Copy No:

Damage Control and Optimized Manning

The DRDC Atlantic Perspective

John A. Hiltz

Defence R&D Canada - Atlantic

Scientific Literature

DRDC Atlantic SL 2005-149

June 2005

Author

John A. Hiltz

Approved by

Calvin V. Hyatt

Head Emerging Materials Section

Approved for release by

Kirk Foster

DRP Chair

Abstract

The two major contributors to through life costs of naval vessels are crewing and maintenance. The Canadian Navy has identified the reduction of through life costs as a priority. This has led to an increased interest in how crewing levels can be reduced without jeopardizing the ship's ability to complete its mission. Of particular concern is how reduced crewing levels will impact of labour intensive operations such as fire and damage control. To aid in accomplishing this goal, DRDC Atlantic has initiated a project entitled Damage Control and Optimized Crewing for Naval Vessels. The aim of this project is to address how damage control on ships can be maintained or enhanced with optimized (reduced) crewing levels.

In this paper, the planned approaches to reducing crewing levels, including the use of modeling and simulation in conjunction with functional analysis, human factors research, automation, and improved sensors and materials, will be reviewed and discussed with respect to maintaining and/or enhancing damage control on CF ships. Modeling and simulation tools provide a means of evaluating the effectiveness of different configurations of crew and technologies (automation) in the performance of tasks. These tools aid in the selection of the best approach to maintaining operational capabilities with fewer crew. Human factors research considers how to best design systems that provide operators with the information/decision making capabilities they need to perform their tasks efficiently. Critical assessment and installation of the most effective fire and damage sensing, suppression and control systems will lessen the effect of fire and battle damage. The development of materials, such as blast resistant coatings and porous materials, that harden ship structures will result in ships that are inherently less vulnerable to damage.

Résumé

Les deux principaux facteurs contributifs au coût du cycle de vie des navires de guerre sont l'armement en équipage et la maintenance. La Marine canadienne s'est donnée comme une priorité de tenter de réduire le coût du cycle de vie et cherche donc à trouver des moyens novateurs de réduire les niveaux d'armement en équipage sans compromettre la capacité du navire à accomplir sa mission. Il est particulièrement important pour elle de savoir quelle incidence une telle réduction pourrait avoir sur les activités à forte intensité de main-d'œuvre comme la lutte contre l'incendie et la lutte contre les avaries. Pour aider la Marine à réaliser cet objectif, RDDC Atlantique a mis sur pied un projet intitulé *Damage Control and Optimized Crewing for Naval Vessels* (Lutte contre les avaries et armement en équipage optimisé pour navires de guerre). Le but de ce projet est de trouver une façon de maintenir ou d'améliorer le niveau de lutte contre les avaries à bord des navires avec des niveaux d'armement en équipage optimisés (réduits).

Le présent document passe en revue le plan mis de l'avant pour réduire les niveaux d'armement en équipage, notamment l'utilisation de modèles et de simulations de concert avec l'analyse des fonctions, l'étude des facteurs humains, l'automatisation et l'utilisation de capteurs et d'instruments améliorés, et examine la faisabilité de maintenir ou d'améliorer la qualité de la lutte contre les avaries à bord des navires des FC avec des effectifs réduits. On a utilisé des outils de modélisation et de simulation pour évaluer les capacités de différentes

configurations d’équipage et de technologies (automatisation) à faire le travail. Ces outils aident à choisir l’approche qui permettra le mieux de maintenir les capacités opérationnelles avec un équipage réduit. La recherche sur les facteurs humains a étudié comment mieux concevoir les systèmes de manière à ce qu’ils procurent aux opérateurs la meilleure information et la meilleure possibilité de prise de décisions possibles dans l’exercice de leur fonction. L’évaluation critique et l’installation des systèmes de détection, de suppression et de contrôle des incendies et des avaries plus efficaces permettront de réduire les effets des dommages causés par l’incendie ou le combat. La mise au point de nouveaux matériaux, comme les revêtements résistant aux explosions et les matériaux poreux, qui raffermissent la structure des navires fera en sorte que les navires seront intrinsèquement moins vulnérables aux dommages.

Executive summary

Introduction

The Canadian Navy has identified the reduction of through life costs as a priority. This has led to an increased interest in how crewing levels can be reduced without jeopardizing the ship's ability to complete its mission. Of particular concern is how reduced crewing levels will impact on labour intensive operations such as fire and damage control. To aid in accomplishing this goal, DRDC Atlantic has initiated Project 11gr - Damage Control and Optimized Manning. The aim of this project is to address how damage control on ships can be maintained or enhanced with optimized (reduced) crewing levels.

Results

The planned approaches to reducing crewing levels, including the use of modeling and simulation in conjunction with functional analysis, human factors research, automation, and improved sensors and materials, are reviewed and discussed with respect to maintaining and/or enhancing damage control on CF ships. Modeling and simulation tools provide a means of evaluating the effectiveness of different configurations of crew and technologies (automation) in the performance of tasks. These tools aid in the selection of the best approach to maintaining operational capabilities with fewer crew. Human factors research considers how to best design systems that provide operators with the information/decision making capabilities they need to perform their tasks efficiently. Critical assessment and installation of the most effective fire and damage sensing, suppression and control systems will lessen the effect of fire and battle damage. The development of materials, such as blast resistant coatings and porous materials, that harden ship structures will result in ships that are inherently less vulnerable to damage.

Significance

Crewing costs are the largest single contributor to the total operating costs of a naval vessel. Research indicates that they represent approximately 30% of the total costs. This paper describes the DRDC Atlantic approach to reducing crew levels while addressing a major concern of naval operators. This concern is how labour intensive tasks, such as damage control, will be carried out if crewing levels are reduced on new ships.

Future plans

Project 11gr "Damage Control and Optimized Manning" is scheduled to run until March 2008. Results of the project will be published as they become available.

John A. Hiltz. 2005. Damage Control and Crew Optimization – The DRDC Atlantic Perspective. DRDC Atlantic SL 2005-149. DRDC Atlantic.

Sommaire

Introduction

La Marine canadienne s'est donnée comme priorité de tenter de réduire les coûts de cycle de vie, ce qui l'a menée à chercher des moyens de réduire les niveaux d'armement en équipage sans compromettre la capacité des navires à accomplir leur mission. Il est particulièrement important de savoir quel impact une réduction des niveaux d'armement en équipage peut avoir sur les activités à forte intensité de main-d'œuvre comme la lutte contre l'incendie et la lutte contre les avaries. Pour aider la Marine à réaliser cet objectif, RDDC Atlantique a mis sur pied le projet 11gr sur la lutte contre les avaries et l'armement en équipage optimisé. Le but de ce projet est de trouver une façon de maintenir ou d'améliorer le niveau de lutte contre les avaries à bord des navires avec des niveaux d'armement en équipage optimisés (réduits).

Résultats

Le plan mis de l'avant pour réduire les niveaux d'armement en équipage, notamment l'utilisation de modèles et de simulations de concert avec l'analyse des fonctions, l'étude des facteurs humains, l'automatisation et l'utilisation de capteurs et d'instruments améliorés, est passé en revue et examiné quant au maintien ou à l'amélioration de la qualité de la lutte contre les avaries à bord des navires des FC. On a utilisé des outils de modélisation et de simulation pour évaluer la capacité des différentes configurations d'équipage et de technologies (automatisation) à faire le travail. Ces outils aident à choisir l'approche qui permettra le mieux de maintenir les capacités opérationnelles avec un équipage réduit. La recherche sur les facteurs humains étudie comment mieux concevoir les systèmes de manière à ce qu'ils procurent aux opérateurs la meilleure information et la meilleure possibilité de prise de décisions possibles dans l'exercice de leur fonction. L'évaluation critique et l'installation des systèmes de détection, de suppression et de contrôle des incendies et des avaries des plus efficaces permettront de réduire les effets des dommages causés par l'incendie ou le combat. La mise au point de nouveaux matériaux, comme les revêtements résistant aux explosions et les matériaux poreux, qui raffermissent la structure des navires fera en sorte que les navires seront intrinsèquement moins vulnérables aux dommages.

Portée

Les coûts reliés à l'armement en équipage sont la partie la plus importante du coût total d'opération d'un navire de guerre. La recherche indique qu'ils représentent environ 30 p. cent du coût total. Le présent document décrit une méthode étudiée par RDDC Atlantique pour réduire les niveaux d'armement en équipage tout en tenant compte des principales préoccupations des responsables de la marine de guerre, notamment de savoir comment les activités à forte intensité de main-d'œuvre, comme la lutte contre les avaries, vont être exécutées si l'on réduit les niveaux d'armement en équipage sur les nouveaux navires.

Recherches futures

Les travaux dans le cadre du projet 11gr sur la lutte contre les avaries et l'armement en équipage optimisé doivent continuer jusqu'en mars 2008. Les résultats de ces travaux seront publiés dès qu'ils seront disponibles**.**

John A. Hiltz. 2005. Lutte contre les avaries et armement en équipage optimisé pour navires de guerre. DRDC Atlantic SL 2005-149. RDDC Atlantique.

Table of contents

List of figures

List of tables

.

1. Introduction

Defence Research and Development Canada – Atlantic initiated a project entitled “Damage Control and Optimized Crewing” in April 2005. The aim of this paper is to provide answers to questions that might be asked about this project including: *Why are we concerned with optimized crewing?*, and more specifically, *why are we concerned with damage control and optimized crewing?* In addition, this paper will attempt to answer the questions: *What are the best approaches to ensuring damage control capabilities are maintained or enhanced if crewing levels are reduced*? and *how do we plan to address these concerns*?

Malone (1) defines optimized manning as “the minimum number of personnel consistent with human performance, workload, safety requirements, and affordability, risk and reliability constraints”. In most instances optimized manning can be equated to reduced manning. The driving force for reduced manning levels on Naval vessels is the reduction in the total operating costs of ships.

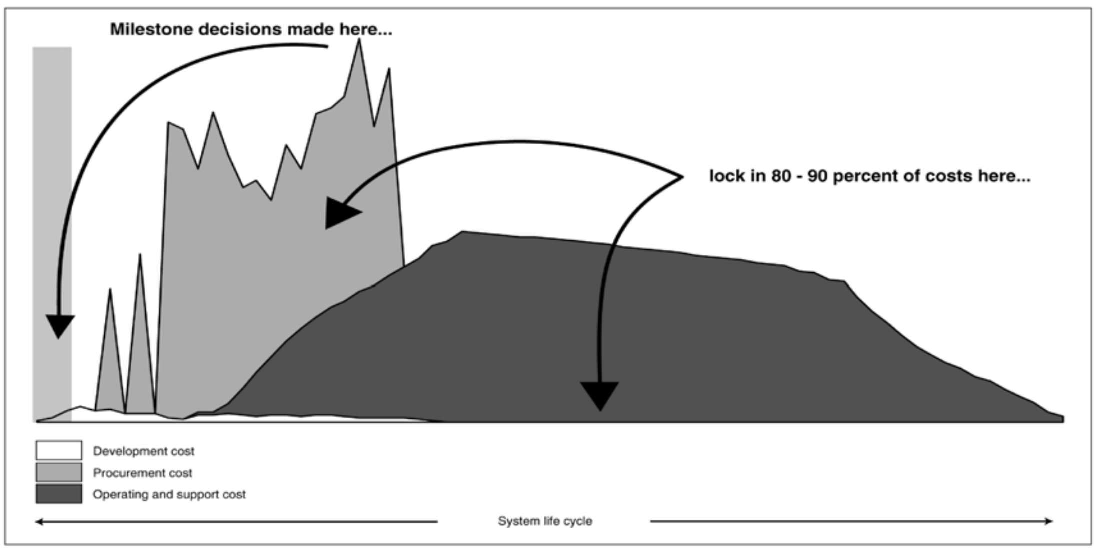

Figure 1. Contribution of development costs, procurement costs, and operation and maintenance costs to the through life (total ownership) costs of a naval ship. (Taken from reference 2)

The total operating costs of a ship can be separated into three components; development costs, procurement costs, and operation and support (O&S) costs. The contributions of these components to the total operating costs of a ship are shown in Figure 1. It is important to note that a large percentage of the total operating costs of a ship (between 80 and 90%) are locked in by decisions made very early in development stage of the ship life cycle. It can be seen in Figure 1 that the major contributor to the total operating costs of a ship are O&S costs.

A breakdown of O&S costs is shown in Figure 2. The largest contributor to O&S costs is personnel costs and this accounts for 30% of the total operating cost of a ship. This is the reason why optimized or reduced manning is seen as a primary way to effect a reduction in though life costs of ships.

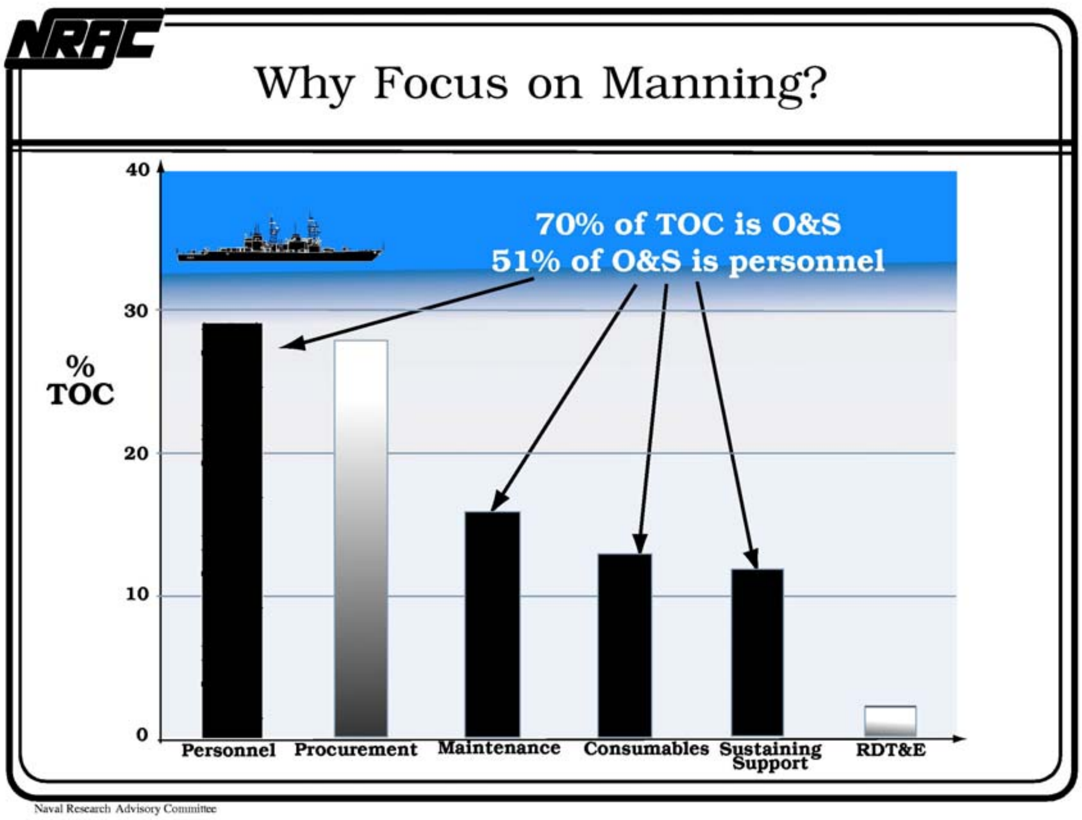

Figure2. Breakdown of factors contributing to the total operating cost of a ship. O&S costs are the major contributing factor and personnel costs are approximately 50% of O&S costs. (Taken from reference 3)

The drive to reduce manning raises questions of its own. The most important of these is how will labour intensive tasks, such as damage control, replenishment at sea, and maintenance be carried out with fewer crew. When this question is considered, the most promising approach is the introduction of technology (and the concomitant automation of tasks). Tasks that were performed by ships crew are done using new technology or are eliminated by the introduction of technology. The DRDC Atlantic approach to this will be addressed in the body of this paper.

2. Technologies

In 2001, Beevis et al. (4) published a technical report entitled “Technologies for Workload and Crewing Reductions”. In it they recommended that DRDC should support the navy effort in this area with shorter and longer term activities based on a review of technologies that require further development and that build on Canadian industrial capability. In addition, they recommended that DRDC support the development of models for simulating manning levels. They recommended that the technologies developed should be based on successes, such as SHINCOM (shipboard integrated communications) and SHINMACS (shipboard integrated machinery control system), and condition based maintenance technologies.

The report identified a number of technologies available for crew reduction. Those applicable to marine systems engineering and damage control are listed in Table 1.

Table 1. Technologies applicable to marine systems engineering and damage control available for crew reduction. (Taken from reference 4)

MARINE SYSTEMS ENGINEERING	DAMAGE CONTROL
•Corrosion minimizing materials •Enhanced ventilation systems •Electrical propulsion •Integrated machinery control •Smart sensor and actuator technology •Intelligent machinery monitoring and diagnosis •Maintenance management system •Redundant systems •Highly reliable systems	•Redundant systems •Reduce requirement for damage control •Integrated platform control •Automatic fire detection and suppression systems •Unmanned spaces

Areas where further research and development were required were also identified. These are listed in table 2.

Table 2. Areas where further research and development are required for marine systems engineering and damage control technologies applicable to crewing reduction. (Taken from reference 4)

MARINE SYSTEMS ENGINEERING	DAMAGE CONTROL
•Advanced power systems (electrical and fuel cell) •Wear resistant materials •Advanced lubrication systems •Advanced machinery control, monitoring and diagnostics •Robotics •Microelectricalmechanical systems (MEMS) •Virtual presence	•Damage control automation

The report also recommended a way ahead for realizing crew reduction when building new ships. It included the top down functional analysis and modeling of crew tasks, the implementation of damage tolerant systems and improved damage control technologies, the introduction of low maintenance systems, the introduction of increased automation, electrical propulsion and integrated electrical systems, and advanced combat information systems.

The introduction of technology and automation to reduce crewing levels comes at a cost. That is, the technology must be paid for during the procurement phase of the acquisition program. The relationship between total operating costs, capability and manning level are shown in Figure 3. Research has shown (3) that there is an optimum manning level for a particular capability requirement and that this manning level results in reduced total ownership costs compared to an unmanned ship or a manned ship with little technology or automation. It should be noted that at some point the cost of automated systems and advanced technologies will be greater than the savings resulting from further crew reduction.

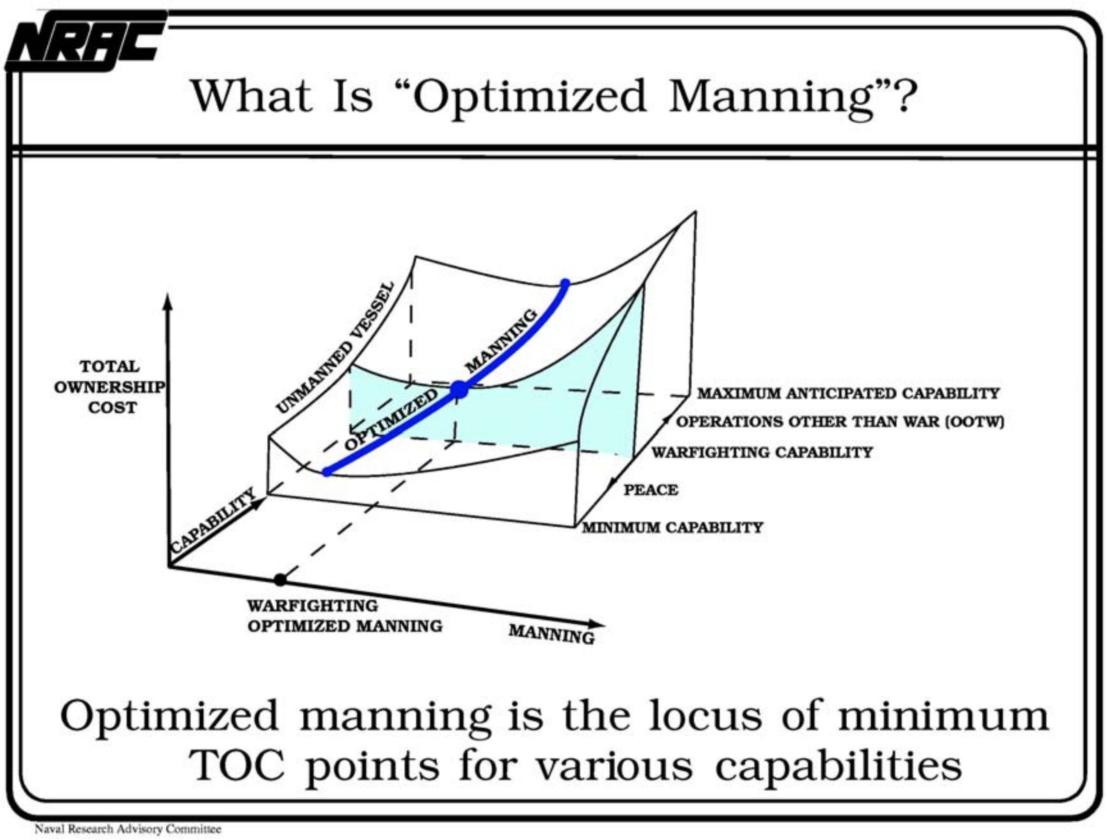

Figure 3. Relationship between manning level, capability and total ownership costs for a naval ship. (Taken from reference 3)

3. Damage Control and Optimized Manning – DRDC Atlantic Project 11gr

To address some of the concerns associated with optimized crewing and its effect on damage control capabilities on CF ships, DRDC Atlantic Project 11gr was initiated in April 2005. A summary of DRDC Atlantic Project 11gr is shown in Figure 4. The objectives of this project are to maintain or enhance damage control on ships with reduced crewing levels and to assess the effect of technology and materials on crew requirements for damage control. Several approaches will be used to achieve the objectives. These include the use of modeling and simulation to study the effect of technology on crewing requirements for various damage control scenarios, the identification of advanced damage/fire control sensors and systems, materials with enhanced damage and/or fire tolerance, condition based sensing systems, and the consideration of human factors, including human systems integration.

11gr: Damage Control and Optimized Crewing

Participants: DRDC Atlantic, DRDC Toronto, DRDC CORA, Contractors
Resources: $300K/yr, 3 FTEs/yr
Project Duration: 3 years 2005-2008
Sponsor: DMRS
Project Manager: Dr. John Hiltz

Objectives:
- to enhance or maintain damage control capabilities on ships with reduced crewing levels
- to assess the effect of technology and materials on damage control crewing requirements

Technologies:
- modeling and simulation
- sensors/control systems
- materials

Outcome:
Reduced through life costs of ships

Outputs:

- state-of-the-art review damage/fire suppression and control systems

- damage/fire tolerant materials

- effect of damage/fire control technologies on crewing levels

Figure 4. Summary of DRDC Atlantic Project 11gr – Damage Control and Crew Optimization.

The project has seven work breakdown elements (WBE). These are described in the next section.

3.1 Work Breakdown Elements Project 11gr

3.1.1 11gr13 – Remote Condition Monitoring Systems

This WBE was initiated in 2004 as a technology application (TA) activity and was moved to Project 11gr because of its fit with the project.

Maintenance of naval vessels is both costly and labour intensive. As such it is a major contributor to the total operating costs of a ship. The introduction of automation will add to the requirement for routine periodic maintenance. If maintenance could be done on an 'as needed' basis this would reduce labour (crewing) requirements. Condition based maintenance (CBM) provides a way to accomplish this. Rather than have crew perform routine periodical maintenance on critical systems, a CBM system monitors the health of these systems and indicates and/or aids the crew in determining when maintenance is required.

The objectives of this WBE, managed by Rangy Haggett at DRDC Atlantic, are the evaluation and characterization of condition based maintenance (CBM) sensor technologies, the demonstration of the advantages of wireless data transfer for shipboard CBM, and the demonstration of novel sensors and wireless data transfer on an operational naval platform. The benefits expected from this research are crew reduction through CBM instead of periodic maintenance of machinery, the ability to monitor the health of mission critical equipment in real time and make maintenance decisions based on this information, and the archiving of radiated noise data from equipment to aid in managing the ship's acoustic signature.

A prototype demonstration system, for testing sensors, data acquisition and data transfer has been constructed and the concept proof tested. A full scale system will be designed, developed and tested in this year, and the system deployed and evaluated on an operational ship in 2006/2007.

3.1.2 11gr16 – Modeling and Simulation of Ship Complements

The objectives of this WBE are to identify and represent functions associated with damage control on a Navy ship, to represent how different configurations of humans and automation will perform damage control, and to simulate different scenarios and evaluate the efficiency of different configuration of humans and automation (technology). Dr. Renee Chow, DRDC Toronto, is the manager of this WBE.

Integrated performance modeling environment (IPME) software will be used for modeling and simulation work. IPME software can be used to investigate how long will it take a crew to perform a particular function/mission, their probability of success, and if they will experience overload during the mission. If the crew experiences overload then the software can be used to identify the tasks/user interfaces that are causing the overload, and determine the consequences in terms of mission time and probability of success. Tasks can be reallocated amongst the crew and/or automated systems during a scenario, or the job/system can be redesigned to determine the gains in crew performance or workload, the consequences of using a more qualified crew, and the effect of potential stresses such as heat and sleep deprivation on completing damage control tasks.

3.1.3 11gr17 – Fire Control/Sensing and Suppression

The objective of this WBE is to identify technologies that facilitate fire sensing, control and suppression on ships. The first phase of research involves a literature review of the state-of-the-art in fire sensors, fire sensor systems and fire suppression systems and related technologies. Reliable and sensitive sensors are critical to early detection of and rapid response to fires. The types of sensors are also critical in any effort to automate detection and response to fires. Typically, ionization, photoelectron, carbon dioxide (CO_2) and carbon monoxide (CO) sensors are used. More recently there has been research into the use of optical detectors (5). Research is also progressing in the use of probabilistic neutral networks to aid in the determination of whether or not a fire has started (based on the response of the fire sensing detector suite) and reduce the number of false alarms (6).

Halon 1301 (bromotrifluoromethane) will not be used in new ship construction. This requires that replacements, such as water mist and non-ozone depleting gaseous agents, be used. There has been a significant amount of research on water mist systems. For instance, the US Damage Control- Automation for Reduced Manning (DC-ARM) program has studied these systems. However, the design of these systems and the technology used to produce the mist will have to be carefully considered to ensure maximum efficacy. Non-ozone depleting gaseous agents have been evaluated as Halon 1301 replacements, but there is a concern about release of toxic/acid gases from these agents. There is also concern about aqueous film forming foams (AFFF) containing fluorinated chemicals. The 3M Company ceased making AFFF in 2000. Their product contained perfluoro-octanyl sulphonate (PFOS), a stable and persistent compound that does not degrade in the environment. Fluorinated aqueous film forming foams that do not contain PFOS are available, but these contain other fluorinated compounds that may be cause for concern.

Technologies that allow remote response to limit smoke, flame and heat spread, such as remote ventilation and access control, are also available. This will have to be evaluated to determine their applicability and cost effectiveness.

3.1.4 11gr18 – Damage Control

The objective of this WBE is to investigate technologies related to damage sensing and damage control systems. The approach to damage control issues will not be significantly different from that taken for fire control. The first phase of the work will involve a state-of-the-art review of damage control sensors, damage control systems, and technologies applicable to damage control.

Technologies that enable sensing and automated actuation will be investigated. Smart valves that sense pressure drops in ruptured fire main or chilled water piping and automatically close to maintain flow in the system are of great interest. Technology that allows the remote closing of doors/hatches to control smoke and flame spread and flooding will be investigated.

This work will also investigate damage control systems and consider what information the damage control officer requires, how it is best presented, and how it can be designed to assure decisions are made on an informed and timely basis.

3.1.5 11gr19 – Remote Condition Monitoring Systems

The objective of WBE 11gr19 is to evaluate systems that allow the remote real-time analysis of machinery and platform conditions. This WBE is similar to WBE 11gr13 and when WBE 11gr13 activities are completed further work in condition monitoring sensors and systems will be carried out in WBE 11gr19. This WBE also has aspects that are similar to those in WBEs 11gr17 and 11gr18.

Continuous monitoring and quantification of platform performance is critical to damage control and reduced crewing levels. Sensors make crew aware of a problem, its extent, and the effectiveness of control measures. Parameters such as flooding, firemain pressure, and hull integrity can all be monitored. For instance, a system could be used to monitor structural damage and the effectiveness of damage control measures in real time.

3.1.6 11gr20 – Materials – Enhanced Reliability, Fire and Damage Tolerance

The objective of this WBE is to identify materials or the opportunities to develop materials that have enhanced damage and fire tolerance or enhanced reliability. The development and introduction of materials that have improved damage or fire tolerance will have an impact on damage control and optimized manning. These materials have the potential to ameliorate the effects of battle damage, damage arising from high sea states, and fires.

Highly porous metals and blast resistant coatings are materials with potential to improve the damage tolerance of naval vessels.

Material developments also have potential applications in the fire hardening of ships. Materials that are less susceptible to fire will affect the level of effort required to bring a fire under control. For instance, materials that prevent the spread of smoke and flame from one compartment to the next, such as bulkhead penetration sealants, intumescent coatings (7, 8), fire resistant cable sheathing, and fire resistant composites would enhance the fire tolerance of shipboard materials. In large below deck spaces the development of materials such as deployable curtains could be used to control the spread of smoke and flame.

3.1.7 11gr21 – Human Factors

Activity in this WBE is not slated to start until 2006. The aim of this WBE is to consider how new technologies and resulting automation of tasks can be integrated with crew on a ship. Questions such as how is the information from sensors and sensor systems best presented to the operator and what are the new training requirements that result from the introduction of these technologies will be addressed.

4. The Potential

With these planned activities in mind, one might ask about the potential for enhanced or effective damage control in an optimized (reduced) crewing environment. Figure 4 is a summary of how damage control automation was used to reduce manning requirements for damage control scenarios from 109 to 45 in testing on the ex-USS Shadwell in Mobile, Alabama. This ship, operated by the Naval Research Laboratory, Washington, DC, is used for evaluation of damage control technologies and doctrines.

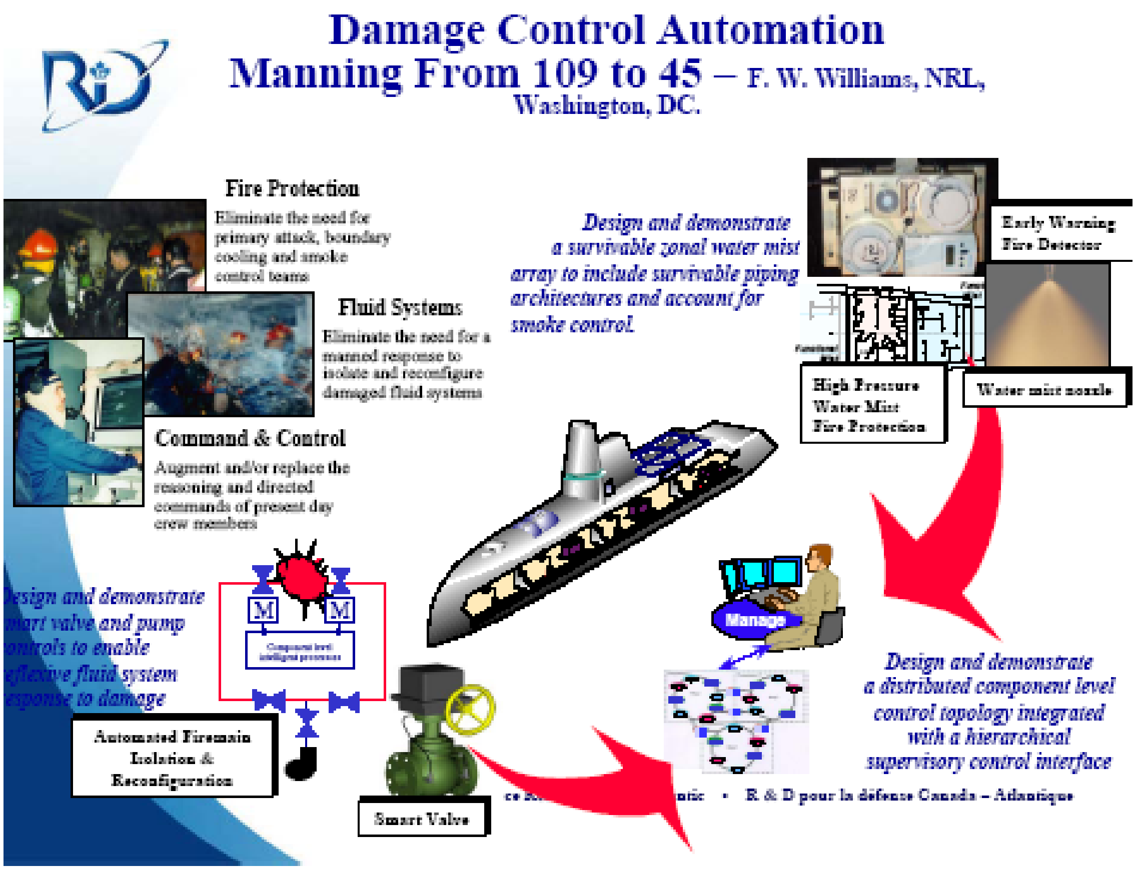

Figure 5. Technologies and automation used to reduce damage control manning levels from 109 to 45 in damage control scenarios on ex-USS Shadwell. (from Dr. Frederick W. Williams, Naval Research Laboratory, Washington, DC)

The testing incorporated fire protection, command and control, and fluid systems technologies developed under the DC-ARM program. These included a zonal water mist array with survivable piping architecture and smoke control, a distributed component level control system integrated with a hierarchical supervisory control interface, and smart valve and pump controls to allow reflexive fluid response to damage.

5. Conclusions

There is a significant opportunity to reduce crewing levels on future CF ships without adversely affecting the ability to perform damage control. Functional analysis of tasks and modeling and simulation of damage control scenarios will be required to ensure that the impact of automation on labour intensive tasks such as damage control is understood. Automation (technology) will result in increased procurement costs and this will have to be weighed against through life cost saving resulting from reduced crewing requirements.

Reduced manning is of interest to our allies and an excellent opportunity for information exchange and collaborative projects exists.

6. References

1. Thomas B. Malone and Frances Carson, "HSI Top Down Requirements Analysis", Naval Engineering Journal, Volume 115, No. 2, page 37.

2. Military Personnel – Navy Actions Needed to Optimize Ship Crew Size and Reduce Total Ownership Costs", United States General Accounting Office – Report to Congressional Requesters, GAO-03-520, June 2003.

3. "Naval Research Advisory Committee Report - Optimized Surface Ship Manning", Office of the Assistant Secretary of the Navy, Report NRAC 00-1, April 2000.

4. David Beevis, Andrew Vallerand, and Mike Greenley, "Technologies for workload and crewing reduction", DRDC Technical Report, DCIEM TR 2001-109, October 2001.

5. James A. Lynch; Susan L. Rose-Pehrsson, Daniel A. Steinhurst, Stephen C. Wales, and Frederick W. Williams, "Volume Sensor Development Test Series 2- Lighting Conditions, Camera Settings, and Spectral and Acoustic Signatures", Naval Research Laboratory Report NRL/MR-MM/6180-04-8843, 24 November 2004.

6. Susan L. Rose-Pehrsson,, Sean J. Hart, Thomas T. Street, Patricia A. Tatem, Frederick W. Williams, Mark H. Hammond, Daniel T. Gottuk, Mark T. Wright, and Jennifer T. Wong, "Real Time Probabilistic Neural network performance and Optimization for Fire Detection and Nuisance Alarm Rejection", Proceedings of AUBE '01 – 12th International Conference on Automatic Fire Detection, NIST, Gaithersburg, Maryland, March 25-28, 2001

7. D. E. Veinot and D. Nguyen, "Inorganic Intumescent Fire Protective Coatings for Marine Use", DREA-NAMT-95-5-PAP-2, 30 may 1995.

8. D. E. Veinot, "Novel Materials for Improved Fire Safety of Naval Platforms", DREA-SR-1999-162-PAP-4, 1 October 1999. "Naval Research Advisory Committee Report – Damage Control and Maintenance", Office of the Assistant Secretary of the Navy, September 1996.