Arctic Day 2017

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Effective Modeling and Simulation of Increased Complexity in Combat System Design

Authored by Samantha Alpert and Robert Stukes

I. Abstract

The Department of Defense uses various complex weapons systems and as the designs in these systems mature through acquisition and sustainment the associated simulations and models become more complex. The large number of redundancies designed into these systems drive a divergence between the analytically predicted optimal sparing solution and the mission applicable availability. Using a robust modeling approach, programs can more accurately predict the effects of design and support changes, identify sustainment cost growth or savings, and provide data based decision support. The AMDR (SPY-6) Program, for example, is currently using the Opus Suite tools (OPUS10, SIMLOX, and CATLOC) to continuously monitor and assess the weapon system's Operational Availability (A_O) Key Performance Parameter (KPP), and Lifecycle O&S cost Key System Attribute (KSA). This allows for informed programmatic decisions based on the impact to these KPPs and KSAs.

II. Background on the Opus Suite

The Opus Suite, a RAM-C (Reliability Availability Maintainability – Cost) tool suite, optimizes supply system performance by balancing Operations and Support (O&S) cost against System Availability (finding the "Knee in the Curve"). Determining the optimal level of spares has been one of the most common uses of the Opus Suite since the 1970s. Developed in Stockholm, Sweden, the software is now used to optimize spares in numerous countries for a wide span of projects that cross the commercial and defense sectors. Opus Suite is comprised of three modules: OPUS10, SIMLOX, and CATLOC. OPUS10 is used for spare parts optimization and logistics support analysis. SIMLOX supports event driven simulation utilizing more dynamic and realistic scenario inputs to model a system's operational effectiveness. CATLOC is used to model development, acquisition, O&S cost over time.

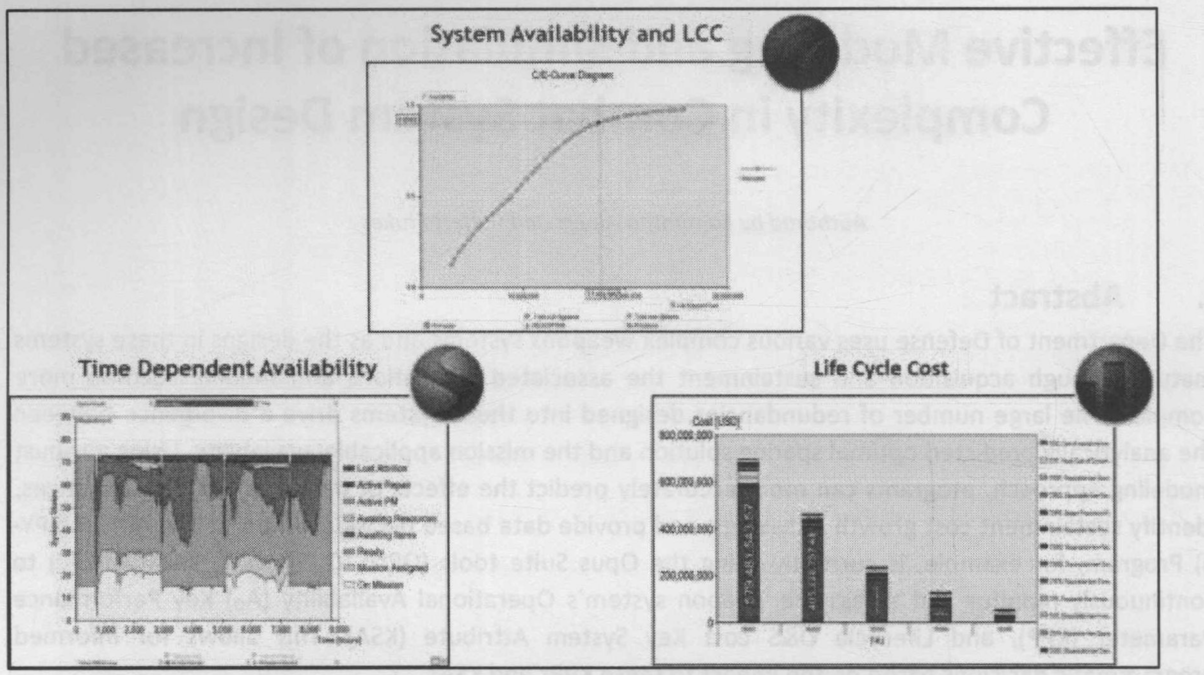

Figure 1: Examples of Results from the tools in the Opus Suite, from right to left; SIMLOX, OPUS10, and CATLOC

One program that has greatly benefitted from the use of the Opus Suite, is the Air Missile Defense Radar (AMDR) Program. The AMDR Program is currently utilizing the OPUS10 and SIMLOX modules to perform Readiness Based Sparing (RBS), conduct decision support and trade study analyses. The modules are also being used to provide O&S cost estimate input data used in budget planning and appropriation of Ship Construction Navy (SCN) and Operation and Maintenance Navy (OMN) funds. Complex redundancies and unique operational profiles associated with AMDR's system design, Design Reference Mission Profile (DRMP), and Concept of Operations (CONOPS) drives a divergence between the analytically predicted steady state availability in the OPUS10 optimization, and the stochastically modeled mission specific availability in SIMLOX. For example, when modeling operational hours in OPUS10, we model that there will be 24 hours of operation, and this will help us get our optimal spares allocation. When we then model the same 24 hours of operation in SIMLOX, there are two very different ways to model this; twenty-four 1-hour missions, or one 24-hour mission. Both operations having an average mission time of 10%, but have drastically different support requirements.

III. Introduction to AMDR

The Air and Missile Defense Radar (AMDR) program is developing a new radar system, the AN/SPY-6(V)1 which replaces AN/SPY-1D(V), to enhance Ballistic Missile Defense and Air Defense capabilities on the Navy's newest class of destroyers, DDG-51 FLTIII. AMDR provides greater detection ranges, increased discrimination accuracy, higher reliability and sustainability, and lower total ownership cost as well as a host of other advantages when compared to the current radar onboard today's destroyers.

The development is consistent with the DoD's objectives to field Modular Open Systems Architecture designs and is comprised of individual 'building blocks' called Radar Modular Assemblies (RMA). Each RMA is a self-contained radar in a 2'x2'x2' box, the number of RMAs can be scaled to meet a variety of mission operational needs, making AMDR the Navy's first truly scalable radar. The array architecture and associated RMAs incorporate complex redundancy trees which allow for graceful degradation, making the radar highly mission reliable and survivable. However, this new design architecture drives unique challenges and opportunities in sustainment.

In addition, AMDR is utilizing commercial off-the-shelf (COTS) x86 processing equipment to perform Digital Signal Processing and Beamforming. The commercial nature of these processors will simplify maintenance and technology refresh strategies, as well as, lower the sustainment costs associated with repair and obsolesce management of the radar's service life.

AMDR has an extremely high operational availability requirement. In order to accurately capture the impact of different failures the complex active radar network and large-scale redundancies have to be included in the support model. This challenge, along with a variety of operational profiles that incorporates allowable maintenance downtime, replenishment cycles, and deployment schedules requires a powerful and flexible modeling toolset.

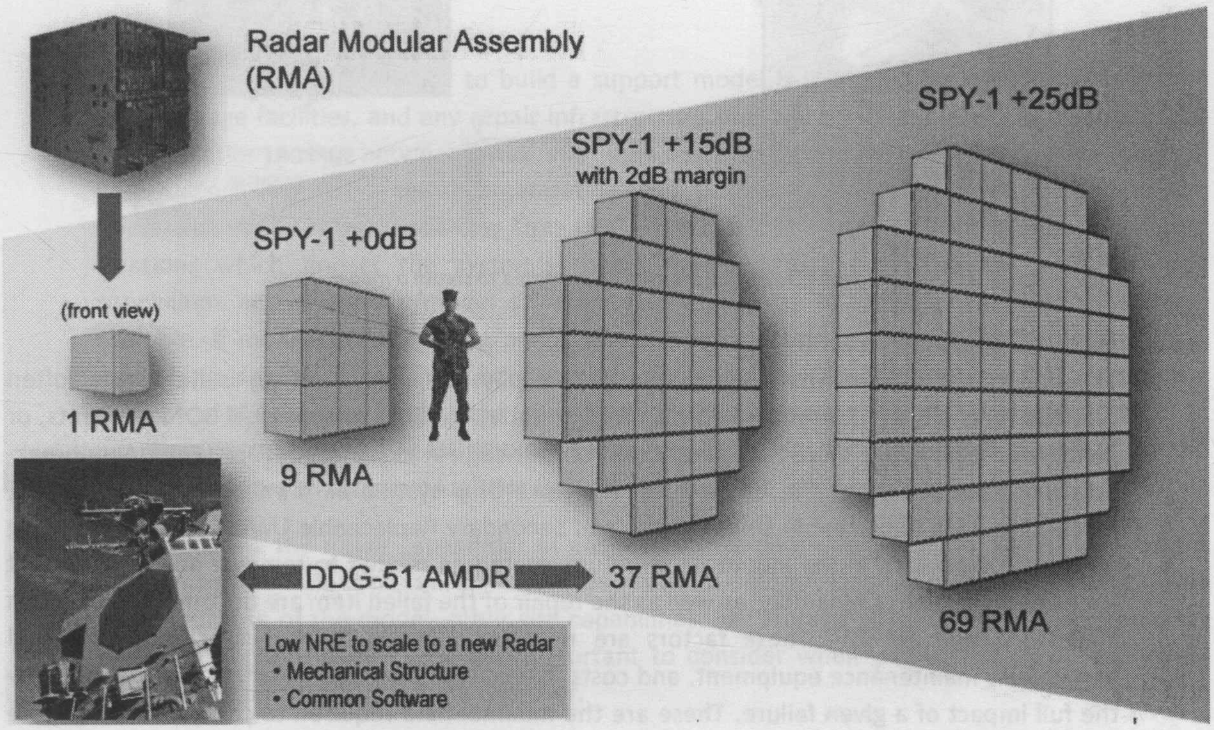

Figure 2: Visual representation of the AMDR (37 RMA Configuration) and the RMA Architecture

The AMDR Program has designated the Opus Suite as the Model Based Engineering solution to Product Support optimization and simulation. The Opus Suite is used to verify system design compliance to mission performance and affordability requirements, and supports programmatic decision making.

IV. Modeling Methods

Developing a Product Support model involves three related input data: Technical System Design, Support System Design and Optional Concept (Figure 3). These input data categories are used to create an integrated model that represents not only the system being supported, but also the support system itself. Data is modeled to the level of detail required to provide decisions makers the accuracy need to support real-time decision making.

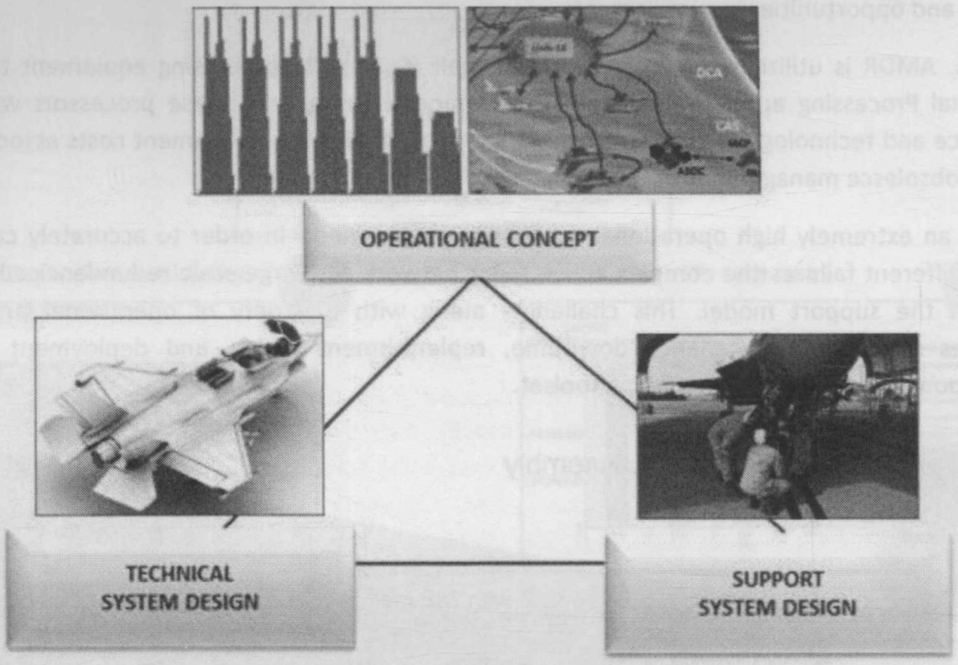

Figure 3: The three areas of data needed to create a model

A. Technical System Design

The first major data element associated with a physical system design is item data, often referred to as a Bill of Material (BOM). Crucial metadata related to individual BOM elements, or parts, are Reliability (Failure Rate) and Cost (Unit Price). An indentured BOM (Top-down breakdown) further describes the hierarchical structure of a system as it relates to sub-systems, assemblies, Line Replaceable Units (LRUs), and Secondary Replaceable Units (SRUs). Depending on the LRUs position in the indenture structure, metadata related to removal and replacement from the Next Higher Assembly, as well as the repair of the failed item are documented as Mean Time to Repair (MTTR). These factors are modeled along with the associated unit level manpower, maintenance equipment, and costs associated with accomplishing the task to show the full impact of a given failure. These are the minimal data required to perform steady-state (analytical) optimization on a repairable system, agnostic of the support system or utilization profile.

In order to preform "Readiness Based" optimizations two more major categories of data are required, detailed operational concept (discussed later) and the systems redundancy characteristics as it relates to Mission Critical Failures/System Mean Time Between Critical Failure. A system/mission critical failure can be described by Reliability Block Diagrams (RBDs), or Failure Modes, Effects, and Criticality Analysis (FMECA) or a combination of both. Systems designed with built in redundancy/graceful degradation may continue to perform their function without immediate repair. Similarly, particular LRU or SRU Failure Modes (FMs) may have "next higher" effects that in isolation do not effective the top level system or sub-system's ability to perform its function. In this way the FMECA, and sometimes Fault Tree Analysis, are used to describe aggregated failures' top-level effects and form the basis for number required of number in system (M of N) redundancy. In simple parallel redundancy cases M of N requirements can be modeled in independent series. However, some complex systems exhibit a "fan out" of failure effects as multiple LRUs work in conjunction to perform a particular system function. The result of complex system fan out can drive extreme mission criticality dependencies on particular "controller" LRUs, making their effect on readiness more significant then modeled in the analytical case.

Long run analytical optimizations are excellent at meeting average system effectiveness across an enterprise of systems; eventually all failures that occurred (both critical and non-critical) will generate supply system demands and need to be replaced within the system. However, in order to meet strict, independent missions, a Readiness Based stochastic approach is needed to ensure the desired level of mission effectiveness is achieved on an individual system basis.

B. Support System Design

The next type of data needed to build a support model is location data, such as operational sites, storage facilities, and any repair infrastructure that will or already exist. Additionally, the transportation policy between sites and how they will support one another are vital to determining how the support organization and possible repair strategies will dictate the calculation of Mean Logistics Delay Time (MLDT). When modeling complex systems, only model locations which impact the system(s) being modeled. Grouping locations with common capabilities into one node/model structure is a good way to simplify complex models. For example, if modeling the sparing needs of different operational sites and intermediate level supporting depots, it may not be necessary to model individual part manufacturers if the purpose of the model is to develop Operational and Intermediate results. Since the model does not need to account for manufacturer spares one location can be used to model all of the manufacturers with different logistics times for each of the individual parts.

Understanding the repair capabilities at each support location, for example MTTR, is important to defining item and location repair policies within the model. Depending on the data available or the purpose of the model, other site capabilities, like storage of spares and/or resources, or ability to deploy systems, are also important to consider when pulling the technical system design and operational concepts together.

C. Operational Concept

The operational concept, or CONOPs, describes the systems' mission(s) objectives. Each mission can be decomposed into an operational profile, or DRMP, which defines the mode(s) in which system will operate and in what duration(s) and system/sub-system utilization(s) will be needed to achieve mission objectives. In the long run analytical case operational concept can be simply described as the product of system utilization and the optimization length. However, complex missions aggregated in to operational profiles, may leverage a variety of common and unique RBD systems architectures (to include different M of N requirements) depending on the system operational modes defined by the mission criteria, as well as varying sub-mission durations. Moreover, the criticality of a failure is dictated by the failures effect on the mission being performed in the operational profile. Therefore, dynamic operational concepts (modeled stochastically) are also a key contributor to a Readiness Based Sparing optimization.

D. Summary

These three related input data are used in product support optimizations such as Multi-Echelon Readiness Based Sparing, Location of Repair Analysis (LORA), and Manpower Planning. The product support model leverages the discussed input parameters to calculate metrics which are balanced against cost and resource constraints to achieve an optimized system effectiveness/readiness level (Figure 4).

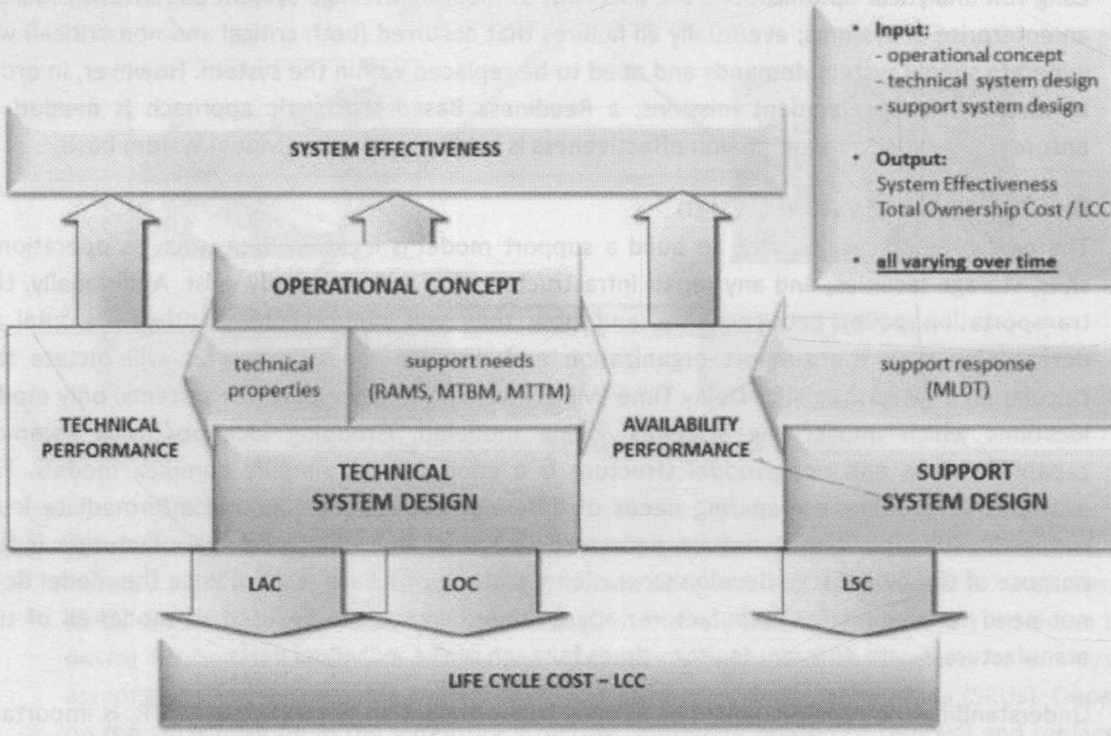

Figure 4: Summary of inputs and outputs of a model

V. AMDR Example

The AMDR Program established a RAM-C Model to reflect the AN/SPY-6(V)1 system and its associated Product Support Strategy across the program's life cycle. The model leverages Contract Deliverable Requirement Lists (CDRLs) was jointly developed with Government and Prime Contractor Subject Matter Experts (SMEs). Throughout system design iterative updates to the model have been used to validate and verify (V&V) system design compliance against requirements to include Top Level Requirement (TLRs): Operational Availability (A_O), Probability of Successful Mission (P_{SM}), and Operations and Support (O&S) Cost. The AMDR RAM-C Team is committed to continuously update and monitor the system design compliance through production, fielding, and sustainment of the systems' life cycles.

A. AMDR Technical System Design

1. Simple Item Data Example

The indentured BOM below is a representation of the Cooling Equipment Sub-system (CES). The model data base (not shown) includes Reliability, Maintainability (R&M), and Cost metadata associated with LRU/SRUs.

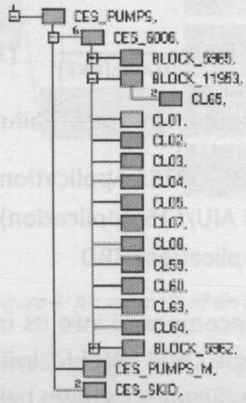

Figure 5: A visual representation of the CES BOM

2. Simplifying Unnecessary Complexity to the LRU level

In some cases, CDRL deliveries are buildup of components which are not line replaceable, for example the *Hardware Management Server* RBD in the *Hardware Management Subsystems* is a Line Replaceable Unit (LRU) internal RBD. Therefore, a single block comprised of one item, PE70 (Figure 3) represents the servers in its entirety.

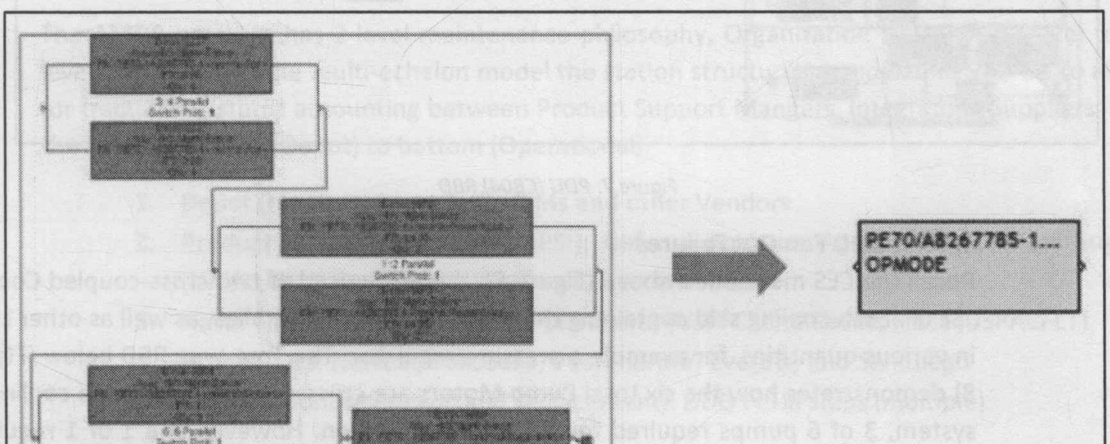

Figure 6: Hardware Management Server RBD

3. Decomposition of below LRU Failure Modes

The Power Distribution Unit (PDU) is an LRU with Unique Spares ID, CB04. Within the Power Distribution Subsystem (PDS) the PDU has a variety of Failure Modes and associated Effects (documented in the FMECA). In order to accurately portray end effect (on system) the Failure Rate of the PDU LRU is proportionally divided up and allocated to multiple RBDs by Failure Mode frequency. Internal (below LRU) RBD Failure Rates are used to determine the portion of the total FR applicable to the LRU level RBD by Equation 1. Environment Factor (ENVF), applied to the LRU indenture level in OPUS10, equal to the Failure Mode frequency (below LRU RBD FR) divided by CB04's Unit Failure Rate (LRU total FR).

$$ENVF = \frac{RBD\ FR}{[Item].[FRT]} \quad (1)$$

In this example the PDU is split into several Failure Mode Effect RBDs:

1. Cabinet Items (DBF1, DBF2, RTSS Application) RBD
2. Cabinet Items (RCP and AIU/FTS Application) RBD
3. Cabinet Items (DSPS Application) RBD

Since Unit Failure Rate is decomposed into its modes, the sum of these separate mode blocks is equivalent to a single CB04 LRU block. Therefore, the aforementioned RBDs will simplified in to the example (Figure 4) shown below.

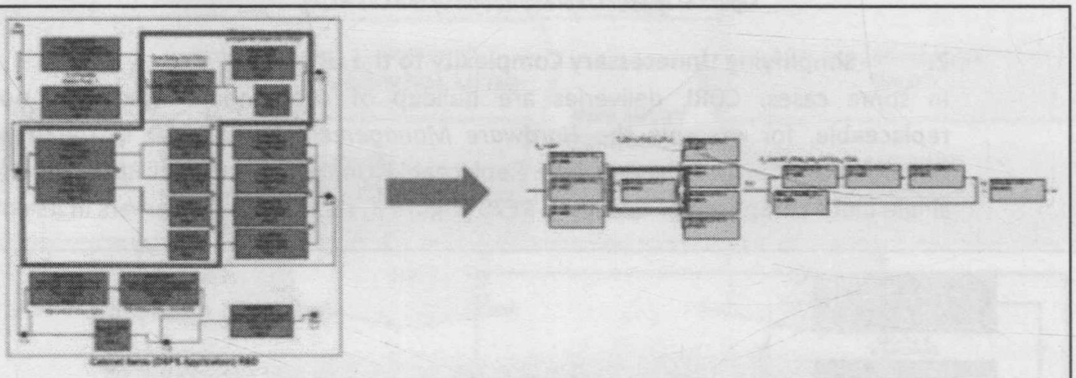

Figure 7: PDU (CB04) RBD

4. RBD Fan Out Failures

Recall the CES mentioned above (Figure 5). It is comprised of two cross-coupled Cooling "Skid". Each cooling skid containing three pump motor assemblies, as well as other LRUs in various quantities, for example a pressure regulator. The Tree type RBD below (Figure 8) demonstrates how the six total Pump Motors are cross-coupled to provide cooling to system, 3 of 6 pumps required for compliant operation. However, if a 1 of 1 required pressure regulator contained in either of the root skid blocks fails then the subsequent trickledown effect is a loss of 3 pumps. Thus, the RBD demonstrates a critical failure event occurring when a both a pleasure regulator and cross-coupled pump fail within the same mission time as designed.

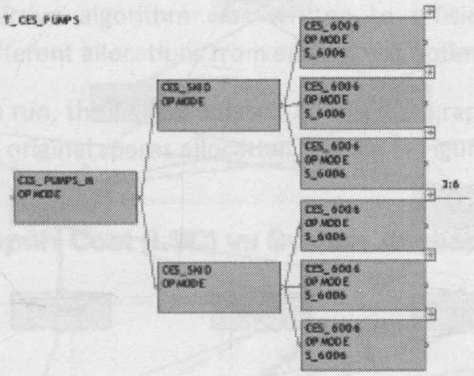

Figure 8: An example of an RBD

B. AMDR Support System Design

Models can be complex because of more than their technical system design, for example: organizational structure, operation schedules, repair concepts, and scheduled maintenance planning. For AMDR, other complex parts of the model, operations and organizations, are programmatically determined and therefore have little variation during the Technology Development, Engineering Manufacturing Development, and Production phases. However, as systems begin to enter Initial Operational Capability the program expects to modify the support structure to represent tactical reality.

The AMDR program has 2-level maintenance philosophy, Organization to Depot (O-level to D-level). However, in the multi-echelon model the station structure is modeled in 5 levels to allow for tractability/status accounting between Product Support Mangers, Integrators, Suppliers, and the Fleet : from top (Depot) to bottom (Operational).

1. Depot (repair and reorder): OEMs and other Vendors
2. Product Support Integrators (PSI): Defense Logistics Agency (DLA), Naval Supply (NAVSUP), Naval Surface Warfare Centers (NSWCs)
3. Naval Commands: Fleet Forces Command (USFFC) and Pacific Fleet (USPACFLT)
4. Home Ports: Norfolk, Yokosuka, Pearl harbor, Everett, and San Diego
5. Organizational (removal and replacement): DDG FLTIII ships (multiple)

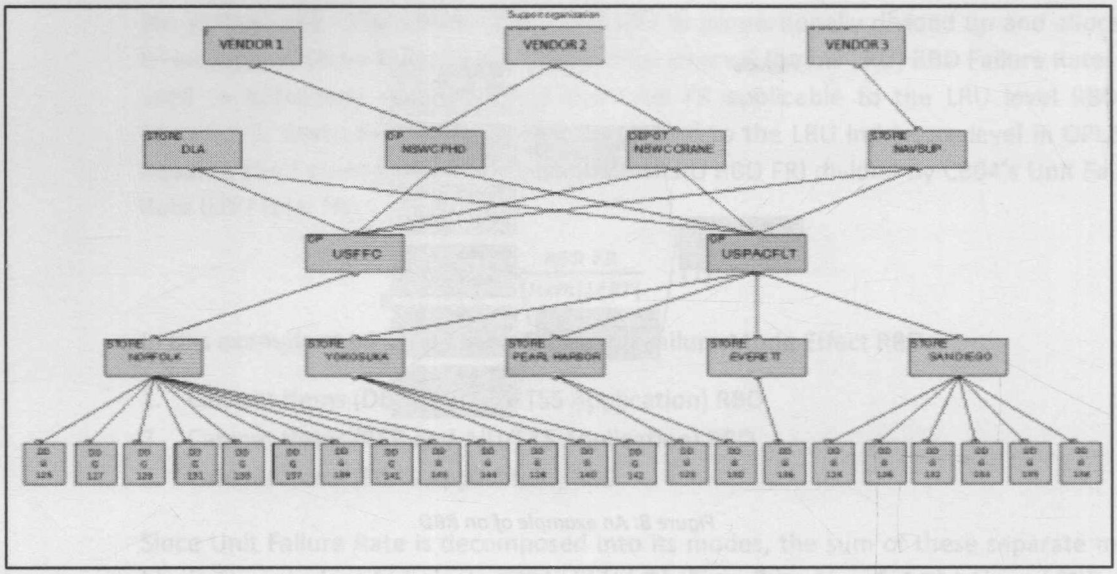

Figure 9: Modeled Support Structure

C. AMDR Operational Concept

The phased deployment of systems through production is aligned to the Program of Record (PoR) documentation that defines production and fielding plans. Operations and mission lengths, equipment state (system/subsystem/LRU utilization), allowable downtime, maintenance philosophy/constraints, ship's forces requirements (technicians), and other planning parameters are gathered from the DRMP, CONOPS, TLR, Initial Capabilities Document (ICD), Capabilities Develop Document (CDD), Manpower Estimate Report (MER) and other PoR documentation are used to create general timelines of when the systems will be in operation, when the system will be available for maintenance, or when items may be transported on or off the ship. These mission profiles can be aggregated into a mixture of operational profiles, see Figure 10.

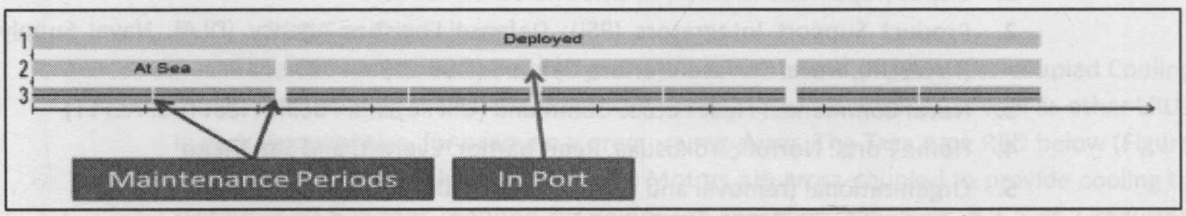

Figure 10: Modeled Operations Profile

D. AMDR Summary

Once the data are gathered and translated into a model, a preliminary optimal spares assortment based on a steady state calculation for the AMDR, is performed using Opus10. This is the first step of the modeling process. The results of this optimization are displayed in a graph of average Operational Availability (A_O) vs Life Support Cost (LSC) curve made up of a chosen number of optimal solution points (e.g. 50 points). Then each point, containing a different allocation of spares, is simulated in SIMLOX to find the A_O over time using Monte Carlo based simulation and predict how each spares assortment would perform when mission effectiveness is considered. A recursive algorithm was written to efficiently automate the process of simulating all of the different allocations from each of the optimal solution points on the curve.

Once the Simulation is run, the new simulated A_O result is graphed on a similar curve based on the same LSC from the original spares allocation. Shown in Figure 5.

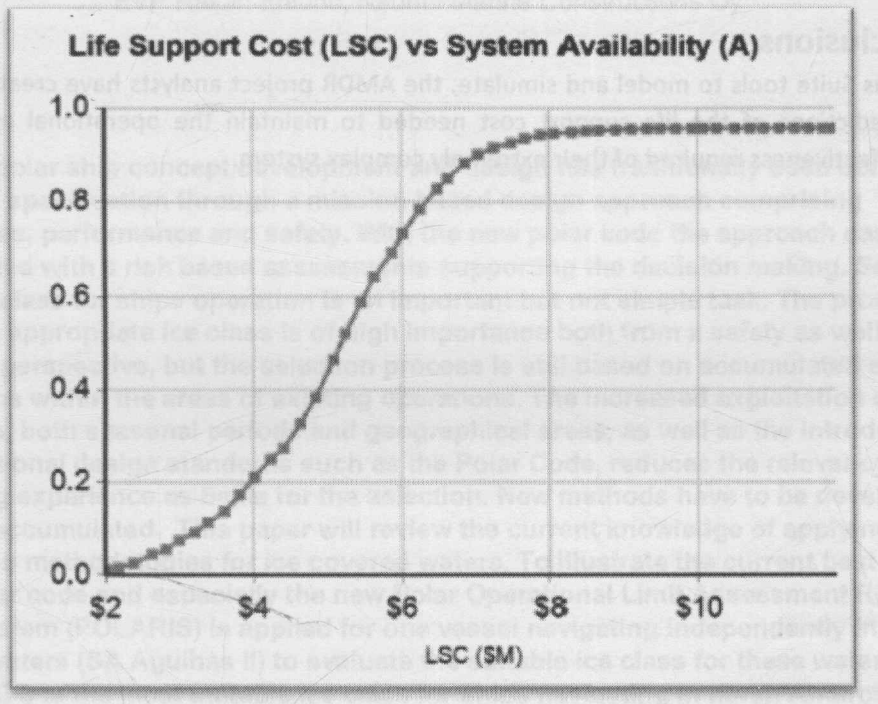

Figure 11: Example graph of AMDR System Availability as calculated in SIMLOX vs Life Support Cost as calculated in OPUS10

These results are then used to offer the customer a range of solutions based on requirements on either cost or availability to suggest a proper assortment of spare parts. The automated recursion algorithm to validate OPUS10 results in SIMLOX has already been developed. The next step is to further automate out process by enhancing the recursion algorithm to utilizes applicable Importance Measures (Subsystem Unavailability) in SIMLOX to deconflict the OPUS10 results and generate a truly optimal supply posture, this capability is currently being tested by Systecon development engineers.

VI. Future Work

As the system grows to maturity and continues to change over time, these models will be updated and adjusted as necessary in order to properly continue to predict the cost of maintaining the required operational availability. The modeling tools software code will also continue to update annually, and will adjust to upcoming changes and take models like AMDR and all of its complexities into account. The Enterprise Air Surveillance Radar (EASR) Opus Suite Model is currently being developed and is leveraging all of the lessons learned from AMDR. Since the programs have many shared (identical) parts the goal would be to combine the models and leverage economies of scale between the programs. This would require a re-baselining the AMDR model to incorporate the improvements developed during the EASR modeling effort including: Failure Mode modeling vs. ENVF work around, Preventative Maintenance (PM) modeling, Maintenance Task Analysis (MTA) model, use of the Level of Repair Analysis (LORA-XT) functionality, multi mission modeling including P_{SM}, Subsystem Unavailability prioritization (Beta capability), as well as many other modeling concepts, all utilizing the Opus Suite.

VII. Conclusions

Using the Opus Suite tools to model and simulate, the AMDR project analysts have created usable and defensible predictions of the life support cost needed to maintain the operational availability and operational effectiveness required of their extremely complex system.

Challenges for complementing a Mission Based Concept Development with a Risk Based Design Approach for Ice-Class Selection

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EVP Håkan Enlund, Rauma Marine Constructions Oy

ABSTRACT

Successful polar ship concept development and design has traditionally been done from a requirement specification through a mission based design approach comprising functionalities, performance and safety. With the new polar code the approach can be complemented with a risk based assessments supporting the decision making. Selection of suitable ice class for ships operation is an important but not simple task. The process of selecting an appropriate ice class is of high importance both from a safety as well as an economical perspective, but the selection process is still based on accumulated experience and traditions within the areas of existing operations. The increased exploitation of the Polar waters, both seasonal periods and geographical areas, as well as the introduction of new international design standards such as the Polar Code, reduces the relevancy of using only existing experience as basis for the selection. New methods have to be developed and knowledge accumulated. This paper will review the current knowledge of applying risk based design methodologies for ice covered waters. To illustrate the current best practice, the new polar code and especially the new Polar Operational Limit Assessment Risk Indexing System (POLARIS) is applied for one vessel navigating independently in the Antarctica waters (SA Agulhas II) to evaluate the suitable ice class for these waters. It is found the PC 3 is the most suitable ice class for ships navigating in harsh Antarctic ice conditions.

INTRODUCTION

The concept design of special purpose ship with a variety of functionalities has traditionally been approached through a mission based principle. The task has been divided into three main areas, i.e. Functionalities – Safety – Performance. This mission based approach starts from the operational requirements, which typically are divided into categories like navigational, environment, capacities and logistics, support, special facilities all for both open and ice covered waters, winterization and safety standards.

The increased activity in the Arctic involves extreme hazards such as remoteness and lack of infrastructure, lack of information about bathymetry, among others. Ice cover is also highly variable and dynamic with increasing variation in future as due to the changing effects of the world climate. Even ice conditions on all ice-covered areas are under dynamic change. This effect on Arctic operations is a complicated task to solve. The remoteness of the Arctic areas means that in case of an accident, the search and rescue (SAR) capability is low. Also the fairways are not marked very extensively and especially the soundings taken for charting are relatively scarce. These Arctic hazards are compounded by the fact that the rate of recovery of the Arctic nature is slow, meaning that environmental hazards are made more serious.