Manning Analysis in Naval Ship Concept Design

Eric J Velez

Thesis submitted to the Faculty of
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Ocean Engineering

Alan J. Brown, Chair
Wayne L. Neu
Jon A. Greene

May 5, 2014
Blacksburg, VA

Keywords: manning, optimization, naval, automation

Manning Analysis in Naval Ship Concept Design

Eric J Velez

Abstract

The total cost of ownership of a naval ship is largely influenced by decisions made during concept design. In recent years the US Navy has undertaken numerous initiatives to reduce total ownership cost. This has prompted particular interest in reducing manning, as this is the largest single expenditure in total ownership cost. Normally ships are designed and then a study is performed to determine their required manning, but manning has a significant design impact and designs can either be too small to accommodate necessary manning or too large and costly if manning is overestimated. Manpower analysis implemented early in the design process and included in design synthesis could significantly minimize total ownership cost while optimizing ship design performance. The Department of Aerospace and Ocean Engineering at Virginia Tech has developed a Multi-Objective Genetic Optimization process to aid in ship concept exploration. This thesis describes a manning model created to be incorporated into this ship synthesis and optimization. DDG-51 guided missile destroyer manning is used as a baseline for a guided missile destroyer (DDGx) concept exploration. ISMAT (Integrated Simulation Manning Analysis Tool) discrete event manning tool is used to decompose complex ship operations into functions and tasks to build scenarios and assign crewmembers to accomplish maintenance and ship operations and ultimately calculate manning requirements as a function of ship mission, system, size, automation and maintenance strategy. The manning model results are then linked to the ship synthesis model and design optimization to determine an estimated crew number for a particular ship design. This thesis demonstrates that a manning estimation tool can effectively be linked to a naval ship concept exploration process and have a significant impact on selected designs.

Dedication

To the greatest gift I received in my life, my son Noah. His smiles have been the inspiration to complete this journey.

Acknowledgements

I would like to thank

- My advisor Dr. Alan J. Brown, for his guidance, understanding and support over these past two years.

- The United States Coast Guard for giving me the opportunity to attend graduate school.

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Motivation

An important recommendation made by the Government Accounting Office (GAO) to Congress [1] identified the reduction of manning as essential to reduce the overall life-cycle cost of US Navy ships. Manpower is one of the principal factors contributing to a ship's life-cycle cost. Government manpower reduction initiatives mandate changes in Navy policy, culture, and business practices to accomplish this goal. To reduce manning levels, the Navy must reassess their manpower allocation process on existing vessels and reconfigure the ship design process for new ships. Over the years, the Navy has made significant effort to reduce crew sizes on surface combatant ships, but most of this effort was made to current ships that are restricted by their existing architecture.

In an interview in 2003 the Commander of the Naval Sea Systems Command emphasized that:

> "You don't build a ship and then put men on it. You build a ship around the human when you start it. The man/machine interface becomes critical. And at the same time on every program that we are developing within NAVSEA's arena of influence, we're going to use this as a gauge to say; is that program properly addressing the human system integration requirement? And so this organization will examine how we have captured the features for human systems integration in whatever we're doing."[2]

A new ship design allows designers to implement emerging technologies into the design, balancing mission requirements with manning reduction initiatives. Existing ship manning requirements due to antiquated practices and dated systems can be avoided in the design process by investing in new operating practices and accepting more automation. Implementing emerging technologies means sailors will perform their jobs in a more efficient environment that does not requires the same level of manning to be effective. Consequently, more capable sailors may be needed to accomplish tasks completed by multiple crewmembers in the past. The overall product is a reduced manning level consistent with manpower reduction initiatives.

1.2 Background

In two separate reports by the Government Accounting Office (GAO) to Congress, the GAO asked the Navy to review and assess their current initiatives to reduce manning levels in surface combatant ships [1][3]. These changes were noted as necessary to help reduce the total ownership cost of new and existing warships. Furthermore the GAO report stated that a ship's crew was the single largest cost incurred over the ship's life cycle. Typically, ship's personnel account for up to 50% of the total Operations and Support (O&S) cost incurred by a ship throughout its lifetime. To counteract the increasing costs, the report calls for a change in design practices by incorporating Human Systems Integration (HSI) early in the design process. Bost and Galdorisi define HSI as a "recognized analysis and design methodology used to optimize ship manning at the lowest total ownership cost while simultaneously achieving the highest quality of service" [4]. This HSI discipline allows designers to build effective surface combatant ship platforms with fewer personnel.

The integration of workload reducing technology is fundamental to achieving cost reduction in the fleet. The decisions made early in concept design largely determine the ship's lifecycle cost. Therefore, conducting manning analyses as part of the design process is key to achieve total ownership costs reductions. Figure 1 illustrates the lifecycle cost of a surface combatant ship where decisions in the development stages drive the procurement and O&S costs. Ship designers have a number of options to reduce manning, but how to combine these and maintain ship effectiveness has proven to be a difficult task. Manning reduction strategies include new technology integration, automation, policy change, functions removed from the ship, and additional training for sailors. New technology integration requires smarter sailors who can perform under pressure. New technologies enable ship designers to add system automation, making the crewmembers supervisors of process and systems, and reducing the need for multiple operators. As a result of technology insertion there is an increased level of risk associated with manpower reduction that must be understood and considered in the design. Customers must determine if the ship cost savings and resulting effectiveness outweighs the risks.

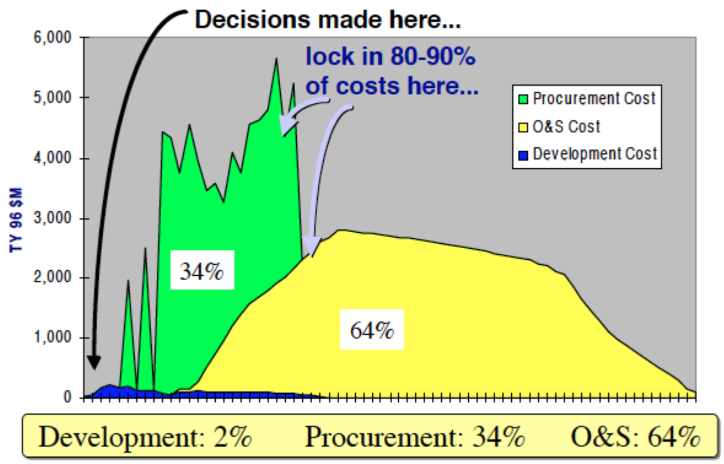

Figure 1 Surface Combatant Life Cycle Cost, Military Personnel Navy Action Needed to Optimize Ship Crew Size and Reduce Total Ownership Costs, G.A. Office, Editor, 2003, GAO. p. 54. Used under fair use, 2014.

Traditionally, manning analysis is one of the last steps in the design process. It is normally completed by a group of manpower experts and accomplished considering the ship's missions and systems installed on the design. A computer-based manpower optimization is a more complex approach where a series of design input variables are used to determine crew size for a given configuration of ship systems and level of automation. The insertion of a manning optimization tool can determine crew reduction by considering technologies that directly reduce crew workload while maximizing operational effectiveness for a given level of risk.

The Naval Research Advisory Committee defined optimal manning as depending on three important variables: total ownership cost (TOC), manning level and ship capability. Figure 2 shows a graph representation between the three variables used to identify the optimal manning point. Optimal manning represents the minimum crew meeting necessary capabilities at the lowest TOC. The crew size obtained from the graph meets the affordability, risk, performance and safety requirement goals for a ship's intended mission. This thesis considers cost, effectiveness and risk simultaneously with required manning.

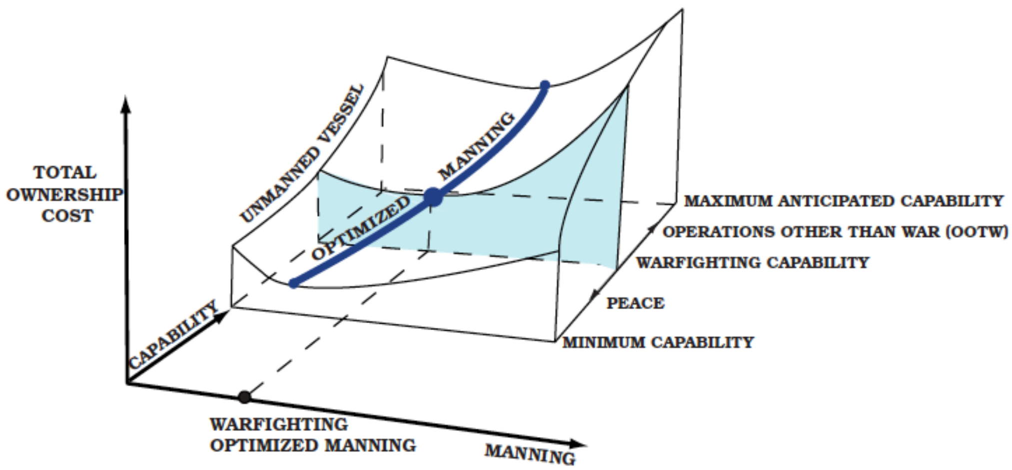

Figure 2 Optimal Manning Curves, Spindel, et al., Optimized Surface Ship Manning, N.R.A. Committee, Editor. 2000. p. 25. Used under fair use, 2014.

Naval ship design is a multi stage process, where ideas and decisions made early in the process have a subsequent impact on future design and construction. Concept design is one of the most important stages in this process, as decisions made during this stage define the final design. Brown describes past naval ship concept design as an "ad hoc" process, traditionally done by a group of design experts guided by their experience, design lanes, rules-of-thumb, preference and imagination [7]. Furthermore, communication and coordination between design disciplines requires significant designer involvement and effort. Ultimately, concept design studies continue until resources or time runs out [8]. Engineers try to synthesize decisions to meet design objectives, but the process becomes inefficient since numerous design configurations may arise from the design space that are never assessed in a structured way. A more efficient and systematic process is essential to search for non-dominated designs in the design space. One solution for this problem is the Multiple-Objective Genetic Optimization (MOGO) developed by Brown [6][7][8].

Dr. Brown's research recognized the importance of manning and automation in this process and conducted a study in 2005-2006 that developed a method using (now) Alion's Integrated Simulation Manpower Analysis Tool (ISMAT) to obtain early manning requirements as a function of ship mission, systems, size and level of automation [9]. This was very much a preliminary study, and it was necessary to revisit this study to implement new manning reduction techniques and automation options in a missile guided destroyer class ship.

1.2.1 Multiple-Objective Genetic Optimization

This thesis uses the Multiple-Objective Genetic Optimization (MOGO) for Naval Ship design developed by Brown [7]. This method considers a series of system combinations including hull form, propulsion, hull materials, combat systems, arrangements, and manning and searches at the design space to identify non-dominated designs. The optimization method enables designers to conduct a systematic comparison and trade-off analysis of output designs in terms of effectiveness, cost and risk.

Figure 3 illustrates a non-dominated frontier (NDF) where a series of ship designs in a design space are presented in a two objective attribute space. The intent is to show the designer how to best maximize effectiveness while minimizing design cost and risk. A preferred design must be selected from the non-dominated frontier (heavy curve). Brown describes a non-dominated solution as a "feasible solution for which no other feasible solution exists which is better in one objective attribute and at least as good in all others" [7]. Figure 5 represents a non-dominated frontier in a three objective attribute space (Life Cycle Cost (LCC), Overall Mission of Effectiveness (OMOE) and Risk). The points on the surface represent non-dominated solutions in the feasible region.

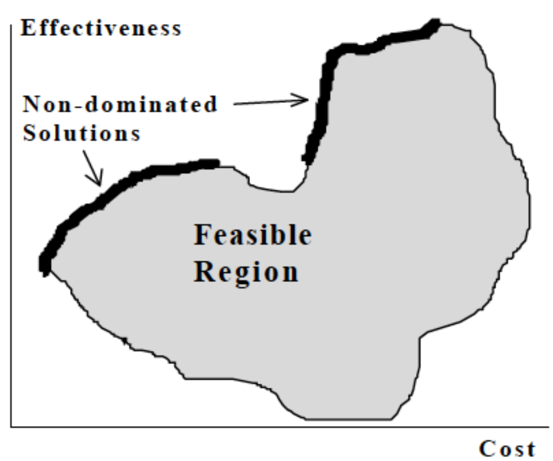

Figure 3 Two-Objective Attribute Space, Brown, A.J. and Thomas M., "Reengineering the Naval Ship Concept Design Process, From Research to Reality in Ship Systems Engineering Symposium. ASNE, 1998. Used under fair use, 2014.

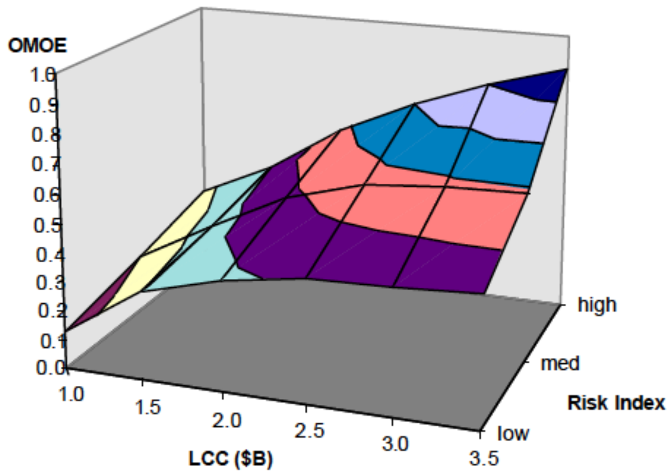

Figure 4 Three Objective Attribute Space, Brown, A.J. and Thomas M., "Reengineering the Naval Ship Concept Design Process, From Research to Reality in Ship Systems Engineering Symposium. ASNE, 1998. Used under fair use, 2014.

Designs are selected from the frontier by decision makers to further study and refine. Decision makers often prefer "knees in the curve". The "knees" are identified by squares in Figure 5 and represent major changes in the NDF slope. Normally, it is advantageous to make a design selection at the high effectiveness to cost slope.

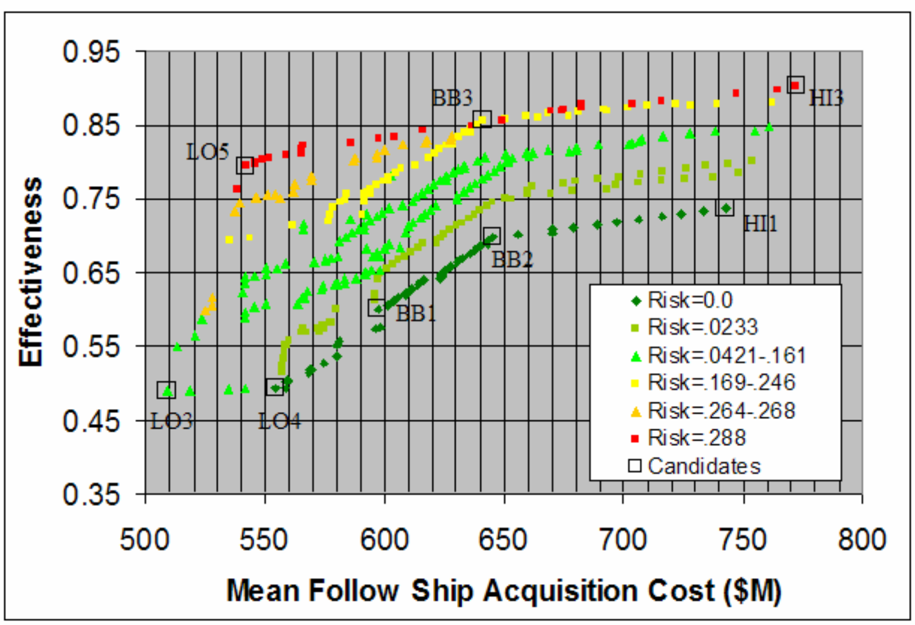

Figure 5 Non Dominated Frontier (NDF), Scofield, T., "Manning and Automation for Naval Ship Analysis and Optimization" Master's Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, April, 2006. Used under fair use, 2014.

In this thesis manning exploration and ship design multiple-objective genetic optimization are executed in Model Center (MC). Model Center is a computer-based design software created by Phoenix Integration that allows multiple engineering programs to work together and share design model components. This software permits the designer to access remote design programs and bring the data to one environment to perform trade studies, analysis and design space optimization. MC is an effective tool that saves the designer time and increases process effectiveness. The manning analysis presented in this thesis is used to calculate the manning requirements for a naval ship defined as a set of input design variable (DV) values. The output data is then used to build a surrogate-manning model. Then the surrogate model is implemented in the ship design synthesis and optimization.

1.2.2 Manning Analysis

Currently, US Navy manpower analyses are guided by a Ship Manpower Document (SMD). An SMD simply states the number and type of billets needed to man a particular ship class in its intended operations. This analysis is not performed early in concept exploration, but much later in the ship design process. The Naval Manpower Analysis Center (NAVMAC) leads the process with the cooperation of cognizant Type Commanders and Warfighting Enterprises. The SMD creation is summarized in the Navy Total Force Manpower Policies and Procedures (OPNAVINST 1000.16K). The components of an SMD for a ship are outlined below:

- Required Operational Capability (ROC)/ Projected Operational environment (POE) parameters and analysis.
- Directed manpower requirements
- Operational Manning (OM), also known as Watch stations.
- Preventive Maintenance (PM).
- Corrective Maintenance (CM).
- Facilities Maintenance (FM).
- Application of approved staffing standards.
- Workload measurement and analysis.

- Utility tasking (e.g., Underway Replenishment (UNREP), Connected or Vertical Replenishment, Flight Quarters (FQ), Sea and Anchor Detail, etc.).
- Allowances (e.g., Productivity Allowance (PA), Production Delay (PO))
- Development of officer requirements.
- Warfighting Enterprise, TYCOM, Enabler, and Activity review of draft documents.

The goals of SMDs are not to reduce cost or reduce manning, but to fill important roles in a ship to establish and maintain readiness. This type of analysis is slow and manpower intensive, making it inefficient for ship concept exploration that must often consider 1000's of designs. The naval ship design process implemented at Virginia Tech for concept exploration uses Top Down Requirements Analysis (TDRA), a much faster approach than the traditional SMD process. Thomas Malone first introduced the TDRA to assess approaches for workload and manpower reduction. Top Down Requirement Analysis employs HSI disciplines to maximize effectiveness and accuracy of the analysis. The TDRA process is used in this thesis in a much earlier stage than normally employed. Figure 6 shows the TDRA described by Malone.

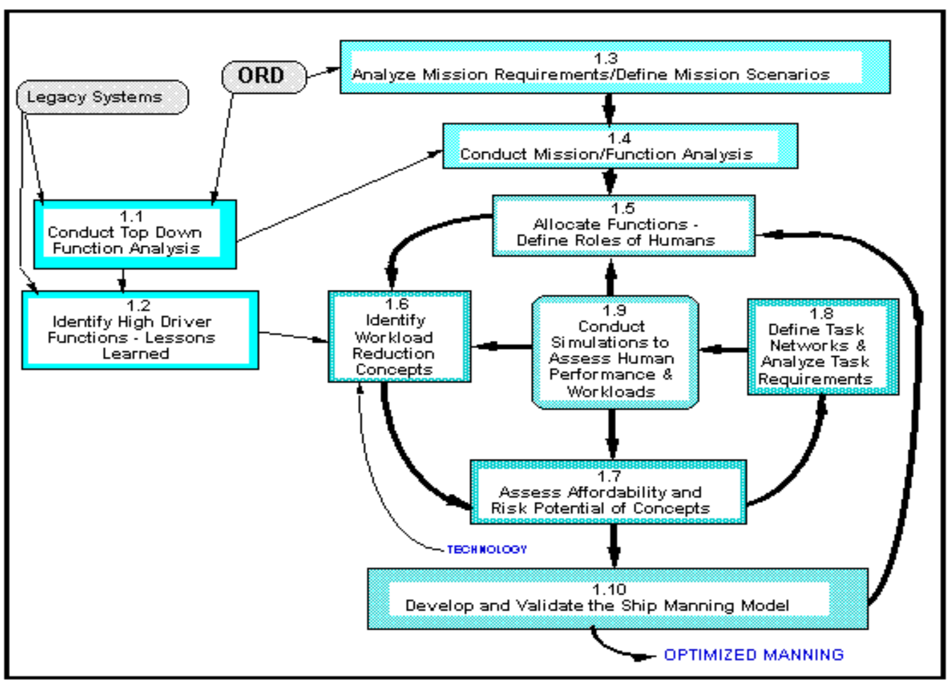

Figure 6 Top Down Requirements Analysis, Malone, T.B, "HSI Top-Down Requirements Analysis for Ship Manpower Reduction". [Internet] [cited 2014]. Used under fair use, 2014.

The TDRA process followed in this thesis is outlined below:

1- Conduct top-down functional analysis – identify ship's functions and requirements by WQSB positions and locations.
2- Identify high driver functions and lessons learned – compare with legacy system functions.
3- Analyze mission requirements and define mission scenarios from the Initial Capabilities Document (ICD). Mission scenarios are developed with different manning levels.
4- Allocate functions and defines roles of humans – assign personnel to functions.
5- Identify workload reduction concepts for different ship's systems.
6- Assess affordability and risk potential of reduced workload concepts.
7- Conduct mission/function analysis in ISMAT.
8- Integrate ISMAT results with ship design impact in a ship synthesis model/MOGO.

1.2.3 Manpower Reduction Initiatives

In recent years the Navy has conducted numerous studies on manpower reduction. One of the most common practices discussed is the introduction of new technology systems to assist ship personnel in making more effective decisions while performing their duties. New technologies currently implemented in the Navy incorporate various automation features permitting crewmembers to monitor entire power plants, combat and navigation systems from a central control station, CIC or the bridge with reduced personnel. Implementing newer technologies may also lower maintenance requirements and enable less labor-intensive repairs.

Technology alone is not enough to obtain significant manpower reduction results; there must also be a change in culture, policy, practices and procedures. Other options widely discussed to reduce manpower in ships are the outsourcing of ship's support services to land units and moving equipment maintenance to shore contractors. Furthermore, there are many experts that suggest future system technologies will allow ships to consolidate damage control repair lockers and reduce watch-standing sections [11]. Many of these initiatives are worthy and should be considered early in concept exploration. This thesis implements a number of these initiatives noting the advantages, risks and cost savings of each manpower reduction approach and determines their total ship design impact.

Figure 7 illustrates the results of a multi-phase study conducted by Hinkle and Glover for manning reduction in a DDG-51 [11]. The study presented three possible stages for manning reduction shown in Figure 7.

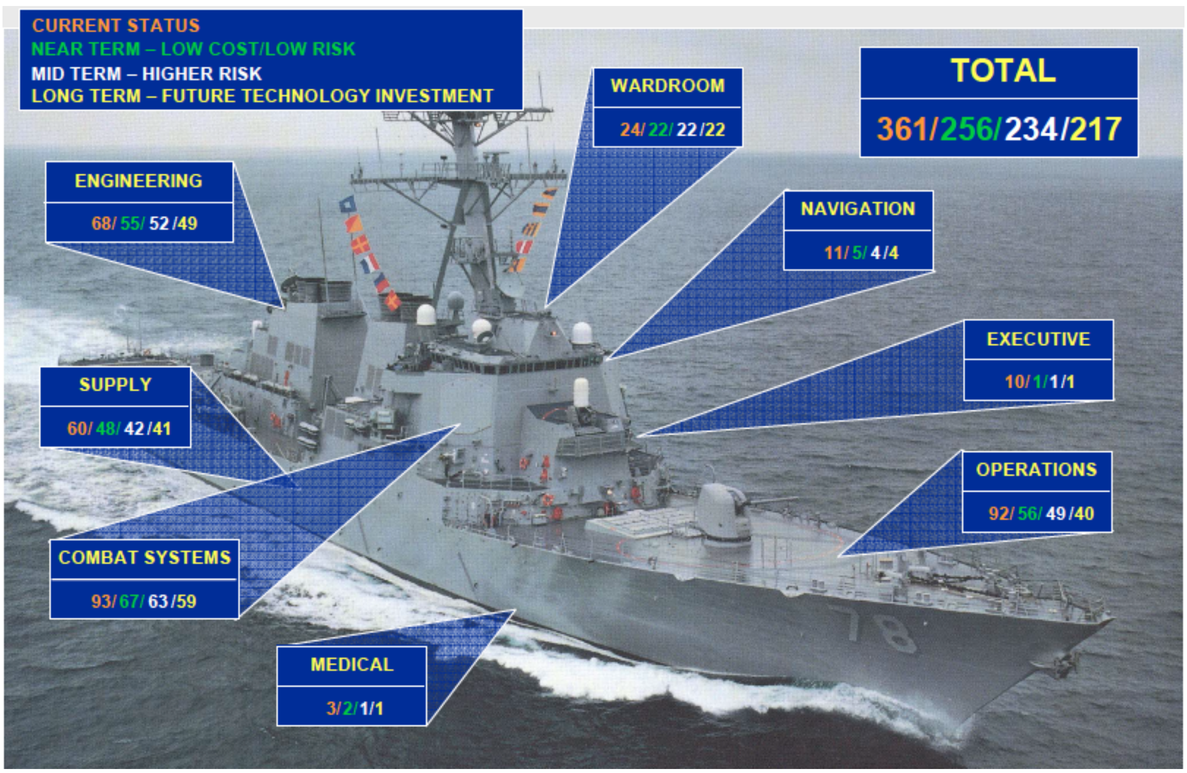

Figure 7 NAVSEA- DDG 51 Manning Reductions, Hinkle, J. and Glover, T., "Reduced Manning in DDG 51 Class Warships: Challenges, Opportunities and the Way Ahead for Reduced Manning on all United States Navy Ships", ASNE, Engineering the Total Ship Symposium, National Institute for Standards and Technology, March 17-18, 2004. Used under fair use, 2014.

The study considered changes in Navy policy to conduct operations and technology implementation to reduce personnel in the near, mid and long term future. Most of the assumptions for reducing personnel were made by technical and area experts, but the details of how these numbers were obtained are not provided in the paper. Significantly, the study identifies three areas of manning reduction initiatives needed to maximize a ship's warfighting effectiveness and reduce its O&S cost. Bost and Galdorisi describe the implementations of these initiatives as necessary to recapitalize and modernize the Navy [4].

The three manning reduction initiatives implemented in this study are:

1. Achieving economies of scale by moving many functions currently performed by the crew off the ship.
2. Accepting increased levels of risk by eliminating or consolidating watch stations and reducing some support and hotel services.
3. Investing in and implementing new technologies that reduce the number of sailors needed onboard.

It is noteworthy that their strategy for a 40% personnel reduction in a DDG-51 would have a significant positive impact in the Navy's strategy for reducing fleet costs.

The efforts of this study led to the Optimal Manning Experiment (OME) where manning reduction practices were implemented in DDG and CG class ships to understand the effects of reduced crew sizes on these platforms. Support from shore maintenance and a pay and personnel administrator (PAPA) detachment were incorporated as part of the OME with positive impact for future implementation. The OME participants submitted a lesson learned report with recommendations for manpower reduction techniques to industry. This report was studied in detail and some initiatives were incorporated in the DD(X) project (DDG 1000) [13].

1.2.4 Enabling Technologies in Manpower Reduction Initiatives

Technology implementation is an important component in the manpower reduction initiative. Designer teams are currently implementing technologies in naval ships using HSI, a sailor centric approach that evaluates engineering designs and workplaces around the sailor to maximize the design effectiveness. Enabling technologies like single multimodal watch stations (MMWS) provide real-time feedback to sailors and allow them to make informed and accurate decisions in multiple mission areas simultaneously from one station [13]. MMWS employs a centric human computer interface that provides all display screens needed for the watch stander to complete their tasks. The implementation of this intuitive display design in the interface improves workplace process and reduces the manpower required to maintain situational awareness and respond to developing scenarios. The Dual Band Radar (DBR) is another example where technology decreases the amount of personnel to operate. The DBR system is capable of operating over two frequency ranges (S-band and X-band) and only requires a single resource manager. The radar combines the functionality of the two radars to provide a higher level of performance and capability to detect and track hostile targets. One of the advantages of this radar system over it predecessors is that it does not requires a dedicated operator or manned display consoles. [14].

Bridge operations watch-standing technologies including GPS, automated route planning, electronic charting and navigation, collision avoidance, and electronic log keeping are also implemented for ship operations automation. For example, Wartsila IAS automation offers three variants of automation systems that can integrate multiple aspects of the ship. Propulsion systems, engines, and auxiliaries can be monitored from a central location with an easy to use interface. The entire system is integrated with alarms to provide the crew with situational awareness. Additionally, the system allows access remotely, eliminating the need for additional crewmembers onboard with technical knowledge. This product is a Commercial-off-the-shelf (COTS) type of technology that allows increased lifespan and low-cost replacement parts [15]. Reduction of man-hours spent monitoring ship mission readiness may be achieved through condition-based maintenance technologies, such as an Integrated Condition Assessment System (ICAS), trend analysis, expert assistance, link to Interactive Electronic Tech Manuals (IETMs), or an Integrated Survivability Management System (ISMS).

In engineering, the Integrated Power System (IPS) implemented in the DDG 1000 uses gas turbines to generate electricity, and then uses that power for propulsion, combat systems and ship services managed by an Engineering Control System (ECS) [16]. In a test conducted the designers elaborated on the system saying “ECS reports the current operating state, configuration, health status of power, auxiliary and damage control systems back to the operator for use in command/control, conditioned-based maintenance and operator engineering screens” [16]. The Engineering Control System allows a few operators to control the entire fully electric system. Simple human-machine interfaces can be called up on common terminals from multiple locations in the ship, providing redundancy and situational awareness. Coupled with a condition based maintenance system and a plethora of alarm and messages, this system provides a great opportunity to reduce manpower [17].

Damage control operations depend on a large part of the required personnel onboard. Crewmembers are assigned to man DC watch stations during different ship conditions, preventing the ship from using the personnel for other duties or removing them from the ship. The Autonomic Fire Suppression Systems (AFSS) was introduced in the DD(X) to automate and respond to damage control operations. This system eliminates the need for multiple crewmembers to be on stand-by to engage in these damage control situations. The AFSS features the ability to isolate damage to fire main piping components, detect fire, smoke and heat conditions using cameras and sensors. AFSS then activates suppression systems and suppresses fires using a water mist for suppressing peacetime machinery space fires and combat induced fires and sprinkling for magazines [18].

Traditionally, the process of loading ammunition into a naval gun is a manpower intensive process. The Otobreda 127mm/64 naval gun is a weapon system developed by OTO Melara. The intended use for the gun is surface fire and naval surface fire support (NSFS), with a secondary anti-air warfare (AAW) role. While this gun is very similar to the DDG-51 Mk45 Mod 4 5"/62 gun, a major advantage over the Mk45 Mod 4 is the automatic ammunition handling system [19]. Another combat system option is the Advanced Gun Systems (AGS) from BAE Systems currently use in the DDG 1000. The AGS is similar to the Otobreda gun and is capable of launching projectiles over the horizon in very quick succession with accuracy. This system combines gun control and fire control elements within the AGS architecture for seamless integration to the total ship-computing environment allowing control with minimum personnel [20].

Although outsourcing admin personnel to shore units is currently being evaluated for fleet implementation, one of the most promising technology initiatives for reduced administrative workload is the R-Rider system. Developed in 2012 by Logistics Specialist 2nd Class Joseph

Williams of the USS Theodore Roosevelt (CVN-71), R-Rider has the "capability to route awards, basic allowance for housing requests, evaluations, special request chits, leave chits, and more, all with a few clicks of a mouse." This technology, or another based on it, would greatly reduce the amount of paper needed aboard a ship. With less paper the ship will be lighter, operating costs will decrease, and administrative workload will greatly decrease. Paperwork requiring the signature of the CO or XO can be viewed and processed in nearly half the time of the paper based system, and there is potential to eliminate billets entirely. As of April 2014, there are no new updates on the development or implementation of the R-Rider system, although the program is promising for fleet wide adoption [21].

To reduce the crew sizes in unit support personnel, the Navy is incorporating centralized galleys to reduce the number of culinary specialists onboard. Streamlined food inventory control and automated provision access has also been implemented. This food service management system has been used in a variety of USN platforms. It is Windows -7 based, and has a simple user interface with drop down tabs. It is coupled with a barcode system to simplify the process of receipt, stowage, and issue of the products [22]. This system reduces inventory and can order items automatically.

Table 1 Enabling Technologies Summary

Technology	Departments benefited from Technology	Description
Single Multimodal Watch Stations (MMWS)	Operations, Engineering, Weapons, Navigation	Human computer interface that provide watch standers with multiple display screens to complete their tasks from one station.
Dual Band Radar (DBR)	Operations, Navigation	Type of radar that combines the functionality of the two radars to provide a higher level of performance and capability.
IAS automation	Navigation, Operations	Automation systems that can integrate multiple aspects of the ship.
Integrated Condition Assessment System	Engineering	Automatically analyzes vibrations in the ship's engineering equipment and generates an automatic work order for repair

Technology	Departments benefited from Technology	Description
Integrated Power System (IPS)	Engineering	Power plant that uses electricity to power propulsion and combat systems.
Engineering Control System (ECS)	Engineering	Human-machine interface for ECS monitoring.
Autonomic Fire Suppression Systems (AFSS)	Engineering	Automate and responds to damage control operations by activating fire suppression systems.
The Otobreda 127mm/64 naval gun	Weapons	Surface fire and naval surface fire support gun with automatic ammunition handling system.
Advanced Gun Systems (AGS)	Weapons	Surface fire and naval surface fire support gun with automatic ammunition handling system.
R-Rider system	Executive, Admin	Initiative for reduced administrative workload by eliminating paperwork routing.
Streamlined food inventory control automated provision	Logistics	Food service management system program for inventory tracking and ordering.

1.3 Thesis Objectives

The objectives of this thesis are:

- Explore and improve current tools for performing naval ship manning analyses.
- Develop functional mission scenario to incorporate in the manning model for a DDG ship.
- Develop DDG maintenance manning data consistent with design options.
- Improve the current synthesis model design by implementing a DDG manning model analysis tool within the context of system architecture.
- Develop a DDG manning model implementing automation and other manning reduction options.
- Integrate the DDG manning model into the Ship Synthesis Model and MOGO.
- Provide recommendations to improve manning prediction in concept exploration.
- Develop manning risk register.
- Provide conclusions about total ship impact of manning reductions.

1.4 Outline

Chapter 1 provides an introduction and motivation for implementation of a manning estimate module in a multi-objective ship synthesis model as a continuation of a previous study.

Chapter 2 investigates the tools and methods that are currently available for conducting shipboard manpower estimates, describes each tool examined with the advantages and disadvantages, describes methods and tools selected for determining manpower requirements in concept design.

Chapter 3 describes the DDG manning model developed in this research.

Chapter 4 applies the manning model to a VT ship design case study.

Chapter 5 documents the results of the VT case study and discusses total ship impact of manning reductions.

Chapter 2 Naval Ship Manning Analysis Process

2.1 Current Methods and Analysis Tools

Designers have used discrete event simulation in the past to help them understand the relationship of manning and work systems. P. Ball describes discrete event simulation "as one way of building up models to observe the time based (or dynamic) behavior of a system" [23]. A discrete event simulation consists of a series of tasks creating a time-based event to form a scenario. Although not fully integrated with the ship design process, new software for discrete event simulation is now available and used for military and commercial applications. Discrete event simulations have permitted designers to model interactions between personnel and work systems in order to estimate crew levels. One of the discrete event simulations available is Micro Saint Sharp. Micro Saint Sharp is a discrete event simulation software package program from Alion MA&D Operations. Wetteland describes Micro Saint Sharp as "a discrete-event task network simulation tool that stochastically models the impact of human interaction in system operations of varying complexity and can provide realistic outcome expectations" [24]. One of their software models available to conduct manning analysis is the Total Crew Model (TCM). This dynamic simulation predicts crew capabilities to perform required duties and estimate crew fatigue levels. TCM looks at Watch Quarter Station Bill (WQSB) manning requirements from a dynamic perspective to determine the adequacy of a proposed crew complement [25]. TCM uses Microsoft Excel to record its data for crew assignments, daily schedule, and manning requirements (Figure 8). Simulations are run to determine if the crew can accomplish the operational tasks in the scenario within acceptable fatigue levels. With the model results, designers can make adjustments in crew assignments to optimize the crew size. This software is limited for military use and was not available for this thesis. One of the major drawbacks for this model is that equipment and maintenance are not considered directly in the model.

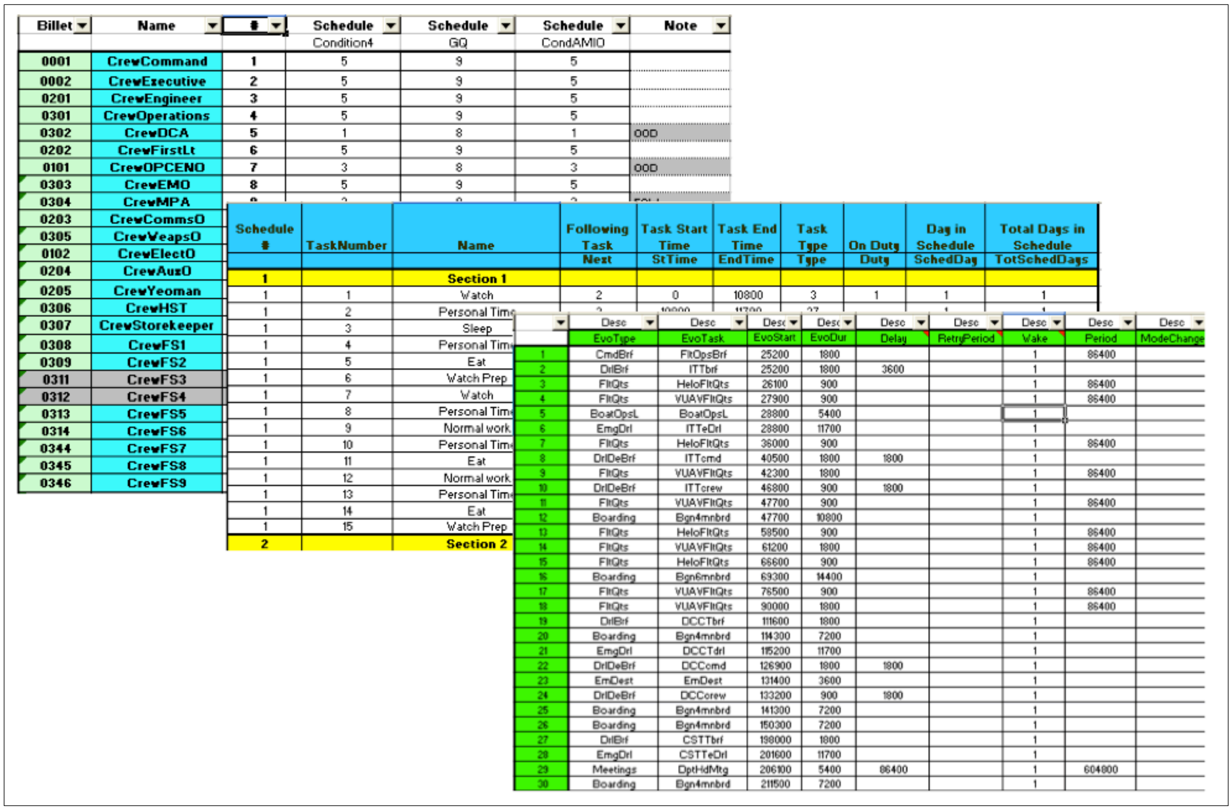

Figure 8 TCM Microsoft Excel Sheets (Crew list, Schedule, Scenario), Scofield, T., "Manning and Automation for Naval Ship Analysis and Optimization" Master's Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, April, 2006. Used under fair use, 2014.

Ship Manning Analysis and Requirements Tool (SMART) is another software model used with Micro Saint Sharp. SMART was a US Navy-funded project to create a manpower-modeling tool. The SMART Build 3 program supports a flexible analysis approach in which analysts can apply different levels of fidelity to manning analysis and automation alternatives. The software conducts functional analyses on shipboard operations, facilities maintenance, unplanned corrective maintenance, and preventative maintenance. SMART assesses the impact of reduced manning levels due to automation and crewmembers operator allocations on the performance of systems given different levels of automation required and allocation to crewmember operators. Users can then evaluate and trade-off performance factors to determine the ultimate affordability of the new system [9].

Watch Stander Model (WSM) is another software model that uses Micro Saint Sharp for its simulation. This is a complex method consisting of task networks, scenarios and manning hypotheses. The model builds a series of tasks and evaluates the crew's ability to perform these mission tasks. The user can measure the effectiveness of each watch stander and compare it to the manning plan.

Integrated Simulation Manning Analysis Tool (ISMAT) was used for this thesis. Similar to these other simulation tools, ISMAT also uses Micro Saint Sharp for its task network analysis. Similar to SMART, the ISMAT tool includes equipment, manning and compartment libraries. These files are in XML format and can be edited or new files can be created for new ship analyses. Designers can simulate complex scenarios and apply varying levels of manning and automation alternatives to reduce crew size. To use ISMAT, the user must first load the equipment, manning and compartment files corresponding to the ship on which the analysis is to be performed. Users then create scenarios by adding functions and then populating tasks into those functions. Crewmembers are assigned to a task or the task can be fully or partially automated. A series of functions create a scenario and are given start and stop times to build a schedule. One of the advantages of ISMAT is that it provides a solution for the optimal crew manning level based on the designer's goals by sequentially reducing manning until task performance becomes unacceptable.

These discrete event simulation programs enable designers to explore manning levels, automation, and maintenance configurations for new ship designs, but to actually apply these manning analyses to the total ship design they must be incorporated into a ship synthesis model.

2.2 ISMAT Top Down Requirement Analysis Process

In this thesis the TDRA process is followed to create an ISMAT manning surrogate module for application in a ship synthesis model. Scofield first introduced this method in a previous manning study conducted at Virginia Tech [9]. The results obtained by Scofield in his research proved to be reasonable and therefore the same approach was selected for this study but the process was more completely structured and documented. Analogous to his research, the ISMAT tool was also selected for this manning study. Equipment files were created for a DDGx, varying the types of systems in the files consistent with the propulsion and combat systems to be considered in the DDGx design synthesis. A compartment list for a DDGx was also developed and loaded with the facility maintenance (FM) associated with each compartment. Finally, a baseline crew list for a DDGx was developed as the baseline model to include in the ISMAT scenario file. The DDGx crew list included enlisted ratings and officers categorized by departments and divisions. Once these files are loaded into ISMAT the user can create a scenario, given the mission and requirements set by the customer. The user changes the types of systems in the ship designs by varying the equipment files representing different equipment systems available for a ship. The user can also select to reduce crew levels by eliminating or consolidating tasks in the design that can be outsourced to support units. Each equipment system has unique features that can reduce manning by automating the process, requiring less maintenance or fewer personnel. The equipment lists selected by the user are run in the scenario to determine the minimum crew size needed to perform the tasks in the scenario.

2.3 Ship Analysis Strategy- Concept Exploration

The first step in the Concept and Requirements Exploration (C&RE) process shown in Figure 9 and introduced by Brown [12], is to define the mission and operational goals and thresholds outlined by the Initial Capabilities Document (ICD). The ICD is expanded to include a greater level of detail by incorporating: a more complete Concept of Operations (CONOPS), Navy Mission Essential Task List (NMTL), a Design Reference Mission (DRM), Operational Situations (OpSits) and Required Operational capabilities (ROCs), all to create and develop Measure of Effectiveness (MOEs), Measures of Performance (MOPs) and Operational Effectiveness Models (OEMs). Next, a design space is defined by considering the available technology options that provide required capabilities to accomplish the mission. Before starting the Ship Synthesis Model (SSM) the (C&RE) process requires a more comprehensive exploration in six areas: hullform and deckhouse geometry, machinery and propulsion, mission systems, structures, manning and automation, and survivability.

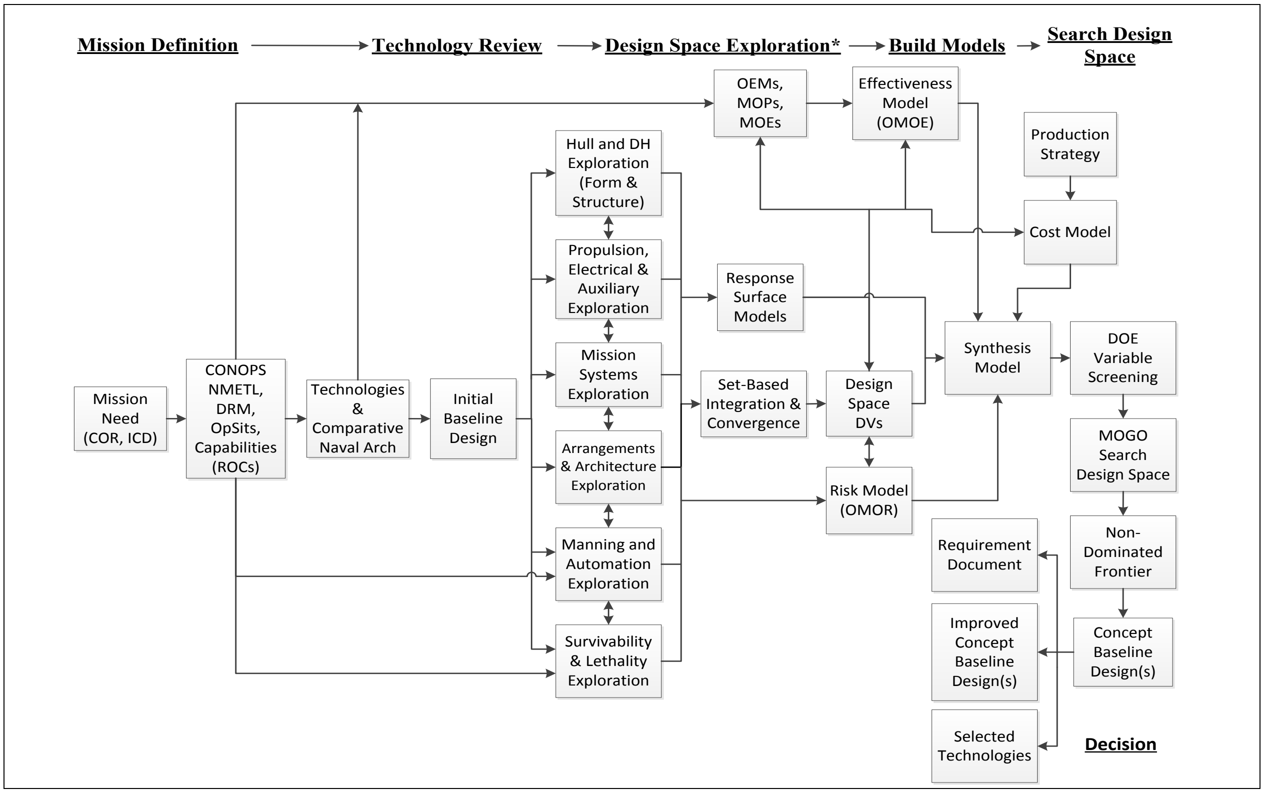

Figure 9 Concept and Requirements Exploration (C&RE) Process, Brown, A.J. and Waltham-Sajdak, J., "Still Re-Engineering the Naval Ship Concept Design Process", paper presented at ASNE Day, 2014. Used under fair use, 2014.

The data collected from these studies using a design of experiments (DOE) allows the designer to identify dominant variables and to later build response surface models (RSMs) that approximate relationships between the input design variables and response characteristics for use in the design specific ship synthesis model. A Design of Experiments is used in MC to create a data sample relating the crew size to the input design variables that represent the design space. In this thesis, a scenario is created to assess manning requirements given a certain ship design. The scenario typically consists of functions and tasks that must be completed by the ship and crew to accomplish a mission. If the crew cannot accomplish these tasks the ship design will not be feasible. In the SSM, variables and design options are assembled in Model Center (MC) where modules synthesize ship designs using the multi-objective optimization. ISMAT is run in a MC DOE to collect crew size data. The data results are approximated using a response surface model (RSM) and added to the SSM as a surrogate manning model “Man_Mod1” (Figure 10). Then the SSM evaluates the feasibility of the design space given the different maintenance, equipment, compartment, and automation levels to estimate a minimum manning level. The data obtained is used in the MOGO to evaluate the cost, risk and effectiveness of the designs. Finally, the results of the MOGO are presented in a risk-cost-effectiveness plot where the user may select a concept baseline design from the non-dominated frontier.

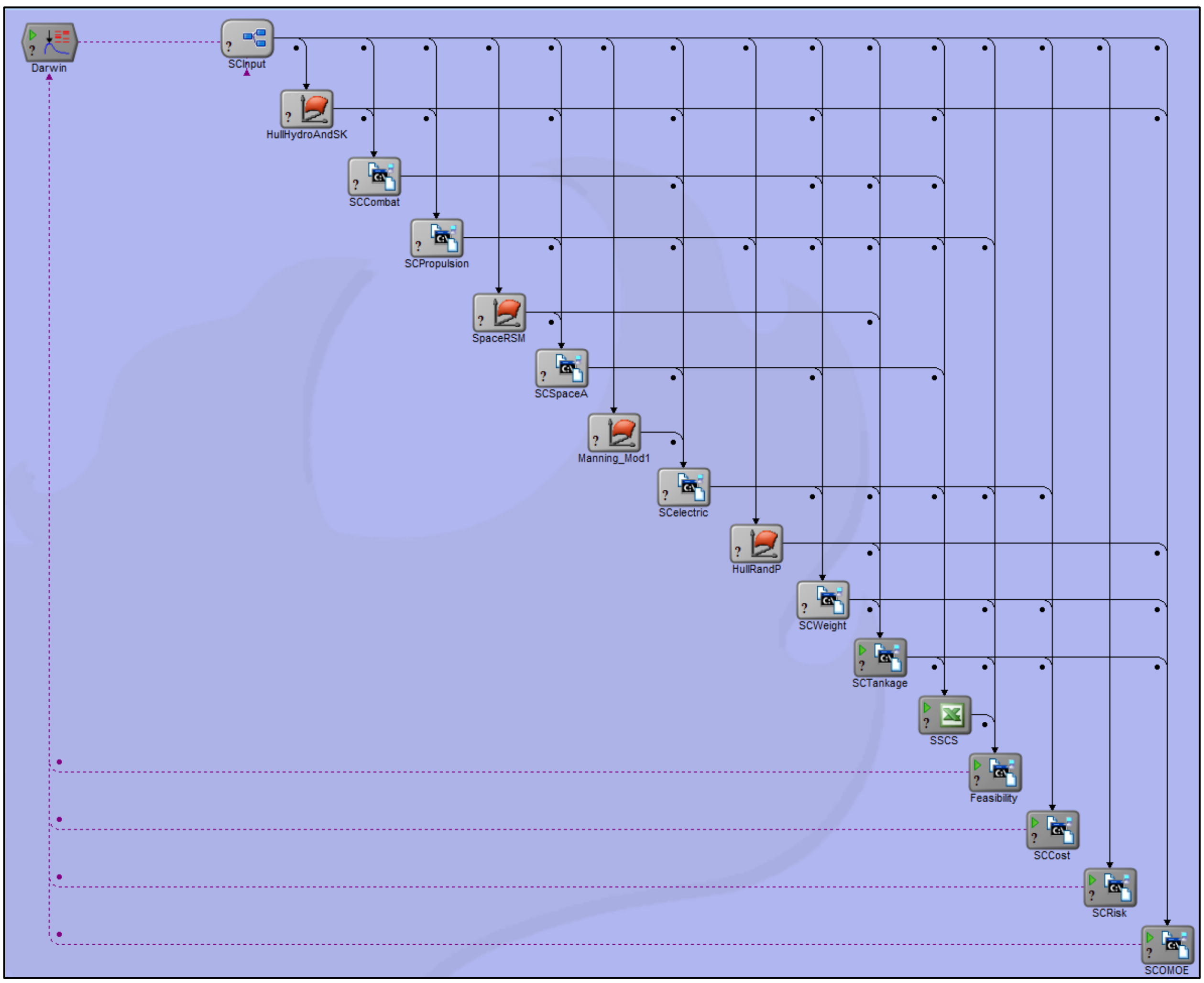

Figure 10 Ship Synthesis Model and MOGO in Model Center

Chapter 3 Naval Ship Manning Model

3.1 Overview

The surrogate manning model created from the ISMAT DOE data will ultimately receive its design variable input from the input module in MC as part of the ship synthesis model (SSM). The process to create the surrogate manning model is:

1. Run ISMAT in a MC DOE and collect data (manning exploration model).
2. Study the results.
3. Build a surrogate RSM with the ISMAT DOE data.
4. Insert the RSM in the SSM.

We use a manning exploration model to perform manning and automation exploration. It uses a simple visual basic code in MC to interface with ISMAT as shown in Figure 11. The model loads the necessary files for equipment systems (AAW, ASUW, ASW, PSYS, AIR), maintenance level (Maint), and manning and automation factor (CMAN) into ISMAT to calculate the minimum crew needed to accomplish the mission scenario with a particular design. The equipment systems used in the model require different levels of manning for maintenance and operation.

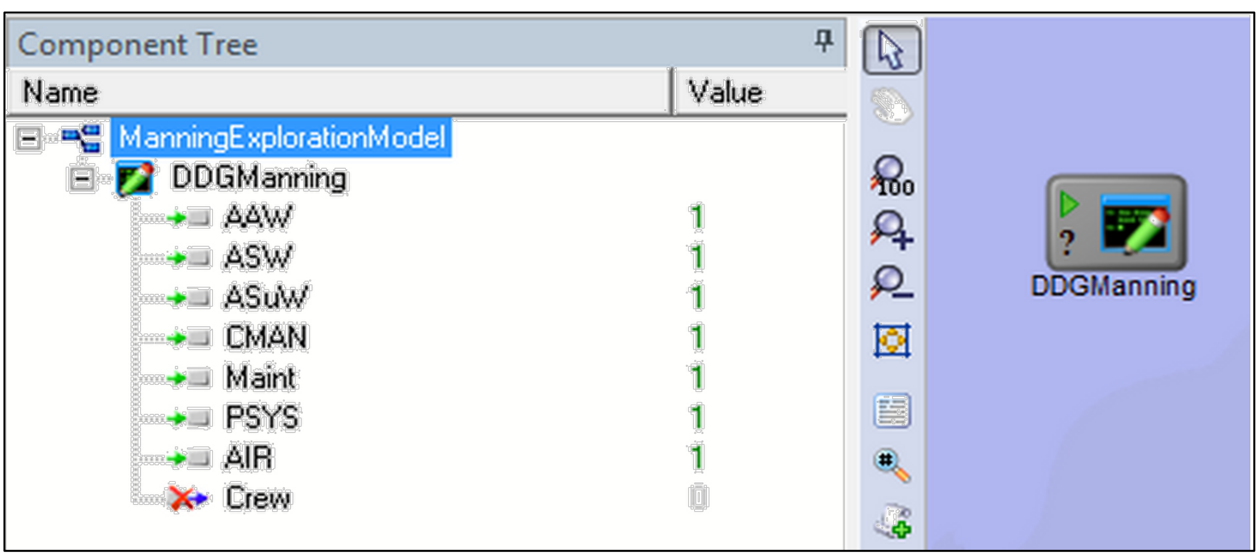

Figure 11 Manning Exploration Model, ISMAT and MC interface

The manning and automation factor (CMAN) design variable (DV) is used to specify the crew workload reductions for the different equipment systems due to automation (Table 2). In addition, some tasks in the scenario can be removed from the ship and outsourced to shore personnel. These actions are also specified as a CMAN option. The maintenance DV (Maint) is used in the model to specify who performs maintenance tasks in the scenario or whether the work is performed by a shore activity (Table 2).

Table 2 CMAN and Maint Design Variables (DV)

DV	Option	Description
CMAN	1	Baseline manning level. All crewmembers in the crew list are assigned to daily tasks.
	2	Administrative personnel and personal services are removed from tasks and outsourced.
	3	Watch standing automation for WQSB Condition III and General Quarters events and tasks
	4	Food services automation is implemented, centralized galleys and pre-prepared food menus.
	5	Administrative personnel and personal services are removed from tasks + Watch standing automation for WQSB Condition III and General Quarters events.
	6	Administrative personnel and personal services are removed from tasks + Food services automation is implemented, centralized galleys and pre-prepared food menus
	7	Watch standing automation for WQSB Condition III and General Quarters events + Food services automation is implemented, centralized galleys and pre-prepared food menus.
	8	Administrative personnel and personal services are removed from tasks + Watch standing automation for Condition III and General Quarters + Food services automation is implemented.
Maint	1	Crew completes all equipment preventive maintenance.
	2	Crew completes equipment preventive maintenance tasks up to and including annual tasks.
	3	Crew completes equipment preventive maintenance tasks up to and including monthly tasks.

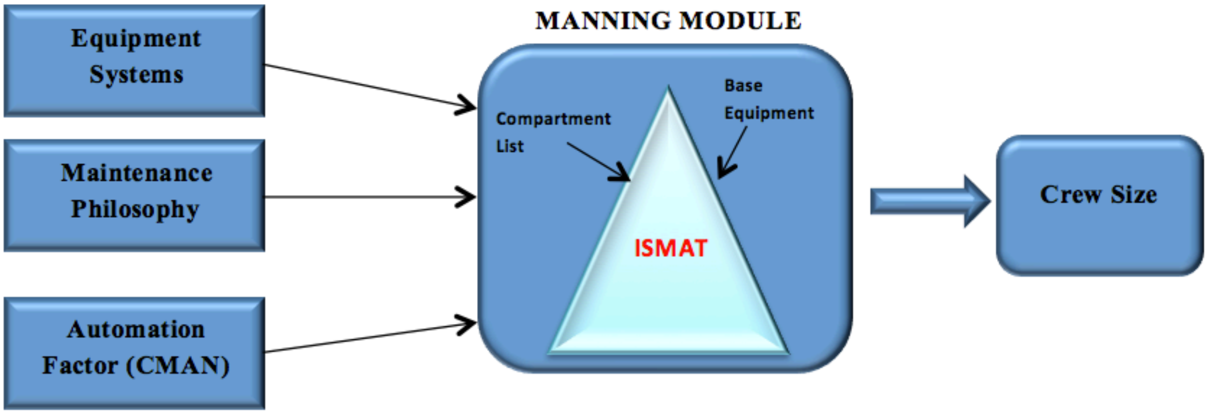

Figure 12 Manning Exploration Model

Figure 12 shows the process methodology for the manning module followed in this study. A DDG crew list is created to use as a baseline manning document to reduce and optimize in ISMAT (Appendix E). Equipment and compartment files are also created to input into the ISMAT manning model. Different equipment files are required for each equipment configuration for combat, propulsion, and machinery systems given the values for different design and maintenance level options. These files specify associated scheduled routine equipment maintenance for each system. The crew list is loaded into an ISMAT file with the scenario variations that represent the different automation and manning factor options selected. In ISMAT the personnel in the crew list are assigned tasks in the event operational functions defining the scenarios. To execute the simulation from Model Center, a code in Visual Basic (VB) was modified from Scofield's [9] study to manage these inputs, interface with ISMAT and obtain a crew size for the DDGx. The VB code reads input data and loads the compartment file, equipment files with appropriate maintenance level, and the scenario for a specified level of automation into ISMAT. Model Center inputs the data through the VB executable and runs input configurations in ISMAT to output crew size. This can be done manually or using a DOE in Model Center (MC). Inputs are explained more fully in Section 3.2. MC is able to perform a variety of DOEs and build RSMs using this ISMAT interface. Ultimately an RSM is built as a surrogate manning model and inserted into SSM. Manning Exploration, DOEs and RSMs are described in Sections 3.3 – 3.5.

3.2 Manning Exploration Model Inputs

3.2.1 Model Scenario

A representative 7-day ISMAT scenario was developed to examine the crew's capability to accomplish its mission given different ship equipment, watch standing requirements and automation configurations. In the scenario, crewmembers are assigned to functions and tasks representing normal watch standing and ship's work on a naval surface combatant. A series of these together forms a mission scenario. The tasks in the functions must be manned by crew members to accomplish the function event operations. The functions used to build the scenario are described in the following list:

- Prepare ship for movement – Before departing the crew must conduct equipment system checks, prepare navigation plans and brief personnel on the upcoming mission.
- Special Sea and Anchor Detail - Crew is assigned to special stations whenever the ship leaves and enters port. This event is a critical operation due to the nature of mooring, anchoring, getting underway, and maneuvering in restricted waters. The mission requires trained and experienced personnel to complete the functions safely. Some of the task locations required for this function include: Bridge, Machinery Control Center, Forepeak, Fantail and the Command Information Center.
- Condition III (Watch Sections I, II & III) – Represents normal peacetime cruising operations. Crew watch sections are assigned to stand watch on a 1 in 3 duty rotation, working 4 hours and having 8 hours off. Tasks are assigned to crewmembers according to the Watch Quarter and Station Bill (WQSB). They are assigned to different ship locations where equipment monitoring and operation is required.
- Ship's Work – During normal ship working hours there are numerous administrative and maintenance tasks occurring in the ship. Not all crewmembers are assigned to a specific job for all WQSB events. If a crewmember is not assigned to a watch during working hours they are assigned to administrative or maintenance jobs. These jobs are summarized as daily crew task occurring from 0800-1700.
- General Quarters - In this event all battle stations are manned to engage an enemy force or deal with an emergency. Every crewmember on the crew list is assigned to a watch

position in the ship. This WQSB assignment structure permits a rapid response to other emergency events including damage control situations.

Functions are composed of tasks linking together "Start" and "End" tasks. Adding a series of tasks together creates a function that then forms a scenario when combined with other functions. Tasks are assigned to crewmembers and the sum of these determines the function duration.

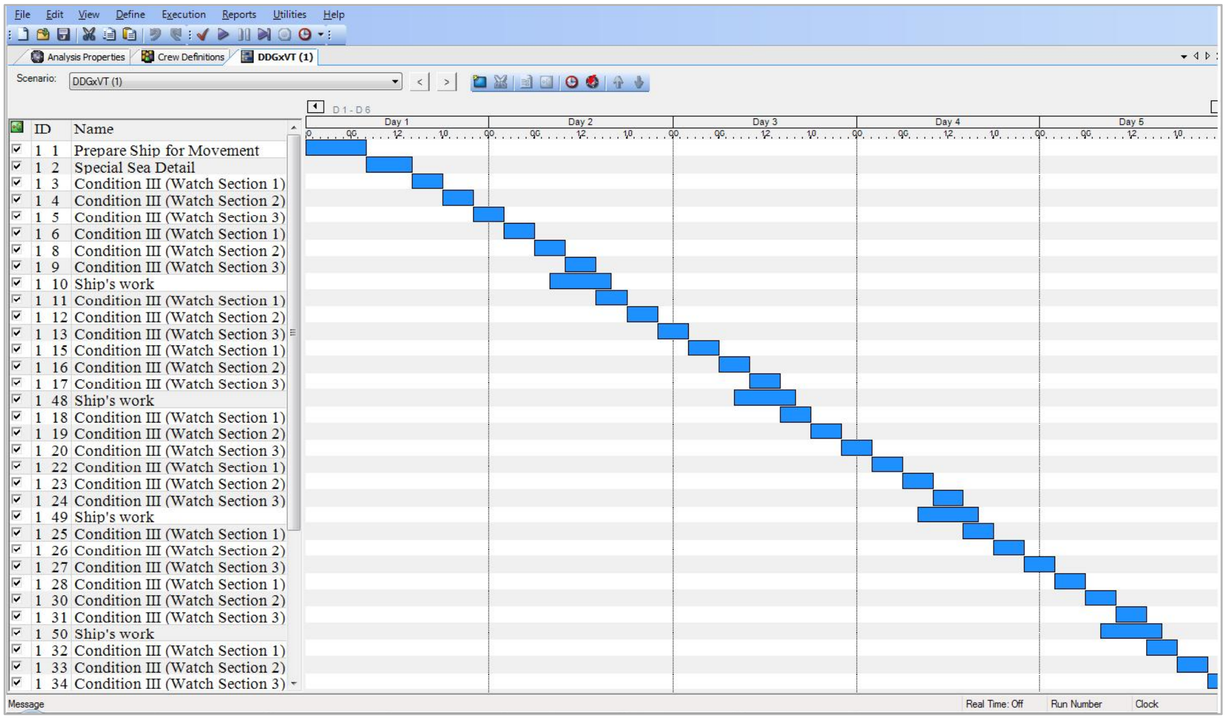

Figure 13 ISMAT DDGx Schedule Scenario

Figure 13 shows a portion of a 7-day scenario schedule in a Gantt chart. The horizontal blue bars represent the time and duration of the functions in the scenario. The clock in ISMAT controls the occurrence of each function in the scenario.

After examining the crew assignments in a WQSB, the locations for these watch assignments are identified and used to label tasks forming the functions. Each ship has a unique WQSB that is outlined by their ship Organization and Regulation's Manual. For example, the Condition III function shown in Figure 14 illustrates tasks defining the watch stations manned by the crew during this evolution.

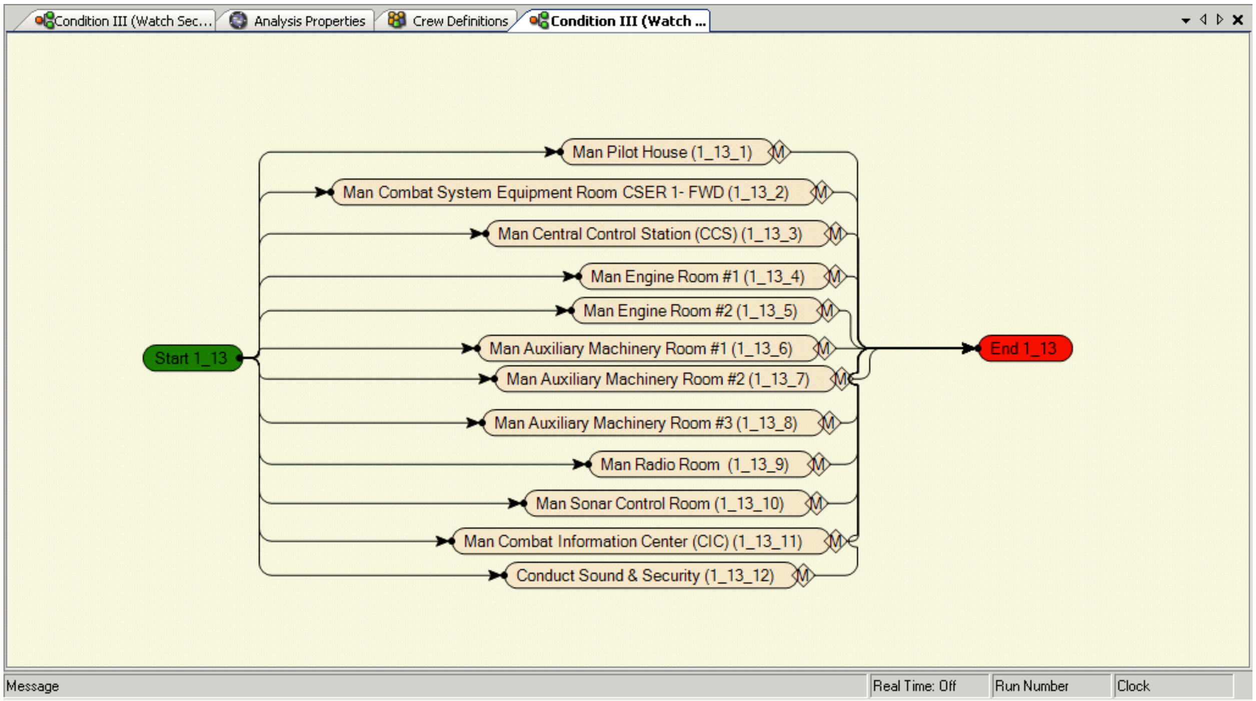

Figure 14 ISMAT Condition III Function

Ship's personnel in the watch section are allocated to these tasks to build the function. The crew that is assigned to a task cannot start on another task until they have accomplished the first one. Each task is allocated multiple possible crewmembers, the minimum number needed to accomplish it, and the rate/qualification of the crewmember. This allows ISMAT to maximize the use of available crewmembers assigned to multiple tasks and remove the excess. This permits the program to reduce the crew size depending on the user input. One advantage of building the functions this way is that they can be copied and pasted and used multiple times in the scenario. For the scenario shown in Figure 13 a three Section Duty Watch rotation using the Figure 14 function and others is implemented for the scenario simulation. The duration of the Figure 14 function is 4 hours.

3.2.2 Crew List

ISMAT contains a library of SMDs for a number of USN ships including a manning document for a DDG-51. The ISMAT crew list contains skills and annual cost for each crewmember. These features were not employed for this study but can be used in future research studies to determine manning costs. In addition the user can also modify the standard workweek a crewmember is allowed. For this study this was set to 72 hours (at sea). A manning document ".ismd" file can be edited or created, but it is limited to include only Navy enlisted ratings already defined by ISMAT. In our study, the existing DDG-51 manning document in the operator library was loaded into ISMAT and modified there for the scenario. The "Crew Definitions" tab in ISMAT permits the user to edit the crew list and selects crewmembers for the scenario (Figure 15). The crew list created this way stays with the ISMAT scenario file.

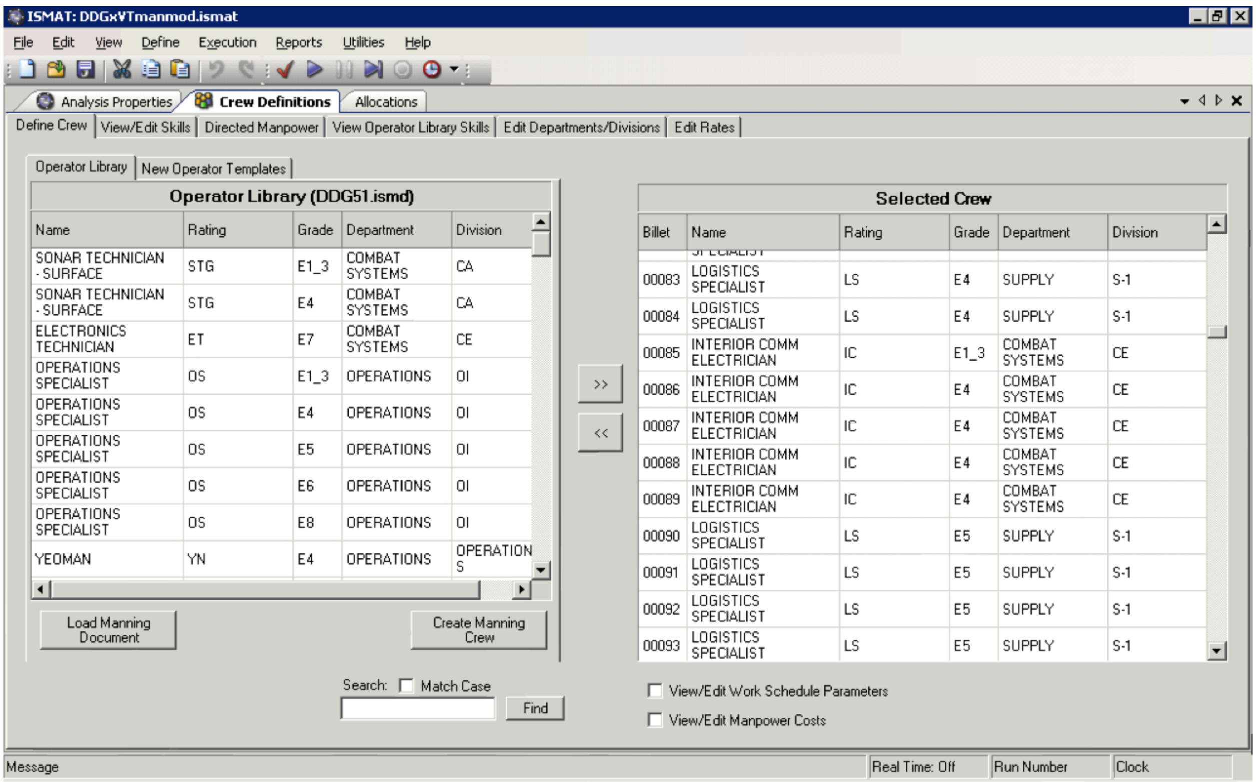

Figure 15 ISMAT Scenario Crew Allocation

The ISMAT DDG-51 manning document was modified extensively to represent a current SMD for a new DDG. Disestablished and merged enlisted Navy ratings were changed to current Navy ratings. In addition, the crew list's department and division categories were renamed and reorganized to de more current. The baseline crew list used in our study was represented as a 363- man crew with 28 Officers and 16 CPOs. Table 3 is the officer crew list added to the selected crew window for the scenarios.

Table 3 DDGx Officer Crew List

POSITION	RANK	DEPARTMENT
COMMANDING OFFICER	CDR/O5	COMMAND
EXECUTIVE OFFICER	LCDR/O4	EXECUTIVE
OPERATIONS OFFICER (OPS)	LCDR/O4	OPERATIONS
CIC OFFICER	LT/O3	OPERATIONS
FIRST LT	LT/O3	OPERATIONS
NAVIGATOR	LT/O3	OPERATIONS
COMM OFFICER (COMM)	LTJG/O2	OPERATIONS
ENGINEERING OFFICER (ENG)	LCDR/O4	ENGINEERING
DCA	LT/O3	ENGINEERING
MPA	LT/O3	ENGINEERING
AUX OFFICER	LTJG/O2	ENGINEERING
ELECTRICAL OFFICER	CWO/W3	ENGINEERING
WEAPONS OFFICER (WEPS)	LT/O3	WEAPONS
WA DIV OFFICER (ASW)	LTJG/O2	WEAPONS
WO DIV OFFICER (GUN+MISSILES)	LTJG/O2	WEAPONS
COMBAT SYSTEM OFFICER (CSO)	LCDR/O4	COMBAT SYSTEMS
CF/CG DIVISION OFF (GUN FC)	LT/O3	COMBAT SYSTEMS
CM/CX DIVISION OFF (MISSILE FC)	LT/O3	COMBAT SYSTEMS
CS MAINT MANAGER	LTJG/O2	COMBAT SYSTEMS
CA DIVISION OFF (ASW)	LTJG/O2	COMBAT SYSTEMS
SYSTEM TEST OFFICER	LTJG/O2	COMBAT SYSTEMS
CE DIVISION OFF (ELECTRONICS RPR)	CWO/W3	COMBAT SYSTEMS
SUPPLY OFFICER	LCDR/O4	SUPPLY
DISBURSING OFFICER	LTJG/O2	SUPPLY
SH-60B PILOT	LT/O3	AIR
SH-60B PILOT	LT/O3	AIR
SH-60B PILOT	LTJG/O2	AIR
SH-60B PILOT	LTJG/O2	AIR

For the purpose of this study, crewmembers assigned to tasks must be qualified to complete them. It is also assumed that the crew onboard is trained to complete the jobs related to their rating. Figure 16 shows the crew assignment for the "Man Pilot House" task. All other tasks are assigned crewmembers in a similar way.

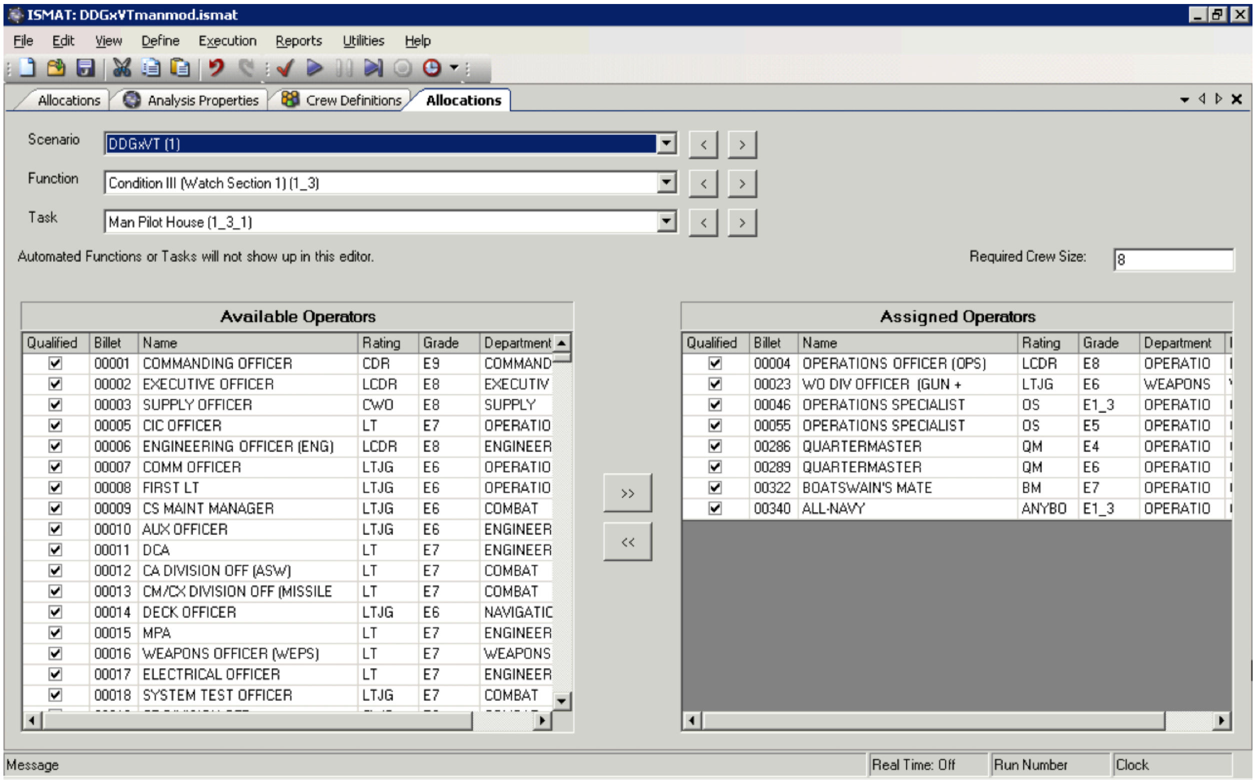

Figure 16 Crew Assignment- "Man Pilot House" Task, Condition III Watch Section 1

3.2.3 Ship Compartments

A compartment file is also required to run an ISMAT simulation. In naval ships, compartments contain machinery, communications equipment, combat systems, and accommodations among others things, some of which must be manned by crewmembers, all of which must be maintained Compartments must be maintained and cleaned by the crew to remain effective and to conduct its mission. ISMAT uses ships compartment maintenance in its simulations to calculate manpower. ISMAT does not provide a DDG-51 compartment file in its library so a compartment list for the DDGx was built in ISMAT using a CG-47 class ship as a starting point. For this study the compartment space remained constant in the ISMAT simulation although areas would change with different designs. The compartment files are written in XML code and contain different facility maintenance (FM) tasks required for the space, the time it takes to complete them and how often they must be performed. XML Notepad 2007 editor was selected to create the ".icmp" file. Figure 17 shows a portion of the "DDGxVT.icmp" file created for the study using XML Notepad.

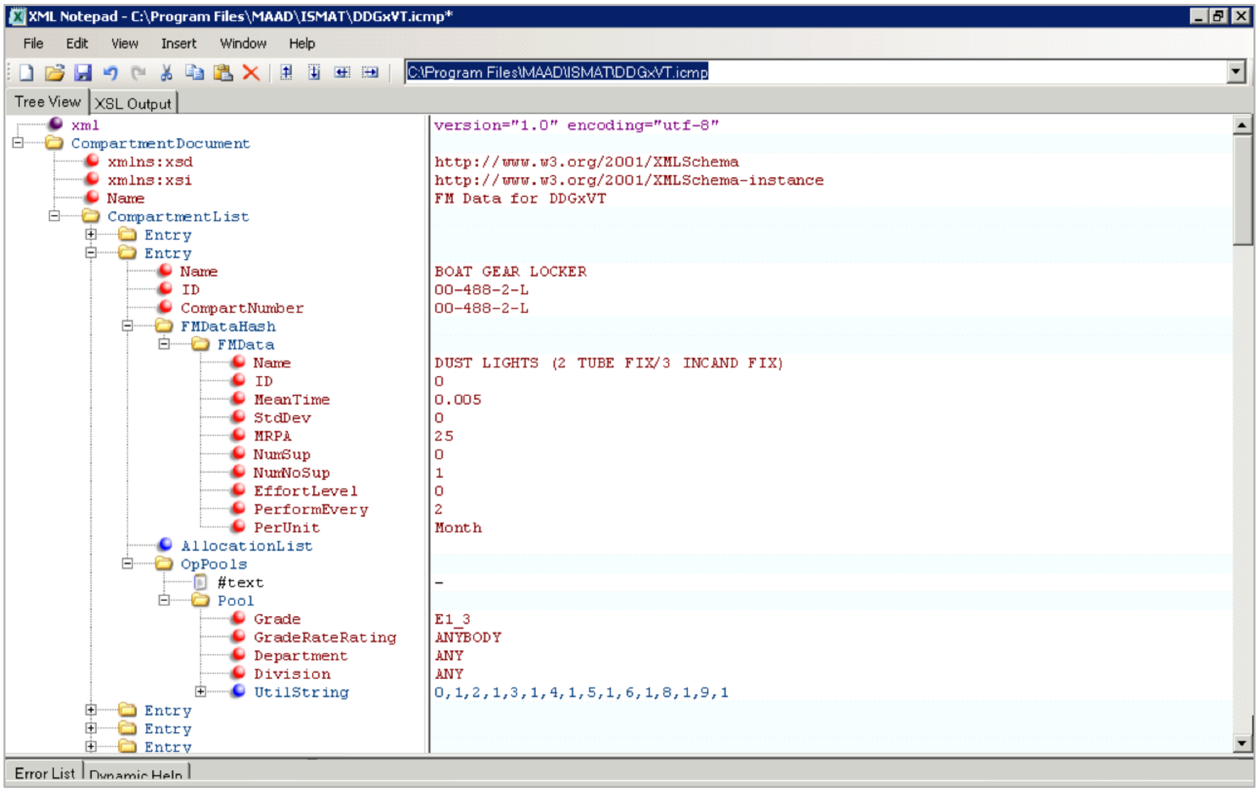

Figure 17 DDGxVT Compartment List

To create a compartment space “Entry” under the compartment list, the user must populate the FM data. These data details specify the FM job tasks required for the space. For this study only FM tasks of less than a year “Per Unit” and performed less than once a year “PerformEvery” were considered. In addition, an “OpPools” tab was added under each “Entry” folder to provide the manning module in ISMAT a pool of crewmembers available to perform the space FM in the scenario. This process is further explained in Section 3.2.5. The DDGxVT file built for the model contains the required facility maintenance (FM) given the default “MeanTime” values to accomplish the FM and the crew library to conduct the job tasks.

3.2.4 Ship Equipment

During Concept Exploration multiple equipment systems are evaluated for implementation. Each system considered has different operator, service and maintenance requirements that must be satisfied with the available personnel. ISMAT contains a library of US Navy ship equipment files that are used to run simulations. The equipment files are in XML code format and contain preventive maintenance (PM) and corrective maintenance (CM) requirement data. These files are generated from NAVSEA PMS data CDs and are converted to ".ieqd" extension files so they can be run in ISMAT. To create files with new equipment if no PMS CDs are available, the user can manually enter the equipment details and maintenance information following the process described in the ISMAT User's Manual [26]. The equipment files for each vessel include over 1000 equipment pieces plus the PMs and CMs requirements for each one. Having the PMS files certainly improves the equipment file speed creation process in contrast with manual creation where the process can be very time consuming and slow. To create the equipment files for this study a DDG-51 file was used from the program library as a baseline document. Equipment identified in ship design variables were removed from the DDG-51 equipment file and the remaining file is renamed to BaseM1. DV related equipment was then added back in separate files as required for DV option selection. The equipment options considered in the study are:

- AAW/SEW/GMLS/STK – Anti-Air Warfare/Signal & Electronic Warfare/Guided Missile Launching Systems/Strike Warfare
- ASuW/NSFS – Anti-Surface Warfare/Naval Surface Fire Support
- ASW/MCM – Anti-Submarine Warfare/Mine Countermeasures
- AIR – Air Support
- PSYS – Propulsion

DV-specific equipment cut from the DDG-51 equipment file are pasted into new design option files created using XML Notepad. Equipment items from other ships could also be added to create different equipment options. New equipment systems not in use by the Navy could also be entered into a file using existing equipment item entries as a template. The format of these files are very specific as shown in Figure 18 and any mistake in the file format prevents ISMAT from running properly.

AAW_SEW_GMLS_STK_1_M2.ieqd - Notepad

File Edit Format View Help


```
<?xml version="1.0" encoding="utf-8"?>
<EquipmentDocument xmlns:xsd="http://www.w3.org/2001/XMLSchema" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
HullClassSymbol="GUIDED MISSILE DESTROYER" Name="DDGxVT" ID="DDGxVT">
  <EntryList>
    <Entry Name="Active-Receiver Beamformer (ARBF)" ID="Active-Receiver Beamformer (ARBF)" Cost="0" Redundant="false">
      <PMs>
        <PM Name="Inspect and Clean Active-Receiver Beamformer (ARBF) Unit.&#xA;Perform annually and after maintenance, prior
to deployment and as required to secure equipment prior to entering a hostile environment." ID="EYZ5" MRC_MIP="4688/017/EYZ5"
MeanTime="1" StdDev="0" MRPA="0.15" NumSup="0" NumNoSup="1" RR="1 STG/E4 1 STG/E3" EffortLevel="100" PerformEvery="1"
PerUnit="Year">
          <Allocs />
          <Skills />
        </PM>
      </PMs>
      <CMs />
      <AllocationList />
      <PMAllocationList />
      <CMAllocationList />
      <OpPools>
        - <Pool Grade="E4" GradeRateRating="STG" Department="COMBAT SYSTEMS"
Division="ANY"><UtilString>EYZ5,1</UtilString></Pool></OpPools>
    </Entry>
    <Entry Name="MISSILES, ASROC X 8" ID="MISSILES, ASROC X 8" Cost="0" Redundant="false">
      <PMs>
        <PM Name="Prepare AFT Clock Converter Cabinet to Enter a Hostile Environment.&#xA;Perform (as appropriate) before
pre-shock trial preparations, predeployment, availability/overhaul periods, custody transfer, setting of DEFCON 2, or as
required to secure equipment for shock before entering a hostile environment." ID="FPLZ" MRC_MIP="4840/008/FPLZ" MeanTime="1"
StdDev="0" MRPA="0.15" NumSup="0" NumNoSup="1" RR="1 FC/E4" EffortLevel="100" PerformEvery="1" PerUnit="Day">
          <Allocs />
          <Skills />
        </PM>
        <PM Name="Prepare AFT clock converter cabinet to enter a hostile environment.&#xA;Perform (as appropriate) before
pre-shock trial preparations, predeployment, availability/overhaul periods, custody transfer, setting of DEFCON 2, or as
required to secure equipment for shock before entering a hostile environment." ID="XCFW" MRC_MIP="4840/JP1/XCFW" MeanTime="1"
StdDev="0" MRPA="0.15" NumSup="0" NumNoSup="1" RR="1 FC/E4" EffortLevel="100" PerformEvery="1" PerUnit="Day">
          <Allocs />
          <Skills />
        </PM>
      </PMs>
      <CMs />
      <AllocationList />
      <PMAllocationList />
      <CMAllocationList />
      <OpPools>
        - <Pool Grade="E4" GradeRateRating="STG" Department="COMBAT SYSTEMS"
```


Figure 18 DDGx AAW/SEW/GMLS/STK Equipment

The best approach to build these files is to use XML Notepad Editor since this program allows adding equipment without affecting the format. The XML Notepad program format is shown in Figure 19.

When all the equipment items are entered with their PMs, the design files are saved with the design equipment name, number option and maintenance level. For example, the equipment system design option saved as “AAW_SEW_GMLS_STK_1_M2.ieqd” corresponds to the first AAW option with a maintenance level 2. The equipment maintenance levels are created by modifying the baseline design option files by reducing equipment PMs to reflect a change in required maintenance. This process is further discussed on Section 3.2.5.

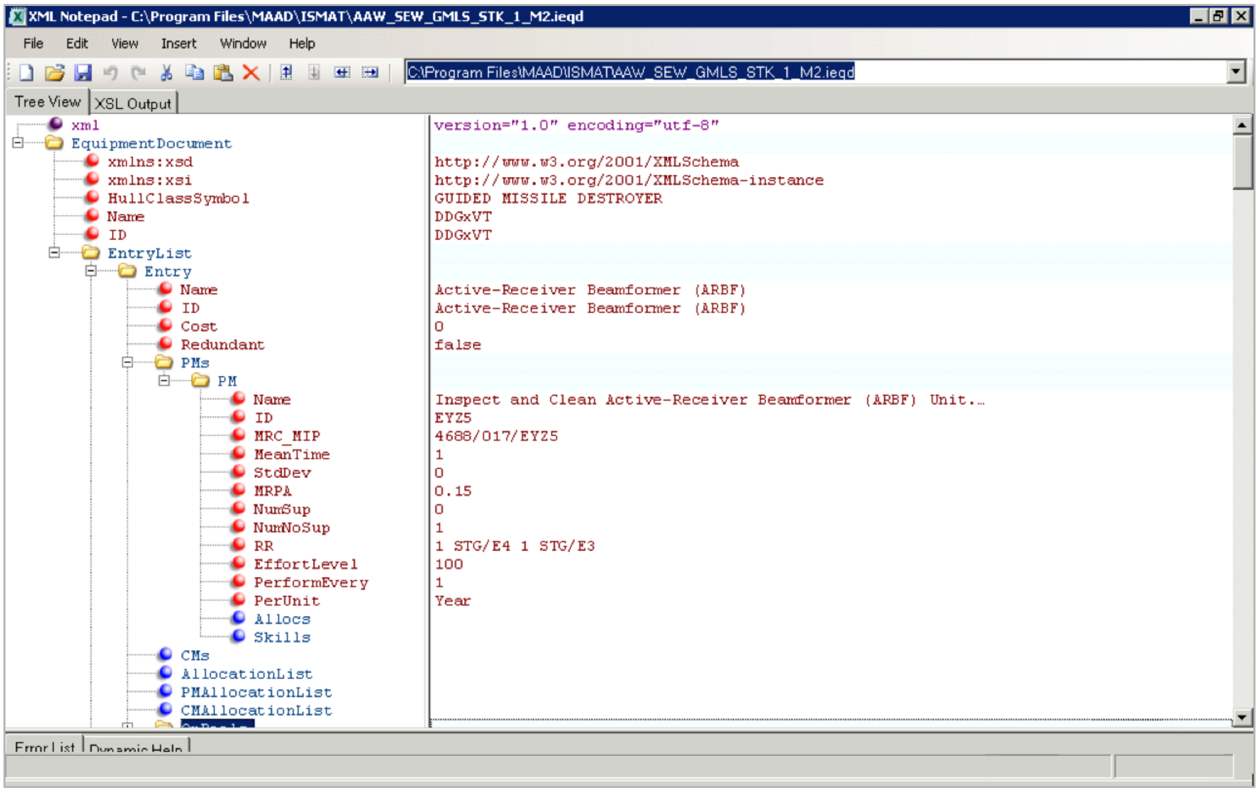

Figure 19 AAW/SEW/GMLS/STK Equipment file in XML Notepad Editor

3.2.5 Maintenance Level

ISMAT follows the US Navy's current maintenance approach to develop SMDs. The three types of maintenance considered by the Navy are: preventive maintenance (PM), corrective maintenance (CM) and facility maintenance (FM). Preventive maintenance is included in the equipment files as time-base scheduled work performed on the equipment to keep it in service. Some of the PMs included in the ".ieqd" files for the equipment systems are to test, inspect, conduct systems checks, clean, and lubricate among many other tasks to keep the equipment operational. Each PM entry contains a schedule interval that indicates how often this maintenance must be performed (Day, Week, Month, Quarter, Year). In addition, the PM data contained in the file indicates who should do this PM and how long it takes a crewmember to complete it. To reduce manpower, Navy leaders have considered outsourcing PMs to shore Navy [11]. Implementing a new system that requires fewer PMs or that can be guided remotely from shore is another possibility to reduce crew personnel. Implementing a manning level philosophy of PM reduction is considered in this study. To implement this philosophy, separate maintenance level files are built for each design option equipment file. Maintenance levels for the manning level are described below:

- Maintenance Level 1 - The crew is assigned to complete all equipment PM tasks. No work is outsourced to shore units, contractors or eliminated.
- Maintenance Level 2 – The crew is assigned to complete all equipment PM tasks up to and including annual tasks. Other PM tasks are outsourced to be completed when they are necessary.
- Maintenance Level 3 - The crew is assigned to complete all equipment PM tasks up to and including monthly tasks. Other PM tasks are outsourced to be completed by shore units when they are necessary.

These reduced maintenance requirements can reduce number of crewmembers from the DDGx crew list. To run the manning model, design option equipment files must be created for each maintenance level. These equipment files are created by opening the baseline equipment files and deleting the PM tasks consistent with the specified maintenance level. To assign personnel to equipment a code string must be added at the end of the equipment entry to define a pool of qualified operators available to perform the PM task. The code to insert is:

```
<OpPools>
     -  <Pool Grade="XX" GradeRateRating="XXX" Department="XXXXX"
        Division="XXX"><UtilString>XXXX,X</UtilString></Pool>
        </OpPools>
```

Figure 20 Equipment/Compartment Operator Pool Code

Figure 21 illustrates an operator pool allocation for a PM task named “Measure Insulation Resistance” with an ID number that is used to assign personnel in the pool folder below. “MeanTime” indicates that it will take one hour to complete the task that is scheduled to be conducted every Quarter. “RR” is the recommended rate to complete the PM, and is used as guidance to assign the personnel in the pool. In the OpPools folder the grade, rating, department, and division can be specified to narrow the operator pool. Finally, “UtilString” calls the PM to be completed with an ID number followed by the number of crewmembers required to perform it.

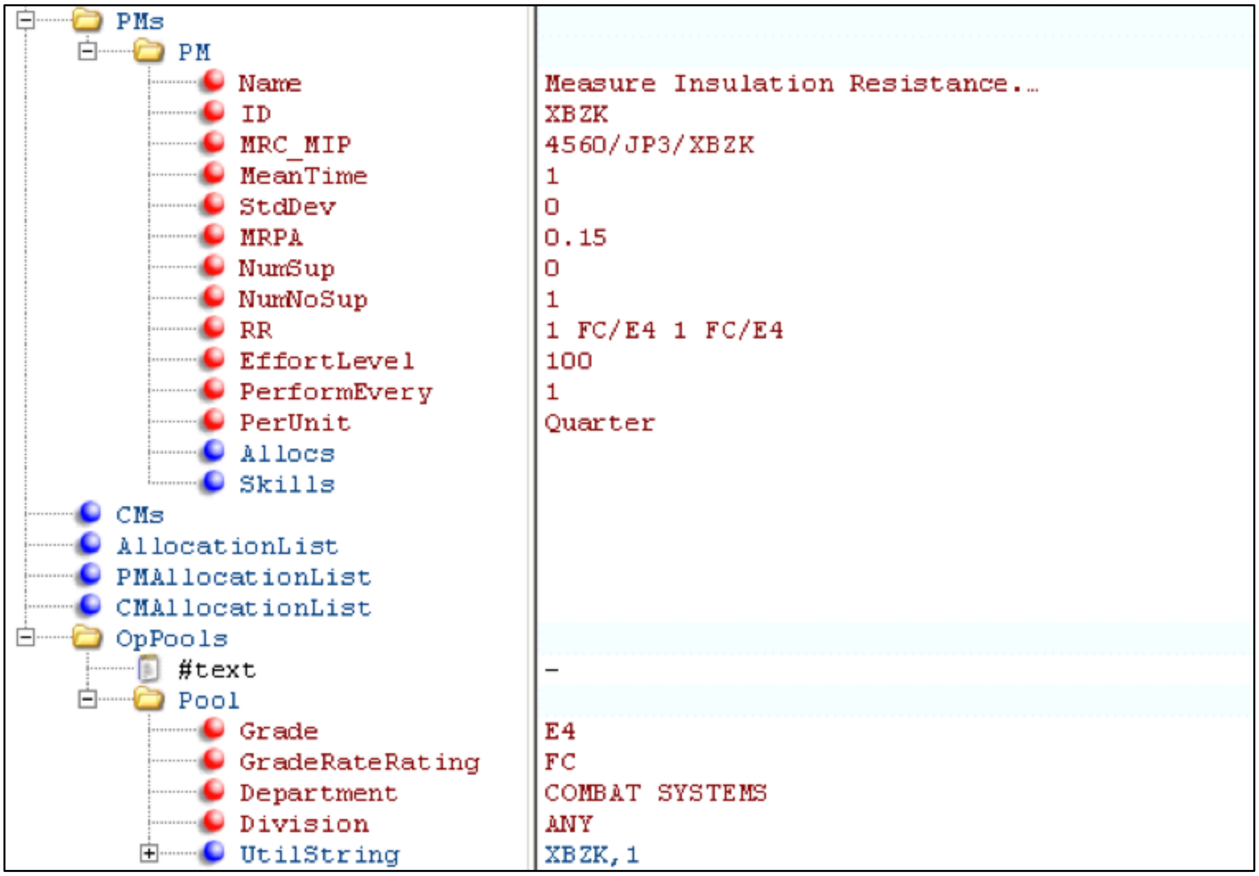

Figure 21 Equipment PM Operator Pool XML Notepad

The second type of maintenance in the equipment files is corrective maintenance (CM) actions. CM is an unscheduled type of maintenance occurring when equipment fails due to malfunction or deterioration and needs to be repaired by the crew. ISMAT uses the particular equipment use over time to create a probable casualty for the crew to handle in the scenario. The CMs tasks were not included in the equipment files since they were considered as operations covered in the Ship's work function.

Facility maintenance (FM) is the last type of maintenance task and refers to the upkeep of compartments in the ship to maintain their material condition. The types of FM tasks in the compartment files are to sweep, swab, dust, scrub, and paint spaces. In Navy ships junior crewmembers are normally assigned to these routine maintenance tasks. The same crew assignment approach is followed for the scenarios in this research. To assign crewmembers to

FM tasks the code in Figure 20 is entered in the compartment file code under the considered compartment entry.

To run the manning model simulation, a maintenance variable "Maint" is created in the manning model Visual Basic (VB) code. Model Center inputs an option number for the Maint variable and an equipment option that will select a file with the specified maintenance level to be loaded in ISMAT. This approach permits ISMAT to evaluate all combinations of maintenance strategies and equipment in the simulation. Each equipment file option created is labeled with equipment system names and maintenance levels. Table 3 illustrates equipment files created to run in the manning module given different design options and maintenance levels.

Table 4 Equipment Systems File Matrix

Equipment Systems	**Option**	**Maintenance Level 1**	**Maintenance Level 2**	**Maintenance Level 3**
Base Equipment	-	BaseM1	BaseM2	BaseM3
AAW/SEW/ GMLS/STK	1	AAW_SEW_GMLS_STK_1_M1	AAW_SEW_GMLS_STK_1_M2	AAW_SEW_GMLS_STK_1_M3
	2	AAW_SEW_GMLS_STK_2_M1	AAW_SEW_GMLS_STK_2_M2	AAW_SEW_GMLS_STK_2_M3
	3	AAW_SEW_GMLS_STK_3_M1	AAW_SEW_GMLS_STK_3_M2	AAW_SEW_GMLS_STK_3_M3
ASUW/NSFS	1	ASUW_NSFS_1_M1	ASUW_NSFS_1_M2	ASUW_NSFS_1_M3
	2	ASUW_NSFS_2_M1	ASUW_NSFS_2_M2	ASUW_NSFS_2_M3
	3	ASUW_NSFS_3_M1	ASUW_NSFS_3_M2	ASUW_NSFS_3_M3
ASW/MCM	1	ASW_MCM_1_M1	ASW_MCM_1_M2	ASW_MCM_1_M3
	2	ASW_MCM_2_M1	ASW_MCM_2_M2	ASW_MCM_2_M3
	3	ASW_MCM_3_M1	ASW_MCM_3_M2	ASW_MCM_3_M3
AIR	1	LAMPS_1_M1	LAMPS_2_M2	LAMPS_1_M3
	2	LAMPS_2_M1	LAMPS_2_M2	LAMPS_2_M3
	3	LAMPS_3_M1	LAMPS_3_M2	LAMPS_3_M3
PSYS	1	PSYS_1_M1	PSYS_1_M2	PSYS_1_M3
	2	PSYS_2_M1	PSYS_2_M2	PSYS_2_M3
	3	PSYS_3_M1	PSYS_3_M2	PSYS_3_M3
	4	PSYS_4_M1	PSYS_4_M2	PSYS_4_M3
	5	PSYS_5_M1	PSYS_5_M2	PSYS_5_M3
	6	PSYS_6_M1	PSYS_6_M2	PSYS_6_M3
	7	PSYS_7_M1	PSYS_7_M2	PSYS_7_M3

3.2.6 Automation and Manning Factor

Another method to reduce manning is by system automation also remote sensors, valves, switches and system reconfiguration. This can be accomplished on-board by implementing new technologies that reduce the need for multiple crewmembers to operate or monitor a system. Additionally, central control stations where sailors monitor multiple systems from remote locations can be implemented to reduce personnel. However, implementing automation by itself does not guarantee a reduction in crew size since the crew at sea is also assigned to routine tasks, maintenance, and other duties that are not easily automated.

Hinkle and Glover point out three areas of manning reduction that could have the greatest impact in reducing crew size in a ship: moving functions currently performed by the crew off the ship, accepting increased levels of risk by eliminating or consolidating watch stations, reducing support and hotel services, and implementing new technologies that reduce the number of sailors needed onboard [11]. These strategies are implemented in this research in a series of manning and automation factor options integrated as part of the scenarios in this study:

- CMAN=1 – Baseline manning level where all crewmembers listed in the crew list are assigned to ship's work, WQSB positions and maintenance. No tasks are automated or jobs outsourced to shore personnel.
- CMAN=2 – Administrative personnel and personal services are removed from task assignments and sent to shore support units.
- CMAN=3 – Watch standing automation is implemented for WQSB Condition III and General Quarters tasks. Some tasks are fully automated and others enable a reduction in required personnel. As discussed in Sections 1.2.3 and 1.2.4 this manning and automation factor implements multimodal watch stations where a centric human computer interface provide watch standers all displays screens needed for them to complete multiple mission tasks from one station. Also, it implements the an IAS automation system that integrates propulsion systems, engines, and auxiliaries that be monitored from a central location. Additionally, the use of automated naval guns to replace more manual weapon systems like the Mk45 Mod 4 gun would provide an automatic ammunition handling system and to reduce personnel.

- CMAN=4 – Food services automation is implemented. Galley and mess deck tasks requiring personnel to complete are reduced in the ship's work function. This automation and manning factor implements centralized galleys, and the use of pre-prepared food in the ship's menus to reduce the number of culinary specialists needed. Also implemented in this option is a streamlined food service management and automated provision program that monitors supplies and help sailors prepare menus.
- CMAN=5 – Administrative personnel and personal services are removed from tasks assignments and sent to shore support units and watch standing automation is implemented for WQSB Condition III and General Quarter events. (= CMAN 2+3)
- CMAN=6 – Administrative personnel and personal services are removed from tasks assignments and sent to shore support units. Food services automation is implemented. Galley and mess deck tasks requiring personnel to complete are reduced for the ship's work function. (= CMAN 2 + 4)
- CMAN=7 – Watch standing automation is implemented for WQSB Condition III and General Quarters events and food services automation is implemented. Galley and mess deck tasks requiring personnel to complete are reduced for the ship's work function. (= CMAN 3 + 4)
- CMAN=8 - Administrative personnel and personal services are removed from task assignments and sent to shore support units. Watch standing automation is implemented for WQSB Condition III and General Quarters events. Food services automation is implemented. Galley and mess deck tasks requiring personnel to complete are reduced for the ship's work function. (= CMAN 2 + 3 + 4)

The automation and manning factor levels are specified in ISMAT in the tasks specified for each function. The user does not need to describe the method the crew uses to perform the task, only the time it takes to complete. Tasks can be automated or partially automated using the ISMAT task skill/automation screen in Figure 21. The skills/automation menu allows the user to select personnel required for a task and also permits ISMAT to finish a task faster by using more personnel. The "Required Skills" tab under the skills automation menu can be use to select the skills necessary to perform the task if required. These features were not used in this research as it was assumed that all personnel in the crew list were fully qualified and with the skills to complete tasks normally assigned to their rating. Figure 22 shows the "Man Combat System Equipment Room" task as automated in scenario CMAN 8. For this automation and manning factor option watch standing automation is applied to this task indicating the job is automated and no personnel are assigned to it.

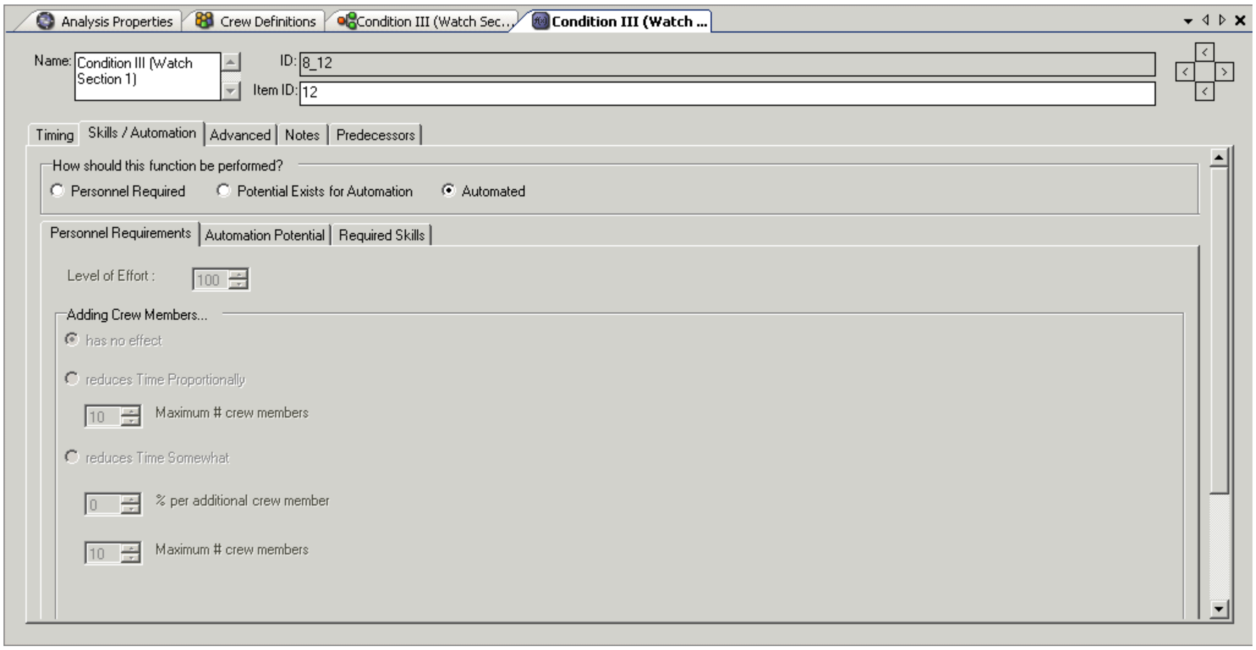

Figure 22 ISMAT Skills/Automation Screen Menu

Each CMAN option is represented by a scenario in the ISMAT file. Tasks are the same for each scenario but the automation for the tasks is changed. When the simulation is run, the CMAN variable input number is read by the Visual Basic program script that then executes the scenario corresponding to CMAN option. Figure 23 shows the Condition III watch function for a manning and automation factor of CMAN 1. Similarly, Figure 24 shows the same function but for a manning and automation factor of CMAN 8. In the first figure no tasks were automated and all the personnel assigned to them are employed in the scenario. In Figure 24 most of the tasks are colored red or orange indicating a change in its manning requirement. The red colored tasks in the figure indicate that these tasks are fully automated. Orange colored tasks indicate that there was a reduction in the number of personnel required to complete the task.

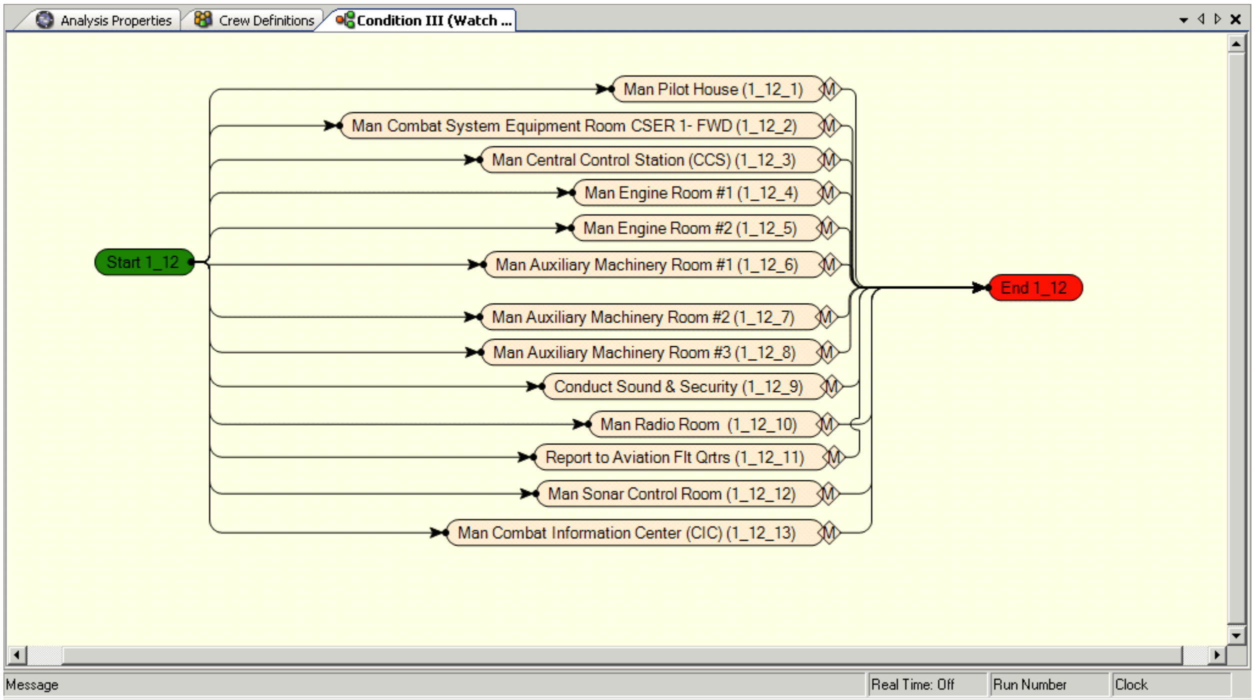

Figure 23 CMAN 1 - Condition III (Watch Section 2) Function

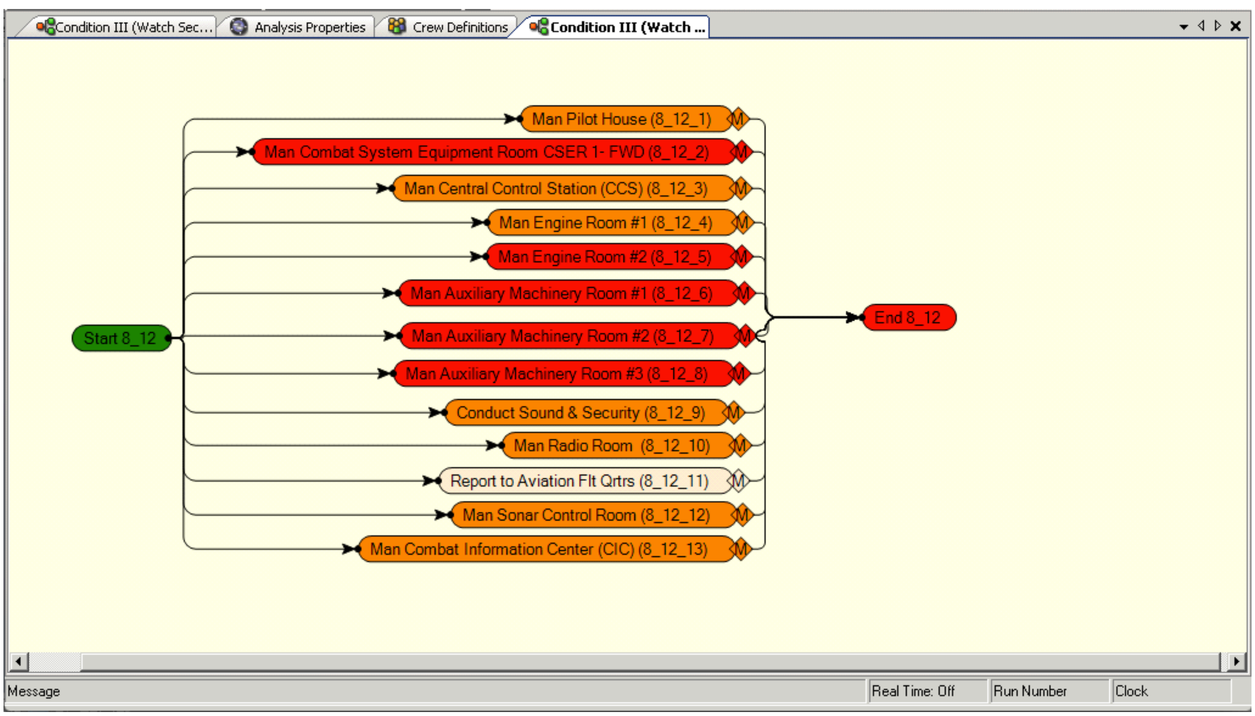

Figure 24 CMAN 8 -Condition III (Watch Section 2) Function

3.3 Manning Model Exploration Execution

3.3.1 ISMAT Console

To execute the manning model exploration, ISMAT input files corresponding to all DV options are created and saved into the program default folder. The main ISMAT file is preloaded with the crew list and saved at the same location. To run multiple simulations for data gathering without opening the ISMAT GUI, a console application has been added that can load multiple design variable configurations with different equipment and compartment files from outside the program. A Visual Basic code is written to take input variable values from Model Center and run ISMAT using the console application that executes the simulation. After the simulation is complete, the required crew size number is retrieved for each configuration and stored in Model Center. This data is then used to create a surrogate manning model (RSM) which is inserted into the ship synthesis model (SSM) for running the ship MOGO.

To build and run the simulation from an outside program the console application code format shown in Figure 25 is required.

```
MAAD.ISMAT.Console.exe –f {filename of simulation} –e {equipment
file} –c {compartment file} –s {number of the scenario to run} –g
{goal for the function} –k {kills the program upon completion of the
scenario}
```

Figure 25 ISMAT Console Input Format

Prior to running the simulation the baseline manning document must be created using the ISMAT GUI. The ISMAT file containing the scenarios and crew list is loaded first using the "–f {filename of simulation}" input argument string. The equipment input follows with "–e {equipment file}" argument string, where multiple equipment files configurations can be entered individually into the simulation. This method permits the user to evaluate different equipment system configurations in the simulation. The equipment systems are loaded given the design variable input received from MC for the equipment option and given the maintenance level DV input (Table 3). The compartment file is loaded into the simulation using the "–c {compartment file}" command argument. This file is only loaded once, as is it not associated with a design variable. The "–s {number of the scenario to run}" loads the scenario corresponding to the manning and automation factor CMAN where the crew and equipment are evaluated. The goal for all the simulations is to minimize the crew and this is simply entered as " -g ""MinimizeCrewSize"". The last command entry " –k" is to indicate the end of the scenario with just a "True or False" statement.

The ISMAT GUI version does not contain a function that outputs the total number of crewmembers required in the scenario. It only provides the user with a list of crewmembers utilized. To obtain the total crew number a C Sharp code shown in Appendix B is added in the "Finalization Code" window under the "Execution Settings" link found in the program's tree view. This writes the total crew number to a "manning.out" file.

3.3.2 Model Center and ISMAT

The manning exploration model VB code attached in Appendix B contains the command arguments to execute the ISMAT console application described in Section 3.3.1. In the code a series of "Else", "If" and "Then" command statements are used to build loops that select equipment systems at different maintenance levels to run in the scenarios. A MC wrapper code inputs data from Model Center and runs "manningDDG.exe" (Figure 11). The MC wrapper also writes the ISMAT output data back to a "manning.out" file and loads the result into MC. The wrapper file code is provided in Appendix C.

3.3.3 Design of Experiments and Manning Model Exploration

To collect manning data results a Design of Experiments (DOE) is used in Model Center. The DOE creates a data file for all configurations given by the design input variables with the crew size as an output or response variable and runs ISMAT. It takes ISMAT four minutes to run a single simulation and over six hours to complete the full DOE. After the experiment concludes the results are displayed in a data table and DV histograms are used to investigate its trends. A Kriging response surface model (RSM) is created in MC to fit the data results of the DOE into an equation that treats the discrete values as representative of a continuous function. The RSM treats CMAN and Maint as continuous DVs with combinations in-between integer numbers. This allows a complete range of crew sizes from minimum to maximum in the ship design. The RSM is added to MC as a surrogate-manning model in the Ship Synthesis Model (SSM) and ship design optimization.

3.4 Design of Experiment Data Analysis

The data results obtained from the DOE are studied using MC data visualizers. The influence of the DVs on the crew number output result can be observed in chart and plot forms before they are added into the SSM. The first experiment (half-factorial) conducted for the manning model considered 7 DVs as part of the manning study (AAW, ASUW, CMAN, ASW, PSYS, AIR and Maint). The influence of these variables can be observed in a DV histogram (Figure 26) and in an Main Effects diagram (Figure 27).

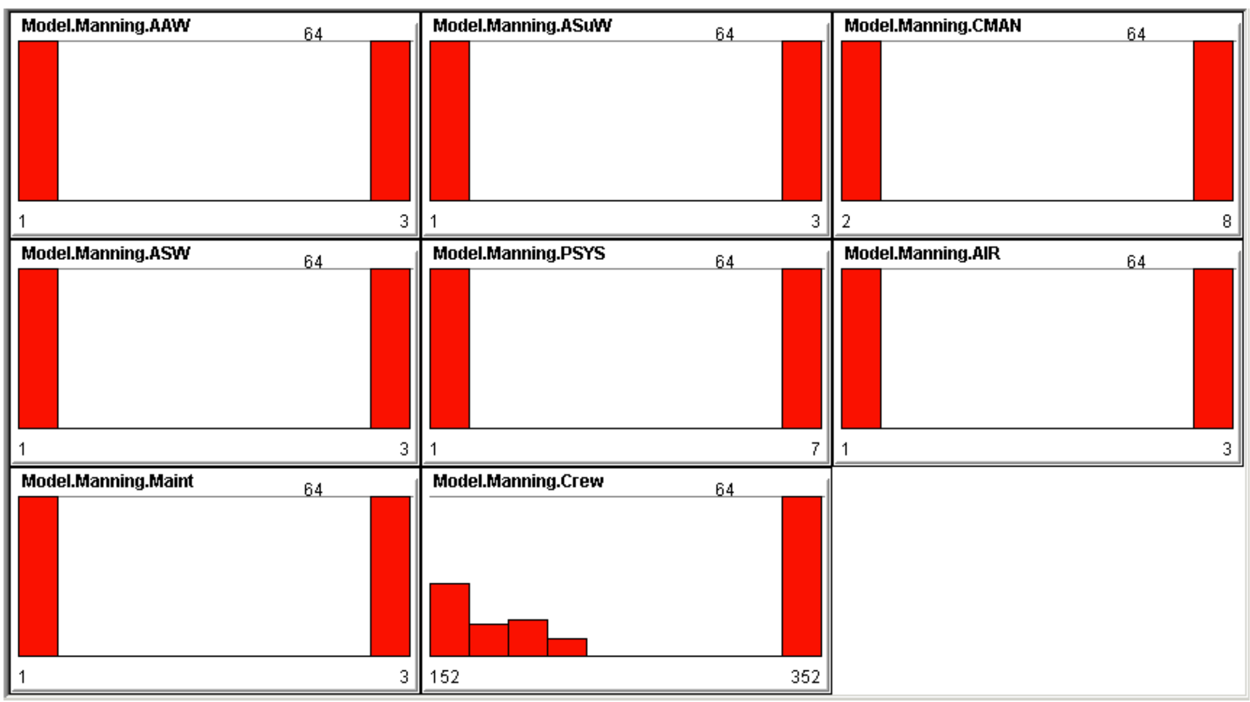

Figure 26 DV Histogram

The Design Variable Main Effects plot (Figure 27) shows the influence of each design variable by percentage on the crew size output. From this plot AAW, PSYS and ASUW are identified as the DVs with the smallest influence (1%) in the crew size output result. To minimize the number of DVs, and improve DOE run time they are removed from the manning model and not considered for manning calculations. The automation and manning factor (CMAN) has the largest impact on the crew size output. This plot result demonstrates the importance of automation in ship crew size reduction calculations. The manpower reductions due to job functions moved off the ship, and watch section consolidation in conjunction with automation significantly reduces the number of personnel required on board. Maintenance is the second largest factor influencing the crew size and must be considered in the manning model. The ship systems AIR and AAW had smaller impacts on the crew size output, but were significant enough to be considered in the manning model.

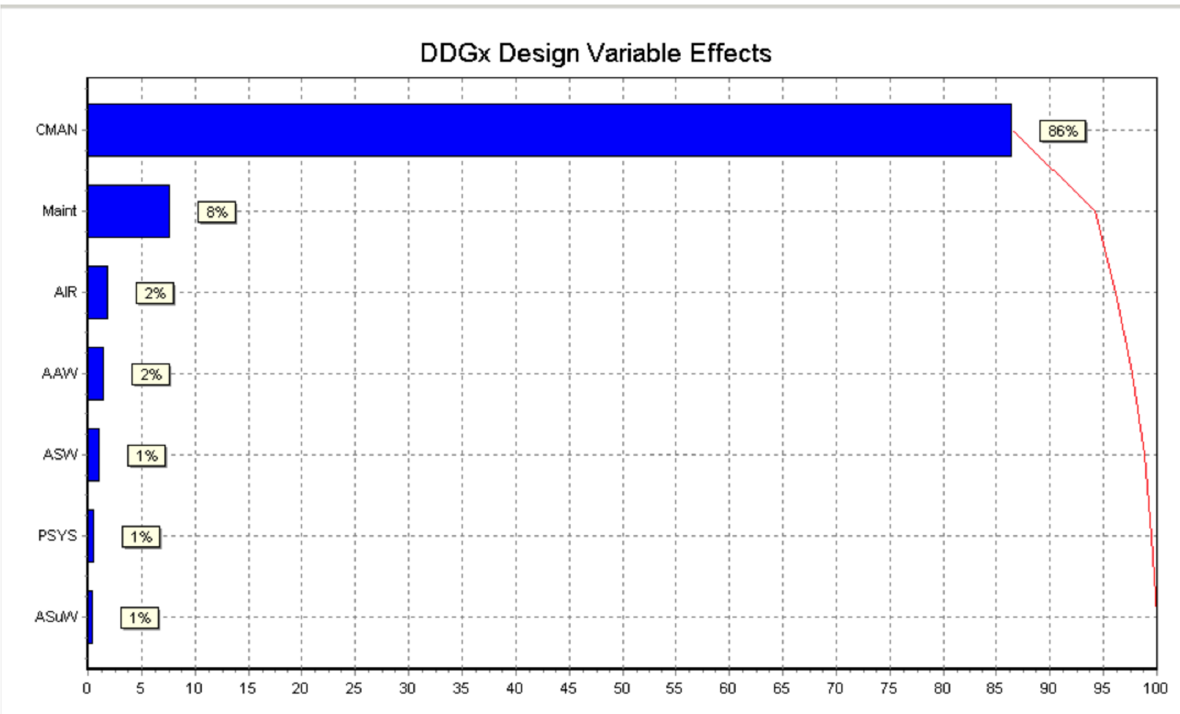

Figure 27 DDGx Design Variable Effects

After studying the half factorial DOE results, the DVs with the largest influence (CMAN, Maint, AIR and AAW) were selected to conduct a complete custom DOE to generate data for a response surface model. To conduct a custom DOE we entered all possible DV value configurations for the manning DVs in the MC data table tab. When the experiment is completed its results are examined again to assess their influence on the crew size output. Figure 28 shows the DV effects result of this complete run. Unlike the first experiment, the DVs selected here all had a significant impact on the crew size output result.

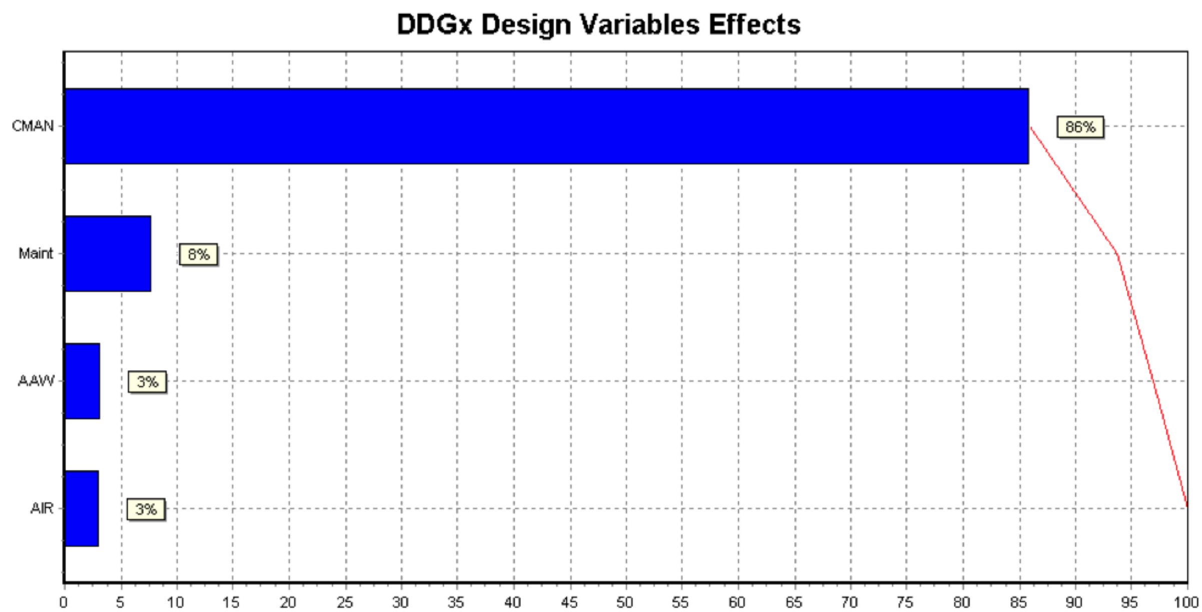

Figure 28 DDGx Design Variable Effects (Dominant Variables)

3.5 Response Surface Model

The RSM tool-kit in Model Center offers several options to fit an equation to the data generated by the manning module exploration. Design Explorer Kriging was selected as the best option available for the RSM because of the discontinuous and un-smooth nature of the data. Although this option gave 79% prediction confidence it was necessary to improve it by reorganizing the DOE data. Figure 29 shows the crew size output data versus the CMAN DV options in the original order it was run for the manning model exploration.

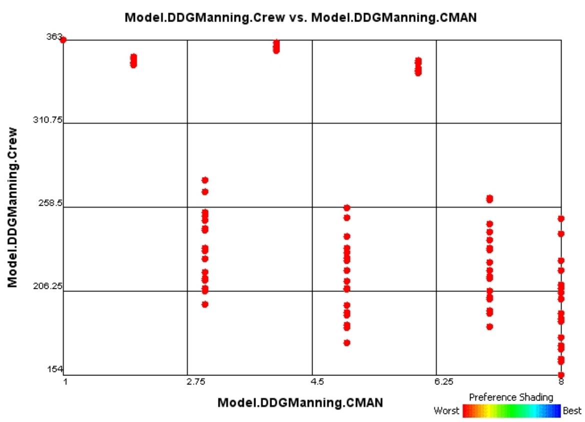

Figure 29 DOE Crew vs CMAN

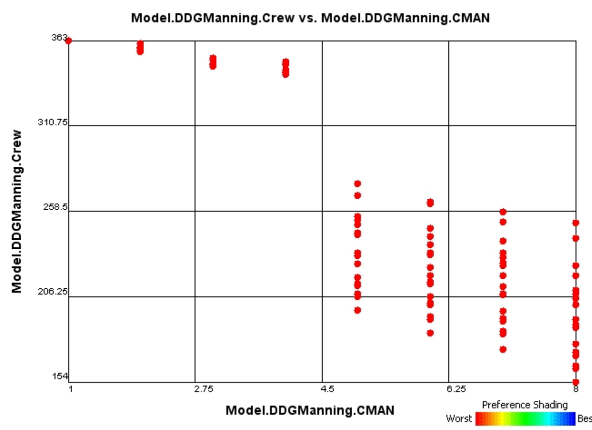

Figure 30 DOE Crew vs CMAN (Fixed for RSM)

To improve the accuracy of the Kriging RSM it was necessary to rearrange the input DVs (CMAN and Maint) options numbers such that the crew output size was reduced (better behaved) with each increase of CMAN and Maint option number (Figure 30). By transposing the data, the Kriging RSM gave us 94% prediction reliability, good enough to use the RSM. Using an RSM also allowed us to treat CMAN and Maint as continuous DVs. The DV option order changes are summarized in Table 5.

Once the reordering was completed and the results of the experiment compiled in a table, the Kriging RSM is used to fit the data. Figure 31 shows the statistical data results for the Kriging RSM.

Table 5 CMAN and Maint DV options reordered for Kriging RSM

DV	Original Option #	New Option #	Description
CMAN	1	1	Baseline manning level. All crewmembers in the crew list are assigned to daily tasks.
	2	3	Administrative personnel and personal services are removed from tasks and outsourced.
	3	5	Watch standing automation for WQSB Condition III and General Quarters events and tasks.
	4	2	Food services automation is implemented, centralized galleys and pre-prepared food menus.
	5	7	Administrative personnel and personal services are removed from tasks + Watch standing automation for WQSB Condition III and General Quarters events.
	6	4	Administrative personnel and personal services are removed from tasks + Food services automation is implemented, centralized galleys and pre-prepared food menus
	7	6	Watch standing automation for WQSB Condition III and General Quarters events + Food services automation is implemented, centralized galleys and pre-prepared food menus.
	8	8	Administrative personnel and personal services are removed from tasks + Watch standing automation for WQSB Condition III and General Quarters + Food services automation is implemented, centralized galleys and pre-prepared food menus
Maint	1	2	Crew completes all equipment preventive maintenance.
	2	1	Crew completes equipment preventive maintenance tasks up to and including annual tasks.
	3	3	Crew completes equipment preventive maintenance tasks up to and including monthly tasks.

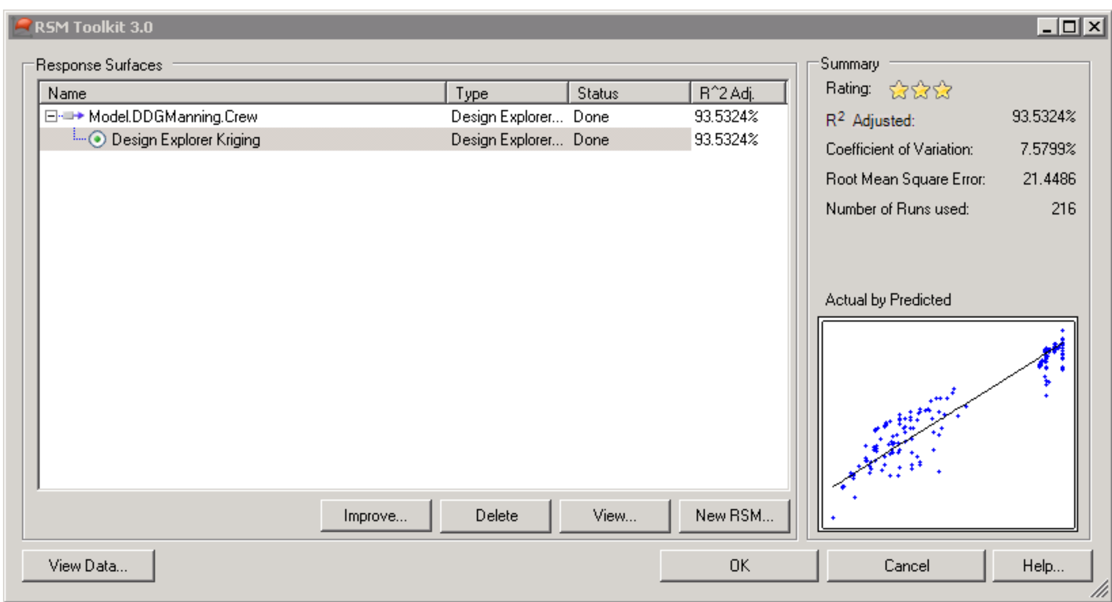

Figure 31 Kriging RSM

The R^2 value represents the reliability of the RSM in predicting the crew size for any given design option. This value should be as close to 100% as possible. The coefficient of variantion and the root mean square should be as close as possible to zero to maintain the model result reliability. Figures 31 and 32 show the Kriging RSM prediction fitted with the dominant DVs data from the custom DOE. The prediction percentage (94%) demonstrates reasonable RSM reliability and application for the purposes of this study. The Kriging RSM is used as a surrogate manning model in the SSM. The Kriging RSM permits fractional continuous values of CMAN and Maint to be part of the ship synthesis model. The feasible designs selected from the MOGO non-dominated frontier that contain fractional continuous values can be evaluated to implement partial levels of automation and maintenance between the whole integer values.

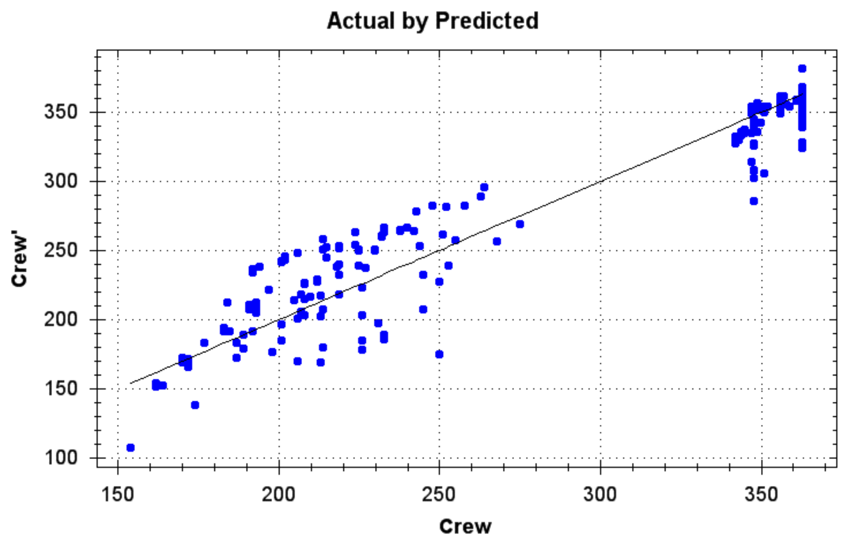

Figure 32 Kriging RSM Data Prediction Chart

Chapter 4 DDGx Case Study

To determine the total ship impact of our DDGx manning, a DDGx Concept Exploration design case study was created based on the ship design from the Virginia Tech undergraduate ship design project for the 2013-2014 [28]. The design project is for a Small Guided Missile Destroyer (DDGx). The new ship must have capabilities approaching DDG-51, but be more affordable which means some compromises and changes like automation and off-ship support must be made. DDGx must operate independently, with Carrier Battle Groups, Surface Action Groups and in support of Expeditionary (Amphibious) Strike Groups providing AAW, ASUW and ASW support.

4.1 Design Problem Description

The DDGx design requirements are specified in the DDGx Initial Capabilities Document (ICD) included in Appendix C. The design must be capable to deploy for 6 months with underway replenishment, a few port visits, all-weather operations and limited maintenance opportunities. The undergraduate design team created a 90-day scenario for the ship's intended mission and environment. Based on the team's scenario a sample one-week scenario was built in ISMAT to obtain minimum crew sizes for the designs. Table 6 outlines the required operational capabilities of the DDGx design.

Table 6 DDGx Required Operational Capabilities (ROC)

ROC	Description
AAW 1	Provide anti-air defense
AAW 1.1	Provide area anti-air defense
AAW 1.2	Support area anti-air defense
AAW 1.3	Provide unit anti-air self defense
AAW 2	Provide anti-air defense in cooperation with other forces
AAW 5	Provide passive and soft kill anti-air defense
AAW 6	Detect, identify and track air targets
AAW 9	Engage airborne threats using surface-to-air armament
AMW 6	Conduct day and night helicopter, Short/Vertical Take-off and Landing and airborne autonomous vehicle (AAV) operations
AMW 6.3	Conduct all-weather helo ops
AMW 6.4	Serve as a helo hangar
AMW 6.5	Serve as a helo haven

ROC	Description
AMW 6.6	Conduct helo air refueling
AMW 12	Provide air control and coordination of air operations
AMW 14	Support/conduct Naval Surface Fire Support (NSFS) against designated targets in support of an amphibious operation
AMW 15	Provide air operations to support amphibious operations
ASU 1	Engage surface threats with anti-surface armaments
ASU 1.1	Engage surface ships at long range
ASU 1.2	Engage surface ships at medium range
ASU 1.3	Engage surface ships at close range (gun)
ASU 1.4	Engage surface ships with large caliber gunfire
ASU 1.5	Engage surface ships with medium caliber gunfire
ASU 1.6	Engage surface ships with minor caliber gunfire
ASU 1.9	Engage surface ships with small arms gunfire
ASU 2	Engage surface ships in cooperation with other forces
ASU 4	Detect and track a surface target
ASU 4.1	Detect and track a surface target with radar
ASU 6	Disengage, evade and avoid surface attack
ASW 1	Engage submarines
ASW 1.1	Engage submarines at long range
ASW 1.2	Engage submarines at medium range
ASW 1.3	Engage submarines at close range
ASW 4	Conduct airborne ASW/recon
ASW 5	Support airborne ASW/recon
ASW 7	Attack submarines with antisubmarine armament
ASW 7.6	Engage submarines with torpedoes
ASW 8	Disengage, evade, avoid and deceive submarines
CCC 1	Provide command and control facilities
CCC 1.6	Provide a Helicopter Direction Center (HDC)
CCC 2	Coordinate and control the operations of the task organization or functional force to carry out assigned missions
CCC 3	Provide own unit Command and Control
CCC 4	Maintain data link capability
CCC 6	Provide communications for own unit
CCC 9	Relay communications
CCC 21	Perform cooperative engagement
FSO 3	Provide support services to other units
FSO 5	Conduct towing/search/salvage rescue operations
FSO 6	Conduct SAR operations
FSO 7	Provide explosive ordnance disposal services
FSO 8	Conduct port control functions
FSO 9	Provide routine health care
FSO 10	Provide first aid assistance
FSO 11	Provide triage of casualties/patients
FSO 12	Provide medical/surgical treatment for casualties/patients
FSO 13	Provide medical, surgical, post-operative and nursing care for casualties/ patients

ROC	Description
FSO 14	Provide medical regulation, transport/evacuation and receipt of casualties and patients
FSO 16	Provide routine and emergency dental care
INT 1	Support/conduct intelligence collection
INT 2	Provide intelligence
INT 3	Conduct surveillance and reconnaissance
INT 8	Process surveillance and reconnaissance information
INT 9	Disseminate surveillance and reconnaissance information
INT 15	Provide intelligence support for non-combatant evacuation operation (NEO)
LOG 1	Conduct underway replenishment
LOG 2	Transfer/receive cargo and personnel
LOG 6	Provide airlift of cargo and personnel
MIW 3	Conduct mine neutralization/destruction
MIW 4	Conduct mine avoidance
MIW 6	Conduct magnetic silencing (degaussing, deperming)
MIW 6.7	Maintain magnetic signature limits
MOB 1	Steam to design capacity in most fuel efficient manner
MOB 2	Support/provide aircraft for all-weather operations
MOB 3	Prevent and control damage
MOB 3.2	Counter and control NBC contaminants and agents
MOB 5	Maneuver in formation
MOB 7	Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)
MOB 10	Replenish at sea
MOB 12	Maintain health and well being of crew
MOB 13	Operate and sustain self as a forward deployed unit for an extended period of time during peace and war without shore-based support
MOB 16	Operate in day and night environments
MOB 17	Operate in heavy weather
MOB 18	Operate in full compliance of existing US and international pollution control laws and regulations
NCO 3	Provide upkeep and maintenance of own unit
NCO 19	Conduct maritime law enforcement operations
SEW 2	Conduct sensor and ECM operations
SEW 3	Conduct sensor and ECCM operations
SEW 5	Conduct coordinated SEW operations with other units
STW 3	Support/conduct multiple cruise missile strikes

4.2 Design Space

The design variables and ranges for DDGx are listed in Table 7.

Table 7 Study Design Variables (DVs)

DV	Design Variables	Values	Description
1	Length on Deck (LOA)	130 to 160m	Hydro, Structure, Vulnerability, RCS, IR
2	LtoB Ratio	7 to 8.5	Hydro, Structure, Vulnerability, RCS, IR
3	B to T Ratio		Hydro, Structure, Vulnerability, RCS, IR
3	Long'l Prismatic Control	0.1 to .4	Hydro, Structure
4	Section Tightness Fwd	.15 to .99	Hydro
5	Deadrise Mid	.1-.8	Hydro, Structure
6	Fullenss Fwd	.3 to .6	Hydro
7	Stem Curvature	`-0.3 to 0.3	Hydro
9	Minimum Volume of Deckhouse (VD)	4000-8000 m3	Vulnerability, RCS, IR
10	Manning and Automation Factor (CMAN)*	1=Baseline; 2=Admin and personal services ashore; 3=Automated watch standing; 4=Automated food services; 5=2+3; 6=2+4; 7=3+4; 8=2+3+4 ***Kriging RSM DVs** 1=Baseline; 2=Automated food services; 3=Admin and personal services ashore; 4=3+2; 5=Automated watch standing; 6=2+5; 7=3+5; 8=2+3+5	Vulnerability, Recoverability, Manning
11	Maintenance Plan*	1=Baseline; 2=CBM (longer than Annual ashore); 3 = CBM (longer than monthly ashore) ***Kriging RSM DVs** 1=CBM (longer than Annual ashore); 2=Baseline; 3 = CBM (longer than monthly ashore)	
12	Degaussing (DEGAUS)	0=none, 1=yes	OEM
13	CPS	0=none, 1=partial, 2=full	Vulnerability, Recoverability
14	Provisions Duration (Ts)	30-60 days	
15	Deckhouse Material (CDHMAT)	1=steel, 2=aluminum, 3=composite	Vulnerability, Recoverability, Structure

DV	Design Variables	Values	Description
16	Power and Propulsion System (PSYS) - Architecture	1=MD COGAG,1 shaft,2xGTMPE,3xSSG 2=MD CODAG,1 shaft,1xGTMPE,1xDMPE,3xSSG 3=MD CODAG,1 shaft,1xGTMPE,2xDMPE,3xSSG 4=HB,1 shaft,1xGTMPE,2xDMPEG,3xDG 5=MD CODAG,2 shafts,2xGTMPE,2xDMPE,3xSSG 6=HB,2 shafts,2xGTMPE,3xSSG 7=IPS,2 shafts,2xGTG,3xSSG	Vulnerability, Recoverability, IR, Acoustic, Manning
17	Main Gas Turbine Engine (GTMPE)	1=MT30 2=LM2500+	
18	Main Diesel Engine (DMPE)	1=20PA6B STC 2=16PA6B STC 3=CAT 280V16 4=CAT 280V12	
19	Ship Service Generator Engine (SSGENG)	1=Allison 501K SSGTG 2=CAT 280V12 SSDG 3=CAT 280V8 SSDG	
20	AAW/SEW/GMLS/STK	Option 1	SPY-1D radar, AEGIS Combat System, MK99 GMFCS, MK 37 Tomahawk Weapon System (TWS) , AN/SPQ-9B radar, 2 x SPG 62, 64 Cell VLS MK 41, 2 x CIWS, SLQ-32[V]3, 6 x MK 137 LCHRs (combined MK 53 SRBOC & NULKA LCHR), 6 x Mk137 LCHR loads, NULKA Magazine, SRBOC Magazine, IRST, IFF,VLS Missile Loadout (SM2, ASROC, Tomahawk, ESSM, LRASM)
		Option 2	SPY-1F Radar, AEGIS Combat System, MK99 GMFCS, MK 37 Tomahawk Weapon System (TWS), 1 x SPG 62, AN/SPQ-9B radar, 32 Cell MK 41, 16 Cell MK 48, 2 x CIWS, SLQ-32[V]3, 4 x MK 137 LCHRS Loads (4 NULKA, 12 SRBOC), NULKA magazine (12 NULKA), SRBOC Magazine, IRST, IFF,VLS Missile Loadout (SM2, ASROC, Tomahawk, ESSM, LRASM)

DV	Design Variables	Values	Description
		Option 3	EADS TRS 3D, COBATSS-21, 16 Cell MK 48 VLS, MK 37 Tomahawk Weapon System (TWS), AN/SWG-1 Harpoon WCS, 2 x MK 141 Harpoon Launcher, 1 x MK 143 ASROC Launcher, 2 x MK 112 Tomahawk Launcher, 1 x CIWS, WBR 2000 ESM, 2XSKWS DECOY LAUNCHER, IRST, IFF,VLS Missile Loadout (ESSM)
21	ASUW/NSFS	Option 1	AN/SPS-73 Radar, 5in/62 MK 45 Gun, MK86 GFCS, 2 x 30 mm CIGS, 2 x 50 cal Machine Guns, SMALL ARMS and Pyro Locker, 1 x 11m RHIB
		Option 2	AN/SPS-73 Radar, 76mm Gun, MK86 GFCS, 1 x 30 mm CIGS, 2 x 50 cal Machine Guns, SMALL ARMS and Pyro Locker, 1 x 7m RHIB
		Option 3	AN/SPS-73 Radar, 57 mm Gun, DORNA EOD EO/IR Fire Control, 1 x 30 mm CIGS, 2 x 50 cal Machine Guns, SMALL ARMS and Pyro Locker, 1 x 7m RHIB
22	ASW/MCM	Option 1	SQS-53D sonar, AN/SQR-19 Tactical Towed Array SONAR (TACTAS), AN/SLQ-25 NIXIE, 2 x MK 32 SVTT, AN/SQQ-89(V)14 ASWCS, MINE AVOIDANCE SONAR
		Option 2	AN/SQS-56 / DE 1160 Sonar, AN/SLQ-25 NIXIE, 2 x MK 32 SVTT, AN/SQQ-89(V)14 ASWCS, MINE AVOIDANCE SONAR
		Option 3	2 x MK 32 SVTT, AN/SLQ-25 NIXIE, AN/SQQ-28 LAMPS MK III Sonobuoy Processing System, NDS 3070 Vanguard Mine Avoidance Sonar
23	CCC	Option 1	ExComm Level A, Cooperative Engagement Capability (CEC) and Link 11, Navigation System
		Option 2	ExComm Level B, Cooperative Engagement Capability (CEC) and Link 11, Navigation System
24	AIR	Option 1	Embarked 2xLAMPS w/ Hangar, 2 x UAV
		Option 2	Embarked 1xLAMPS w/ Hangar, 2 x UAV
		Option 3	LAMPS haven (flight deck), 2 x UAV

The DVs originally used by ISMAT in the DDGx Manning Model were CMAN, Maint, PSYS, AAW, ASUW, ASW, and AIR (10, 18-22 and 24). All of the DVs selected have different levels of impact in the output crew size. As discussed in Section 3.4 the CMAN design variable is represented, as scenarios in the ISMAT file. The manning reduction techniques and automation levels are represented in 8 different scenarios that are described in Section 3.2.6. The maintenance level is determined by the DV "Maint" that corresponds to a maintenance strategy discussed in Section 3.2.5. The maintenance strategies are implemented in the equipment files.

4.3 Ship Synthesis Model (SSM)

The Ship Synthesis Model is used to build designs and assess their feasibility, balance, performance, cost, effectiveness and risk. The SSM for the DDGx is built in MC by connecting a series of modules that allow the modules to calculate ship characteristics by using the output result of preceding modules in the model. The modules were developed in FORTRAN. A Multi-Objective Genetic Optimization is also run in MC using the SSM and MC's Darwin optimizer to search the designs space for "non-dominated designs". The SSM contains the modules described in the list below.

- **Input Module** - The input module allows the user to input all the design variables and parameters to be called in the analysis and synthesis.
- **Hydrostatics Module** – The hydrostatics module receives the geometric inputs from the input module and calculates the hullform characteristics like: mass, VCB, BM, Cp and Cb.
- **Combat Module** – The combat module uses the combat system inputs (AAW, SEW, GMLS, STK, ASUW, NSFS, ASW, and MCM) for the selected options and calculates payload weights, centers of gravity and power requirements for the equipment.
- **Propulsion Module** – The propulsion module uses the selected propulsive system options from the input module and calculates the propulsion and power characteristics for the design.

- **Available Space Module** – The available space module calculates the volume and arrangeable area that can be used to satisfy ship space requirements.
- **Manning Module** – The manning module estimates the crew size for a given set of design variables. The description and process methodology for the creation of this surrogate module is explained in Chapter 3.
- **Electric Module** – The electric module calculates electrical loads, required cooling power, and volume needed for the auxiliary machinery rooms. The module also receives the total crew number size from the surrogate-manning model and outputs the total number of commissioned officers, chief petty officers and enlisted crew for the design.
- **Hull Performance Module** – The hull performance module calculates the power requirements for endurance speed, sustained speed, and seakeeping characteristics for the design.
- **Weight Module** – The weight module calculates lightship weights for the design. The lightship KG and KB are also calculated by this module.
- **Tankage Module** – The tankage module calculates the tankage requirements for the design. The DDS 200-1 procedure is used in the fuel tankage calculations. The outputs for this module include: fuel tank volume, total tank volume, and endurance range.
- **Space Required Module** – The space required module calculates the total volume and arrangeable required to contain all ship systems and functions.
- **Feasibility Module** – The feasibility module calculates the feasibility ratios of available to required characteristics available. The module determines the feasibility of a design by testing if any of the ratios calculated are negative. The ratios tested by the module are: arrangement area, deckhouse area, sustained speed, minimum and maximum GM/B, endurance range, and sprint range.
- **Cost Module** – The cost modules calculates the lead and follow ship acquisition costs as well as the life cycle cost using an adjusted weight-based cost model. These values are used in the optimization process explained in Section 4.5.3.

- **Risk Module** – The risk module calculates the overall measure of risk (OMOR) as explained in Section 4.5.2.
- **Effectiveness Module** – The effectiveness module calculates the overall measure of effectiveness using an analytical hierarchy process as explained in Section 4.5.1

4.4 Integration of the Surrogate Manning Model

As discussed in Chapter 3, to create the surrogate manning model for the DDGx design, the following process was followed:

1- Create equipment files corresponding to the design options considered in the ship design space. The equipment files for this study are found in Table 3.

2- Create a baseline equipment file containing non-design variables equipment necessary in all DDGx designs.

3- Build a concept compartment list for the DDGx design using a CG-47 list and other compartments files as guidance. The compartment list does not change during the simulation.

4- Modify each equipment file option and baseline file to consider the maintenance levels (1-3) philosophies discussed in Section 3.2.5.

5- Select a crew list from the ISMAT library and build a crew list that includes officers and correct enlisted ratings.

6- Build a series of scenarios to test the automation and manning factors against the crew available. A 7-day scenario was built that included the following event operations:

- Prepare the ship for movement
- Special sea and anchor detail
- Condition III
- Ship's Work
- General Quarters

The created scenarios represent the eight automation and manning factors (CMAN) discussed in Section 3.2.6. Each scenario contains the same event operations but the task and job assignments are changed to represent the different tasks that are automated or reduced in required personnel.

7- Create a VB code that reads input data and loads files into ISMAT.

8- Use the ISMAT console application to run multiple simulations in the manning model to obtain crew number outputs (Chapter 3).

9- Build RSM with DOE data and integrate the surrogate manning module in the ship synthesis model (SSM) to execute a MOGO.

To integrate the surrogate manning model RSM into the SSM it is simply dragged into the MC screen and linked with the input module and other SSM modules.

4.5 Objective Attributes

4.5.1 Overall Measure of Effectiveness (OMOE)

The Overall Measure of Effectiveness is defined as a single figure of merit to quantify a ship's performance and effectiveness. The OMOE assigns a ship design on a specified mission a figure of merit ranging from zero to one based on Measures of Performance (MOP), Values of Performance (VOP) and weighting factor (w_i) of the design. The OMOE is calculated by using a summation of the weighted product of the individual MOPs and VOPs. The equation for the OMOE is shown in the equation below.

$$\boldsymbol{OMOE = g[VOP_i(MOP_i)] = \sum_i w_i VOP_i(MOP_i)} \quad (\mathbf{1})$$

The MOPs are ship or equipment systems performance metrics based on required capabilities. VOPs are an index indicating the value of a MOP relative to the mission goal based on an index spanning from zero to one (Table 9). Table 8 shows the MOPs organized by their relationship with ROCs and DVs. To develop an OMOE, the MOPs critical to the ship's mission are selected with their goal and threshold values as shown in Table 9. The MOPs are organized into an OMOE Hierarchy as shown in Figure 33 to conduct a pairwise comparison and calculate MOP weights. With the respective weights for each MOP (Figure 34), Multi-Attribute Value Theory was used to build value functions (VOPs) for each MOP with a value from zero to one. Using the respective weights and VOP for each MOP, the OMOE was calculated using equation (1).

Table 8 ROC/MOP/DV Summary

ROC	Description	MOP	Related DV	Goal	Threshold
AAW 1	Provide anti-air defense	AAW	AAW, GMLS	AAW=1 GMLS=1	AAW=2 GMLS=2
AAW 1.1	Provide area anti-air defense	AAW	AAW, GMLS	AAW=1 GMLS=1	AAW=2 GMLS=2
AAW 1.2	Support area anti-air defense	AAW	AAW, GMLS	AAW=1 GMLS=1	AAW=2 GMLS=2
AAW 1.3	Provide unit anti-air self defense	AAW, RCS, IR	PSYS	PSYS = 5, 6, 7, 8	PSYS = 1,2,3,4
AAW 2	Provide anti-air defense in cooperation with other forces	AAW, FSO	C4I	C4I=1	C4I=2
AAW 5	Provide passive and soft kill anti-air defense	AAW, RCS, IR	VD	8000^3	12000m^3
AAW 6	Detect, identify and track air targets	AAW, RCS, IR	VD	8000^3	12000m^3
AAW 9	Engage airborne threats using surface-to-air armament	AAW, RCS, IR	AAW, GMLS	AAW=1 GMLS=1	AAW=2 GMLS=2
AMW 6	Conduct day and night helicopter, Short/Vertical Take-off and Landing and airborne autonomous vehicle (AAV) operations	ASW, ASUW, FSO	AIR	AIR=1	AIR=3
AMW 6.3	Conduct all-weather helo ops	ASW, ASUW, FSO	AIR	AIR=1	AIR=3
AMW 6.4	Serve as a helo hangar	ASW, ASUW, FSO	AIR	AIR=1	AIR=3
AMW 6.5	Serve as a helo haven	ASW, ASUW, FSO	AIR	AIR=1	AIR=3
AMW 6.6	Conduct helo air refueling	ASW, ASUW, FSO	AIR	AIR=1	AIR=3
AMW 12	Provide air control and coordination of air operations	ASW, ASUW, FSO	AIR	AIR=1	AIR=3
AMW 14	Support/conduct Naval Surface Fire Support (NSFS) against designated targets in support of an amphibious ops	NSFS	NSFS	NSFS=1	NSFS=2
AMW 15	Provide air operations to support amphibious operations	ASW, ASUW, FSO	AIR	AIR=1	AIR=3

ROC	Description	MOP	Related DV	Goal	Threshold
ASU 1	Engage surface threats with anti-surface armaments	ASUW	ASUW AIR	ASUW=1 AIR=1	ASUW=1 AIR=2
ASU 1.1	Engage surface ships at long range	ASUW	ASUW AIR	ASUW=1 AIR=1	ASUW=1 AIR=2
ASU 1.2	Engage surface ships at medium range	ASUW	ASUW AIR	ASUW=1 AIR=1	ASUW=1 AIR=2
ASU 1.3	Engage surface ships at close range (gun)	ASUW	NSFS	NSFS=1	NSFS=2
ASU 1.4	Engage surface ships with large caliber gunfire	ASUW	NSFS	NSFS=1	NSFS=2
ASU 1.5	Engage surface ships with medium caliber gunfire	ASUW	NSFS	NSFS=1	NSFS=2
ASU 1.6	Engage surface ships with minor caliber gunfire	ASUW	NSFS	NSFS=1	NSFS=2
ASU 1.9	Engage surface ships with small arms gunfire	ASUW	NSFS	NSFS=1	NSFS=2
ASU 2	Engage surface ships in cooperation with other forces	ASUW, FSO	C4I	C4I=1	C4I=2
ASU 4	Detect and track a surface target	ASUW	ASUW AIR	ASUW=1 AIR=1	ASUW=1 AIR=2
ASU 4.1	Detect and track a surface target with radar	ASUW	ASUW AIR	ASUW=1 AIR=1	ASUW=1 AIR=2
ASU 6	Disengage, evade and avoid surface attack	ASUW	ASUW	ASUW=1	ASUW=1
ASW 1	Engage submarines	ASW	ASW	ASW=1	ASW=2
ASW 1.1	Engage submarines at long range	ASW	ASW	ASW=1	ASW=2
ASW 1.2	Engage submarines at medium range	ASW	ASW	ASW=1	ASW=2
ASW 1.3	Engage submarines at close range	ASW	ASW PSYS	ASW=1 PSYS=3,4,7,8	ASW=2 PSYS=1,2,5,6
ASW 4	Conduct airborne ASW/recon	ASW	AIR	AIR=1	AIR=3
ASW 5	Support airborne ASW/recon	ASW	AIR C4I	AIR=1 C4I=1	AIR=3 C4I=2
ASW 7	Attack submarines with antisubmarine armament	ASW	ASW AIR C4I	ASW=1 AIR=1 C4I=1	ASW=2 AIR=3 C4I=2
ASW 7.6	Engage submarines with torpedoes	ASW	ASW AIR C4I	ASW=1 AIR=1 C4I=1	ASW=2 AIR=3 C4I=2
ASW 8	Disengage, evade, avoid and deceive submarines	ASW	ASW	ASW=1	ASW=2
CCC 1	Provide command and control facilities	CCC	C4I	C4I=1	C4I=2
CCC 1.6	Provide a Helicopter Direction Center (HDC)	CCC, ASW, ASUW	C4I	C4I=1	C4I=2

ROC	Description	MOP	Related DV	Goal	Threshold
CCC 2	Coordinate and control the operations of the task organization or functional force to carry out assigned missions	CCC, FSO	C4I	C4I=1	C4I=2
CCC 3	Provide own unit Command and Control	CCC	C4I	C4I=1	C4I=2
CCC 4	Maintain data link capability	ASW, ASUW, AAW	C4I	C4I=1	C4I=2
CCC 6	Provide communications for own unit	CCC	C4I	C4I=1	C4I=2
CCC 9	Relay communications	CCC	C4I	C4I=1	C4I=2
CCC 21	Perform cooperative engagement	CCC, FSO	C4I	C4I=1	C4I=2
FSO 3	Provide support services to other units	CCC, FSO	C4I	C4I=1	C4I=2
FSO 5	Conduct towing/search/salvage rescue operations	FSO	AIR	AIR=1	AIR=2
FSO 6	Conduct SAR operations	FSO	AIR	AIR=1	AIR=2
FSO 7	Provide explosive ordnance disposal services	FSO	ASW	ASW=1	ASW=2
FSO 8	Conduct port control functions	FSO	C4I	C4I=1	C4I=2
FSO 9	Provide routine health care	All Designs			
FSO 10	Provide first aid assistance	All Designs			
FSO 11	Provide triage of casualties/patients	All Designs			
FSO 12	Provide medical/surgical treatment for casualties/patients	All Designs			
FSO 13	Provide medical, surgical, post-operative and nursing care for casualties/ patients	All Designs			
FSO 14	Provide medical regulation, transport/evacuation and receipt of casualties and patients	CCC, FSO	AIR	AIR=1	AIR=3
FSO 16	Provide routine and emergency dental care	All Designs			
INT 1	Support/conduct intelligence collection	INT	C4I	C4I=1	C4I=2
INT 2	Provide intelligence	INT	C4I	C4I=1	C4I=2
INT 3	Conduct surveillance and reconnaissance	INT	AIR	AIR=1	AIR=3
INT 8	Process surveillance and reconnaissance information	INT, CCC	C4I	C4I=1	C4I=2
INT 9	Disseminate surveillance and reconnaissance information	INT, CCC	C4I	C4I=1	C4I=2
INT 15	Provide intelligence support for non-combatant evacuation operation (NEO)	INT, CCC	C4I	C4I=1	C4I=2
LOG 1	Conduct underway replenishment	All Designs			
LOG 2	Transfer/receive cargo and personnel	All Designs			

ROC	Description	MOP	Related DV	Goal	Threshold
LOG 6	Provide airlift of cargo and personnel	All Designs			
MIW 3	Conduct mine neutralization/destruction	MIW,ASW	ASW	ASW=1	ASW=2
MIW 4	Conduct mine avoidance	MIW	Degaus	Ndegaus=1	Ndegaus=0
MIW 6	Conduct magnetic silencing (degaussing, deperming)	Magnetic Signature	Degaus	Ndegaus=1	Ndegaus=0
MIW 6.7	Maintain magnetic signature limits	Magnetic Signature	Degaus	Ndegaus=1	Ndegaus=0
MOB 1	Steam to design capacity in most fuel efficient manner	Sustained Speed Endurance Range	Vs,E	Vs=30kts E=4000nm	Vs=28kts E=2500nm
MOB 2	Support/provide aircraft for all-weather operations	FSO	AIR	AIR=1	AIR=3
MOB 3	Prevent and control damage	VUL	Cdhmat	Cdmat=1 Composite	Cdmat=3 Steet
MOB 3.2	Counter and control NBC contaminants and agents	NBC	CPS	Neps = 1	Neps = 0
MOB 5	Maneuver information	All Designs			
MOB 7	Perform seamanship, airmanship and navigation tasks (navigate, anchor, mooring, scuttle, life boat/raft capacity, tow/be-towed)	All Designs			
MOB 10	Replenish at sea	All Designs			
MOB 12	Maintain health and well being of crew	All Designs			
MOB 13	Operate and sustain self as a fwd deployed unit for an extended period of time during peace and war without shore-based support	Ts	Ts	Ts=60 days	Ts=45
MOB 16	Operate in day and night environments	All Designs			
MOB 17	Operate in heavy weather	SKI	McCreight	McC = max	McC = min
MOB 18	Operate in full compliance of existing US and international pollution control laws and regulations	Environmen tal	Ballast Option	BAL type = 0	BAL type = 1
NCO 3	Provide upkeep and maintenance of own unit	All Designs			
NCO 19	Conduct maritime law enforcement operations	NCO	ASUW NSFS	ASUW=1 NSFS=1	ASUW=2 NSFS=2
SEW 2	Conduct sensor and ECM operations	AAW	C4I	C4I=1	C4I=2
SEW 3	Conduct sensor and ECCM operations	AAW	C4I	C4I=1	C4I=2
SEW 5	Conduct coordinated SEW operations with other units	AAW	C4I	C4I=1	C4I=2
STW 3	Support/conduct multiple cruise missile strikes	STK	GMLS C4I	GMLS=1 C4I=1	GMLS=2 C4I=2

Table 9 MOP Table

MOP#	MOP	Metric	Goal	Threshold
1	AAW	AAW option GMLS option SEW option SSD option C4I option	AAW = 1 GMLS = 1 SEW = 1 SSD = 1 C4I = 1	AAW = 2 GMLS = 2 SEW = 4 SSD = 3 C4I = 2
2	ASUW	ASUW option LAMPS option SEW option NSFS option C4I option	ASUW = 1 LAMPS = 1 SEW = 1 NSFS = 1 C4I = 1	ASUW = 2 LAMPS = 3 SEW = 4 NSFS = 2 C4I = 2
3	ASW	ASW option LAMPS option C4I	ASW = 1 LAMPS = 1 C4I = 1	ASW = 2 LAMPS = 3 C4I = 2
4	CCC	C4I	C4I = 1	C4I = 2
5	NSFS	NSFS option	NSFS = 1	NSFS = 2
6	FSO	LAMPS option	LAMPS = 1	LAMPS = 3
7	INT	LAMPS option C4I option	LAMPS = 1 C4I = 1	LAMPS = 3 C4I = 2
8	STK	STK option GMLS option	STK = 1 GMLS = 1	STK = 4 GMLS = 2
9	Vs	knots	Vs = 30 knt	Vs = 28 knt
10	E	nm	E = 4000 nm	E = 2500 nm
11	Ts	days	Ts = 60 days	Ts = 45 days
12	VUL	Deckhouse material	Cdhmat = 1	Cdhmat = 2
13	NBC	CPS option	Neps = 1	Neps = 0
14	Sea keeping	McCreight	McC = max	McC = min
15	Environmental	Ballast Option	BAL type = 0	BAL type = 1
16	RCS	Deckhouse volume	VD = 8000 m3	VD = 12000 m3
17	Acoustic Signature	PSYS option	PSYS = 3, 4, 7, 8	PSYS = 1, 2, 5, 6
18	IR Signature	PSYS option	PSYS = 5, 6, 7, 8	PSYS = 1, 2, 3, 4
19	Magnetic Signature	Degaussing option	Nde gaus = 1	Nde gaus = 0

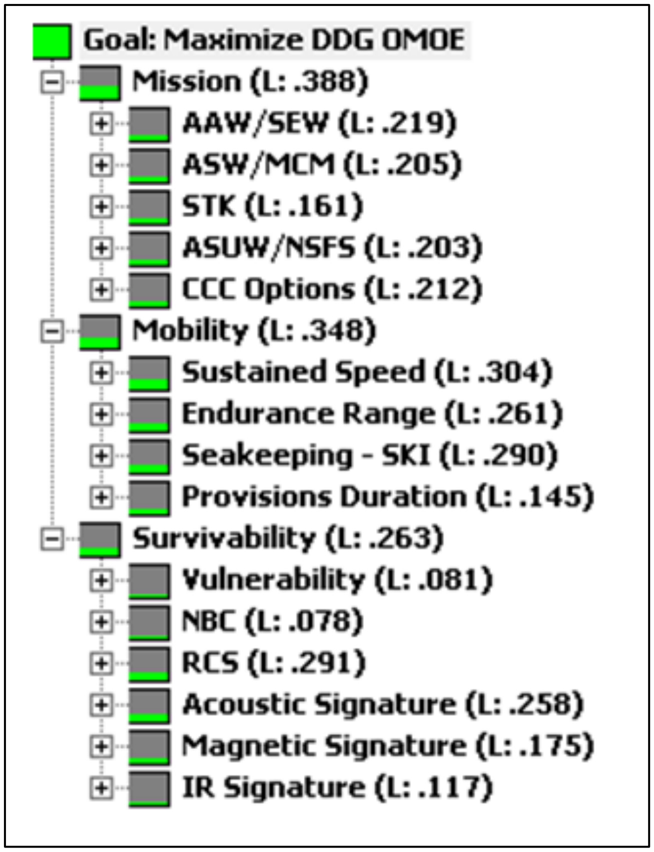

Figure 33 OMOE Hierarchy, Kennelly, N., et al., "Design Report: Guided Missile Destroyer (DDGx) VT Total Ship Systems Engineering", Virginia Polytechnic Institute and State University, Blacksburg, VA, 2013. Used under fair use, 2014.

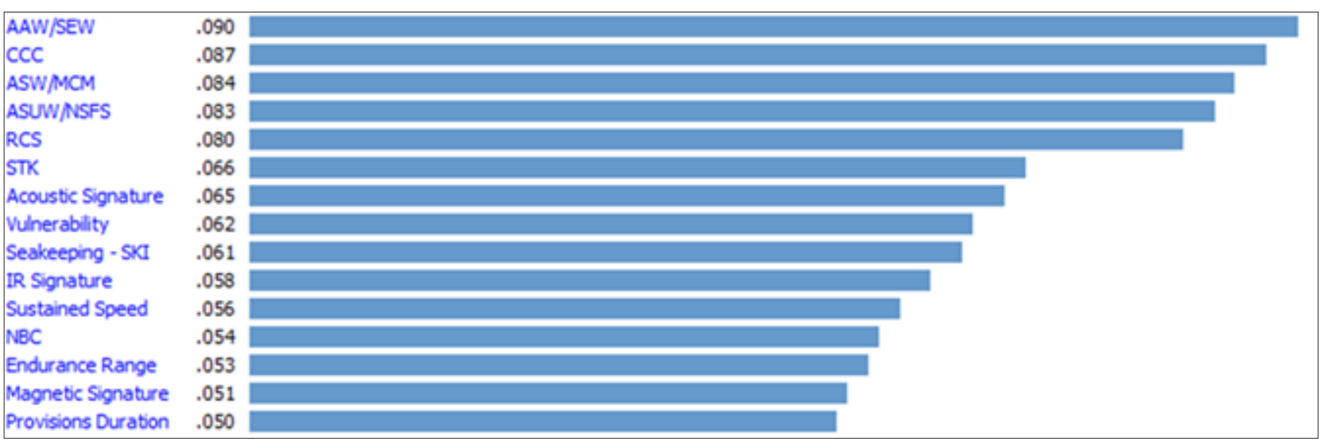

Figure 34 MOP Weights, Kennelly, N., et al., "Design Report: Guided Missile Destroyer (DDGx) VT Total Ship Systems Engineering", Virginia Polytechnic Institute and State University, Blacksburg, VA, 2013. Used under fair use, 2014.

4.5.2 Overall Measure of Risk (OMOR)

The Overall Measure of Risk is used to assign a quantitative risk value to the technologies and options considered in the designs. Each equipment considered for the design contains a level of risk that is based on performance, cost and schedule events. Each risk event for particular technology is determined as the product of probability of failure occurrence (P_i) and the consequences of failure (C_i). The values for P_i and C_i to estimate the risk of each event are taken from Table 10 and Table 11. The product of these two values represents the risk (R_i) for a specific event. The three risk events contain a weight factor (W_{perf}, W_{cost}, W_{sched}) that is included in the OMOR equation. Risk values are shown in the Risk Register Table 12. The OMOR value is obtained by using these weights and probabilities in equation (2).

$$OMOR = W_{perf} \sum_i \frac{w_i}{\sum_i w_i} P_i C_i + W_{cost} \sum_j w_j P_j C_j + W_{sched} \sum_k w_k P_k C_k \quad (2)$$

The implementation of automation in the designs has associated risk that must be considered in our case study. Automation systems reduce the number of required personnel onboard, but their implementation originates a higher probability and consequence of a adverse event. For our study a series of risk events were identified for each CMAN and Maint option that are used to calculate the OMOR in the MOGO (Table 12). The resulting risk associated with the CMAN and Maint variables is shown in Figures 41 and 43 in Chapter 5.

Table 10 Event Probability Estimate, Brown, A.J., AOE 4265/5315 Ship Design Course Notes, Aerospace and Ocean Engineering, Virginia Tech, 2013. Used under fair use, 2014.

Probability	What is the Likelihood the Risk Event Will Occur?
0.1	Remote
0.3	Unlikely
0.5	Likely
0.7	Highly Likely
0.9	Near Certain

Table 11 Event Consequences Estimate, Brown, A.J., AOE 4265/5315 Ship Design Course Notes, Aerospace and Ocean Engineering, Virginia Tech, 2013. Used under fair use, 2014.

Consequences Level	Given the Risk is Realized, What is the Magnitude of the Impact?		
	Performance	Schedule	Cost
0.1	Minimal or no impact	Minimal or no impact	Minimal or no Impact
0.3	Acceptable with some reduction in margin	Additional resources required; able to meet need dates	< 5%
0.5	Acceptable with significant reduction in margin	Minor slip in key milestone; not able to meet need date	5 – 7%
0.7	Acceptable; no reduction in margin	Major slip in key milestone or critical path impacted	7 – 10%
0.9	Unacceptable	Can't achieve key team or major program milestone	> 10%

Table 12 Risk Register

SWBS	Risk Type	Related DV#	DV Option	DV Description	Risk Event, i	Risk Description	Event #	Pi	Ci	Ri
4	Performance	DV10	2	Automation and Manning Factor	Automation systems development and implementation	Reduced Reliability and Performance (un-proven)	1	0.3	0.3	0.09
4	Cost	DV10	2	Automation and Manning Factor	Automation systems development, acquisition & integration cost overruns	Research and Development cost overruns	2	0.1	0.3	0.03
4	Schedule	DV10	2	Automation and Manning Factor	Automation systems schedule delays impact program	Research and Development schedule delays	3	0.3	0.4	0.12
4	Performance	DV10	3	Automation and Manning Factor	Automation systems development and implementation	Reduced Reliability and Performance (un-proven)	4	0.5	0.7	0.35
4	Cost	DV10	3	Automation and Manning Factor	Automation systems development, acquisition & integration cost overruns	Research and Development cost overruns	5	0.5	0.5	0.25
4	Schedule	DV10	3	Automation and Manning Factor	Automation systems schedule delays impact program	Research and Development schedule delays	6	0.5	0.7	0.35
4	Performance	DV10	4	Automation and Manning Factor	Automation systems development and implementation	Reduced Reliability and Performance (un-proven)	7	0.3	0.5	0.15
4	Cost	DV10	4	Automation and Manning Factor	Automation systems development, acquisition & integration cost overruns	Research and Development cost overruns	8	0.3	0.3	0.09
4	Schedule	DV10	4	Automation and Manning Factor	Automation systems schedule delays impact program	Research and Development schedule delays	9	0.3	0.4	0.12

SWBS	Risk Type	Related DV#	DV Option	DV Description	Risk Event, i	Risk Description	Event #	Pi	Ci	Ri
4	Performance	DV10	5	Automation and Manning Factor	Automation systems development and implementation	Reduced Reliability and Performance (un-proven)	10	0.62	0.7	0.44
4	Cost	DV10	5	Automation and Manning Factor	Automation systems development, acquisition & integration cost overruns	Research and Development cost overruns	11	0.5	0.56	0.28
4	Schedule	DV10	5	Automation and Manning Factor	Automation systems schedule delays impact program	Research and Development schedule delays	12	0.65	0.72	0.47
4	Performance	DV10	6	Automation and Manning Factor	Automation systems development and implementation	Reduced Reliability and Performance (un-proven)	13	0.48	0.5	0.24
4	Cost	DV10	6	Automation and Manning Factor	Automation systems development, acquisition & integration cost overruns	Research and Development cost overruns	14	0.4	0.3	0.12
4	Schedule	DV10	6	Automation and Manning Factor	Automation systems schedule delays impact program	Research and Development schedule delays	15	0.48	0.5	0.25
4	Performance	DV10	7	Automation and Manning Factor	Automation systems development and implementation	Reduced Reliability and Performance (un-proven)	16	0.7	0.71	0.50
4	Cost	DV10	7	Automation and Manning Factor	Automation systems development, acquisition & integration cost overruns	Research and Development cost overruns	17	0.6	0.56	0.34
4	Schedule	DV10	7	Automation and Manning Factor	Automation systems schedule delays impact program	Research and Development schedule delays	18	0.67	0.7	047
4	Performance	DV10	8	Automation and Manning Factor	Automation systems development and implementation	Reduced Reliability and Performance (un-proven)	19	0.7	0.84	0.59
4	Cost	DV10	8	Automation and Manning Factor	Automation systems development, acquisition & integration cost overruns	Research and Development cost overruns	20	0.6	0.62	0.37
4	Schedule	DV10	8	Automation and Manning Factor	Automation systems schedule delays impact program	Research and Development schedule delays	21	0.7	0.84	0.59
2	Performance	DV11	2	Maintenance Plan	Repairs are required due to overdue or lack of maintenance	Reduces equipment availability	24	0.3	0.5	0.15
2	Cost	DV11	2	Maintenance Plan	Logistics to conduct Repair	Limit Ship Availability	25	0.5	0.6	0.30

SWBS	Risk Type	Related DV#	DV Option	DV Description	Risk Event, i	Risk Description	Event #	Pi	Ci	Ri
2	Performance	DV11	3	Maintenance Plan	Repairs are required due to overdue or lack of maintenance	Reduces equipment availability	26	0.4	0.5	0.20
2	Cost	DV11	3	Maintenance Plan	Logistics to conduct Repair	Limit Ship Availability	27	0.5	0.7	0.35
1	Performance	DV15	3	Deckhouse Material	Composite material producibilitty problems	USN lack of experience with material	28	0.5	0.6	0.3
1	Performance	DV15	3	Deckhouse Material	Composite material RCS, and fire performance does not meet performance predictions	In development and test	29	0.4	0.5	0.2
1	Cost	DV15	3	Deckhouse Material	Composite material cost overruns impact program	In development and test	30	0.5	0.3	0.15
1	Schedule	DV15	3	Deckhouse Material	Composite material schedule delays impact program	In development and test	31	0.5	0.2	0.1
2	Performance	DV16	7	Propulsion Systems	IPS Development and Implementation	Reduced reliability and performance (un-proven)	32	0.3	0.6	0.18
2	Cost	DV16	7	Propulsion Systems	IPS Development, acquisition & integration cost overruns	Research and Development cost overruns	33	0.4	0.4	0.16
2	Schedule	DV16	7	Propulsion Systems	IPS Schedule delays impact program	In development and test	34	0.3	0.4	0.12
2	Performance	DV16	3,4,8,9,10,14,15,16	Propulsion Systems	ICR Development & Implementation	Unproven, recuperator problems	35	0.6	0.5	0.3
2	Cost	DV16	3,4,8,9,10,14,15,16	Propulsion Systems	ICR Development, acquisition and integration cost overruns	Unproven, recuperator problems	36	0.6	0.4	0.24
2	Schedule	DV16	3,4,8,9,10,14,15,16	Propulsion Systems	ICR Schedule delays impact program	Unproven, recuperator problems	37	0.6	0.5	0.3
2	Performance	DV16	(11-16)	Propulsion Systems	Development and Implementation of podded propulsion	Reduced Reliability (un-proven)	38	0.7	0.4	0.28
2	Performance	DV16	(11-16)	Propulsion Systems	Development and Implementation of podded propulsion	Shock and vibration of full scale system unproven	39	0.7	0.6	0.42
2	Cost	DV16	(11-16)	Propulsion Systems	Podded Propulsion Implementation Problems	Unproven for USN, large size	40	0.6	0.45	0.27
2	Schedule	DV16	(11-16)	Propulsion Systems	Podded Propulsion Schedule delays impact program	Unproven for USN, large size	41	0.6	0.6	0.36

SWBS	Risk Type	Related DV#	DV Option	DV Description	Risk Event, i	Risk Description	Event #	Pi	Ci	Ri
2	Cost	DV16	3,4,8,9,10,14,15,16	Propulsion Systems	ICR Development, acquisition and integration cost overruns	Unproven, recuperator problems	42	0.6	0.4	0.24
2	Schedule	DV16	3,4,8,9,10,14,15,16	Propulsion Systems	ICR Schedule delays impact program	Unproven, recuperator problems	43	0.6	0.5	0.3

4.5.3 Cost

The cost model used to calculate lead ship acquisition cost is based on the Naval Ship Acquisition Cost Components shown in Figure 35. The lead ship acquisition cost is broken down into two costs: Shipbuilder and Government costs. The shipbuilder cost refers to the cost of constructing the ship. Government costs include the support cost through outfitting during and after the shipbuilder has delivered the vessel. To measure the direct total cost to the government of acquisition and ownership over the ship's effective lifespan, Life Cycle Cost (LCC) is used. LCC is described as the total cost of acquisition and ownership of a ship over its useful life. Total Ownership Cost (TOC) is the third metric used to calculate the cost. TOC is similar to Life Cycle Cost but includes indirect cost like training, logistics support, and any extra cost related to the production of a ship.

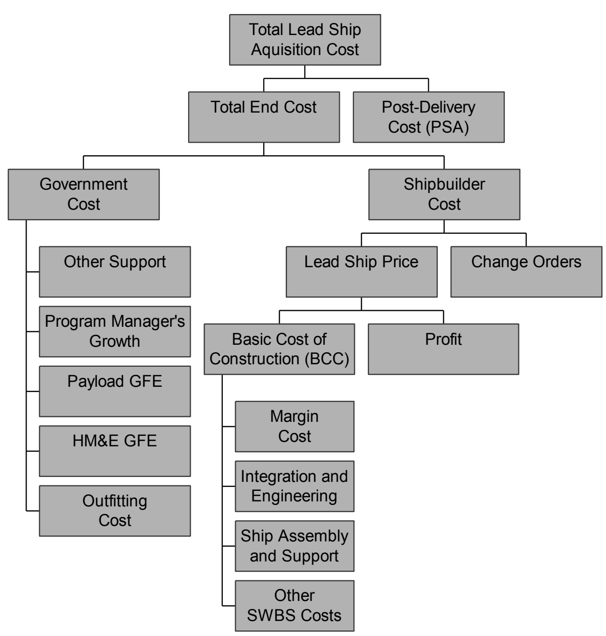

Figure 35 Naval Ship Acquisition Cost Components, Stepanchick, J. and Brown, A.J., "Revisiting DDGX/DDG-51 Concept Exploration", Naval Engineers Journal, Vol. 119, No. 3, 73, 2007. Used under fair use, 2014.

4.6 Concept Exploration

In this concept exploration case study MC runs the SSM in the MOGO to obtain a non-dominated frontier (NDF). After all the modules are added to the SSM and the surrogate manning module is linked with the optimization, the MOGO can be executed to search the design space for non-dominated designs. The MOGO components are the objectives, constraints, and design variable ranges. The objectives are the selected metrics that are being either maximized or minimized to find the best design (Section 4.5). For this case study the objectives used were: OMOE (maximized), OMOR (minimized), and CTOC (minimized). The constraints used are the error ratios from the feasibility module. The DVs and corresponding thresholds are taken from Table 7. After the design population is searched in the optimization, designs can be selected from the NDF for further evaluation. The 3D objective NDF for DDGx is shown in Figure 36.

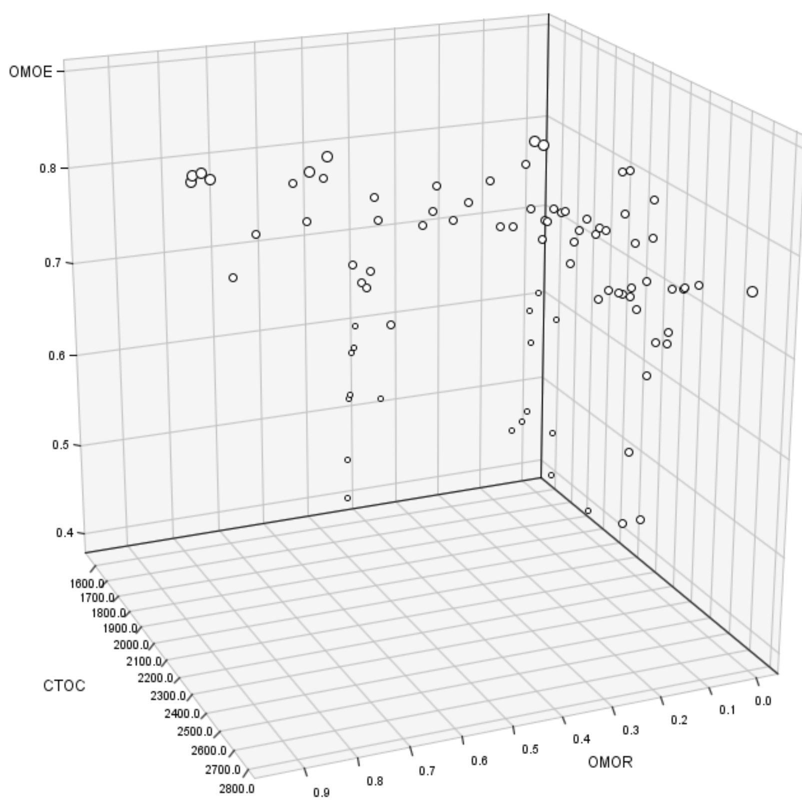

Figure 36 3D Non-Dominated Frontier

Results of the optimization can also be represented in a 2D non-dominated frontier displayed in Figure 37. The 2D NDF facilitates the designers understanding the of relationship between cost, risk and effectiveness. The NDF for the DDGx shows that when the DDGx designs move toward higher cost and risk values the effectiveness increases. This is expected since new higher end designs include emerging technologies that increase performance and effectiveness but have higher risk construction and implementing costs. The designs in the NDF represented with yellow and red dots have higher risk. There is also a relationship between the high risk designs and manning. This relationship is further explained and seen in other NDF plots in Chapter 5. Based on the NDF a customer can select a preferred design given their preferences. Normally a knee in the curve design is chosen because there is only a small increase in effectiveness for large increases in cost above this knee.

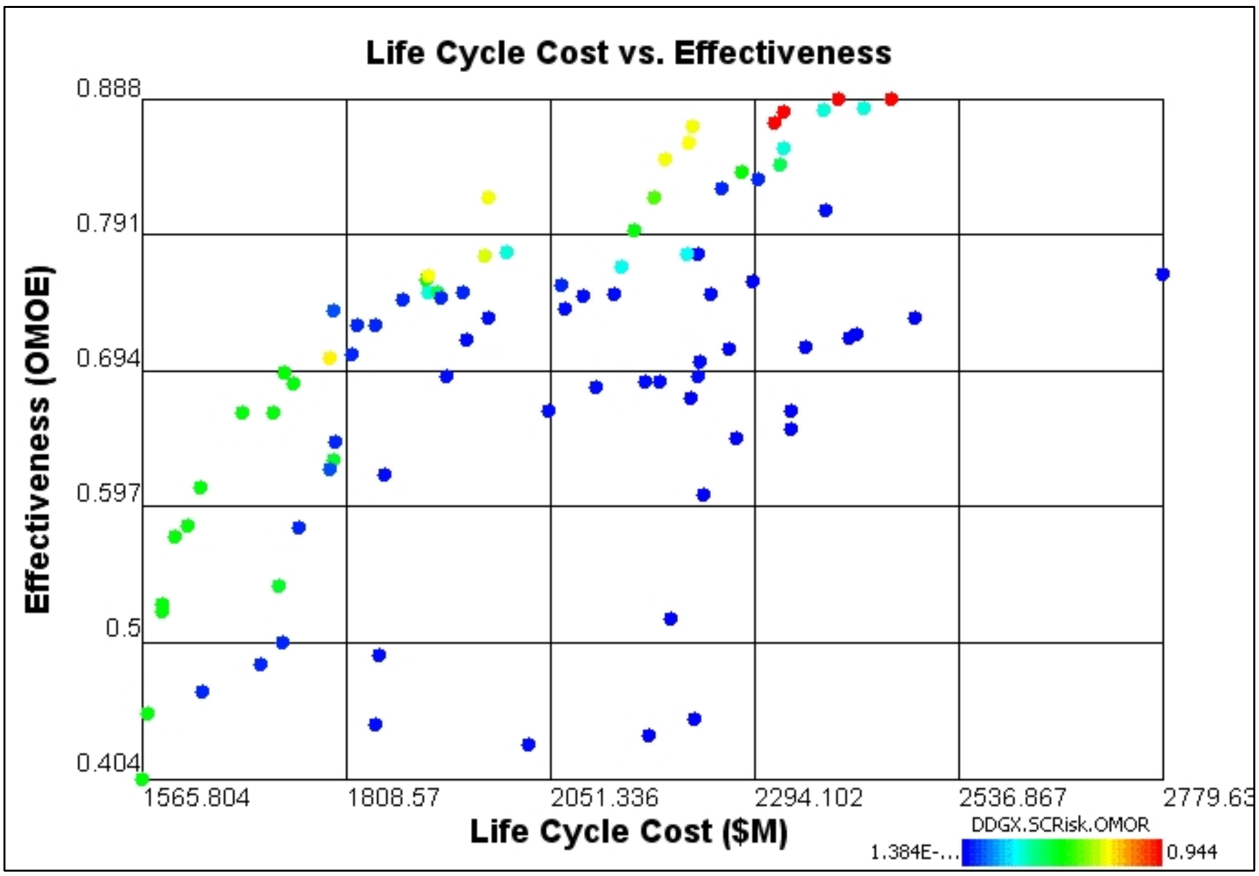

Figure 37 DDGx Non-Dominated Frontier (LCC, OMOE, Risk)

Chapter 5 Results and Conclusion

In this thesis we were able to explore and improve the previous manning analysis method used in naval ship manning analyses by implementing a manning model that considers automation and functions removal in the crew size calculation as part of a total ship design. By integrating a mission scenario with equipment maintenance requirements, the manning model provided useful manning predictions that were incorporated as a surrogate manning model in a Ship Synthesis Model and MOGO. This research is only a preliminary step in determining the full range and impact of possible manning reduction initiatives and technologies that could be implemented in further studies. One of the major accomplishments achieved in this study was to show and quantify the important relationship between automation, watchstanding, cost and crew size reduction in a balanced ship design. Now that the basic manning model infrastructure and ship synthesis interface has been established, future research can address more difficult questions assessing the total impact of reduced manning

5.1 Manning Model Results

To avoid confusion and understand the results of the histograms and plots presented in this chapter a table with the final CMAN and Maint DV definitions is provided below (Table 13).

Table 13 CMAN and Maint DV (New)

DV	New Option #	Description
CMAN	1	Baseline manning level. All crewmembers in the crew list are assigned to daily tasks.
	2	Food services automation is implemented, centralized galleys and pre-prepared food menus.
	3	Administrative personnel and personal services are removed from tasks and outsourced.
	4	Administrative personnel and personal services are removed from tasks + Food services automation is implemented, centralized galleys and pre-prepared food menus
	5	Watch standing automation for WQSB Condition III and General Quarters events and tasks.
	6	Watch standing automation for WQSB Condition III and General Quarters events + Food services automation is implemented, centralized galleys and pre-prepared food menus.
	7	Administrative personnel and personal services are removed from tasks + Watch standing automation for WQSB Condition III and General Quarters events.
	8	Administrative personnel and personal services are removed from tasks + Watch standing automation for WQSB Condition III and General Quarters + Food services automation is implemented, centralized galleys and pre-prepared food menus.
Maint	1	Crew completes equipment preventive maintenance tasks up to and including annual tasks.
	2	Crew completes all equipment preventive maintenance.
	3	Crew completes equipment preventive maintenance tasks up to and including monthly tasks.

5.1.1 Crew Size Occurrence Results

The crew size occurrence histogram is used as an indication of the crew size output occurrence in the MOGO non-dominated designs. These are the best designs for a given cost and risk. In general, risk always increases with reduced manning (see Figure 39, next page). The manning surrogate model estimated a required non-dominated design crew size from 183 to 364 crewmembers given the non-dominated ship design configurations. The majority of the non-dominated solutions have smaller crew sizes with increased risk compared to the baseline. Figures 39, 40 and 41 achieve lower crew size results primarily by selecting CMAN options 5-8.

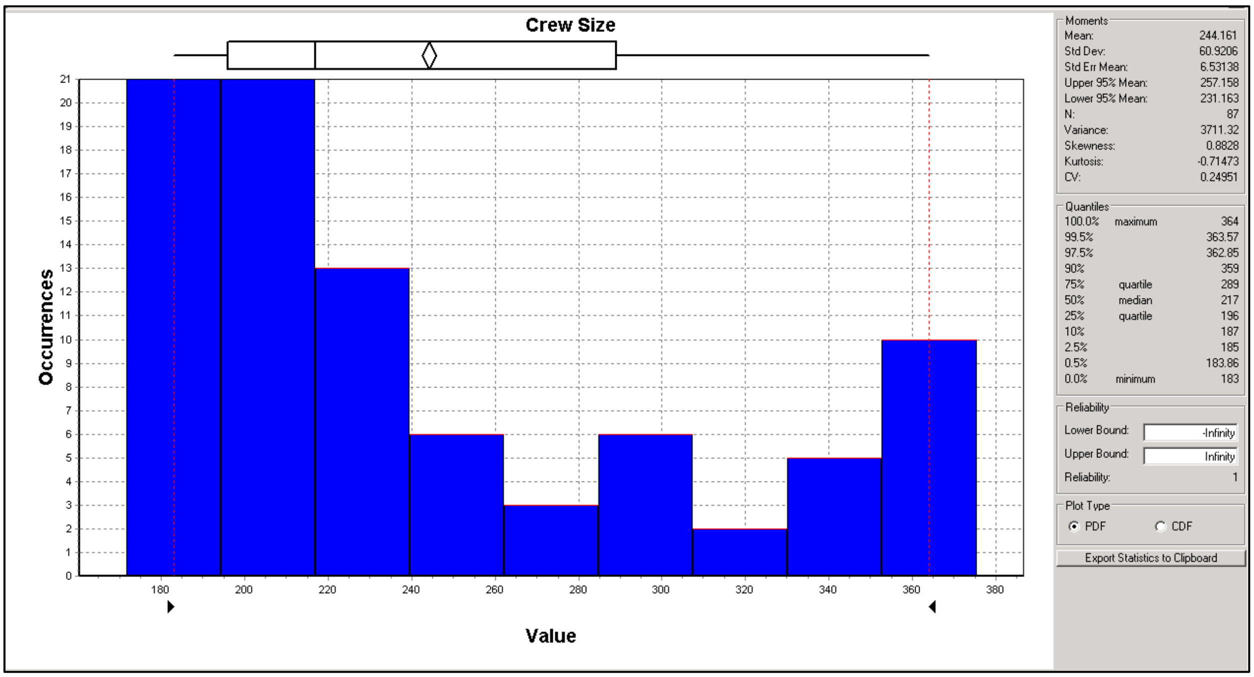

Figure 38 Crew Size Occurrences Histogram

5.1.2 Crew Size Non-Dominated Frontier

The result of the MOGO for DDGx can also be represented in a non-dominated frontier (NDF) as shown previously in Figure 37. A modified DDGx non-dominated frontier is displayed in Figure 40. LCC, Effectiveness and total crew size (vice OMOR) are represented in this NDF. The x-axis shows life cycle cost and the y-axis shows Overall Measure of Effectiveness. The colors of the points correspond to the total DDGx crew size. The higher effectiveness and lower LCC designs in Figure 40 are design solutions with lower crew size (red points), but as shown in Figure 39, these designs have higher risk. Designers must accept this risk as tradeoff for smaller crew size. The blue points in the NDF are design options with baseline equipment configurations and low risk that produce designs with large crew sizes. Baseline designs (blue points) have higher LCC and moderate effectiveness, but designs with the same level of effectiveness can be obtained at lower cost only if we move towards higher risk, left in the curve. It is clear that the crew size and cost relationship is significant. Life cycle cost reduction is difficult to achieve if manning levels are not reduced. This reduction can be obtained by placing new technologies with automation capabilities in these ships, but with added risk.

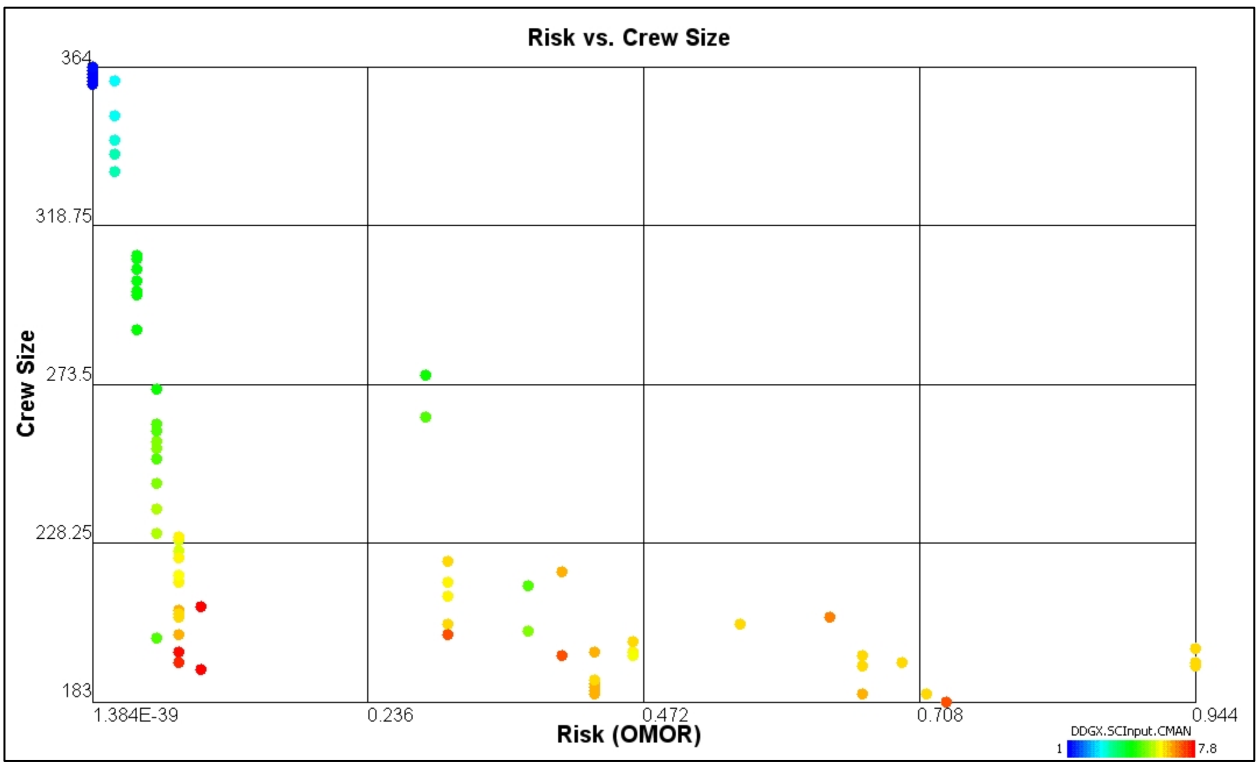

Figure 39 Crew size as a function of Risk and CMAN for ND designs

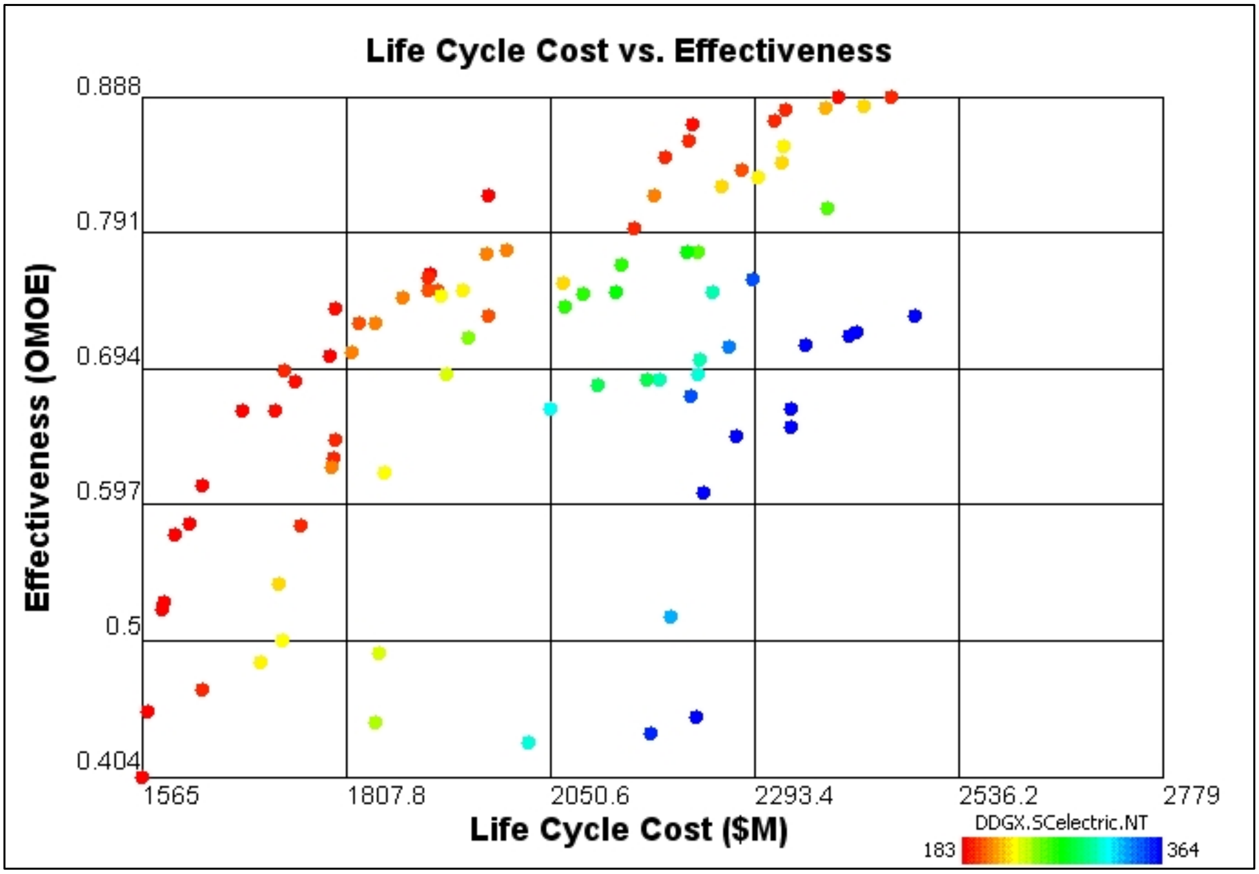

Figure 40 Non-Dominated Frontier (LCC, OMOE, Crew Total)

5.1.3 CMAN Occurrence Results

Figure 41 shows the automation and manning factor (CMAN) occurrence in the non-dominated designs. This DV has the largest impact on manning reduction. Most of the occurrences for this DV occur between options 5 and 8. Since this variable was treated as a continuous variable in the manning model the results indicate fractional values that could be interpreted as the partial implementation of the automation and manning factor options. The mean value for this DV was 5.3, which implements watch standing automation plus portions of food services automation. There were no non-dominated occurrences for CMAN = 2 (Food Service Automation). This is due to the crew reduction being limited by operational watch standers for this option even with food service automation. The CMAN = 6 option (Watchstanding automation + Food Service automation) resulted in 23 non-dominated designs indicating that food service automation is effective in reducing manning when combined with watchstanding automation.

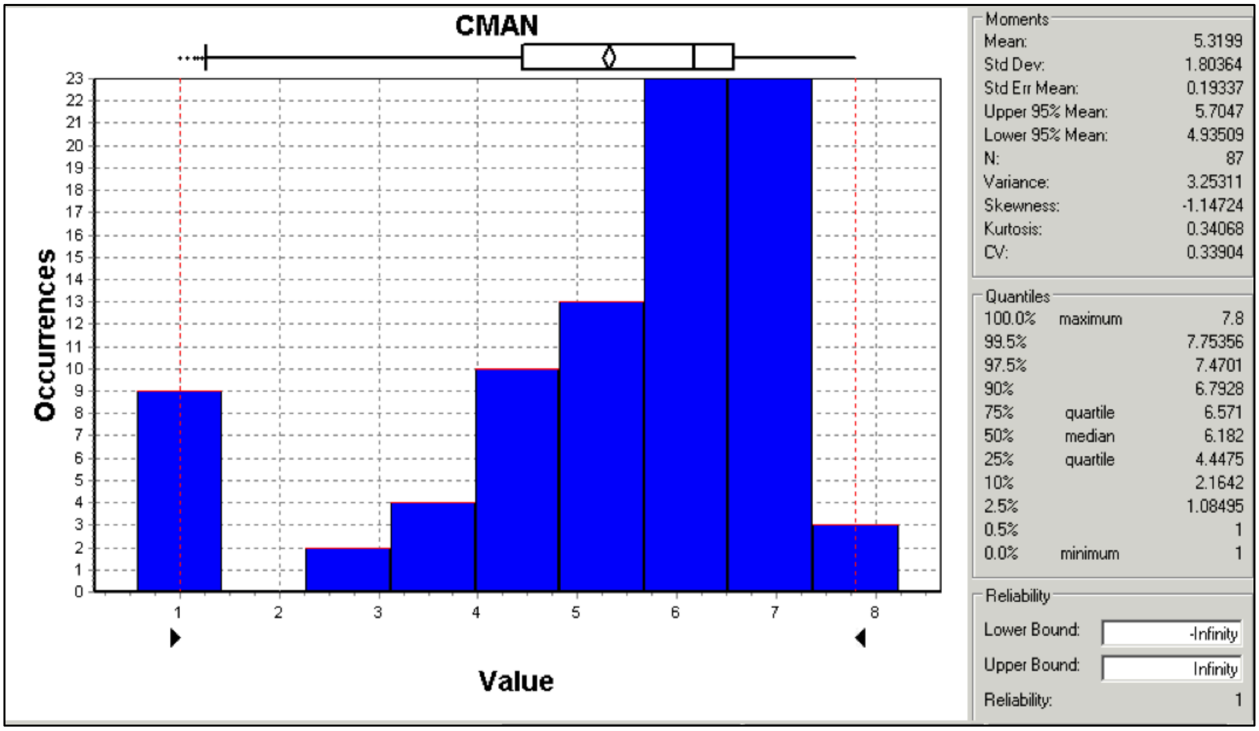

Figure 41 CMAN Occurrences Histogram

The LCC, Effectiveness and CMAN non-dominated frontier are shown in Figure 42. The x-axis shows life cycle cost and the y-axis shows Overall the Measure of Effectiveness. The colors of the points correspond to the automation manning factor (CMAN). The upper designs in the non-dominate solutions in Figure 42 show that designs with CMAN options 6-8 (orange/yellow points) have higher effectiveness and lower LLC, but higher risk. The blue points in the NDF are the design options with baseline equipment configurations that produce the highest crew sizes in the model with low risk. Similar to the NDF in Figure 40 these solutions do not provide higher effectiveness and lower LCC. The minimum life cycle cost for these designs is $2.2 Billion, almost $500 million more than other designs in the NDF with the same level of effectiveness. The mid region of non-dominate solutions are populated by green points (CMAN = option 5) that produce moderate levels of effectiveness and cost for their level of automation. We can conclude that if automation is not implemented (shown by blue points) the effectiveness of the feasible solutions remains below 0.767 with higher lifecycle cost than other non-dominated solutions. Applying automation and function outsourcing by implementing new technologies reduces ship life cycle cost and creates more effective design solutions. Again, this is only achieved with higher risk.

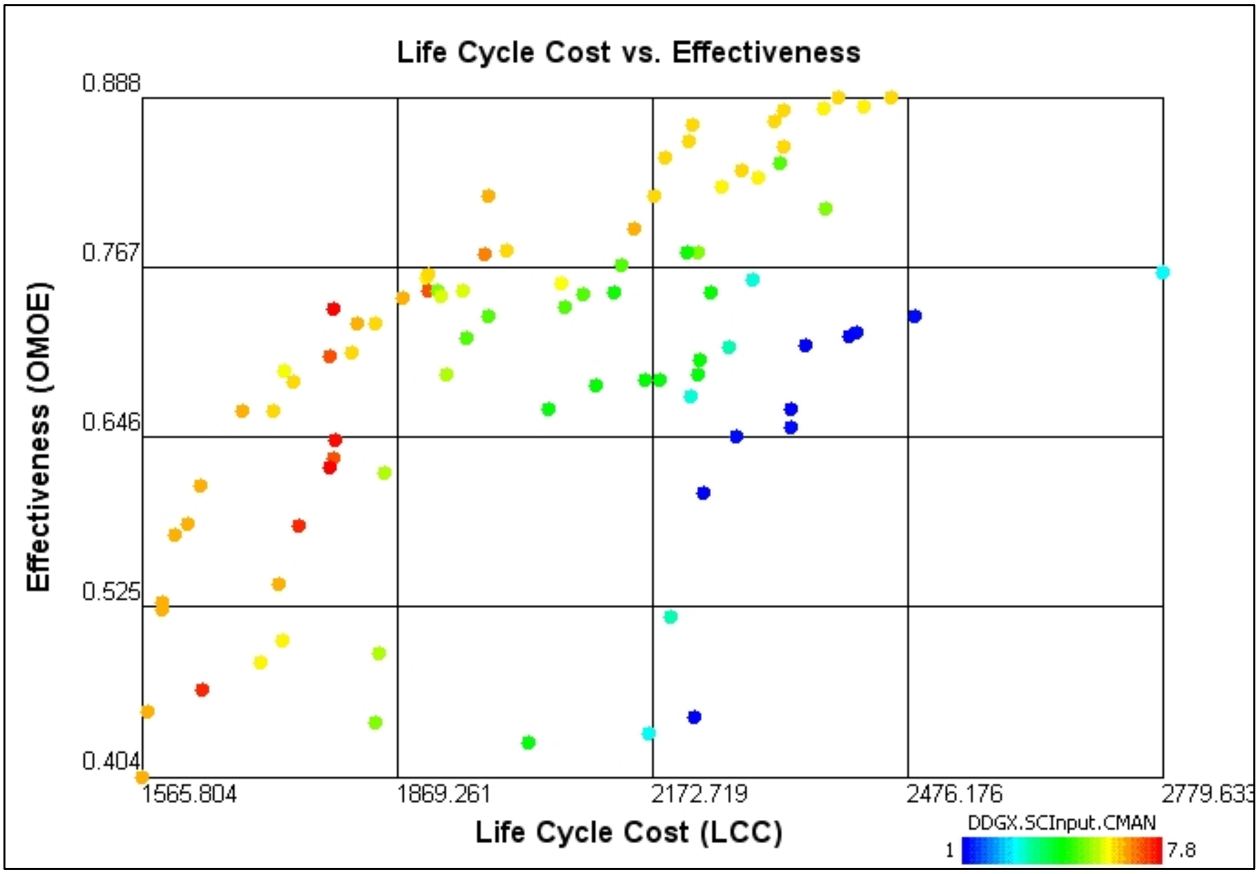

Figure 42 Non-Dominated Frontier (LCC, OMOE, CMAN)

5.1.4 Maint Occurrence Results

The maintenance occurrence chart (Figure 43) shows the maintenance DV ND design occurrences. It also treats the Maintenance DV as a continuous variable. Most of the occurrences for this variable have values between 2 and 3. The mean value for this DV is 2.3 which means the maintenance level chosen will reduce the crew required maintenance onboard tasks to annual or less PMs. The Maint variable contributes to crew size reduction in ship designs and its implementation is necessary to achieve the highest level of manning reduction. The graph shows that Maint option 1 (Baseline) was not implemented as frequently as the other options in the non-dominating designs.

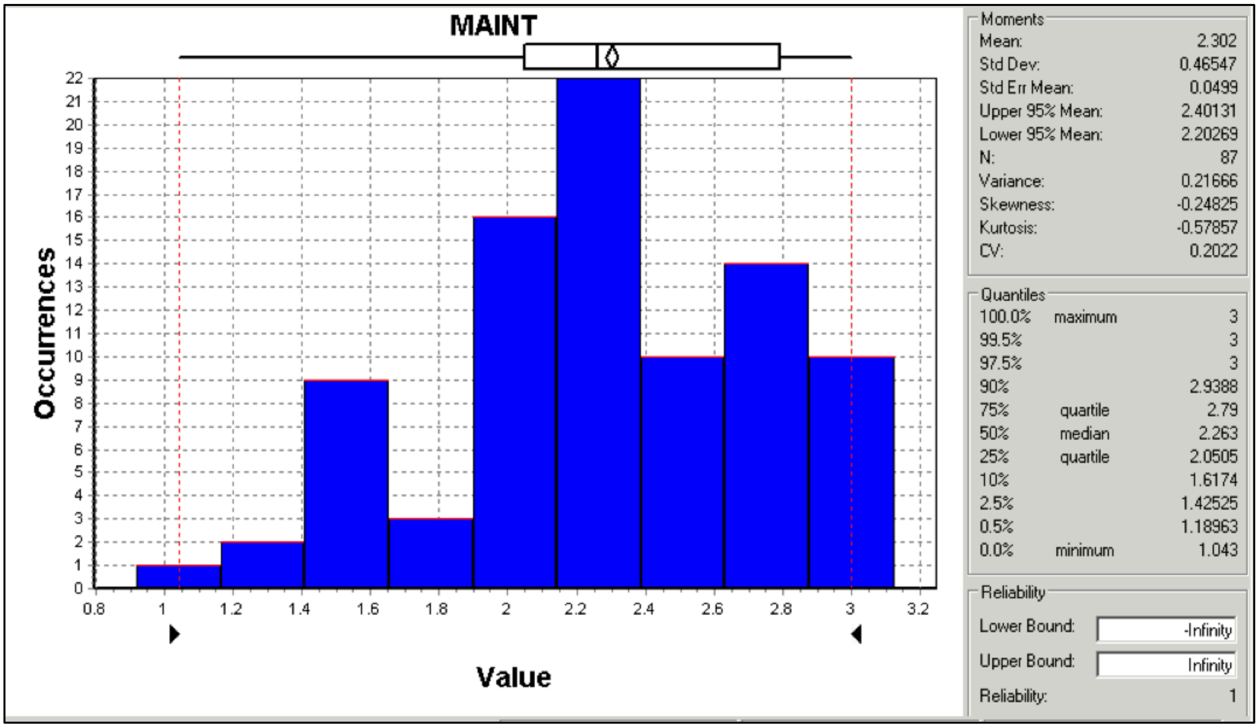

Figure 43 Maint Occurrences Histogram

LCC, Effectiveness and the Maint DV are shown in the NDF (Figure 44). The colors of the points correspond to maintenance level one to three. The higher OMOE non-dominated solutions are designs with the lowest Maint levels (red points). These solutions provide very effective designs with small crew sizes levels, but have greater risk. The lower OMOE non-dominated solutions are design options with baseline maintenance levels which produce larger crew sizes. From this graph it is determined that the maintenance, cost and crew size relationship is significant. Maximum life cycle cost reduction and crew size reduction is only achievable if maintenance reduction is implemented. These reductions can be obtained using new technologies that require less frequent maintenance or by moving maintenance ashore.

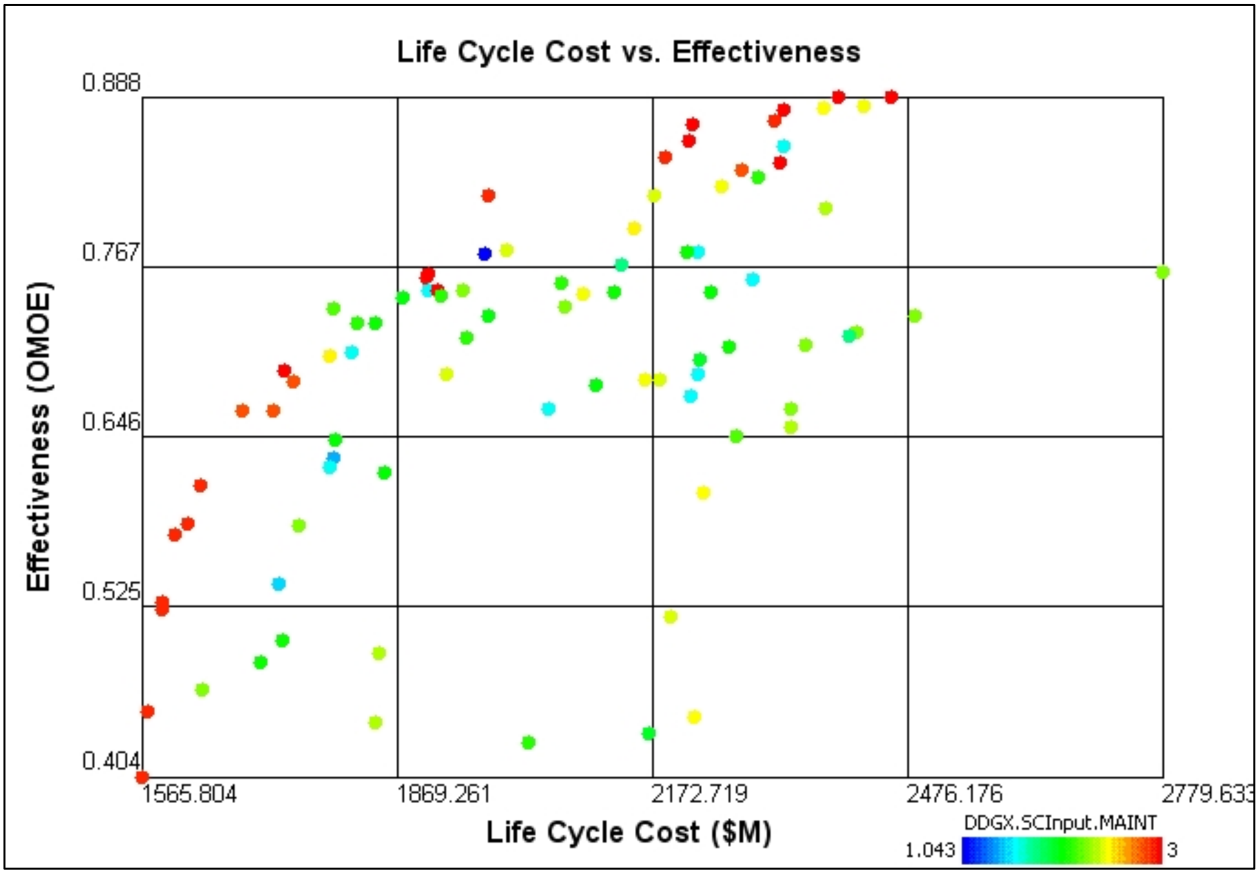

Figure 44 Non-Dominated Frontier (LCC, OMOE, Maint)

Crew size as a function of CMAN and Maint for non-dominated designs is plotted in Figure 45. The x-axis is the manning and automation factor and the y-axis is the crew size. The colors of the points correspond to the Maint DV. The plot shows that the crew size reduces as we move to a Maint level 3 and to a CMAN 8 option.

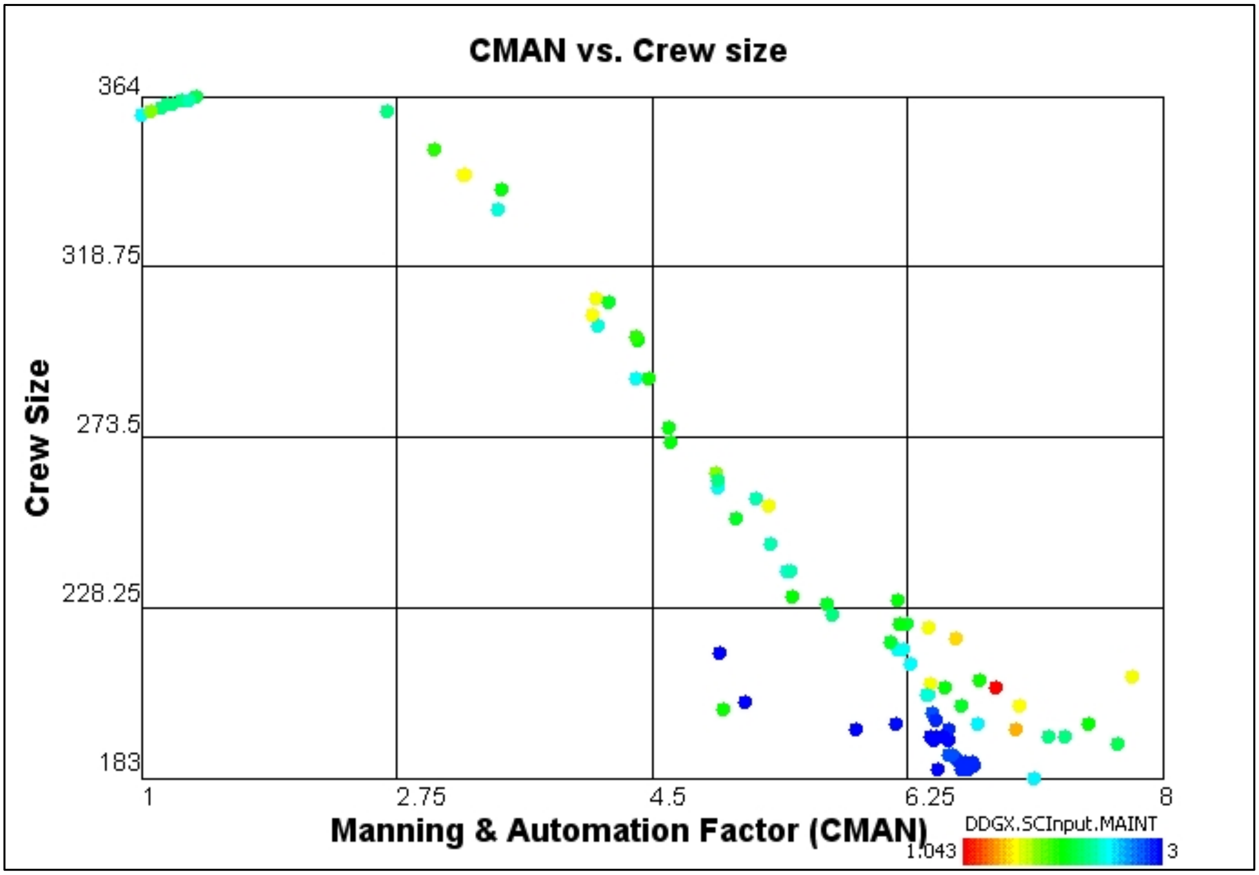

Figure 45 Crew size as a function of CMAN and Maint for ND designs

There is a direct relationship between CMAN, Maint DVs and crew size in the design exploration. However, manpower reduction increases risk levels that must be dealt with. Owner and designers must balance effectiveness requirements with risk levels and cost.

5.2 Manning Study Comparison

The results of our case study were compared with the study performed by Hinkle and Glover [11]. Their study stated that in a long term technology investment a DDG-51 crew SMD could be reduced from 361 to 217. Our study reduced a baseline crew list for a DDGx notional concept design from 363 to 183 crew members with significant technology and program risk. This represents almost a 50% reduction from the original crew list and slightly more than the Hinkle and Glover study. It is important to note that our designs were smaller than the DDG-51 because of their total ship impact.

5.3 Important Issues Not Addressed In This Study

Important issues not addressed in this study are outlined in the list below:

1. The direct impact of automation on performance and effectiveness.
2. Corrective Maintenance is not addressed explicitly in this study. Corrective Maintenance tasks could have a major impact on the analysis. ISMAT allows the designer to specify equipment mean time between failures requiring corrective maintenance with the mean time to repair, but this function was not used in our study.
3. The task completion time is treated as deterministic vice probabilistic. This is not realistic.
4. PMS data could be incomplete or inaccurate.
5. Moving maintenance requirements to other activities impacts ship force knowledge of their ship and ship systems, which may be important in day to day operations and crisis.
6. Damage control scenarios must consider response after loss of systems and crew.
7. Many tasks and event evolutions are not considered including at sea training.
8. Simple study results can be misleading and this can be a major problem.

5.4 Recommendations and Future Work

Section 5.3 identified several areas that this thesis did not consider. These areas suggest a variety of research directions that need to be pursued individually to improve the manning model effectiveness, credibility and crew prediction accuracy. Each area contains a particular recommendation for further study and their effects must be analyzed individually before they are implemented together in the manning model. The areas for further study are:

1. Improve manning model data
    - Include PMS data for IPS systems and emerging technologies available for naval ships in the analysis data. Preventive maintenance and corrective maintenance data will improve the designs manning requirement accuracy.
    - Include a damage control automation design variable for different fire suppression equipment systems and other DC systems. Test options in the manning model to assess their total ship impact.

2. Improve manning model scenarios

- Include damage control operations in the scenarios. Damage control scenarios must consider fire, flooding events and crew response after loss of vital systems and crew.
- Incorporate probabilistic events in the scenarios. Consider other generic software tools with probabilistic discrete event analysis.
- Consider crew fatigue in scenarios. For our study a 72hr work week was used, but this may be excessive and unreasonable for a multiple week scenario.
- Model actual tasks and functions in a ship scenario vice watch station locations.
- Incorporate crew "Skills" when assigning maintenance tasks.
- Consider human subsystems as part of system architecture.

3. Improve MOGO objective attributes

- Explore assigning a reliability factor to automation options when implemented. These systems don't have back-up systems in the event of a complete system failure.
- Consider implications of PMs outsourcing that would create crew unfamiliarity with machinery systems and potentially delays in ship operations if repairs are needed. Future analysis work can assign a crew reliability factor to complete tasks or use the ISMAT crew skill required.
- Consider crew fatigue levels in the OMOR.
- Consider the training benefit of a crew doing maintenance.
- Reassess the cost model to correctly reflect manning reduction in TOC.

References

1. *Military Personnel Navy Action Needed to Optimize Ship Crew Size and Reduce Total Ownership Costs*, G.A. Office, Editor, 2003, GAO. p. 54.
2. Castelli, NAVSEA Media Forum, January 29, 2003, *"Balisle's NAVSEA Media Forum with Reporters"*, *Inside the Navy*, February 3, 2003, pp. 11-14.
3. *Military Readiness Navy Need to Reassess Its Metrics and Assumptions for Ship Crewing Requirements and Training*, G.A. Office, Editor, 2009 GAO. p. 46.
4. Bost R.J. and Galdorisi G., *Transforming Coalition Naval Operations by Using Human Systems Integration to Reduce Warship Manning: Lessons Learned from the United States Navy DDG 51 Class warship Reduced Manning Study,* Naval Sea Systems Command, 2005. p.4.
5. Spindel, et al., *Optimized Surface Ship Manning*, N.R.A. Committee, Editor. 2000. p. 100.
6. Brown, A.J. and Salcedo J., "Multiple Objective Genetic Optimization in Naval Ship Design", *Naval Engineers Journal*, Vol. 115, No. 4, pp. 49-61, 2003.
7. Brown, A.J. and Thomas M., "Reengineering the Naval Ship Concept Design Process, *From Research to Reality in Ship Systems Engineering Symposium*. ASNE, 1998.
8. Stepanchick, J. and Brown, A.J., "Revisiting DDGX/DDG-51 Concept Exploration", *Naval Engineers Journal,* Vol. 119, No. 3, 67-88, 2007.
9. Scofield, T., "Manning and Automation for Naval Ship Analysis and Optimization" Master's Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, April, 2006.
10. Malone, T.B, "HSI Top-Down Requirements Analysis for Ship Manpower Reduction". [Internet] [cited 2014].
11. Hinkle, J. and Glover, T., "Reduced Manning in DDG 51 Class Warships: Challenges, Opportunities and the Way Ahead for Reduced Manning on all United States Navy Ships"*, ASNE, Engineering the Total Ship Symposium, National Institute for Standards and Technology*, March 17-18, 2004.
12. Brown, A.J. and Waltham-Sajdak, J., "Still Re-Engineering the Naval Ship Concept Design Process", paper presented at ASNE Day, 2014.
13. Hagan, J., *Human System Integration and Crew Design Process Development in the Zumwalt Destroyer Program A Case Study in the Importance of Wide Collaboration,* Special Report 306: Committee of Naval Engineering in the 21st Century Transportation Research Board, Bath Iron Works, 2011.
14. *Raytheon Home Page*, http://www.raytheon.com/capabilities/products/dbr/. [cited 2014]
15. *Wartsila Home Page*, http://www.wartsila.com/en/automation/vessel-automation/ias. [cited 2014]
16. Lundquist, E.H., "DDG 1000's Integrated Power System Software, Hardware Come Together in Successful Test", http://www.defensemedianetwork.com/stories/ddg-1000s-integrated-power-system-software-hardware-come-together-in-successful-test/, April 20, 2012. [cited 2014]
17. Henry, M., Iacovelli, M., and Thatcher, J., "DDG 1000 Engineering Control System (ECS)"*, ASNE Intelligent Ship VIII Symposium,* 20-21 May 2009.

18. Lebaudy, A., Callahan, B. and Famme, J., "Survivable Computing Environment to Support Distributed Autonomic Automation*", ASNE Controls Symposium*, 2007.
19. *OTO Melara Home Page*, http://www.otomelara.it/products-services/naval-systems/127-64-lw?WT.ac=127/64%20LW%20-%20VULCANO%20SYSTEM. [cited 2014]
20. *BAE Systems Homepage*, http://www.baesystems.com/product/BAES_020037/advanced-gun-system-ags. [cited 2014]
21. Morris, T. K, (MC3), "TR Leads the Way in Implementing Paperless Process"*, November 28, 2012.* http://www.navy.mil/submit/display.asp?story_id=70827 [cited 2014]
22. Office of Naval Research, "*Office of Naval Research Serves Up Revamped Software for Navy Chefs,"* Arlington, VA, March 2011. http://www.onr.navy.mil/en/Media-Center/Press-Releases/2011/Food-Service-Management-TechSolutions.aspx. [cited 2014]
23. Ball, P., "Introduction to Discrete Event Simulation, in 2nd DYCOMANS workshop on Management and Control: Tools in Action", *DYCOMANS*: Algarve, Portugal, 1996.
24. Wetteland, C.R., et al. "The Human Simulation: Resolving Manning Issues Onboard DD21", *2000 Winter Simulation Conference*. 2000.
25. Bowen, S.A.M., Wetteland C.R., and French J., "The Total Crew Model (TCM): Using task network models to solve manning optimization issues", Micro Analysis and Design. p. 1-12.
26. Wenger, T. and Plott B., *Software User's Manual for the Integrated Simulation Manpower Analysis Tool (ISMAT)*, 2005, Micro Analysis and Design, Inc. p. 1-237.
27. Endsley, M.R. and Kaber D.B., "Level of automation effects on performance, situation awareness and workload in a dynamic control task". Ergonomics, 1999.42(3): p. 462-492.
28. Kennelly, N., et al., "Design Report: Guided Missile Destroyer (DDGx) VT Total Ship Systems Engineering", Virginia Polytechnic Institute and State University, Blacksburg, VA, 2013.
29. Brown, A.J., AOE 4265/5315 Ship Design Course Notes, Aerospace and Ocean Engineering, Virginia Tech, 2013.

Appendix A- ISMAT Crew Output C# Code

```
int resultnumber=ISMATModel.GetNumOperatorsUtilized();
Console.WriteLine(resultnumber);
	try
	{
		System.IO.FileInfo f = new System.IO.FileInfo("manning.out");
		System.IO.StreamWriter w=f.CreateText();
		{
			w.WriteLine(resultnumber);
		}
		w.Close();
	}
	catch(Exception e)
	{
		Console.WriteLine("Exception: " + e.Message);
	}
	finally
	{
		Console.WriteLine("Executing finally block.");
	}
```

Appendix B – Manning DDG.exe Code

```
Module Module1

    Sub Main()
        Dim ApptoRun As String              'String required to start the console version of ISMAT
        Dim FiletoRun As String             'Name of the ISMAT file to be executed
        Dim Baseequip As String             'Base Equipment
        Dim ManModel As String              'Gathers all the inputs together to launch console ISMAT
        Dim Goal As String                  'Specifies the objective for the optimizer.  may not need this
        Dim Consolekill As String           'Used to shut down console ISMAT after the simulation is complete
        Dim DDGxCrew As Integer             'Used for the shell application
        Dim AAW_SEW_GMLS_STK As String      'Equipment info for the AAW/SEW/GMLS/STK system
        Dim AAW_SEW_GMLS_STKopt As Integer          'Input from MC for the AAW/SEW/GMLS/STK
        option
        Dim ASuW_NSFS As String             'Equipment info for the ASUW_NSFS system
        Dim ASW_MSM As String               'Equipment info for the ASW_MSM system
        Dim ASW_MSMopt As Integer           'Input from MC for ASW_MSM option
        Dim ASuW_NSFSopt As Integer         'Input from MC for ASUW_NSFS option
        Dim PSYS As String                  'Equipment info for the Power and Propulsion system
        Dim PSYSopt As Integer              'Input from MC for Power and Propulsion Option
        Dim LAMPS As String                 'Equipment info for the LAMPS system
        Dim AIR As Integer                  'Input from MC for LAMPS option
        Dim CMAN As Integer                 'Level of Automation of the ship
        Dim Scenario As String              'Sets the scenario to run based on the CMAN
        Dim Maint As Integer                'Maintenance Level for the ship
        Dim Comp As String                  'The DDGx compartments in the ship
        '
        ApptoRun = """c:\Program Files\MAAD\ISMAT\MAAD.ISMAT.Console.exe"""
        FiletoRun = " -f "" c:\Program Files\MAAD\ISMAT\DDGxVTmanmod.ismat"""

        'Read the inputs variables for the model from Model Center
        FileOpen(1, "z:\ Analyses\DDGManning\manning.in", OpenMode.Input, OpenAccess.Read)
        Input(1, AAW_SEW_GMLS_STKopt)
        Input(1, ASW_MSMopt)
        Input(1, ASuW_NSFSopt)
        Input(1, CMAN)
        Input(1, Maint)
        Input(1, PSYSopt)
        Input(1, AIR)
        FileClose(1)
        'Based on the input prepare strings to run Console ISMAT
        'Loop for Base equip
        If Maint = 1 Then
        Baseequip = " -e "" c:\Program Files\MAAD\ISMAT\BaseM1.ieqd"""
        ElseIf Maint = 2 Then
        Baseequip = " -e "" c:\Program Files\MAAD\ISMAT\BaseM2.ieqd"""
        Else : Baseequip = " -e "" c:\Program Files\MAAD\ISMAT\BaseM3.ieqd"""
        EndIf

        'Loop for AAW/SEW/GMLS/STK
        If AAW_SEW_GMLS_STKopt = 1 And Maint = 1 Then
        AAW_SEW_GMLS_STK = " -e "" c:\Program
        Files\MAAD\ISMAT\AAW_SEW_GMLS_STK_1_M1.ieqd"""
        ElseIf AAW_SEW_GMLS_STKopt = 1 And Maint = 2 Then
```

```
AAW_SEW_GMLS_STK = " -e "" c:\Program
Files\MAAD\ISMAT\AAW_SEW_GMLS_STK_1_M2.ieqd"""
ElseIf AAW_SEW_GMLS_STKopt = 1 And Maint = 3 Then
AAW_SEW_GMLS_STK = " -e "" c:\Program
Files\MAAD\ISMAT\AAW_SEW_GMLS_STK_1_M3.ieqd"""
ElseIf AAW_SEW_GMLS_STKopt = 2 And Maint = 1 Then
AAW_SEW_GMLS_STK = " -e "" c:\Program
Files\MAAD\ISMAT\AAW_SEW_GMLS_STK_2_M1.ieqd"""
ElseIf AAW_SEW_GMLS_STKopt = 2 And Maint = 2 Then
AAW_SEW_GMLS_STK = " -e "" c:\Program
Files\MAAD\ISMAT\AAW_SEW_GMLS_STK_2_M2.ieqd"""
ElseIf AAW_SEW_GMLS_STKopt = 2 And Maint = 3 Then
AAW_SEW_GMLS_STK = " -e "" c:\Program
Files\MAAD\ISMAT\AAW_SEW_GMLS_STK_2_M3.ieqd"""
ElseIf AAW_SEW_GMLS_STKopt = 3 And Maint = 1 Then
AAW_SEW_GMLS_STK = " -e "" c:\Program
Files\MAAD\ISMAT\AAW_SEW_GMLS_STK_3_M1.ieqd"""
ElseIf AAW_SEW_GMLS_STKopt = 3 And Maint = 2 Then
AAW_SEW_GMLS_STK = " -e "" c:\Program
Files\MAAD\ISMAT\AAW_SEW_GMLS_STK_3_M2.ieqd"""
Else : AAW_SEW_GMLS_STK = " -e "" c:\Program
Files\MAAD\ISMAT\AAW_SEW_GMLS_STK_3_M3.ieqd"""
EndIf

'Loop for ASuW/NSFS
If ASuW_NSFSopt = 1 And Maint = 1 Then
ASuW_NSFS = " -e "" c:\Program Files\MAAD\ISMAT\ASuW_NSFS_1_M1.ieqd"""
ElseIf ASuW_NSFSopt = 1 And Maint = 2 Then
ASuW_NSFS = " -e "" c:\Program Files\MAAD\ISMAT\ASuW_NSFS_1_M2.ieqd"""
ElseIf ASuW_NSFSopt = 1 And Maint = 3 Then
ASuW_NSFS = " -e "" c:\Program Files\MAAD\ISMAT\ASuW_NSFS_1_M3.ieqd"""
ElseIf ASuW_NSFSopt = 2 And Maint = 1 Then
ASuW_NSFS = " -e "" c:\Program Files\MAAD\ISMAT\ASuW_NSFS_2_M1.ieqd"""
ElseIf ASuW_NSFSopt = 2 And Maint = 2 Then
ASuW_NSFS = " -e "" c:\Program Files\MAAD\ISMAT\ASuW_NSFS_2_M2.ieqd"""
ElseIf ASuW_NSFSopt = 2 And Maint = 3 Then
ASuW_NSFS = " -e "" c:\Program Files\MAAD\ISMAT\ASuW_NSFS_2_M3.ieqd"""
ElseIf ASuW_NSFSopt = 3 And Maint = 1 Then
ASuW_NSFS = " -e "" c:\Program Files\MAAD\ISMAT\ASuW_NSFS_3_M1.ieqd"""
ElseIf ASuW_NSFSopt = 3 And Maint = 2 Then
ASuW_NSFS = " -e "" c:\Program Files\MAAD\ISMAT\ASuW_NSFS_3_M2.ieqd"""
Else : ASuW_NSFS = " -e "" c:\Program Files\MAAD\ISMAT\ASuW_NSFS_3_M3.ieqd"""
EndIf

'Loop for ASW/MSM
If ASW_MSMopt = 1 And Maint = 1 Then
ASW_MSM = " -e "" c:\Program Files\MAAD\ISMAT\ASW_MSM_1_M1.ieqd"""
ElseIf ASW_MSMopt = 1 And Maint = 2 Then
ASW_MSM = " -e "" c:\Program Files\MAAD\ISMAT\ASW_MSM_1_M2.ieqd"""
ElseIf ASW_MSMopt = 1 And Maint = 3 Then
ASW_MSM = " -e "" c:\Program Files\MAAD\ISMAT\ASW_MSM _1_M3.ieqd"""
ElseIf ASW_MSMopt = 2 And Maint = 1 Then
ASW_MSM = " -e "" c:\Program Files\MAAD\ISMAT\ASW_MSM _2_M1.ieqd"""
ElseIf ASW_MSMopt = 2 And Maint = 2 Then
ASW_MSM = " -e "" c:\Program Files\MAAD\ISMAT\ ASW_MSM _2_M2.ieqd"""
ElseIf ASW_MSMopt = 2 And Maint = 3 Then
```

```
ASW_MSM = " -e "" c:\Program Files\MAAD\ISMAT\ASW_MSM _2_M3.ieqd"""
ElseIf ASW_MSMopt = 3 And Maint = 1 Then
ASW_MSM = " -e "" c:\Program Files\MAAD\ISMAT\ASW_MSM _3_M1.ieqd"""
ElseIf ASW_MSMopt = 3 And Maint = 2 Then
ASW_MSM = " -e "" c:\Program Files\MAAD\ISMAT\ASW_MSM_3_M2.ieqd"""
Else : ASW_MSM = " -e "" c:\Program Files\MAAD\ISMAT\ASW_MSM_3_M3.ieqd"""
EndIf

'Loop for PSYS
If PSYSopt = 1 And Maint = 1 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_1_M1.ieqd"""
ElseIf PSYSopt = 1 And Maint = 2 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_1_M2.ieqd"""
ElseIf PSYSopt = 1 And Maint = 3 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_1_M3.ieqd"""
ElseIf PSYSopt = 2 And Maint = 1 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_2_M1.ieqd"""
ElseIf PSYSopt = 2 And Maint = 2 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_2_M2.ieqd"""
ElseIf PSYSopt = 2 And Maint = 3 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_2_M3.ieqd"""
ElseIf PSYSopt = 3 And Maint = 1 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_3_M1.ieqd"""
ElseIf PSYSopt = 3 And Maint = 2 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_3_M2.ieqd"""
ElseIf PSYSopt = 3 And Maint = 3 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_3_M3.ieqd"""
ElseIf PSYSopt = 4 And Maint = 1 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_4_M1.ieqd"""
ElseIf PSYSopt = 4 And Maint = 2 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_4_M2.ieqd"""
ElseIf PSYSopt = 4 And Maint = 3 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_4_M3.ieqd"""
ElseIf PSYSopt = 5 And Maint = 1 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_5_M1.ieqd"""
ElseIf PSYSopt = 5 And Maint = 2 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\ PSYS_5_M2.ieqd"""
ElseIf PSYSopt = 5 And Maint = 3 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\ PSYS_5_M3.ieqd"""
ElseIf PSYSopt = 6 And Maint = 1 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_6_M1.ieqd"""
ElseIf PSYSopt = 6 And Maint = 2 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_6_M2.ieqd"""
ElseIf PSYSopt = 6 And Maint = 3 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_6_M3.ieqd"""
ElseIf PSYSopt = 7 And Maint = 1 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_7_M1.ieqd"""
ElseIf PSYSopt = 7 And Maint = 2 Then
PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_7_M2.ieqd"""
Else : PSYS = " -e "" c:\Program Files\MAAD\ISMAT\PSYS_7_M3.ieqd"""
EndIf

'Looop for AIR
If AIR = 1 And Maint = 1 Then
LAMPS = " -e "" c:\Program Files\MAAD\ISMAT\LAMPS_1_M1.ieqd"""
ElseIf AIR = 1 And Maint = 2 Then
```

```
        LAMPS = " -e "" c:\Program Files\MAAD\ISMAT\LAMPS_1_M2.ieqd"""
        ElseIf AIR = 1 And Maint = 3 Then
        LAMPS = " -e "" c:\Program Files\MAAD\ISMAT\LAMPS_1_M3.ieqd"""
        ElseIf AIR = 2 And Maint = 1 Then
        LAMPS = " -e "" c:\Program Files\MAAD\ISMAT\LAMPS_2_M1.ieqd"""
        ElseIf AIR = 2 And Maint = 2 Then
        LAMPS = " -e "" c:\Program Files\MAAD\ISMAT\LAMPS_2_M2.ieqd"""
        ElseIf AIR = 2 And Maint = 3 Then
        LAMPS = " -e "" c:\Program Files\MAAD\ISMAT\LAMPS_2_M3.ieqd"""
        ElseIf AIR = 3 And Maint = 1 Then
        LAMPS = " -e "" c:\Program Files\MAAD\ISMAT\LAMPS_3_M1.ieqd"""
        ElseIf AIR = 3 And Maint = 2 Then
        LAMPS = " -e "" c:\Program Files\MAAD\ISMAT\LAMPS_3_M2.ieqd"""
        Else : LAMPS = " -e "" c:\Program Files\MAAD\ISMAT\LAMPS_3_M3.ieqd"""
        EndIf

        'Compartments
        Comp = " -c "" c:\Program Files\MAAD\ISMAT\DDGxVT.icmp"""

        'Loop for Automation and Manning factor
        If CMAN = 1 Then
        Scenario = " -s 1"
        ElseIf CMAN = 2 Then
        Scenario = " -s 2"
        ElseIf CMAN = 3 Then
        Scenario = " -s 3"
        ElseIf CMAN = 4 Then
        Scenario = " -s 4"
        ElseIf CMAN = 5 Then
        Scenario = " -s 5"
        ElseIf CMAN = 6 Then
        Scenario = " -s 6"
        ElseIf CMAN = 7 Then
        Scenario = " -s 7"
        Else : Scenario = " -s 8"
        EndIf

        Consolekill = " -k "" True"""
        Goal = " -g ""MinimizeCrewSize"""
        ManModel = ApptoRun & FiletoRun & Baseequip & AAW_SEW_GMLS_STK & ASuW_NSFS &
        ASW_MSM & PSYS & LAMPS & Comp & Goal & Scenario & Consolekill
        DDGxCrew = Shell(ManModel, AppWinStyle.MinimizedNoFocus, True, -1)
    EndSub

EndModule
```

Appendix C - Model Center File Wrapper

```
#
# Analysis Server FileWrapper component for Manning
#
# @description: Fortran FileWrapper for Manning
#

RunCommands
{
  generate inputFile
  run "manningDDG.exe"
  parse outputFile
  # run "del manning.out"
}

RowFieldInputFile inputFile
{
 templateFile:      manning.template
 fileToGenerate:   manning.in

 setDelimiters ", "

 #       name       type       row   field
 #----------------------------------------------------
 variable: AAW       integer     1    1
 variable: ASW       integer  1    2
 variable: ASuW       integer  1    3
 variable: CMAN        integer  1    4
 variable: Maint         integer     1    5
 variable: PSYS       integer     1    6
 variable: AIR       integer  1    7

}

RowFieldOutputFile outputFile
{
   fileToParse: manning.out

 #       name           type           row   field
 #------------------------------------------------------------
   variable: Crew       integer       1    1
```

Appendix D – Initial Capabilities Document (ICD)

UNCLASSIFIED

INITIAL CAPABILITIES DOCUMENT

FOR A

Small Guided Missile Destroyer (DDGx)

1- PRIMARY JOINT FUNCTIONAL AREAS

Force and Homeland Protection - The range of military application for this function includes: force protection and awareness at sea; and protection of homeland and critical bases from the sea.

Intelligence, Surveillance and Reconnaissance (ISR) - The range of military application for this function includes: onboard sensors; and support of manned and unmanned air, surface and subsurface vehicles.

Power Projection - The range of military application for this function includes strike warfare and naval surface fire support.

Operational timeframe considered: 2020-2070. This extended timeframe demands flexibility in upgrade and capability over time.

2- REQUIRED FORCE CAPABILITY(S)

Provide air, surface and subsurface defense around own coast, ports, friends, joint forces and critical bases of operations
Provide a sea-based layer of homeland defense.
Provide persistent surveillance and reconnaissance.
Provide strike and naval surface fire support.

These capabilities may be provided as a coordinated force, in support of a larger force, or individually with combinations of inherent multi-mission capabilities and tailored modular capabilities. Affordability is a critical issue which must enable sufficient force numbers to satisfy commitments consistent with national defense policy. In addition to providing necessary capabilities, rising acquisition, manning, logistics support, maintenance and energy costs must be addressed with a comprehensive plan including the application of new technologies, automation, modularity, and a necessary rational compromise of full multi-mission capabilities in all platforms.

3- CONCEPT OF OPERATIONS SUMMARY

It is expected that DDGx may operate independently, with Surface Action Groups and in support of Expeditionary (Amphibious) Strike Groups providing AAW, ASUW and ASW support. Surface Action Groups (SAGs) will perform various EW, ISR and Strike missions in addition to providing their own AAW, ASUW and ASW defense. ISR missions will include the use of autonomous air, surface and subsurface vehicles and LAMPS. Some anti-ballistic missile defense capability would also be of value if affordable.

Deployments will typically be have 3 month duration with underway replenishment, a few port visits, all-weather operations, cluttered air and shipping environments, blue water and littoral, and limited maintenance opportunities.

Operations will primarily be confined to the Western Pacific, but with occasional world-wide deployment in support of friendly nations.

4- MISSION TYPES

- Independent Operations - ISR, Strike, Peacetime Presence
- Carrier Battle Group (CBG) – AAW, ASW, ASUW
- Surface Action Group (SAG) – AAW, ASW, ASUW, ISR and CCC
- Amphibious Readiness Group – AAW, ASW, ASUW, ISR, NSFS, Strike
- Other Escort

5- CAPABILITY GAP(S)

The overarching capability gap addressed by this ICD is to provide affordable multi-mission surface combatant capabilities. Specific capabilities consistent with the following systems:

Priority	Capability Description	Threshold Systems or metric	Goal Systems or metric
1	Air Defense Radar	Sea Giraffe AMB, 1xSPG-62	SPY-1D Radar, 2xSPG-62
2	Missile Capacity	32 Cell, MK-41 VLS	96 Cell, MK-41 VLS
3	NSFS/ASUW	1 x 76mm/62 Gun, 4 x Harpoon (1 box launcher), IRST	1 x 5in/62, 8 x Harpoon (2 box launchers), IRST
4	Platform Mobility	28knt, full SS4, 2500 nm, 45 days	30knt, full SS5, 4000 nm, 60 days
5	Combat System	COMBATSS-21, TWS	AEGIS, TWS
6	ASW	1.5m Hull-Mounted Sonar, 1xLAMPS (embarked), SVTT, SQQ-89	5m Hull-Mounted Sonar, 2xLAMPS (embarked), SVTT, SQQ-89, NIXIE
7	Platform Self Defense, Other Multi-Mission	WBR 2000 ESM, 2xCIWS, SRBOC/NULKA, mine-hunting sonar, 7m RIB, UAVs	SLQ-32, 2xCIWS, 1xSEARAM, SRBOC/NULKA, mine-hunting sonar, 11m RIB, UAVs

6- THREAT AND OPERATIONAL ENVIRONMENT

Since many potentially unstable nations are located on or near geographically constrained (littoral) bodies of water, the tactical picture may be at smaller scales relative to open ocean warfare. Threats in such an environment include: (1) technologically advanced weapons - cruise missiles like the Silkworm and Exocet, land-launched attack aircraft, fast gunboats armed with guns and smaller missiles, and diesel-electric submarines / mini-subs; and (2) unsophisticated and inexpensive passive weapons – mines (surface, moored and bottom), chemical and biological weapons. Encounters may occur in shallow water which increases the difficulty of detecting and successfully prosecuting targets.

The sea-based environment includes:

- Open ocean (sea states 0 through 8) and littoral
- Shallow and deep water
- Noisy and reverberation-limited
- Degraded radar picture
- Crowded shipping
- Dense contacts and threats with complicated targeting
- Biological, chemical and nuclear weapons
- All-Weather

7- FUNCTIONAL SOLUTION ANALYSIS SUMMARY

a. ***Ideas for Non-Materiel Approaches (DOTMLPF Analysis).***

- Increase reliance on foreign support

b. ***Ideas for Materiel Approaches***

- More large destroyers, frigates and corvettes
- Upgrade and extend service life of existing ships
- Build 6+ new small multi-mission destroyer

8- FINAL RECOMMENDATIONS

a. Non-material solutions are not consistent with national policy.
b. More large destroyers are not affordable in numbers required for force structure
c. Corvettes and frigates are not sufficiently capable
d. Upgrade and extend service life not cost-effective

9- NOTIONAL SHIP

- Proposed displacement of 5600 ~ 7500 tons
- More emphasis on stealth
- Improved data links with integrated force
- $500~$700 million

Displacement:	5600~7000 tons
Length:	150 m (492 feet)
Beam:	17.4 m (57 feet)
Draft:	9.5 m (31 feet)
Propulsion:	CODOG
Speed:	29 knots
Complement:	300

Appendix E – Baseline Manning Document

Name	Rating	Department	Division
COMMANDING OFFICER	O5	COMMAND	CO
EXECUTIVE OFFICER	O4	EXECUTIVE	XO
SUPPLY OFFICER	O4	SUPPLY	DEPT HEAD
OPERATIONS OFFICER (OPS)	O4	OPERATIONS	DEPT HEAD
CIC OFFICER	O3	OPERATIONS	OI DIV OFF
ENGINEERING OFFICER (ENG)	O4	ENGINEERING	DEPT HEAD
COMM OFFICER (COMM)	O2	OPERATIONS	OC DIV OFF
FIRST LT	O3	OPERATIONS	FIRST
CS MAINT MANAGER	O2	COMBAT SYSTEMS	CS
AUX OFFICER	O2	ENGINEERING	A
DCA	O3	ENGINEERING	R
CA DIVISION OFF (ASW)	O2	COMBAT SYSTEMS	CA
CM/CX DIVISION OFF (MISSILE FC)	O3	COMBAT SYSTEMS	CM
NAVIGATOR	O3	OPERATIONS	ON DIV OFF
MPA	O3	ENGINEERING	MP
WEAPONS OFFICER (WEPS)	O3	WEAPONS	DEPT HEAD
ELECTRICAL OFFICER	O3/CWO	ENGINEERING	E
SYSTEM TEST OFFICER	02	COMBAT SYSTEMS	CS
CE DIVISION OFF (ELECTRONICS RPR)	CWO	COMBAT SYSTEMS	CE
CF/CG DIVISION OFF (GUN FC)	O3	COMBAT SYSTEMS	CG
COMBAT SYSTEM OFFICER (CSO)	O4	COMBAT SYSTEMS	DEPT HEAD
WA DIV OFFICER (ASW)	O2	WEAPONS	WA
WO DIV OFFICER (GUN+MISSILES)	O2	WEAPONS	WO
DISBURSING OFFICER	O2	SUPPLY	S4
SH-60B PILOT	O2	AIR	AIR
SH-60B PILOT	O3	AIR	AIR
SH-60B PILOT	O2	AIR	AIR
SH-60B PILOT	O3	AIR	AIR
AVIATION MACHINIST'S MATE	AD/E5	AIR	AIR
AVIATION MACHINIST'S MATE	AD/E5	AIR	AIR
AIRCREWMEMBER HELICOPTER	AWS/E6	AIR	AIR
AVIATION ELECTRONICS	AT/E6	AIR	AIR
AVIATION MAINTENACE	AZ/E7	AIR	AIR
AIR CREWMEMBER	AWS/E6	AIR	AIR

Name	Rating	Department	Division
HELICOPTER			
AVIATION STRUCTURAL	AME/E6	AIR	AIR
SONAR TECHNICIAN - SURFACE	STG/E1-3	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E1-3	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E1-4	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E1-4	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E1-4	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E1-4	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E1-4	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E1-4	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E1-4	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E1-4	COMBAT SYSTEMS	CA
ELECTRONICS TECHNICIAN	ET/E7	COMBAT SYSTEMS	CE
OPERATIONS SPECIALIST	OS/E1-3	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E1-3	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E1-3	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E4	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E4	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E4	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI

Name	Rating	Department	Division
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E5	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E6	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E6	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E6	OPERATIONS	OI
OPERATIONS SPECIALIST	OS/E8	OPERATIONS	OI
YEOMAN	YN/E4	OPERATIONS	OPERATIONS
BOATSWAIN'S MATE	BM/E5	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E5	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E1-3	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E1-3	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E1-3	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E4	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E4	SUPPLY	S-1
INTERIOR COMM ELECTRICIAN	IC/E4	COMBAT SYSTEMS	CE
INTERIOR COMM ELECTRICIAN	IC/E4	COMBAT SYSTEMS	CE
INTERIOR COMM ELECTRICIAN	IC/E4	COMBAT SYSTEMS	CE
INTERIOR COMM ELECTRICIAN	IC/E4	COMBAT SYSTEMS	CE
INTERIOR COMM ELECTRICIAN	IC/E4	COMBAT SYSTEMS	CE
LOGISTICS SPECIALIST	LS/E5	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E5	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E5	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E5	SUPPLY	S-1
LOGISTICS SPECIALIST	LS/E5	SUPPLY	S-1
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-1
CULINARY SPECIALIST	CS/E1-3	SUPPLY	S-2
CULINARY SPECIALIST	CS/E1-3	SUPPLY	S-2
CULINARY SPECIALIST	CS/E4	SUPPLY	S-2
CULINARY SPECIALIST	CS/E4	SUPPLY	S-2
CULINARY SPECIALIST	CS/E4	SUPPLY	S-2
CULINARY SPECIALIST	CS/E5	SUPPLY	S-2
CULINARY SPECIALIST	CS/E5	SUPPLY	S-2
CULINARY SPECIALIST	CS/E6	SUPPLY	S-2
CULINARY SPECIALIST	CS/E6	SUPPLY	S-2
CULINARY SPECIALIST	CS/E7	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2

Name	Rating	Department	Division
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-2
INTERIOR COMM ELECTRICIAN	IC/E5	COMBAT SYSTEMS	CE
SHIP'S SERVICEMAN	SH/E1-3	SUPPLY	S-3
SHIP'S SERVICEMAN	SH/E1-3	SUPPLY	S-3
SHIP'S SERVICEMAN	SH/E1-3	SUPPLY	S-3
SHIP'S SERVICEMAN	SH/E4	SUPPLY	S-3
SHIP'S SERVICEMAN	SH/E5	SUPPLY	S-3
SHIP'S SERVICEMAN	SH/E6	SUPPLY	S-3
PERSONNELMAN	PN/E1-3	SUPPLY	S-4
PERSONNELMAN	PN/E6	SUPPLY	S-4
CULINARY SPECIALIST	CS/E1-3	SUPPLY	S-5
CULINARY SPECIALIST	CS/E1-3	SUPPLY	S-5
CULINARY SPECIALIST	CS/E4	SUPPLY	S-5
CULINARY SPECIALIST	CS/E5	SUPPLY	S-5
CULINARY SPECIALIST	CS/E6	SUPPLY	S-5
INTERIOR COMM ELECTRICIAN	IC/E6	COMBAT SYSTEMS	CE
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-5
ALL-NAVY	ANYBODY/E1-3	SUPPLY	S-5
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CG
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CG
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CG
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CG
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CG
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CG
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CG
FIRE CONTROLMAN	FC/E6	COMBAT SYSTEMS	CG
FIRE CONTROLMAN	FC/E7	COMBAT SYSTEMS	CG
GUNNER'S MATE GMM	GM/E1-3	WEAPONS	WO
GUNNER'S MATE GMM	GM/E4	WEAPONS	WO
GUNNER'S MATE GMM	GM/E4	WEAPONS	WO

Name	Rating	Department	Division
SONAR TECHNICIAN - SURFACE	STG/E5	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E5	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E5	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E5	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E5	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E5	COMBAT SYSTEMS	CA
GUNNER'S MATE GMM	GM/E5	WEAPONS	WO
GUNNER'S MATE GMM	GM/E6	WEAPONS	WO
GUNNER'S MATE GMM	GM/E7	WEAPONS	WO
FIRE CONTROLMAN	FC/E1-4	COMBAT SYSTEMS	CG
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E4	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E5	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E6	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E6	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E6	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E6	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E6	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E6	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E6	COMBAT SYSTEMS	CM
FIRE CONTROLMAN	FC/E6	COMBAT SYSTEMS	CM
GUNNER'S MATE GMG	GM/E1-3	WEAPONS	WO

Name	Rating	Department	Division
SONAR TECHNICIAN - SURFACE	STG/E6	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E6	COMBAT SYSTEMS	CA
SONAR TECHNICIAN - SURFACE	STG/E6	COMBAT SYSTEMS	CA
GUNNER'S MATE GMG	GM/E4	WEAPONS	WO
GUNNER'S MATE GMG	GM/E4	WEAPONS	WO
GUNNER'S MATE GMG	GM/E4	WEAPONS	WO
GUNNER'S MATE GMM	GM/E4	WEAPONS	WO
GUNNER'S MATE GMG	GM/E5	WEAPONS	WO
GUNNER'S MATE GMM	GM/E5	WEAPONS	WO
GUNNER'S MATE GMG	GM/E6	WEAPONS	WO
GUNNER'S MATE GMG	GM/E6	WEAPONS	WO
GUNNER'S MATE GMM	GM/E6	WEAPONS	WO
GUNNER'S MATE GMG	GM/E7	WEAPONS	WO
YEOMAN	YN/E4	COMBAT SYSTEMS	COMBAT
ENGINEMAN	EN/E1-3	ENGINEERING	A
ENGINEMAN	EN/E1-3	ENGINEERING	A
ENGINEMAN	EN/E4	ENGINEERING	A
ENGINEMAN	EN/E4	ENGINEERING	A
ENGINEMAN	EN/E4	ENGINEERING	A
ENGINEMAN	EN/E5	ENGINEERING	A
ENGINEMAN	EN/E5	ENGINEERING	A
ENGINEMAN	EN/E6	ENGINEERING	A
ENGINEMAN	EN/E7	ENGINEERING	A
SONAR TECHNICIAN - SURFACE	STG/E8	COMBAT SYSTEMS	CA
ELECTRICIAN'S MATE	EM/E4	ENGINEERING	E
ELECTRICIAN'S MATE	EM/E4	ENGINEERING	E
ELECTRICIAN'S MATE	EM/E5	ENGINEERING	E
ELECTRICIAN'S MATE	EM/E6	ENGINEERING	E
ELECTRICIAN'S MATE	EM/E7	ENGINEERING	E
YEOMAN	YN/E4	ENGINEERING	ENGINEERING
GAS TURBINE SYSTEMS TECHNICIAN	GS/E8	ENGINEERING	MP
GAS TURBINE - ELECTRICAL	GSE/E4	ENGINEERING	MP
GAS TURBINE - ELECTRICAL	GSE/E4	ENGINEERING	MP
GAS TURBINE - ELECTRICAL	GSE/E4	ENGINEERING	MP
GAS TURBINE - ELECTRICAL	GSE/E4	ENGINEERING	MP
GAS TURBINE - ELECTRICAL	GSE/E5	ENGINEERING	MP
GAS TURBINE -	GSE/E5	ENGINEERING	MP

Name	Rating	Department	Division
ELECTRICAL			
GAS TURBINE - ELECTRICAL	GSE/E7	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E4	ENGINEERING	MP
GUNNER'S MATE GMG	GM/E4	WEAPONS	WA
GAS TURBINE - MECHANICAL	GSM/E5	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E5	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E5	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E5	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E5	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E5	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E5	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E5	ENGINEERING	MP
GAS TURBINE - MECHANICAL	GSM/E5	ENGINEERING	MP
FIREMAN	ANYBODY/E1-3	ENGINEERING	MP
FIREMAN	ANYBODY/E1-3	ENGINEERING	MP
FIREMAN	ANYBODY/E1-3	ENGINEERING	MP
DAMAGE CONTROL	DC/E1-3	ENGINEERING	R
DAMAGE CONTROL	DC/E4	ENGINEERING	R
DAMAGE CONTROL	DC/E4	ENGINEERING	R
DAMAGE CONTROL	DC/E4	ENGINEERING	R
DAMAGE CONTROL	DC/E4	ENGINEERING	R
DAMAGE CONTROL	DC/E5	ENGINEERING	R

Name	Rating	Department	Division
DAMAGE CONTROL	DC/E5	ENGINEERING	R
DAMAGE CONTROL	DC/E6	ENGINEERING	R
DAMAGE CONTROL	DC/E7	ENGINEERING	R
HULL MAINTENANCE TECHNICIAN	HT/E4	ENGINEERING	R
HULL MAINTENANCE TECHNICIAN	HT/E4	ENGINEERING	R
GUNNER'S MATE GMG	GM/E5	WEAPONS	WA
HULL MAINTENANCE TECHNICIAN	HT/E5	ENGINEERING	R
HULL MAINTENANCE TECHNICIAN	HT/E6	ENGINEERING	R
MACHINERY REPAIRMAN	MR/E4	ENGINEERING	R
FIREMAN	ANYBODY/E1-3	ENGINEERING	R
FIREMAN	ANYBODY/E1-3	ENGINEERING	R
FIREMAN	ANYBODY/E1-3	ENGINEERING	R
FIREMAN	ANYBODY/E1-3	ENGINEERING	R
MA/E6	MA/E6	EXECUTIVE	EXECUTIVE
NAVY COUNSELOR	NC/E6	EXECUTIVE	EXECUTIVE
PERSONNELMAN	PN/E1-3	EXECUTIVE	EXECUTIVE
PERSONNELMAN	PN/E4	EXECUTIVE	EXECUTIVE
PERSONNELMAN	PN/E7	EXECUTIVE	EXECUTIVE
YEOMAN	YN/E4	EXECUTIVE	EXECUTIVE
ELECTRONICS TECHNICIAN	ET/E4	COMBAT SYSTEMS	CE
ELECTRONICS TECHNICIAN	ET/E4	COMBAT SYSTEMS	CE
ELECTRONICS TECHNICIAN	ET/E4	COMBAT SYSTEMS	CE
ELECTRONICS TECHNICIAN	ET/E4	COMBAT SYSTEMS	CE
ELECTRONICS TECHNICIAN	ET/E4	COMBAT SYSTEMS	CE
YEOMAN	YN/E5	EXECUTIVE	EXECUTIVE
YEOMAN	YN/E5	EXECUTIVE	EXECUTIVE
ALL-NAVY	ANYBODY/E8	EXECUTIVE	EXECUTIVE
ALL-NAVY	ANYBODY/E9	EXECUTIVE	EXECUTIVE
HOSPITAL CORPSMAN	HM/E4	MEDICAL	H
HOSPITAL CORPSMAN	HM/E7	MEDICAL	H
QUARTERMASTER	QM/E1-3	OPERATIONS	ON
QUARTERMASTER	QM/E4	OPERATIONS	ON
QUARTERMASTER	QM/E4	OPERATIONS	ON
QUARTERMASTER	QM/E5	OPERATIONS	ON
QUARTERMASTER	QM/E6	OPERATIONS	ON
ELECTRONICS TECHNICIAN	ET/E5	COMBAT SYSTEMS	CE
ELECTRONICS TECHNICIAN	ET/E5	COMBAT SYSTEMS	CE
ELECTRONICS TECHNICIAN	ET/E5	COMBAT SYSTEMS	CE
QUARTERMASTER	QM/E1-3	OPERATIONS	ON
QUARTERMASTER	QM/E1-3	OPERATIONS	ON
QUARTERMASTER	QM/E4	OPERATIONS	ON

Name	Rating	Department	Division
QUARTERMASTER	QM/E4	OPERATIONS	ON
QUARTERMASTER	QM/E5	OPERATIONS	ON
QUARTERMASTER	QM/E6	OPERATIONS	ON
INFORMATION SYSTEMS TECHNICIAN	IT/E1-3	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E4	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E4	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E4	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E4	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E5	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E5	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E5	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E5	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E5	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E5	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E6	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E6	OPERATIONS	OC
INFORMATION SYSTEMS TECHNICIAN	IT/E7	OPERATIONS	OC
BOATSWAIN'S MATE	BM/E4	OPERATIONS	OD
BOATSWAIN'S MATE	BM/E4	OPERATIONS	OD
BOATSWAIN'S MATE	BM/E4	OPERATIONS	OD
BOATSWAIN'S MATE	BM/E4	OPERATIONS	OD
ELECTRONICS TECHNICIAN	ET/E6	COMBAT SYSTEMS	CE
ELECTRONICS TECHNICIAN	ET/E6	COMBAT SYSTEMS	CE
BOATSWAIN'S MATE	BM/E5	OPERATIONS	OD
BOATSWAIN'S MATE	BM/E5	OPERATIONS	OD
BOATSWAIN'S MATE	BM/E6	OPERATIONS	OD
BOATSWAIN'S MATE	BM/E7	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD

Name	Rating	Department	Division
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-3	OPERATIONS	OD
ALL-NAVY	ANYBODY/E1-4	OPERATIONS	OI
ELECTRONIC WARFARE	EW/E1-3	OPERATIONS	OI
ELECTRONIC WARFARE	EW/E1-3	OPERATIONS	OI
ELECTRONIC WARFARE	EW/E4	OPERATIONS	OI
ELECTRONIC WARFARE	EW/E5	OPERATIONS	OI
ELECTRONIC WARFARE	EW/E5	OPERATIONS	OI
ELECTRONIC WARFARE	EW/E6	OPERATIONS	OI
ELECTRONIC WARFARE	EW/E7	OPERATIONS	OI
INTELLIGENCE SPECIALIST	IS/E6	OPERATIONS	OI
AVIATION ORDNANCE	AO/E1-5	AIR	AIR
AVIATION ORDNANCE	AO/E1-4	AIR	AIR
AVIATION ORDNANCE	AO/E5	AIR	AIR
AVIATION ORDNANCE	AO/E6	AIR	AIR
AVIATION ELECTRONICS	AT/E1-4	AIR	AIR
AVIATION MACHINIST'S MATE	AD/E7	AIR	AIR
AVIATION ELECTRONICS	AT/E5	AIR	AIR
AIR CREWMEMBER HELICOPTER	AWS/E6	AIR	AIR
AVIATION MACHINIST'S MATE	AD/E6	AIR	AIR
AVIATION MACHINIST'S MATE	AD/E1-4	AIR	AIR
AVIATION STRUCTURAL	AME/E1-4	AIR	AIR
AVIATION STRUCTURAL	AME/E5	AIR	AIR

Appendix F – ISMAT Details and Lessons Learned

The following is a list of details and lessons learned implementing the ship-manning model in ISMAT.

1. Tasks and functions from an ISMAT scenario can be copied and pasted into a new scenario only if the recipient scenario is in the same ISMAT file.
2. Crew list created remain in the file and cannot be copied to be use in another ISMAT file.
3. Multiple crewmembers can be assigned to a task but the operator defines the number of crewmembers that are needed to effectively accomplish a task. But if crewmember is assigned to another task inside the function is only considered for only one task.
4. To copy big sections of equipment and compartment files it is easier to use Microsoft Windows Notepad.
5. To delete PMs occurring at a particular period from an equipment file use the search tool from XML notepad to speed the process of PM removal.
6. ISMAT does not contain a rank or pay grade to allocate to officers in a crew list.
7. The Visual Basic executable groups the equipment systems and compartment strings data arguments with command strings to form a string needed to run ISMAT console application. The files used to build the equipment strings are shown on Table 4. The command and arguments are grouped into one string variable "ManModel" in the VB code. This variable is then called by the VB executable command statement "Shell" that runs the ISMAT simulation. The following command in the executable executes the simulation: "*DDGxCrew = Shell(ManModel, AppWinStyle.MinimizedNoFocus, True, -1)*". The DDGxCrew application tells the console to hide during the simulation and wait for ISMAT to run the simulation before continuing.