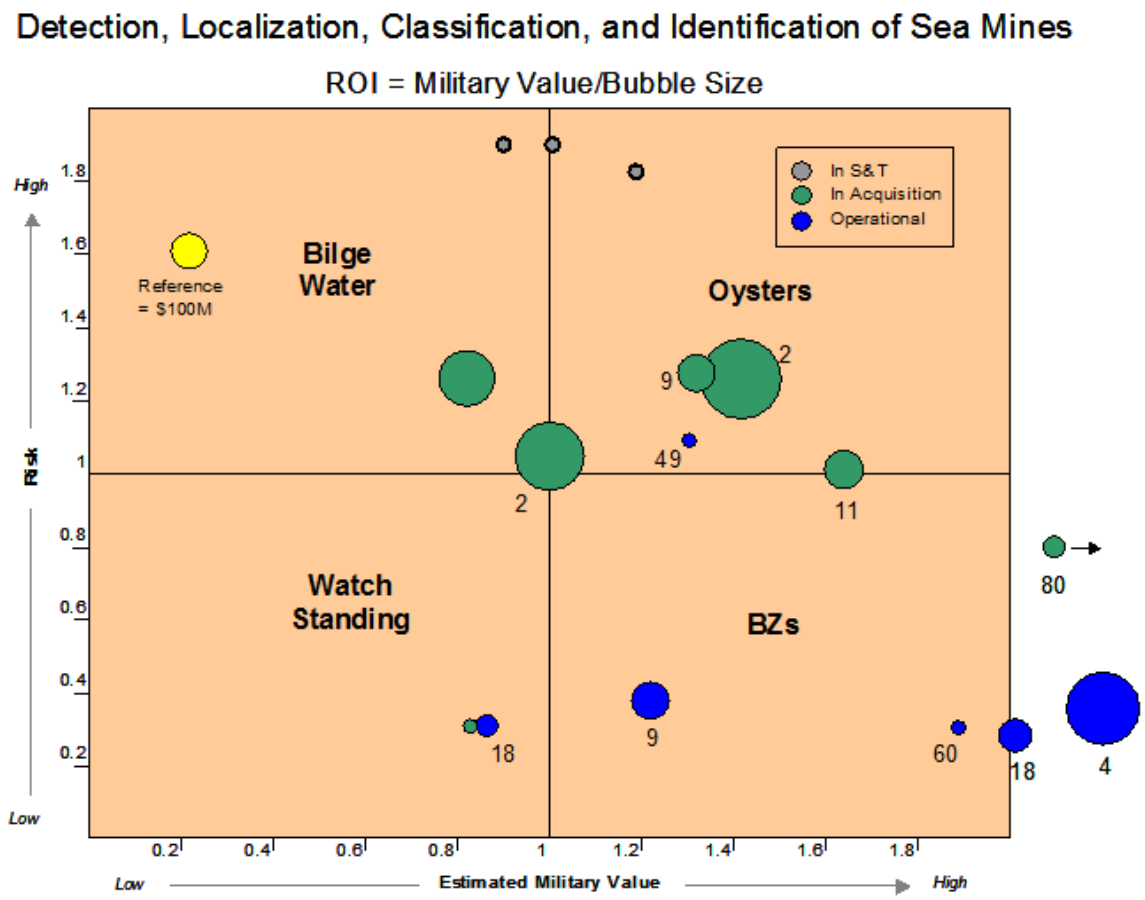

Figure 10: Risk-reward bubble diagram (example)

- Most of the sample nations described their process to identify needs. They all use capabilities as a part of defense planning and execute a gap analysis. All nations seem to have alternative solutions that in different ways are prioritized before any decisions for future acquisition are made. Scenarios are for identifying needs or for describing strategic frameworks or both. This also means that some scenarios are not as detailed as others. Due to different governmental organizations in each country the responsibility for working with needs and solutions differs between the nations.

- Lexicon and Taxonomy
  - Most nations from the sample seem to define capability in terms of ability to achieve a desired outcome. Regarding components of the capabilities there seems to be a significant commonality. The result of the template shows that some nations use a much more extensive structure than others.

- Role of Life-Cycle Cost Analysis
  - Of the seven nations answering the template only one nation uses life-cycle costing both for identifying defense needs, for defense programming and budgeting and for acquisition of materiel solutions. The best commonality is identified in the field of acquisition of materiel solutions.

Figure 11 provides a high-level summary of the SAS-076 analysis. As indicated by the legend in Figure 11, colours are used to evaluate the degree of use and role played played by life-cycle cost analysis during the various stages of defence planning and acquisition. Green indicates that life-cycle cost analysis is usually performed and plays a role in decision making. Red indicates the opposite—life-cycle costing does not play a role.

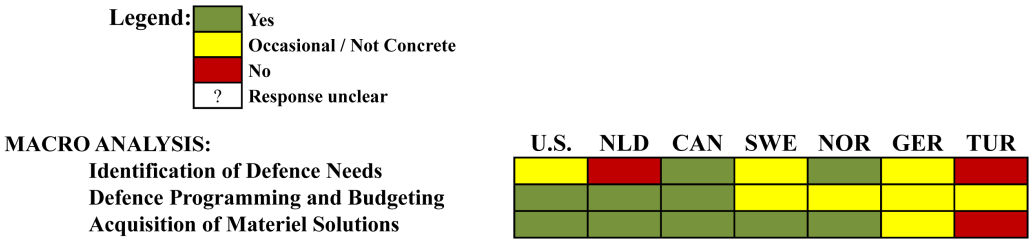

Figure 11: Macro analysis of role of life-cycle cost analysis in defence planning.

4.0 LESSONS IDENTIFIED

The goal of this effort was to apply the guideline that was developed by SAS-054 in multi-national programs, to gather lessons learned related to the guideline and, if necessary, to adapt or enhance the guideline. In Section 4.1 main lessons identified per each of the six main steps in generating an ICE (as per Figure 3) are specified with a detailed SAS-076 experience. Section 4.2 presents other, more generalized, ICE lessons identified that enhance the findings of SAS-054. Section 4.3 presents lessons learned from the SAS-076 capability portfolio analysis study.

4.1 Main ICE Lessons and Related SAS-076 Experience

4.1.1 Establishing Needs with Customers

Lessons Identified: Obtain stakeholder buy-in early on, generate an ICE development plan, and obtain key signatures

Example SAS-076 Experience: It is essential to obtain consensus if not unanimity on objectives and scope of the cost estimate. On NATO AGS, key discussions were required with major players to obtain permission to generate an ICE on the program, to obtain cooperation throughout the estimating process, and to publish results. An ICE development plan was generated to foster common understanding and to document agreements.

4.1.2 Establishing a Program Baseline

Lesson Identified: While the aim and the objective of the study are fundamental for the way the cost analysis is conducted, cost analysts should be flexible and anticipate changes to the cost boundary during the cost estimating process.

Example SAS-076 Experience: The cost boundary changed during the cost estimating process of the O&S costs of the Netherlands' LPDs: helicopters were at first not included but additional informations from the

RNLN required a change. Similarly, 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 and this caused the removal of these costs from the Cost Breakdown Structure.

4.1.3 Developing Baseline Cost Estimates

Lesson Identified: Don't limit the scope of historical data to use and be open to new costing methods.

Example SAS-076 Experience: When SAS-076 gathered data for ships similar to the Netherlands LPD's (for the acquisition ICE) the group did not limit themselves to ships very close to the Netherlands' LPDs. For example, civilian ships like icebreakers were also included because data related to these ships could have relevant information (e.g., same size/different function and different size/same function). Similarly, for each ship a plethora of technical and performance characteristics where gathered. In some cases data was unobtainable, but rather than discarding such ships, methodologies were proposed that could handle missing values. The data available determined, in a large extent, the choice of methods. It was a continuous interaction between choices of methods and computer models and availability of data. The new methodology used, based on data mining, is very valuable as it requires only publicly available technical data of attributes and some cost data. On the other hand the complexity of the analogy method based on hierarchical clustering lead to computational difficulties when using over one hundred attributes per ship. This issue was dealt with by applying principal component analysis and reducing the dimensionality of the input without significant loss of information.

4.1.4 Conducting Risk and Uncertainty Analysis

Lesson Identified: When possible, use multiple techniques for risk and uncertainty analysis.

Example SAS-076 Experience: The use of historical CVs within the context of scenario-based analysis is easier and more complete than traditional Monte Carlo simulation. All elements of risk and captured, and considerable time saved, by employing benchmark CVs. Use of more than one technique may be in order, and a best practice. For example, AGS risks might be first estimated using Monte Carlo simulation, with benchmark CVs then serving as an independent validation check on results.

4.1.5 Verifying and Validating Estimates

Lesson Identified: Scrutinize initial cost model outputs in detail and if necessary determine whether to change the model or adjust results before considering omitting historical data.

Example SAS-076 Experience: A closer look at the Netherlands LPD acquisition CER showed that the individual linear regression models were mostly intuitive: the cost of a ship increases as the length or the number of landing craft supported or number of torpedo decoy systems increase(s). The regression models also predict a shipbuilding learning curve as the cost of constructing a ship decreases as a function of the ship's rank in class. However, the negative coefficient for a ship's range (sailing time) in the regression models was counter-intuitive. It seemed unlikely that a ship would cost less if its range was increased. A closer look at the SAS-076 ship data explained the anomaly: a small subset of the ships had a combination of low cost and outlying sailing time ranges. Adjusting the regression models (by disabling the particular sailing time attribute) offered no

guarantee that the regenerated model would not substitute this attribute with another also allocated a negative coefficient. Similarly, removing certain ships from the data set provided no guarantees. Rather than subjectively diminishing the data set, SAS-076 noted the anomaly and discussing them as part of the results. As a post analysis SAS-076 substituted the Johan de Witt sailing range (also an outlier) with the median sailing range of the SAS-076 ship data set, effectively neutralizing the attribute. This resulted in a revised estimate which turned out to be within 1% of the actual cost.

4.1.6 Presenting and Defending Estimates

Lesson Identified: It is best to start documenting the cost estimate as it is developed. Trying to recapture rationale, judgments, and the details of intricate statistical analyses after the fact is, at best, extremely difficult and time consuming.

Example SAS-076 Experience: Due to the nature of the SAS-076 task group, which met 3-4 times a year for three years, it was necessary to compile presentations on methodologies, assumptions, and results in preparation for each meeting in order to facilitate discussion and progress. A turnover in participants over the years also forced the group to regularly document its findings in order not to lose any information. Although hindered by the discontinuous nature of the meetings (naturally SAS-076 participants had national obligations to attend to between meetings), the regular updating of models and presentations facilitated report documentation and offered a trace of the decisions made at various stages.

4.2 Other ICE Lessons

- A sound, robust life-cycle cost estimate is based on a well-defined program. Accuracy and completeness of the definition are critical in producing an estimate that informs rather than confuses decisions on the allocation of scare resources within NATO and PfP nations. The better the definition, ceteris paribus, the higher will be the quality, flexibility, and usability of the cost estimate.
- An ambiguously defined program increases the use of assumptions, drives up estimation risk, and shifts the burden of uncertainty to senior decision makers.
- Defining the program is not a one-step-and-stop activity. It's common to refine the definition of the program throughout the estimation process.
- Life cycle costing is a data driven process, as the amount, quality and other characteristics of the available data often define what methods and models can be applied, what analyses can be performed, and hence, the results that can be achieved.
- Robust life-cycle cost analysis requires the collection of metadata from myriad sources.
- There are a wide variety of methods and models available for conducting risk and uncertainty analysis of life-cycle cost estimates of defense acquisition programs. Each, if used properly, can yield scientifically sound results. That said, there's simply no substitute for taking the time and effort to understand the technical risks and challenges in developing and producing sophisticated defense systems.
- It's essential to convey to senior leadership the notion that cost estimates are uncertain, that acquisition programs can and do incur difficulties, and that the probability of a cost estimate becoming reality, when expressed as a single number, is precisely zero.

- Since uncertainty and subjectivity are always present in the cost-estimating process, sound procedures for verification and validation are essential to ensure the delivery of quality products, and, importantly, to capture and store reliable metadata on the estimate for future use and continual process improvement.
- Use of meaningful, well-crafted visual displays is important in communicating the results of detailed cost analyses to stakeholders.
- A best practice is to start documenting the cost estimate as it is developed. Trying to recapture rationale, judgments, and the details of intricate statistical analyses after the fact is, at best, extremely difficult and time consuming.
- Since the precise distribution of the cost estimate is never known with absolute certitude, it's perhaps helpful to provide context through the use of historical norms. An example would be comparing an estimated probability distribution for a current acquisition program to one based on the same point estimate (such as the median or mean) but using a variance based on sample CVs from analogous, historical programs.

4.3 Life Cycle Cost Analysis in Managing the Defense Enterprise

Based on responses from seven countries, and through a process of vigorous discussion and even heated debate, SAS-076 identified the following lessons learned with respect to the role played be cost analysis in managing the defence enterprise.

1. **Engage Early-On:** Use cost assessments to inform the strategic decision planning process on what a country can and cannot afford. Canada and Scandinavian countries seem the best practitioners on this score.
2. **Budget and Program to the Cost Estimate:** Independent cost estimates and cost assessments are valuable only to the degree they are used. A best practice is to generate an independent life-cycle cost estimate for every major weapon system acquisition program and to reflect this estimate in planning and budgeting systems.
3. **Make Cost the Denominator in Needs and Solutions Analysis:** In identifying military needs and solutions, capability-based planning is the gold standard in NATO today. A best practice, within the context of capability portfolio analysis as illustrated in Figure 10, is to compute a return on investment for defence assets defined as:

$$\frac{\text{Military Value}}{\text{Life-Cycle Costs}}.$$

   It's important to note that risk and balance are other essential dimensions of a complete analysis.
4. **Move to the "Left" in Acquisition:** Many, if not all, countries extensively support the acquisition process at key decision points, called "gates" in the United Kingdom, milestones in the United States. However, many cost analysts object to providing cost estimates early in acquisition when systems are only vaguely defined and exist only in design. However, paradoxically, this is when the cost estimates are of the most importance. Much more extensive cost-analysis support needs to be provided in early design phases. Rough order of magnitude estimates a this point in the life cycle will help empower informed decisions on the allocation of scarce defence assets.

5. **Optimize from an Alliance Perspective:** Given pervasive threat to the security of NATO and its alliance members across the broad spectrum of conflict, optimization of military capability seems in order. Duplication of effort, such as several countries possessing extensive sea mine counter-measure capability, might be avoided. Individual Alliance members might develop expertise in a war-fighting domain that could be used to the benefit of the entire Alliance in times of conflict. Savings of hundreds of billions of Euros per annum might be achieved by managing from a NATO enterprise perspective.

6. **Present Decision Makers with Menu of Portfolios:** Senior defense decision makers express a strong demand for a *menu* of acquisition *alternatives* from which to choose. Heretofore, inordinate attention has been devoted, at high levels, to the management of *individual* acquisition programs. Attention to acquisition details, at high levels, might be better delegated to subordinate authorities in each military department or acquisition community. Senior decision makers, instead, would focus on a complete *set* or *portfolio* of systems in any war fighting or mission area. A review of current and alternative portfolios would shift attention of senior decision makers to where it rightfully belongs, to addressing the fundamental, multiple needs of a ministry of defense, and *trade-off space*, in the face of an entire *spectrum of threats*.

5.0 CONCLUSIONS

Working as a coherent team, the Task Group was successful in generating credible, complete, scientifically-sound independent cost estimates on:

- HMS Rotterdam and HMS Johan de Witt Landing Platform Docks (LPD) of the Netherlands; and
- NATO's Alliance Ground Surveillance System (AGS).

These conclusions are offered:

- It is, in fact, possible to generate an ICE on a major acquisition program using an international team of dedicated cost analysts.
- It is difficult, but not impossible, to share cost data across nations. Non-disclosure forms need to be completed, and information closely held. Further, it is useful if not essential to obtain buy-in early on from major stakeholders. For example, for AGS, the SAS-076 team generated an ICE development plan and obtained signatures from the Chairman of the Board of AGS Management Organization (NAGSMO), the Director the AGS Management Agency (NAGSMA), and the Director the SAS-076 study group.
- The SAS-054 guidelines on methods and models for cost analysis are, in fact, applicable in a cost estimating environment. The SAS-076 Task Group followed these guidelines extensively and recommends some enhancements,such as:
  - Differentiate between approaches and methods: parametric, analogy, and engineering methods can each be applied in a top-down or bottom-up approach.
  - The SAS-054 guidelines for cost normalization should be expanded to consider multi-national data sets where different currencies and base years are present. The approach taken by SAS-076 in this study can be used as an example.

  - Describe the new methods for acquisition costs developed by the group based on data mining techniques.

In the realm of managing the defense enterprise, the SAS-076 Task Group offers these conclusions:

- Portfolio analysis techniques can indeed be employed fruitfully in national defense.
- Major goals of portfolio analysis typically include maximizing value of individual projects, balancing investments, and adhering to strategy.
- No model, of course, is perfect. That is, models are parsimonious, plausible, and hopefully informative, but do not provide the ultimate truth.
- Provide senior decision makers a menu of investment portfolios from which to choose.
- Present joint solution space in all investment portfolios.
- Minimize subjectivity in assessing military value.
- Always assess capabilities, risk, and life-cycle costs of assets. All three dimensions are important, and leaving out costs will skew results.
- Newly developed methods in other areas than cost analysis should always be considered for application in the cost analysis area.

6.0 REFERENCES

[1] NATO RTO SAS-054 Task Group, "Methods and Models for Life Cycle Costing," Technical Report RTO-TR-SAS-054, NATO RTO, June 2007.

[2] Stephan Spiegeleire, "*Closing the Loop*," 2008, Hague Centre for Strategic Studies.