# Review of Technologies for Workload or Crew Reduction on Royal Canadian Navy Ships

Lisa Hagen
Sylvain Provonost
Heather Colbert

*CAE Professional Services*

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**Defence R&D Canada**
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Principal Author

*Original signed by Lisa Hagen*

Lisa Hagen

Human Factors Consultant

Approved by

*Original signed by Dr. R.E. Mitchell*

Dr R. E. Mitchell

Head, Maritime and ISR Systems Operational Research

Approved for release by

*Original signed by Paul Comeau*

Paul Comeau

Chief Scientist

DRDC CORA

Defence R&D Canada – Centre for Operational Research and Analysis (CORA)

# Abstract

The Royal Canadian Navy is looking at various technological means to optimize manning for its future fleet programmes. This report documents recent research on technologies for workload and crewing reduction. It constitutes a follow-up to previous research (Beevis et al., 2001) on the same subject, in the form of an annotated bibliography. Online searches using open access databases were used to produce this literature review, which was further categorized into four broad types of technologies (ship function, policies and procedures, personnel and training, and human-systems integration), as well as an assessment of the technology as being current or for future development. Technologies and solutions for workload and crewing reduction used in the Royal Canadian Navy were investigated, as well as those employed by foreign navies, civilian fleets (merchant marines, shipping companies, etc.), and Coast Guards. The resulting annotated bibliography includes abstracts and links to the original source references, as well as a table to quickly map the articles to the categories under which they are classified.



# Résumé

La Marine royale canadienne (MRC) est à la recherche de moyens technologiques pour optimiser la dotation en personnel d’éventuels programmes de la flotte. Le présent compte rendu renferme la récente recherche sur des technologies destinées à réduire la charge de travail et l’équipage. Il constitue un suivi de la recherche antérieure (Beevis et al., 2001) sur le même sujet, sous la forme d’une bibliographie annotée. Des recherches en ligne faisant appel à des bases de données à libre accès ont été utilisées pour réaliser cette révision de la documentation, par la suite subdivisée en quatre grandes classes de technologie (fonctionnement des navires, politiques et procédures, personnel et formation et intégration des systèmes humains), de même qu’une évaluation de la technologie actuelle ou liée à des projets futurs. Des technologies et des solutions visant la réduction de la charge de travail et de l’équipage de la Marine royale canadienne ont été analysées, de même que celles des marines étrangères, des flottes de navires civiles (marine marchande, sociétés de transport maritime, etc.) et des gardes côtières. La bibliographie annotée obtenue comprend des résumés et des liens vers des références originales ainsi qu’un tableau permettant de diriger rapidement les articles vers les catégories où ils ont été classés.

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# Executive summary

## Review of Technologies for Workload or Crew Reduction on Royal Canadian Navy Ships

**Lisa Hagen; Sylvain Pronovost; Heather Colbert; DRDC CORA CR 2012-058, Defence R&D Canada – CORA; March 2012.**

**Introduction:** The Royal Canadian Navy (RCN) is looking at various technological means to optimize manning for its future fleet programmes. A strategic roadmap for the Navy's Future Fleet has been deployed in order to assess the feasibility of reduced ship manning, whether by crew optimization methods, better shift rotation strategies, variations in personnel training, or even ship function automation and enhanced human-technology interfaces. A serious constraint on such manning optimization measures concerns the uncertain impact of crew and operator workload reduction technologies on the eventual crew complement requirements for future ships. The purpose of this report is to document and categorize papers presenting recent research advances in the development of technologies for workload and crewing reduction. It constitutes a follow-up to previous research[1] on the same subject, in the form of an annotated bibliography.

**Results:** A number of search queries were conducted using Google Scholar, the National Technical Information Service (NTIS), and the Defense Technical Information Center (DTIC). The types of documents found through such queries were papers such as internal technical reports, contractual reports, and academic dissertations from various defense agencies of the Department of National Defense (DND) and Canadian Forces (CF) in Canada, Department of Defense (DoD) and various United States Armed Forces, from North Atlantic Treaty Organization (NATO) members, or NATO allies. The papers were then sorted and categorized with regards to four broad classes of technologies and solutions, namely ship function, policies and procedures, personnel and training, and human-systems integration. The development status of such technologies was also characterized as being suitable for either current or future implementations. A table summarizing the research results of the annotated bibliography is provided, as well as the exhaustive list of research papers and their respective abstracts.

**Significance:** This research follows up directly on a report by Beevis et.al. 2(001) entitled Technologies for Workload and Crewing Reduction, which documented and categorized technologies and solutions available for crewing and workload reduction in the RCN at that time. As such, the current report focused on the state of the art in manning optimization/reduction and naval operator workload since 2001 in order to facilitate future work for the elaboration of the strategic roadmap for the RCN's Future Fleet programmes.

**Future plans:** This report segues into another phase of the same research endeavour, whereby an evaluation of each technology documented in the first phase (the current report) would be conducted with regards to costs and applicability to the RCN. This study would help determine estimates in crewing reduction for the Navy's Future Fleet.

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[1] Beevis, D., Vallerand, A. & Greenley, M. (2001). Technologies for workload and crewing reduction. DCIEM Technical Report 2001-109.

# Sommaire

## Review of Technologies for Workload or Crew Reduction on Royal Canadian Navy Ships

**Lisa Hagen; Sylvain Pronovost; Heather Colbert; DRDC CORA CR 2012-058, R & D pour la défense Canada – CORA; mars 2012.**

**Introduction :** La Marine royale canadienne (MRC) est à la recherche de divers moyens technologiques d'optimiser la dotation en personnel d'éventuels programmes de la flotte. Une carte stratégique de la future flotte de la Marine a été dressée afin d'évaluer la faisabilité d'une dotation en personnel réduite, que ce soit à l'aide de méthodes d'optimisation de l'équipage, de meilleures stratégies de rotation des quarts de travail, de variations dans la formation du personnel ou même de l'automatisation du fonctionnement des navires et des interfaces humain-technologie améliorées. De telles mesures d'optimisation de la dotation en personnel comportent une importante contrainte, notamment à l'égard de l'incidence incertaine des technologies de réduction de la charge de travail des membres d'équipage et des opérateurs sur les éventuels besoins supplémentaires de l'équipage des futurs navires. Le présent compte rendu a pour objectif de répertorier et de classer par catégories les documents qui présentent des progrès récents dans l'élaboration de technologies de réduction de la charge de travail et des équipages. Il constitue un suivi de la recherche antérieure[2] sur le même sujet, sous la forme d'une bibliographie annotée.

**Résultats :** Des recherches ont été réalisées à l'aide de *Google Scholar*, du *National Technical Information Service* (NTIS) et du *Defence Technical Information Center* (DTIC). Les documents trouvés dans le cadre de ces recherches sont, notamment, des comptes rendus techniques internes, des comptes rendus contractuels et des dissertations théoriques de divers organismes de défense du ministère de la Défense nationale (MDN) et des Forces canadiennes (FC) au Canada, du Département de la Défense et des diverses Forces armées des États-Unis, de pays membres de l'Organisation du Traité de l'Atlantique Nord (OTAN) ou d'alliés de l'OTAN. Les documents ont ensuite été triés et classés en fonction de quatre grandes classes de technologie et de solution, à savoir fonctionnement des navires, politiques et procédures, personnel et formation et intégration des systèmes humains. L'état d'avancement de ces technologies a également été identifié comme étant approprié aux mises en œuvre actuelle et future. On a élaboré un tableau résumant les résultats de la recherche de la bibliographie annotée ainsi que la liste exhaustive des documents de recherche et de leurs résumés respectifs.

**Portée :** Cette recherche s'inscrit directement dans la foulée du compte rendu de Beevis et.al. 2001 intitulé *Technologies for Workload and Crewing Reduction*, qui documente et classe par catégorie les technologies et solutions permettant de réduire les équipages et la charge de travail dans la MRC à ce moment-là. Ainsi, le compte rendu actuel met l'accent sur le caractère avant-gardiste de la réduction/optimisation de la dotation en personnel et de la charge de travail des opérateurs navals depuis 2001 dans le but de faciliter les travaux futurs pour l'élaboration d'une carte stratégique contenant les futurs programmes de la flotte de la MRC.

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[2] Beevis, D., Vallerand, A. & Greenley, M. (2001). *Technologies for workload and crewing reduction*. Document technique de l'Institut de médecine environnementale pour la défense 2001-109.

**Travaux futurs :** Le présent compte rendu permet de passer à une autre étape du même projet de recherche, dans lequel une évaluation de chaque technologie abordée dans la première étape (le compte rendu actuel) sera réalisée en fonction de son coût et de sa possibilité d'application à la MRC. Cette étude aidera à déterminer des estimations dans la réduction de la dotation en personnel de la future flotte de la Marine.

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# Table of contents

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# 1 Introduction

## 1.1 Purpose

This report presents the results of Defence Research and Development Canada (DRDC) Centre for Operational Research and Analysis (CORA) Task 112 - Review of Technologies for Workload or Crew Reduction on Royal Canadian Navy Ships.

The purpose of this task is to: collect data on workload or crew reduction technologies currently employed on Canadian naval ships, as well as those utilized by foreign navies, merchant marine, coast guard, and civilian shipping companies; collect information on anticipated technological developments in the area of workload or crew reduction in the next two decades and to categorize them into a summary table; and document the findings in an annotated bibliography. This was achieved by conducting a literature survey using operations research, academic research, as well as other sources deemed relevant. The annotated bibliography uses abstracts taken directly from the respective papers and uses the American Psychological Association formatting style.

## 1.2 Scope

The scope of the project includes:

- Task A: Review open literature sources to identify those technologies which currently reduce workload or crew sizes onboard ships, either Royal Canadian Navy (RCN), foreign navies, merchant marine, coast guard or civilian cargo lines.
- Task B: Review open literature sources to identify potential technologies that will be implemented in the next two decades, which are expected to reduce workload or crew sizes onboard the classes of ships listed in Task A.
- Task C: Categorize the technologies identified in Tasks A and B into coherent groupings. The groupings used are Ship Function, Policy and Procedures, Personnel & Training, and Human Systems Integration. These categories were agreed upon through consultations between the Contractor and the Technical Authority.
- Task D: Produce brief descriptions of each of the papers found in Tasks A and B including hyperlinks to the reference material used.

# 2 Methodology

## 2.1 Introduction

The Future Fleet Team in the Directorate of Maritime Personnel is responsible for the creation of a strategic road map to the RCN's Future Fleet (Arctic/Offshore Patrol Ships (AOPS), Joint Support Ships (JSS), Canadian Surface Combatant (CSC) and Sub Surface Killer (SSK)) with respect to its personnel establishment and the implications for human resource (HR) policies and practices. One of the key questions which will drive the navy's future personnel establishment is how the new ships will be manned - one ship/one crew, manning pools, crew optimization, crew rotation, hybrid crews, hybrid sailors, and so forth. However, one of the key mitigating factors that must first be explored is the workload and crew reduction technologies that might be utilized onboard and the impact that they would have on the required crew complement. In 2001, Beevis, Vallerand, & Greenley conducted an extensive literature review to better understand the workload and crew reduction technologies available at the time. This information was categorized and put into a matrix according to general categories (Ship Function, Policy & Procedures, Personnel & Training, and Human Systems Integration) and the cost of implementation (no cost to the ship, at minor cost, at major cost such as a refit, implemented in new ship builds or required further development to implement). Subject matter expert opinions were then collected to better understand the applicability of the technology. As the RCN prepares for its future fleet, the Beevis et al. (2001) literature review needed to be updated and expanded to reflect how technology has changed and evolved over the past ten years. The purpose of the current project was to conduct an extensive literature search using the same four general categories used by Beevis et al. (2001) and to document the findings in an annotated bibliography.

## 2.2 Search Keywords

The following online archives and databases were searched to produce the annotated bibliography:

- Google Scholar,
- National Technical Information Service (NTIS), and
- Defense Technical Information Center (DTIC).

The following keyword combinations were used:

- Google Scholar:
  - manning OR ship+manning OR manning+reduction OR crewing OR crew+reduction OR ship+automation
- NTIS:
  - manning OR manpower OR crew+size OR operation+analysis OR personnel+requirement ships OR shipboard OR naval OR vessel OR smart+ship;
  - manning OR manpower OR crew size OR operation analysis OR personnel requirement AND: ships OR shipboard OR naval OR vessel OR smart ship

- NTIS revised wording:
    - ship manning reduction crewing crew automation;
    - crew workload reduction ship.

The search of Google Scholar produced the most exhaustive list of documents. Most of the references then found through NTIS had already been found via Google Scholar.

The DTIC database was the largest repository of papers found via Google Scholar, under the Open Archives Initiative (OAI) interoperability standard for content dissemination. Those documents consist of internal technical reports, contractual reports, academic dissertations, etc. from various defence agencies of the Department of National Defence (DND) and the Canadian Forces (CF) in Canada, the Department of Defense (DoD) and various Armed Forces in the United States (U.S.), from North Atlantic Treaty Organization (NATO) members or NATO allies.

The large majority of the papers in this report are from 2001 or later with the exception of a few slightly older documents of significant importance, which had not been included in the Beevis et al. (2001) report. A total of 181 applicable papers were identified. Of these papers, six were written by Canadian defence personnel.

## 2.3 Categories

The identified papers were organized according to the same four categories used in the Beevis et al. (2001) report. These include Ship Function, Policies and Procedures, Personnel and Training, and Human-Systems Integration solutions. Some papers were applicable across multiple categories.

**Ship Function** refers to various systems, technologies, and other solutions which seek to enhance, automate, simplify, or eliminate the operator-in-the-loop with regards to ship capabilities such as sensors, weapon systems, maintenance systems, power, and emergency measures. A total of 65 papers were identified in this category.

**Policy and Procedures** refers to organizational solutions and strategies related to the processes of manning and crewing and using simulations of operator performance. A total of 86 papers were identified in this category.

**Personnel and Training** refers to solutions pertaining to the range of skills for operators of reduced crews, strategies to improve performance through the optimized mixture of personnel, bringing awareness about the risks and limitations of reduced manning on ships as well as operator workload reduction measures ranging from research on shiftwork and fatigue to using simulations of operator performance. A total of 64 papers were identified in this category.

**Human-Systems Integration** is a far-ranging category, from the use of simulation solutions to implement strategies of the abovementioned categories, to increasing the ergonomics of systems interfaces, and other human factors-derived solutions pertaining to safety, learning curve, and enhanced human-in-the-loop efficiency. A total of 96 papers were identified in this category.

## 2.4 Annotated Bibliography

The following sections in this report present the results of the literature search according to the four categories. Some papers were identified as applicable in multiple categories. In this case the annotated bibliography information is provided only in the one category where it was deemed most applicable.

For each paper, its bibliographic information is presented, followed by the abstract. Provided the file structure from the original electronic delivery of this report is maintained, clicking on the ".pdf" link at the end of each abstract will then open a PDF version of the paper identified. Not all papers were available free of charge and these are indicated by a "no pdf available" at the end of the abstract.

## 2.5 Summary Table

A summary table showing all papers is included below (Table 1). Clicking on the first author's name in the summary table below will bring the reader to the appropriate annotated bibliography within this report. This table also indicates which categories the papers address with 'X', as well as a check mark in a specific category indicating which category in the annotated bibliography the abstract can be found. The technology described in each paper is also classified in the table as current or potential future technology (see description below).

- **Current** technologies and solutions refer to (i) solutions which have already been deployed, tested, and for which results and/or assessments are available, or (ii) concepts which have been developed to a sufficient degree to obtain prototypes, and are currently being tested and/or used for their intended goal by the people presenting such concepts.

- **Future** technologies and solutions are solutions which do not meet the two aforementioned criteria, i.e., they are merely concepts of operations, or untested prototypes, or limited technology implementations undergoing test trials until a full system is fully implemented or they are future projects altogether.

*Table 1: Summary of Workload/Crew Reduction Literature Search.*

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Albea, L. (2005). *Sea based air operations center.* | Current | X | ✓ | X | |
| Alexopoulos, A. (2007). *Introducing system dynamics modelling into the passenger and cruise markets focusing on the marine manpower.* | Current | | ✓ | X | |
| Allen, P., Wadsworth, E., & Smith, A. (2007). *The prevention and management of seafarers' fatigue.* | Current | | | ✓ | |
| Allender, L. (2000). *Modeling human performance: Impacting system design, performance, and cost.* | Current | | X | X | ✓ |
| Andrews, D., Casarosa, L., Pawling, R., Galea, E., Deere, S., & Lawrence, P. (2007). *Integrating personnel movement simulation into preliminary ship design.* | Current | X | | | ✓ |
| Apsley, J. M., Villasenor, A. G., Barnes, M., Smith, A. C., Williamson, S., Schuddebeurs, J. D., & McDonald, J. R. (2007). *Propulsion drive models for full electric marine propulsion systems for full electric marine propulsion systems.* | Current | ✓ | | | |
| Archer, S., Headley, D., & Allender, L. (2003). *Manpower, personnel, and training integration methods and tools.* | Current | | X | ✓ | X |
| Arcidiacono, V., Castellan, S., Menis, R., & Sulligoi (2006). *Integrated voltage and reactive power control for all electric ship power systems.* | Current | ✓ | | X | |
| Arciszewski H. F. R., de Greef, T. E., & van Delft, J. H. (2009). *Adaptive automation in a naval combat management system.* | Current | | | | ✓ |
| Arslan, O. & Er, I. D. (2008). *A SWOT analysis for successful bridge team organization and safer marine operations.* | Current | | ✓ | X | X |
| Baker, C.C., Krull, R., Snyder, G., Lincoldn, W., & Malone, T. B. (2001). *Survey of reduced workload and crewing strategies for ocean patrol vessels.* | Current | | ✓ | X | X |
| Baker, C. C., Malone, T., & Krull, R. D. (1999). *Survey of maritime experiences in reduced workload and staffing.* | Current | | ✓ | | |
| Barnett, M. L., Stevenson, C. J., & Lang, D. W. (2005). *Shipboard manning.* | Current | | ✓ | X | |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Barr, R. K., & Williams, F. W. (2001). *DC-ARM organizational procedures and manning for smart controller.* | Current | | X | ✓ | |
| Beevis, D., Vallerand, A., & Greenley, M. (2001). *Technologies for workload and crewing reduction.* | Current | ✓ | X | X | X |
| Bennett, P. L. (2007). *Using the non-intrusive load monitor for shipboard supervisory control.* | Future | ✓ | | | |
| Bennington, J. (2010). *Perceptions on social networking: A study on their operational relevance for the navy.* | Current | | | ✓ | |
| Bost, J. & Galdorisi, G. (2004). *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.* | Current | | X | X | ✓ |
| Brockett, C. H., Scott-Nash, S., & Pharmer, J. A. (2001). *Verifying and validating the Aegis air defense warfare human performance model.* | Current | | | X | ✓ |
| Bryce, L., & Lance, S. (2003). *Maximizing rig automation safety and efficiency with remote monitoring and management.* | Current | | | X | ✓ |
| Bucknall, R., & Freire, P. (2004). *Unmanned cargo ships: A 2020 vision?* | Future | | ✓ | X | |
| Burns, J., Gordon, J., Wilson, M., Stretton, M., & Bowdler, D. (2005). *A framework for applying HSI tools in systems acquisition.* | Current | | X | X | ✓ |
| Butler-Purry, K. L., & Sarma, N. D. R. (2003). *Intelligent network reconfiguration of shipboard power systems.* | Current | ✓ | | | |
| Calvano, C. N., Harney, R. C., Papoulias, F., & Ashton, R. (2003). *Sea Force: A sea basing platform.* | Current | ✓ | X | X | |
| Campbell, G. E., Cannon-Bowers, J. A., & Villalon (1997). *Achieving training effectiveness and system affordability through the application of human performance modeling.* | Future | X | X | | ✓ |
| Cannon, K., Clarke, K., Muhi, N., & Davies, J. (2011). *Operators gain significant operational and safety gains with remote data acquisition and virtual rig presence.* | Future | | ✓ | X | |
| Carlson, C., Hayes, B. C., Kamradt, H., & Hoffman, G. (2002). *Littoral Combat Ship (LCS) Characteristics Task Force.* | Current | | ✓ | X | |
| Carreno, J., Galdorisi, G., & Lemon, A. (2010). *The penultimate C4ISR challenge: Reducing military manpower and total operating costs.* | Current | X | X | X | ✓ |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Chipman, S. F., & Kieras, D. E. (2004). *Operator centered design of ship systems.* | Current | | | X | ✓ |
| Clark, D. T. (2009). *Navy officer manpower optimization incorporating budgetary constraints.* | Current | | ✓ | | |
| Cogley, K.M., Green, B.D., & Snodgrass, R.E. (2005). *Reducing the maintenance burden of shipboard collective proection systems.* | Current | | ✓ | X | |
| Cowen, M. B., & Kaiwai, J. L. (2010). *Key human system integration plan elements for command and control acquisition.* | Current | | X | X | ✓ |
| Davies, I. (2001). *Processing and fusion of electro-optic information.* | Current | ✓ | | | |
| Dean, A. W., Reina, J. J., & Bao, H. P. (2008). *Identification of supplementary metrics to sustain fleet readiness from a maintenance perspective.* | Current | | ✓ | X | |
| Desclèves, E., & Letot, L. (2001). *Technologies and sociotechnical systems for future destroyers.* | Current and Future | ✓ | X | | |
| Didonato, L., Famme, J. B., Nordholm, A., & Lemon, A. (2004). *A total ship-crew model to achieve human systems integration.* | Future | | | X | ✓ |
| Dobie, T. (2003). *Critical significance of human factors in ship design.* | Current | | | X | ✓ |
| Doerry, N. H. (2006). *Systems engineering and zonal ship design.* | Current | ✓ | | | X |
| Douangaphaivong, T. (2004). *Littoral combat ship (LCS) manpower requirements analysis.* | Current | | X | ✓ | |
| Drew, K. F., & Scheidt, D. (2004). *Distributed machine intelligence for automated survivability.* | Future | X | | | ✓ |
| Dundics, M., Finley, B., Krooner, K., Roche, T., & Rodgers, R. (2010). *Littoral combat ship (LCS), gas turbine reliability engineering implementation.* | Current | | ✓ | X | |
| Echols, R., Santos, W., Fernandez, C., Didoszak, J., Cabezas, R., Lunt., & Green M. (2003). *SEA SWAT: A littoral combat ship for sea base defense.* | Current | ✓ | X | X | |
| Eckelberry, J. R., & Halloway III, K. E. (2003). *Damage control operational concepts (DCOC) - Impact of technology insertion on shipboard damage control operations*. | Future | ✓ | | | |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Famme, J., Gallagher, C., & Masse, M. (2003). *Achieving human systems integration through design.* | Future | | | | ✓ |
| Famme, J. B., Gallagher, C., & Raitch, T. (2009). *Performance-based design for fleet affordability.* | Future | ✓ | | X | X |
| Fireman, H., Nutting, M., Rivers, T., Carlile, G., & King, K. (1998). *LPD 17 on the shipbuilding frontier: Integrated product & process development.* | Current | ✓ | | | |
| Ford, M. C. (2003). *New waves in workboats: Combined control and monitoring.* | Current | ✓ | | X | X |
| Frank, M. V., & Helmick, D. (2007). *21st century HVAC system for future naval surface combatants - Concept development report.* | Current | ✓ | | | |
| Freeman, J. T. (2002). *Complementary methods of modeling team performance.* | Current | X | | | ✓ |
| Fullerton, J., Scotchlas, M., Smith, T., & Freedner, A. S. (2004). *Operational impacts of the Aegis cruiser smartship system.* | Current | | ✓ | X | |
| GAO-08-1060T-08-1060T (2008). *The Zumwalt-class destroyer program emblematic of challenges facing navy shipbuilding: Testimony before the Subcommittee on Seapower and Expeditionary Forces, Committee on Armed Services, House of Representatives,* | Current | | ✓ | | |
| Gayle, W. (2006). *Analysis of operational manning requirements and deployment procedures for unmanned surface vehicles aboard U. S. Navy ships.* | Future | | | ✓ | X |
| Good, N., & Brown, A. (2006). *Multi-objective concept design of an advanced logistics delivery system ship (ALDV).* | Future | ✓ | | | |
| Golding, H. L. W., Gasch, J. L., Gregory, D., Hattiangadi, A. U., Husted, T. A., Moore, C. S., & Seiver, D. A. (2001). *Fleet attrition: What causes it and what to do about it.* | Future | | X | ✓ | |
| Gould, D., & Twomey, B. J (2004). *Overview of the assessment process for software within the marine sector.* | Current | | X | | ✓ |
| Gould, K. S. (2009). *Faster, better, safer? Studies of safety, workload and performance in naval high-speed ship navigation.* | Current | | | X | ✓ |
| Grech, M. (2005). *Is automation a help or a hindrance?* | Current | | | | ✓ |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Greef, T. de, & Arciszewski, H. (2007). *A closed-loop adaptive system for command and control.* | Current | | | | ✓ |
| Green, K. Y. (2009). *A comparative analysis between the navy standard workweek and the actual work/rest patterns of sailors aboard U.S. Navy frigates.* | Current | | | ✓ | |
| Groskamp, P., Paassen, M. van, & Mulder, M. (2005). *Interface design for engagement planning in anti-air warfare.* | Current | | | | ✓ |
| Haynes, L. E. (2007). *A comparison between the navy standard workweek and actual work and rest patterns of U.S. Navy sailors.* | Current | | | ✓ | |
| Hemmen, H. van. (2009). *Human factors analysis and the shipboard environmental department.* | Current | | | | ✓ |
| Hiltz, J.A. (2005). *Damage control and crew optimization* | Future | X | | X | ✓ |
| Hiltz, J. (2005). *Damage control and optimized manning.* | Future | X | | X | ✓ |
| Hinkle, J. B., & Glover, T. L. (2004). *Reduced manning in DDG 51 class warships: Challenges, opportunities and the way ahead for reduced manning on all United States Navy ships*. | Current | | ✓ | | |
| Horck, J. (2004). *An analysis of decision-making processes in multicultural maritime scenarios.* | Current | | ✓ | | |
| Horn, J., Cofield, A., & Steele, R. (2007). *Culture change in the navy.* | Current | X | ✓ | | |
| Houtman, I., Miedema, M., Jettinghoff, K., Starren, A., Heinrich, J., & Gort, J. (2005). *Fatigue in the shipping industry*. | Current | | | ✓ | |
| Hoyle, S. B., & McSweeney, M. A. (2002). *European Patent Application No. EP1168115A1. European Patent Office.* | Future | ✓ | | | |
| Hughes, R., Balestrini, S., Kelly, K., Weston, N., & Mavris, D. (2006). *Modeling of an Integrated Reconfigurable Intelligent System (IRIS) for ship design, ships and ship systems.* | Future | ✓ | X | | |
| Hunn, B. P. (2006). *Unmanned aerial system, new system manning prediction.* | Future | | ✓ | | X |
| Hursh, S. R., Redmond, D. P., Johnson, M. L., Thorne, D. R., Belenky, G., Balking, T. J., & Eddy, D. R. (2004). *Fatigue models for applied research in warfighting.* | Current | | | ✓ | |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Isler, H. (2001). *Embedded training system for a component level intelligent distributed control system (CLIDCS).* | Future | | | ✓ | |
| Jaglom, P. (2006). *Future naval ship procurement: A case study of the navy's next-generation destroyer.* | Future | ✓ | | | |
| Janssen, J. A. A. J., & Maris, M. G. (2003). *Self-configurable distributed control networks on naval ships.* | Future | ✓ | | | |
| Jebsen, G. (2001). *Electric warship technology overview.* | Future | ✓ | | | |
| Jingsong, Z., Price, W. G., & Wilson, P. A. (2008). *Automatic collision avoidance systems: Towards 21st century.* | Future | ✓ | X | | |
| Johnson, J., Osborn, D., Previc, F., & Prevost, G. (2005). *Human systems integration / manning reduction for LHD-type ships.* | Future | ✓ | | | |
| Johnson, M. E. (2005). *The joint modular intermodal container, is this the future of naval logistics?* | Future | ✓ | | | |
| Johnston, J. M. (2009). *An activity-based non-linear regression model of Sopite Syndrome and its effects on crew performance in high-speed vessel operations.* | Future | | | ✓ | |
| Jones, B. (2005). *Twenty years on the wrong heading dead ahead.* | Future | X | | | ✓ |
| Jones, M. T. (2001). *The potential role of the United States Maritime Service (USMS) in supporting ready reserve force vessel crewing needs.* | Future | | ✓ | | |
| Kennedy, J. S. (2007). *A human-automation interface model to guide automation of system functions: A way to achieve manning goals in new systems.* | Future | | | | ✓ |
| Kertmen, A. (2006). *Evaluation of the littoral combat ship (LCS) potential for the Turkish Navy.* | Current | ✓ | | | |
| King, J. (2001). *Technology and the course of shipping.* | Current | ✓ | | | |
| Kitarovic, J., Tomas, V., & Cisic, D. (2005). *The electronic and informatics age-a new stage in developing highly effective ships.* | Future | | | | ✓ |
| Koopman, M. E., & Golding, H. L. W. (1999). *Optimal manning and technological change.* | Current | | ✓ | X | |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Korchanov, V., Kisselev, V., & Sus, G. (2006). *Integration of technical facility management systems onboard future diesel submarines.* | Current | ✓ | | | X |
| Kott, K., Adams, K. M., & Dove, R. (2008). *Agility and the combat system.* | Future | ✓ | | | |
| Lagodimos, A. G., & Mihiotis, A. N. (2010). *Efficient overtime planning in packing shops with lines of identical manning.* | Future | | ✓ | | |
| Landry, K. (2006). *The performance and compatibility of thin client computing with fleet operations.* | Future | ✓ | | X | X |
| Landsburg, A. C., Avery, L., Beaton, R., Bost, J. R., Competatore, C., Khandpur, R., & Sheridan. T. B. (2008). *The art of successfully applying human systems integration.* | Future | | | | ✓ |
| Lavis, D. R., & Forstell, B. G. (2008). *The cost of requirements and emerging technologies.* | Future | ✓ | | | |
| Leadmon, J., Wilson, W. ,Carl, L., & Woodward, D. (2004). *Submersible combatant concept for improved littoral warfare.* | Future | ✓ | | | X |
| Lee, H. H., & Misra, M. (2005). *Early warning of ship fires using Bayesian probability estimation model.* | Future | ✓ | | | X |
| LeFrere, K. (2002). *An assessment of U.S. Navy junior officer retention from 1998-2000.* | Current | | ✓ | | |
| Levchuk, G., Chopra, K., Paley, M., Levchuk, Y., & Clark, D. (2005). *Model-based organization manning, strategy, and structure design via Team Optimal Design (TOD) methodology.* | Future | | ✓ | | |
| Lewis, G. W. (1996). *Personnel performance workload modeling for a reduced manned bridge: Lessons learned.* | Current | | ✓ | | |
| Litobarski, S., & Rabbets, T. (2004). *Modular designs: HCI in complex naval systems.* | Current | | | | ✓ |
| Liu, L., Logan, K. P., Cartes, D. A., & Srivastava, S. K. (2007). *Fault detection, diagnostics, and prognostics: Software agent solutions.* | Current | ✓ | | | X |
| Lively, K. A., Seman, A. J., & Kirkpatrick, M. (2003). *Human systems integration and advanced technology in engineering department workload and manpower reduction.* | Future | X | | X | ✓ |
| Ljung, M. (2010). *Function based manning and aspects of flexibility.* | Future | | X | ✓ | |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Logan, K. (2007). *Intelligent diagnostic requirements of future all-electric ship integrated power system.* | Future | ✓ | | | |
| Loginovsky, V. A., Gorobtsov, A. P. & Kuzmin, V. E. (2005). *The ISPS Code as a component of onboard resources in Bayesian Analysis.* | Current | | ✓ | | |
| Lorio, G. P. (2005). *The effect of high speed vessel operations on ship's crew and embarked landing force personnel aboard HSV-2 SWIFT in the areas of motion sickness and motion induced task interruptions.* | Future | | | ✓ | |
| Lundh, M. (2010). *A Life on the Ocean Wave-Exploring the interaction between the crew and their adaption to the development of the work situation on board Swedish merchant ships* | Current | | | ✓ | |
| Lyridis, D. V., Ventikos, N. P., Zacharioudakis, P. G., Dilzas, K., & Psaraftis, H. N. (2005). *Introduction to an innovative crew composition approach based on safety/operational and financial* requirements. | Current | | ✓ | | |
| Maas, H. L. M. M., & Keus, H. E. (1999). *A methodological approach to the design of advanced maritime command and control concepts.* | Current | | ✓ | | |
| Maas, H. L. M. M., Wynia, S. J., Birkerod, D., & Houtsma, M. A. W. (2000). *An information filtering and control system to improve the decision making process within future command information centres.* | Current | | X | | ✓ |
| MacDonald, R. (2006). *Safe manning of ships: Yesterday, today and tomorrow.* | Future | | ✓ | | |
| MacKenzie, A. (2010). *An exploration of the effects of maintenance manning on Combat Mission Readiness (CMR) utilizing agent based modeling.* | Future | | ✓ | | |
| MacLeod, I., & Smeall, D. (1999). *A proposed integrated platform management system design for the Royal Navy future surface combatant.* | Future | X | | | ✓ |
| Mahulkar, V., McKay, S., Adams, D .E., & Chaturvedi, A. R. (2009). *System-of-systems modeling and simulation of a ship environment with wireless and intelligent maintenance technologies.* | Future | | ✓ | | X |
| Malone, T. B., & Carson, F. (2003). *HSI top down requirements analysis.* | Current | | X | | ✓ |
| Malone, T. B., & Heasly, C. C. (2003). *Function allocation: Policy, practice, procedures, & process.* | Current | | X | | ✓ |
| Marine Accident Investigation Branch . (2004). *Bridge watchkeeping safety study.* | Current | | | ✓ | |
| Mason, D. R. (2009). *A comparative analysis between the navy standard workweek and the work/rest patterns of sailors aboard U.S. Navy cruisers.* | Current | | | ✓ | |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Matthews, M., Bos, J., & Webb, R. (2003). *A prototype task network model to simulate the analysis of narrow band sonar data and the effects of automation on critical operator tasks*. | Current | | | | ✓ |
| Maturana, F. P, Tichy, P., Slechtab, P., Discenzoa, F., Starona, R. J., & Hall, K. (2004). *Distributed multi-agent architecture for automation systems.* | Future | ✓ | | | X |
| Mavris, D. (2007). *Design methodology and strategies investigation for complex integrated naval systems.* | Future | X | | | ✓ |
| Miller, N.L., & Firehammer, R. (2007). *Avoiding a second hollow force: The case for including crew endurance factors in the afloat staffing policies of the U.S. Navy.* | Current | | | ✓ | |
| Montes, A. (2005). *Network shortest path application for optimum track ship routing.* | Future | ✓ | | | X |
| Moore, C. S., Hattiangadi, A. U., Sicilia, G. T., & Gasch, J. L. (2002). *Inside the black box: Assessing the Navy's manpower requirements process.* | Current | | ✓ | | |
| Muldoon, R. C., Bauer, D., Carroll, S. B., Quast, G. B., & Lantier, L. (2001). *CROSSBOW, Volume 1.* | Future | ✓ | | | X |
| Murphy, B. (2004). *Applying lean manufacturing initiatives to naval ship repair centers: implementation and lessons learned.* | Current | | ✓ | | |
| Neerincx, M., Grootjen, M.., & Veltman, J. A. (2004). *How to manage cognitive task load during supervision and damage control in an all-electric ship.* | Current | | X | | ✓ |
| Nguyen, T., Davidson, L., Skinner, M., & Husband P. (2005). *Benefits and techniques of integrating embedded training capabilities in legacy hardware-specific control systems.* | Current | | | ✓ | X |
| North Atlantic Treaty Organisation: Group 6 Specialist Team on Small Ship Design (2004). *NATO/PfP Working Paper on small ship design.* | Current | | ✓ | | |
| Nugent, W. A., & White, D. (2000). *Manpower modeling and human-centered design for 21st century naval platforms*. | Future | | ✓ | | X |
| Osga, G. A., & Galdorisi, G. (2003). *Human factors engineering: An enabler for military transformation through effective integration of technology and personnel.* | Current | | | | ✓ |
| Osga, G. A., Van Orden, K. V., Kellmeyer, D. & Campbell, N. L. (2001). *"Task-managed" watchstanding: Providing decision support for multi-task naval operations.* | Current | | X | | ✓ |
| Paul, M. A., Gray, G. W., Nesthus, T. E., & Miller, J. C. (2008). *An assessment of the CF submarine watch schedule variants for impact on modeled crew performance*. | Future | | ✓ | | |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Paul, M. A., Hursh, S. R., & Miller, J. C. (2010). *Active submarine watch systems: Recommendation for a new CF submarine watch schedule.* | Future | | ✓ | | |
| Peatross, M. J., & Williams, F. W. (2002). *Options for advanced smoke control onboard ships.* | Future | ✓ | | | |
| Pellin Blin, M., & Bry, A. (2005). *Human factor integration method in complex naval systems design: An example, Military Integrated Bridge IBEO.* | Future | | X | | ✓ |
| Phillips, K. L., Hison, R. L., & Ricci, K. E. (2001). *A new approach to training in a reduced manning environment.* | Current | | X | ✓ | |
| Pomeroy, R. V., & Sherwood Jones, B. M. (2002). *Managing the human element in modern ship design and operation.* | Current | | ✓ | X | |
| Preece, D., Blosch, M., & Strain, J. (2002). *Work restructuring and technical change: A case study of the Royal Navy Warfare Branch.* | Current | | ✓ | | |
| Pringle, C. E. (1998). *Smart Gator: An analysis of the impact of reduced manning on the mission readiness of US Naval amphibious ships.* | Current | | ✓ | X | |
| Progoulaki, M. (2006). *Dealing with the culture of the maritime manpower in a socially responsible manner.* | Current | | ✓ | | |
| Quintana, V., Howells, R. A., & Hettinger, L. (2007). *User-centered design in a large-scale naval ship design program: Usability testing of complex military systems-DDG 1000.* | Future | | | X | ✓ |
| Roos, C. H. (1999). *Modelling combat system manning and manpower reduction.* | Current | | | | ✓ |
| Runnerstrom, E. (2003). *Human systems integration and shipboard damage control.* | Future | | | | ✓ |
| Russell, J. (2006). *The littoral combat ship: Is the US Navy assuming too much risk?* | Future | X | ✓ | X | X |
| Sacks, S. (2003). *A lesson from the Greeneville accident.* | Future | ✓ | | | X |
| Sambracos, E., & Tsiaparikou, J. (2001). *Sea-going labour and Greek owned fleet: A major aspect of fleet competitiveness.* | Current | | ✓ | | |
| Schank, J. F., Yardley, R., Riposo, J., Thie, H., Keating, E., Arena, M. V., & Chiesa, J. R. (2005). *Options for reducing costs in the United Kingdom's future aircraft carrier (CVF) programme.* | Current | | ✓ | X | |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Scofield, T. (2006). *Manning and automation model for naval ship analysis and optimization.* | Current | | ✓ | | X |
| Seman, A. J. (2005). *Next generation navy ship automation systems engineering from sensors to systems.* | Current | ✓ | | | X |
| Seman, A. J., Donnelly, M. E., & Mastro, S. (2007). *Wireless systems development for distributed machinery monitoring and control.* | Current | ✓ | | | X |
| Śmierzchalski, R. (2005). *Intelligent marine control systems.* | Future | ✓ | | | X |
| Smith, A. P., (2007). *Adequate crewing and seafarer's fatigue: The international perspective.* | Current | | X | ✓ | |
| Soller, A., & Morrison, J. (2008). *The effects of automation on battle manager workload and performance.* | Current | | | | ✓ |
| Sorenson, A. J. (2001). *The Coast Guard knowledge base: Building online communities, teams and experts to facilitate rapid creation, capture and sharing of service related knowledge.* | Future | | ✓ | | X |
| Spindel, R. C., Laska, S., Cannon-Bowers, J. A., Cooper, D. L., Hegmann, K. C., Hogan, R. J., Hubbard, & Smith, J. A. (2000). *Optimized surface ship manning.* | Future | | ✓ | X | X |
| Srivastava, N., Horne, G., Pietryka, F., & Theroff, M. (2005). *Simulation environment to assess technology insertion impact and optimized manning.* | Current | | X | | ✓ |
| Street, T. T., Nguyen, X., & Williams. F. W. (2002). *Wireless communication technologies on ex-USS Shadwell.* | Current | ✓ | | | |
| Stubblefield, P. N. (2010). *Security enhancement of littoral combat ship class utilizing an autonomous mustering and pier monitoring system.* | Current | ✓ | | | X |
| Summey, D. C., Rodriguez, R. R., Demartino, D. P., Portmann, H. H., & Moritz, E. (2001). *Shaping the future of naval warfare with unmanned systems.* | Current | ✓ | | | X |
| Swartz, R. A., Zimmerman, A. T., Lunch, J. P., Rosario, J., Brady, T., Salvino, L., & Law, K. H. (2010). *Hybrid wireless hull* | Future | ✓ | | | X |
| Tamez, D. J. (2003). *Using commercial-off-the-shelf speech recognition software for conning US warships.* | Future | ✓ | | | X |
| Tate, C. C., Estes, T., Hagan, J., & Hettinger, L. (2005). *Lessons learned from integrating user-centered design into a large-scale defense procurement.* | Future | | | | ✓ |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Theotokasa, I., & Progoulaki, M. (2007). *Cultural diversity, manning strategies and management practices in Greek shipping.* | Current | | ✓ | | |
| Thie, H. J., Christian, J., Stafford, M., Yardley, R. J., & Schirmer, P. (2008). *Fiscally informed total force manpower.* | Current | | ✓ | | |
| Thie, H. J., Harrell, M. C., McCarthy, A. S., & Jenkins, J. (2009). *Consolidated Afloat Networks and Enterprise Services (CANES): Manpower, personnel, and training implications.* | Current | | | X | ✓ |
| Tichy, P., Marik, V., Vrba, P., & Pechoucek, M. (2005). *Chilled water system automation*. | Future | ✓ | | | X |
| Tomas, V., & Margeta, A. (2006). *Next generation control architectures*. | Future | ✓ | | | X |
| Torenvliet, G., Hilliard, A., Burns, C. M., Lintern, G., & Lamarre, J-Y. (2010). *Modelling and simulation for requirements engineering and options analysis.* | Current | | X | | ✓ |
| Torenvliet, G., Jamieson, G., & Cournoyer, L. (2006). *Functional modelling, scenario development, and options analysis to support optimized crewing for damage control. Phase 1: Functional modelling.* | Current | | X | | ✓ |
| Torenvliet, G. L., Jamieson, G. A., & Chow, R. (2008). *Object worlds in work domain analysis: A model of naval damage control.* | Current | | X | | ✓ |
| Trifonov, I., Bandte, O., Bonabeau, E., & Gaudiano, P. (2005). *Agent-based modeling as a tool for manpower and personnel management.* | Current | | ✓ | X | |
| Tzannatos, E. S. (2004). *GMDSS operability: The operator-equipment interface.* | Current | | X | | ✓ |
| U.S. General Accounting Office (2003). *Military personnel: Navy actions needed to optimize ship crew size and reduce total ownership costs.* | Current | | X | | ✓ |
| Vaughan, E., & Lee, L. (2010). *US Patent Application No. 12/806,259*. | Current | | | ✓ | X |
| Venturi, G., & Troost, J. (2005). *An agile, user-centric approach to combat system concept design.* | Future | | | | ✓ |
| Wallace, D. (2009). *Warfighter inclusion in system development: The operational perspective in defining design requirements*. | Future | | | | ✓ |
| Westdijk, R. (2008). *A monitoring and reasoning framework for applying autonomic computing in a combat management system*. | Future | ✓ | | | X |

| Author and Title | Current / Future Technology | Ship Function | Policy & Procedure | Personnel & Training | Human Systems Integration |
|---|---|---|---|---|---|
| Westermeijer, E., Post, W. M., & Keijer, W. (2003). *Teleknowledge, knowledge-at-a-distance.* | Future | ✓ | | | X |
| Weston, N. (2006). *Strategies for integrating models of interdependent subsystems of complex system-of-systems products.* | Future | ✓ | | | X |
| Wetteland, C., & French, J. (2002). *Task network modeling: Resolving manning issues in complex environments.* | Future | | X | | ✓ |
| Williams-Robinson, M. J. (2007). *A littoral combat ship manpower analysis using the fleet response training plan.* | Future | | ✓ | X | X |
| Yeong, W. (2010). *Layout optimization and manning ratio improvement.* | Current | | | | ✓ |
| Zuzich, J. (2002). *Future US Navy force protection.* | Current | | ✓ | | |

# 3 Ship Function

Papers in this section refer to various systems, technologies, and other solutions which seek to enhance, automate, simplify, or even eliminate the operator-in-the-loop with regards to ship capabilities, such as sensors, weapon systems, maintenance systems, power, and emergency measures.

Apsley, J. M., Villasenor, A. G., Barnes, M., Smith, A. C., Williamson, S., Schuddebeurs, J. D.,McDonald, J. R. (2007). Propulsion drive models for full electric marine propulsion systems for full electric marine propulsion systems. *2007 IEEE International Electric Machines & Drives Conference,* 118-123. doi: 10.1109/IEMDC.2007.383563. Retrieved from http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=4270625.

Integrated full electric propulsion systems are being introduced across both civil and military marine sectors. Standard power system analysis packages cover electrical and electromagnetic components but have limited models of mechanical subsystems and their controllers. Hence, electromechanical system interactions between the prime movers, power network, and driven loads are poorly understood. This paper reviews available models of the propulsion drive system components: the power converter, motor, propeller, and ship. Due to the wide range of time constants in the system, reduced-order models of the power converter are required. A new model using state-averaged models of the inverter and a hybrid model of the rectifier is developed to give an effective solution combining accuracy with speed of simulation and an appropriate interface to the electrical network model. Simulation results for a typical ship maneuver are presented. .pdf

Arcidiacono, V., Castellan, S., Menis, R., & Sulligoi (2006). Integrated voltage and reactive power control for all electric ship power systems. *International Symposium on Power Electronics, Electrical Drives, Automation and Motion,* 878-882. file://localhost/Retrieved from http/::ieeexplore.ieee.org:xpls:abs_all.jsp%3Farnumber =1649892.

All electric ship alternators are connected to a main busbar which feeds all shipboard electric loads. To fulfill power quality requirements of the resulting electrical system, high-performance control of busbar voltage and frequency is needed. Such a task is not of easy accomplishment, due to the complexity of shipboard power station (generators are many and differ by sizes, prime movers, control systems, etc.) and to the intrinsic weakness of the shipboard grid. In this frame, a key power quality issue is voltage control. This paper presents an innovative shipboard voltage and Volt Amp Reactance (VAR) integrated regulator, called WIRE. The WIRE controls main busbar voltage and jointly optimizes the reactive power generated by each alternator. It is designed to be interfaced with onboard automation and to realize the integrated management of all reactive power sources (rotating, capacitive, static). Furthermore it satisfies naval requirements as redundancy and fast commissioning. .pdf

Beevis, D., Vallerand, A & Greenley, M. (2001). Technologies for workload and crewing reduction. (Report No. DCIEM TR 2001-109). Retrieved from Defence Research and Development website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA398371.

At the request of Director General Maritime Development and Operations (DGMDO), DRDC conducted a study of technologies for crewing reduction to catalogue known technologies, identify those that are applicable to the Canadian navy, and prepare proposals for a way ahead. Information received from contacts in Australia, the Netherlands, United Kingdom (UK) and U.S., together with the results of two extensive literature reviews and world-wide-web searches was assembled into a matrix of technologies. The categories include whether the technology can be implemented at no cost to the ship, at minor cost, at major cost such as a refit, can be implemented in new ship builds, or will require further development to implement. Two workshops with the Working Group representatives and four focus groups with fleet operators were held to evaluate the applicability of these technologies to Canadian navy ships. Recommendations for the way ahead are that the Canadian navy should develop its own capability to evaluate workload and crewing reduction technologies and ship complements for existing and future ships. It is also recommended that DRDC should support that effort with short-term and longer-term activities. .pdf

Bennett, P. L. (2007). *Using the non-intrusive load monitor for shipboard supervisory control* (Master's thesis). Retrieved from Massachusetts Institute of Technology. http://dspace.mit.edu/handle/1721.1/39731.

Field studies have demonstrated that it is possible to evaluate the state of many shipboard systems by analyzing the power drawn by electromechanical actuators. One device that can perform such an analysis is the non-intrusive load monitor (NILM). This thesis investigates the use of the NILM as a supervisory control system in the engineering plant of gas-turbine-powered vessel. Field tests demonstrate that the NILM can potentially reduce overall sensor count if used in a supervisory control system. To demonstrate the NILM's capabilities in supervisory control systems, experiments are being conducted at the U.S. Navy (USN)'s Land-Based Engineering Site (LBES) in Philadelphia, Pennsylvania. Following a brief description of the LBES facility and the NILM itself, this thesis presents testing procedures and methodology with results obtained during the extensive field studies. This thesis also describes the on-going efforts to further demonstrate and develop the NILM's capabilities in supervisory control systems. .pdf

Butler-Purry, K. L., & Sarma, N. D. R. (2003). Intelligent network reconfiguration of shipboard power systems. *Proceedings of the Power Engineering Society General Meeting, USA, 4,* 2435-2439. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber= 1271023.

Electric power systems of ships supply energy to sophisticated systems for weapons, communications, navigation and operation. In this new era of the USN, with goals to reduce manning and increase system survivability, automatic reconfiguration of the electrical network in a shipboard power system is critical for quickly restoring service to a section of the power of the power system to survive battle damage. Also, reconfiguration is critical to meet operational requirements such as changing from one mission to another, avoiding possible over loading of the system or removing equipment for maintenance. In this paper various aspects of intelligent reconfiguration of shipboard power systems are presented. .pdf

Calvano, C. N., Harney, R. C., Papoulias, F., & Ashton, R. (2003). *Sea Force: A sea basing platform* (Report No. AMT-KC1223-3027). Monterey, CA: Naval Engineering Research and Education Consortium. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.137.8945&rep=rep1&type=pdf.

The need for effective operation from the sea while conducting amphibious operations ashore has never been more evident than in today's modern conflicts. As important as this task is, it has not been significantly changed since World War I. "Sea Force" is an attempt to show how that sea basing, as discussed by the Chief of Naval Operations (CNO) in Sea Power 21, can be accomplished by the year 2020 with reasonable advances in technology. The Total Ship Systems Engineering Program, under the tasking of CNO (N7) through the Wayne E. Meyer Institute of Systems Engineering, undertook the task of designing a system of ships that could be brought together to enable the sea basing of one Marine Expeditionary Brigade (MEB) for an indefinite period of time. The "Sea Force" design completely supports all of the operational requirements of Ship to Objective Maneuver (STOM), in addition to providing a path for re-supply and method for reconstitution of forces ashore. Sea Force is also designed to be reconfigurable from a warship to a supply ship during a shipyard availability period with minimal effort through the use of modularity. .pdf

Davies, I. (2001). *Processing and fusion of electro-optic information* (Research Report No. ADP010886). Retrieved from Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADP010886.

The UK Defence Evaluation and Research Agency (DERA) has been researching over many years the use of knowledge-based techniques for the automation of information fusion within combat management systems functions. All-source automated data fusion techniques have successfully been demonstrated at the platform level and are currently embodied in a testbed called CMISE (Combat Management Integrated Support Environment). This makes use of own platform sensor data and tracks from other platforms via datalink for the automatic construction of the platform's tactical picture. The requirement for a substantial increase in the level of automated support comes in part from pressures to reduce platform through-life costs, particularly through reduction of manning. .pdf

Desclèves, E., & Letot, L. (2001). Technologies and sociotechnical systems for future destroyers. *Naval Engineers Journal, 113(1),* 81-88. doi: 10.1111/j.1559-3584.2001.tb00013.x. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2001.tb00013.x/.

Beginning in 2010 most of the French Navy's Surface Combatants will have to be replaced. This major investment is being actively prepared through detailed analysis in which technological developments are major considerations that have to be optimally selected and

combined. However, many of the assumptions that guided planners in the past no longer apply. Constrained defence budgets, a wide range of military scenarios, and significant changes in possible threats, as well as sociological evolutions require solutions marking a disruption with current technologies, which have not fundamentally changed since the Second World War. The aim of this paper is to develop different operational requirements and their technological answers, which are currently being investigated. .pdf

Doerry, N. H. (2006, October). *Systems engineering and zonal ship design.* Paper presented at the American Society of Naval Engineers Conference, Arlington, VA. Retrieved from http://doerry.org/norbert/papers/060501SystemsEngineeringZonalShipDesign.pdf.

This paper relates the Defense Acquisition University defined systems engineering process to zonal ship design at the concept and feasibility design level. In particular, it describes an effective way of capturing a complete set of customer requirements based on the Universal Navy Task List (UNTL) and allocating these required functions to system packages comprised of hardware, software, and manpower elements. These system packages are allocated to ship zones such that loss of adjacent zones will result in the retention of sufficient system packages to meet survivability requirements. The allocated system packages also are used to establish zonal distribution system requirements to enable zonal distributed system design in a manner described in a previous paper presented at the American Society of Naval Engineers (ASNE) Reconfiguration and Survivability Symposium in February 2005. System packages can also be used to develop skills based manpower requirements to determine required shipboard accommodations. The software element of the system packages can be used to estimate software development cost as well as Total Ship Computing Environment needs. The paper will also highlight ongoing efforts to incorporate this process into early stage ship design tools at the Naval Sea Systems Command (NAVSEA). .pdf

Echols, R., Santos, W., Fernandez, C., Didoszak, J., Cabezas, R., Lunt., Green M. (2003). *SEA SWAT: A littoral combat ship for sea base defense.* (Technical Report). Retrieved from the Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA422611.

Unlike past conflicts, which were characterized by major naval battles in the open ocean, present day threats are mostly associated with rogue nations and terrorist cells. These threats may strike at unsuspected times and locations. The USN may operate from a Sea Base that protects power ashore through the use of surface and air assets. These assets must transit from the Sea Base in the blue water through the littoral region to reach the objective area. Total ship system designs that include high-speed littoral combat ships (LCS) are required that are capable of operating in these regions and defending the Sea Base, the surface, and air assets from an asymmetric threat. With a modular design and the ability to carry multiple helicopters and unmanned underwater vehicles (UUV), the SEA SWAT LCS concept can be quickly employed as a force multiplier capable of operating as an Air Warfare or Undersea/Mine Warfare mission platform. With the addition of the core and Surface Warfare sensors and weapons to one of these modular mission packages, the SEA SWAT LCS concept for sea base defense will ensure air, surface, and subsurface superiority during conflict. An advanced electrical power system in conjunction with an integrated propulsion system and zonal power distribution provides sustained combat capability against multiple asymmetric

threats. Its enclosed super-structure allows for high survivability in a Chemical, Biological and Radiation (CBR) environment. The paper covers the following topics: analysis of alternatives for ship number, combat systems, and hull design; the design process; propulsion and electrical systems, hydrostatics, combat systems, damage control, CBR systems, manning and habitability, and environmental concerns; signatures, cost, and weight analyses; and threats, including mines, torpedoes, submarines, small boats, unconventional vessels, cruise missiles, Unmanned Aerial Vehicles (UAVs), Surface to Air Missiles (SAMs), and unguided missiles. .pdf

Eckelberry, J. R., & Halloway III, K. E. (2003). *Damage control operational concepts (DCOC) - Impact of technology insertion on shipboard damage control operations.* (Report No. 20030529 064). Retrieved from the Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA413895.

This report satisfies the requirements of the Damage Control Operational Concepts (DCOC) contract with the Office of Naval Research (ONR). The Naval Research Laboratory (NRL) has been conducting research into the effect of reduced manning on the conduct of Damage Control (DC) operations in USN ships under the Damage Control-Automation for Reduced Manning (DC-ARM) program. This research is ongoing. This report will enhance that research by reviewing Water Mist (WM) firefighting technologies. .pdf

Famme, J. B., Gallagher, C., & Raitch, T. (2009). Performance-based design for fleet affordability. *Naval Engineers Journal, 121(4),* 117-132. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2009.00233.x/full.

Affordability remains the biggest challenge facing the USN shipbuilding program. Recent Navy forums discussing fleet requirements and shipbuilding summarized that reforms are needed to support requirements stability, steady-state production, and commonality among design and production elements to rein in skyrocketing shipbuilding costs. This paper describes how affordability objectives can be achieved by expanding the design focus beyond common parts to include common dynamically validated designs that focus on performance metrics within and across all associated systems in the domain of Hull, Mechanical, and Electrical (HM&E) Systems. .pdf

Fireman, H., Nutting, M., Rivers, T., Carlile, G., & King, K. (1998, April). *LPD 17 on the shipbuilding frontier: Integrated product & process development.* Paper presented at the Association of Scientist and Engineers 35th Annual Technical Symposium. Retrieved from http://www.fas.org/man/dod-101/sys/ship/docs/ase98sbf.pdf.

In the April 1996 words of Secretary of the Navy Dalton, “LPD (Landing Platform Dock) 17 is a first. The Navy is on the frontier of a new way of doing things through teaming with our Industry partners and streamlining the administration and acquisition processes.” Truly, in the months since that prophetic statement, the LPD 17 program has crossed the shipbuilding frontier and through its Integrated Product Process Development (IPPD) tools has developed its innovative acquisition strategy - a strategy that has application to many other programs as well. The LPD 17, the first amphibious ship designed for the 21st Century, is on the leading edge of new product and process innovations in Naval shipbuilding. This paper provides a synopsis of the IPPD strategy as implemented by the LPD 17 Government and Industry Team. Components of IPPD will be addressed in terms of goals, people, processes, and tools. In addition, it details the steps in establishing the baseline for IPPD implementation and relates specific examples of early successes. Written by members of the LPD 17 team, it concludes by offering process examples that may enable this edition of IPPD to enhance other applications and programs. .pdf

Ford, M. C. (2003, September). *New waves in workboats: Combined control and monitoring.* Paper presented at the Dynamic Positioning Conference, Houston, TX. Retrieved from http://www.dynamic-positioning.com/dp2003/workboats_ford.pdf.

With budgets getting tighter and offshore support companies looking for methods to get more out of their investments, workboats are being rapidly enhanced with new technology. Integrated control and monitoring systems, long reserved for larger vessels, are now emerging as the latest opportunity for not only money savings but also for safer operations. Through improved modular approaches based on new technology, these systems are affordable and provide substantial improvements in vessel operation including reduced manning requirements and one of the newest elements for workboats, Condition Based Monitoring. This reduces maintenance downtime by monitoring the status of critical systems and reduces failures by predicting the remaining “life” of equipment. In addition, these systems further reduce the vessel manning requirements through automated monitoring. These systems can provide benefits to virtually all of the workboat community from simple supply vessels to seismic survey and well stimulation vessels. This paper presents a short review of the technology used on larger ships and then a scaled down version for use on smaller vessels. Then some of the compelling reasons to introduce integrated control and monitoring systems onto workboats will be discussed. In addition, it will detail the layout of a typical system noting the new technologies that make it easy and affordable to implement these systems on smaller vessels. The conclusion has summaries resulting from current systems in use and opportunities for further enhancements directed at the workboat market based on industry observation and field experience. .pdf

Frank, M. V., & Helmick, D. (2007). *21st century HVAC system for future naval surface combatants - Concept development report.* (Report No. NSWCCD-98-TR-2007/06). Retrieved from the Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA473662.

Thermal management is a critical requirement for today’s and future warships. On the DDG (Guided Missile Destroyer) 91, approximately 25 percent of the ship’s thermal load is removed via the Heating, Ventilation and Air Conditioning (HVAC) system. Projected Next Navy’s thermal loads are two to five times those of today’s ships. It is expected that much of the increased load will be rejected via the HVAC system or directly to the chilled water system. The current HVAC architecture will have major ship design implications in weight, volume, energy usage, acquisition costs and overall operational maintainability. Advancements in the technology and the architecture of the HVAC system of future surface combatants are needed. In this report, a revolutionary new architecture, the 21st Century HVAC system, is described for future shipboard HVAC systems which will enable flexible thermal management at the ship level while providing a comfortable ship environment, rapid and redundant damage control capability, energy efficiency, reduced size and weight, and reduced manning. Four major thrusts are pursued: Automation; Integration with Damage Control and Firefighting Systems and other System Level Networks; Design Paradigm Shifts; and Advanced Component Development. .pdf

Good, N., & Brown, A. (2006, March). *Multi-objective concept design of an advanced logistics delivery system ship (ALDV).* Paper presented at the ASNE Joint Sea Basing Symposium, Arlington, VA. Retrieved from http://www.dept.aoe.vt.edu/~brown/VTShip Design/ASNE2006SeabasePaper.pdf.

This paper proposes a total-ship system design and requirements definition methodology that includes important components necessary for a systematic approach to naval ship concept design. The methodology is described in the context of an Advanced Logistics Delivery System Ship (ALDV) project conducted by senior undergraduate design students at Virginia Tech. This design won second prize in the 2005 ASNE/SNAME (Society of Naval Architects and Marine Engineers) Dr. James A. Lisnyk Ship Design Competition. Concept Exploration trade-off studies and design space exploration are accomplished using a Multi-Objective Genetic Optimization (MOGO) after significant technology research and definition. Objective attributes for this optimization are cost, risk (technology, cost, schedule and performance) and mission effectiveness. The product of this optimization is a series of cost-risk-effectiveness frontiers which are used to select alternative designs and define Operational Requirements based on the customer's preference for cost, risk and effectiveness. The notional ALDV requirement is based on an ALDV Mission Need Statement (MNS) and Virginia Tech ALDV Acquisition Decision Memorandum (ADM). ALDV is required to support troops ashore operating from a seabase or shuttle ship using an Advanced Logistics Delivery System (ALDS). ALDS is a ship-launched, over-the-beach, logistics delivery system that uses cargo-filled unmanned gliders and other revolutionary technologies. ALDS is an original concept developed by the Center for Innovation in Ship Design (CISD) at the Naval Surface Warfare Center – Carderock Division (NSWCCD) (Good et al. 2004). Necessary ALDS support by ALDV includes providing rapid transport of ALDS stores and ammunition, employing automated techniques for assembling the unmanned ALDS gliders, and providing a mechanical launching system for the gliders. ALDV must also support V-22 Ospreys and LAMPS (Light Airborne Multi-Purpose System), providing for launch and takeoff, landing, fueling, planning and control. ALDV will operate in sensitive littoral regions, close-in, depend on passive survivability and stealth, with requirements for high endurance and low manning. The selected ALDV alternative is a low risk, low cost, knee-in-the-curve trimaran design on the cost-risk-effectiveness frontier. This design was chosen because it provides a sharp increase in effectiveness with a minimal increase in cost at a low risk level based on the MOGO results. ALDV has a wave-piercing bow to decrease wave resistance and improve high speed performance in waves. It has a tumblehome hullform and other stealth technology such as an Advanced Enclosed Mast/Sensor (AEM/S) to reduce radar cross section. ALDV has an ALDS mission bay located in the cross-deck for automated glider assembly, and a unique Linear Induction Motor (LIM) for mechanical launch of aircraft. It uses other automation technology such as watch standing technologies that include GPS, automated route planning, electronic charting and navigation (ECDIS), collision avoidance, and electronic log keeping. ALDV also employs automated cargo handling technologies such as conveyor belts, cargo elevators, robotic pickers, and radio frequency identification (RFID)

(Good et al. 2005). The emphasis of this paper is on the concept exploration design and requirements process. .pdf

Hoyle, S. B., & McSweeney, M. A. (2002). *European Patent Application No. EP1168115A1*. European Patent Office. Retrieved from http://www.freepatentsonline.com/EP1168115.html.

A plurality of autonomously controlled valves in a fluid distribution system are interconnected by a data communication network. The system also includes fluid flow sensors which report to the system by way of the network. The autonomous controllers include information as to their neighbors or environment sufficient to determine malfunctions, such as a leak or break in an associated path, and can take autonomous action. The actions are established by the autonomous controllers regardless of the existence of a connection to the network, so that even if the network connection fails or is damaged, the valve can still respond to its own flow sensor with predetermined actions. .pdf

Hughes, R., Balestrini, S., Kelly, K., Weston, N., & Mavris, D. (2006). Modeling of an integrated reconfigurable intelligent system (IRIS) for ship design, ships & ship systems. *American Society of Naval Engineers.* Retrieved from http://www.asdl.gatech.edu/publications/conference_papers/Hughes_2006_Modeling_of_an_Integrated_Reconfigurable_Intelligent_System_(IRIS)_for_Ship_Design.pdf.

As the mission and performance demands for naval ships have increased, they have become more complex, comprising an increasing number of heterogeneous interdependent subsystems. This increased complexity requires new methods for the design and operation of these naval systems. The Georgia Institute of Technology Aerospace Systems Design Laboratory (ASDL) is helping the Navy change its design practices to achieve reduced total ownership costs, increased survivability, and increased mission effectiveness through an initiative called Integrated Reconfigurable Intelligent Systems (IRIS). Using traditional systems engineering practices for the early design process followed by an integrated design environment, IRIS seeks to shift ship design to a distributed, intelligent control architecture through increased automation. .pdf

Jaglom, P. (2006). *Future naval ship procurement: A case study of the navy's next-generation destroyer* (Master’s thesis). Massachusetts Institute of Technology, Cambridge, MA. Retrieved from http://www.lonworks.org.cn/en/LonWorks/SCSS2003.pdf.

Cost growth and inefficiencies are a serious problem in almost all major U.S. defense procurement programs, and have existed for many years despite repeated efforts to control them. These problems are particularly virulent in the design and acquisition of new naval warships. If the Navy cannot bring its costs under control, it will not be able to afford the capabilities it needs to execute the nation's national security. Several factors influence the cost growth of weapons procurement programs. Intentionally low estimates can help convince Congress to commit to programs that are actually very expensive. Bureaucratic politics can cause the Navy to spend money on superfluous features unjustified by strategic requirements. Private industry can push new, expensive technology on the Navy. Members of Congress can include pork-barrel provisions to bring more money to their constituents, often without

national interest justifications. This thesis evaluates the development of the DDG 1000, the Navy's next-generation destroyer, and the dramatic change that occurred to the design of that ship during its development. Based on that analysis, it makes recommendations for the future of the DDG 1000 and for naval ship procurement more generally. The thesis finds that though a new ship was justified in the post-Cold War world, the actual design of that ship was determined by bureaucratic politics and the ship's procurement plan was determined by pork-barrel politics, neither of which properly served the nation's strategic interests. The thesis recommends that the DDG 1000 be used solely as a technology demonstration platform, reducing procurement spending while salvaging its technological advances; that the DDG 1000 be procured from a single shipyard; that the Navy design a smaller and cheaper warship to serve the needs of the future fleet; and that the nation implement specific measures to reduce the influence of bureaucratic politics and pork barrel politics on resource allocation and procurement. .pdf

Janssen, J. A. A. J., & Maris, M. G. (2003). *Self-configurable distributed control networks on naval ships.* Paper presented at the meeting of the International Ship Control Systems Symposium, Orlando, FL. Retrieved from http://www.lonworks.org.cn/en/LonWorks/SCSS2003.pdf.

One significant challenge the Royal Netherlands Navy is facing is how to increase the ship's response capabilities to calamities. In our view, self-configuring distributed control networks are required to reach this goal. The Netherlands Organization Physics and Electronics Laboratory (TNO-FEL), in cooperation with the Royal Netherlands Navy researches such an automated robust ship control system. The researched system consists of autonomous control clusters of sensors and actuators. This novel system makes decisions autonomously, independent of a human operator, based on the information it gathers about its environment. In case of a calamity, it reconfigures itself. For example, when leaks are detected in a fluid system, the flow is automatically rerouted and if needed additional pumps are activated. Furthermore, our approach does not depend on a centralized Ship Control Center. Consequently, it is robust against both Ship Control Center and communication infrastructure failures. Clusters isolated from the rest of the system will still be able to limit autonomously the impact of a calamity. Hence, a distributed control network increases the robustness of ship control systems, improves the reaction time in case of calamities and reduces the required manpower for emergency recovery. This paper focuses on the technology required to realize robust self- configurable distributed control networks for naval ships. .pdf

Jebsen, G. (2001). *Electric warship technology overview*. Office of Naval Research Powerpoint Presentation. Retrieved from http://www.marmach.org/pdf/minutes/arlington010522/ elecwarship.pdf.

A Powerpoint presentation outlining the advantages of an electric warship, including improved reliability, more efficient propulsion and electric power plant which reduces operating and maintenance costs, and simplified controls supports increased automation and reduced manning. .pdf

Jingsong, Z., Price, W. G., & Wilson, P. A. (2008). Automatic collision avoidance systems: towards 21st Century. *Department of Ship Science, 1(1)*, 1-5. Retrieved from http://eprints.soton.ac.uk/51087/1/acas21st.pdf.

The importance of collision avoidance at sea is emphasised to cover four main aspects. A brief review of the research that has been carried out on automatic collision avoidance systems follows. Finally, several issues, which have often been ignored in previous studies are discussed. .pdf

Johnson, J., Osborn, D., Previc, F., & Prevost, G. (2005). Human systems integration / manning reduction for LHD-type ships. *Technology Review Journal. Fall/Winter 2005*, 63–78.

Sailors are the source of one of the USN's highest operating costs. Recognizing that potential cost savings lie in shipboard manning reductions, the U.S. Naval Sea Systems Command contracted in December 2002 with Northrop Grumman Ship Systems to develop a manning-reduction strategy for Landing Helicopter Deck (LHD) amphibious-assault-class ships. Our analysis was carried out jointly with Northrop Grumman's Information Technology, Newport News, and Electronic Systems sectors, as well as a major subcontractor, Micro Analysis & Design. The study results showed that a reduction in manning (over legacy LHD 1 ships) of nearly 35% can be achieved using mature or relatively mature technologies and with no major modifications to the current LHD 8 design. The reduced billet structure proved, in principle, capable of handling all manning conditions, producing an estimated life-cycle cost savings of over $1 billion per ship. (No pdf available.)

Johnson, M. E. (2005). *The joint modular intermodal container, is this the future of naval logistics?* (Unpublished master's thesis). Massachusetts Institute of Technology, Cambridge, MA. Retrieved from Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA447117.

Under the fiscal reality of the 21st century military budget, the typically manpower intensive USN has had to learn to do more with less of everything, in many cases specifically less sailors. One mission area that is prime for manpower reduction is naval logistics. JMIC, the Joint Military Intermodal Container, is a combined Naval Sea Systems Command/ Office of the Chief of Naval Operations (NAVSEA/OPNAV) program that is designed to change the way the USN conducts logistics. Automation and efficiency improvements inherent to the JMIC program are proposed to drastically lower the manpower requirements and complexity of the USN logistics pipeline. JMIC is a program in the very early stages of development. This thesis will examine some of the operational and technical challenges associated with incorporating JMIC into the USN, and ultimately U.S. Military logistics architecture. .pdf

Kertmen, A. (2006). *Evaluation of the littoral combat ship (LCS) potential for the Turkish navy* (Unpublished master's thesis). Naval Postgraduate School, Monterey, California. Retrieved from Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA457219.

This thesis will examine the potential of the two competing designs for the LCS, with regard to potential deployment of this vessel type by the Turkish Navy. The first design is by Lockheed Martin and has been designated the USS Freedom as the U.S. Navy's first LCS. The second design is by General Dynamics. This thesis will focus on the LCS usage concepts in Naval Capability Pillars and Information Operations. As a transformation platform, the LCS will be critical in implementing new operational concepts and in providing a focused, littoral mission platform for joint forces. Its superior speed and maneuverability; low radar, infrared, and acoustic signatures; and ability to lay distributed sensor fields are all fundamental to mission success. It will also carry a "squadron" of unmanned vehicles (air, surface, and undersea) that will considerably extend its sensor and weapon coverage and provide substantial Anti-Submarine Warfare (ASW) capabilities. This thesis will also discuss present and future platforms and their concepts of operation in Turkish littoral waters (Aegean Sea, Black Sea, and Mediterranean Sea). .pdf

King, J. (2001). Technology and the course of shipping. *Ocean & coastal management, 44(9-10)*, 567-577. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0964569101000692.

Technology makes seafaring possible. Thus this paper explores some aspects of the relationship between technology and the evolution of seafaring and shipping. It begins by briefly describing some of the different ways of regarding technology and technological insight, ranging from the classical, instrumental view to ideas originating among 20th century thinkers. It goes on to consider the nature of technological progress and advance, drawing on a number of marine examples. Seafarers have necessarily employed technological means for centuries in order to engage in exploration, trade and, recently, in the exploitation of the resources of the seas and oceans. The final part of the paper is, therefore, concerned with the changing relationship between technology and people. It argues that while enabling people to encounter the world marine technology, like all technology, challenges them to exercise moral judgment and limits their capacity to act freely. .pdf

Korchanov, V., Kisselev, V., & Sus, G. (2006). Integration of technical facility management systems onboard future diesel submarines. *Military Parade, 5,* 20-22. Abstract retrieved from http://dlib.eastview.com/browse/doc/10363020.

Currently, there is an increased interest in integrating management systems for ship-wide systems (SWS), electric power system (EPS) and main propulsion plant (MPP). On third-generation submarines these management systems were in fact autonomous, because they had been designed by various specialized departments. As a result, each of them had its particularities in the circuitry type used, instrumentation integration, software and operator interface architecture, as well as in reliability support and diagnostics aids. That is why, though made to common design specifications, standard customer requirements and for the same submarine, they differed widely, which made their maintenance and repair quite difficult. These differences and the necessity of a higher level of automation to reduce

submarine manning have required new technology solutions in design of the management systems. A way out was found in integrating control of all the technical facilities into a single system operated by one man and built around common terminal equipment having a common operator interface, common operating and service documentation, as well as common spare parts tools and accessories. Precisely such a system was developed as part of the Litiy complex to control SWS, EPS and MPP onboard the diesel submarine Sankt Peterburg. All time-proven and largely mature solutions selected when designing the autonomous systems were reviewed with regards to their suitability to all hardware components in the integrated management system that forms a common software/hardware environment. (No pdf available.)

Kott, K., Adams, K. M., & Dove, R. (2008). Agility and the combat system. *Naval Engineers Journal, 120(4),* 67-78. doi: 10.1111/j.1559-3584.2008.00166.x/full. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2008.00166.x/full.

As future threats increase in number and capability, the future CG(X) (Guided Missile Cruiser) combat system must provide the ability to respond across the spectrum of conflict. In this paper, we present the principles and concepts needed to achieve an agile combat system that can support a wide variety of missions in diverse operating environments. .pdf

Landry, K. (2006). *The performance and compatibility of thin client computing with fleet operations*. (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html &identifier=ADA457531.

This research will explore the feasibility of replacing traditional networked desktop personal computers (PC) with a thin client/server-based computing (TCSBC) architecture. After becoming nearly extinct in the early 1990s, thin clients are emerging on the forefront of technology with numerous bandwidth improvements and cost reduction benefits. The results show that TCSBC could provide a practical and financially sound solution in meeting the Navy's need to reduce costs and propagate the latest technology to all personnel. This solution may not meet the requirements of all naval commands. A thorough performance analysis should be conducted of the applications employed and the overall expenditures prior to implementation. .pdf

Lavis, D. R., & Forstell, B. G. (2008). The cost of requirements and emerging technologies. *Naval Engineers Journal, 120(1),* 59-76. doi: 10.1111/j.1559-3584.2008.00112.x/full. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2008.00112.x/full.

The paper describes a ship design synthesis process and the engineering model that has been successfully used to help assess the cost of requirements, and the cost versus capability of new technologies, for naval and commercial surface ships. An overview of the approach is followed by descriptions of numerous examples. Assessing and understanding the cost of escalating requirements and technology options via "what if" games early in the design process has been the principal key to minimizing or eliminating the potential for spiraling cost overruns. .pdf

Leadmon, J., Wilson, W., Carl, L., & Woodward, D. (2004). *Submersible combatant concept for improved littoral warfare.* Paper presented at the Engineering the Total Ship 2004 Symposium, Gaithersburg, MD. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA422093.

The current proliferation of low cost, low technology means of access denial raises the cost of U.S. power projection in many areas of the world. This problem is especially evident in the littoral environment, where enemy forces may employ a host of access denial methods including submarines, mines, small boats, and undersea sensor systems. These regions also exhibit maneuvering and navigational challenges such as underwater obstacles and civilian shipping vessels. Future naval platforms will rely heavily on the use of unmanned vehicles to more effectively perform their missions. While it is possible to deploy, support, and retrieve many of these unmanned vehicles from a high- end platform (e.g., SSN, SSGN), it is proposed that there may be a more efficient and cost effective means of managing these smaller vehicles and payloads. The KAPPA submersible craft concept, the result of a Carderock Division Naval Surface Warfare Center (CDNSWC) Innovation Center project, may be an effective, cost efficient force multiplier that can perform covert missions in littoral regions and austere ports, assist in providing and maintaining access, and support other joint assets. The KAPPA craft concept is a stealthy, highly maneuverable craft, with a modular payload volume and flexible ocean interface that acts as part of a "cascading payloads" chain for improved littoral warfare operations. .pdf

Lee, H. H., & Misra, M. (2005). Early warning of ship fires using Bayesian probability estimation model. *Proceedings of American Control Conference,* 1637-1641. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1470202.

Economic pressure to reduce the cost of the USN ships has brought into focus, the need to significantly reduce the size of a ship's crew. In order for an automated system to replace humans while making critical decisions, it is required that such a system be able to accurately predict future events. This paper presents a wavelet theory based prediction system to predict the occurrences of ship's fires. Furthermore, while the prediction model predicts the future events, the accuracy of prediction has to be quantified by formulating a probability index that would mirror the confidence on the prediction. As such, a Bayesian theory based probability estimation model (BPEM) is developed for estimating the probability that the predicted values are within specified limits of tolerance. Tests with U.S. Naval Research Laboratory data, covering various fire scenarios, validate that the proposed methodology consistently provides earlier detection as compared to the published results from the INRL early warning fire detection (EWFD) system. .pdf

Liu, L., Logan, K. P., Cartes, D. A., & Srivastava, S. K.(2007). Fault detection, diagnostics, and prognostics: Software agent solutions. *IEEE Transactions on Vehicular Technology, 56(4),* 1613-1622. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp? arnumber=4273732.

Fault diagnosis and prognosis are important tools for the reliability, availability, and survivability of Navy all-electric ships (AES). Extending the fault detection and diagnosis into

predictive maintenance increases the value of this technology. The traditional diagnosis can be viewed as a single diagnostic agent having a model of the component or the whole system to be diagnosed. This becomes inadequate when the components or system become large, complex, and even distributed as on Navy electric ships. For such systems, the software multiagents may offer a solution. A key benefit of software agents is their ability to automatically perform complex tasks in place of human operators. After briefly reviewing traditional fault diagnosis and software agent technologies, this paper discusses how these technologies can be used to support the drastic manning reduction requirements for future navy ships. Examples are given on the existing naval applications and research on detection, diagnostic, and prognostic software agents. Current work on a multiagent system for shipboard power systems is presented as an example of system-level application. .pdf

Logan, K. (2007). Intelligent diagnostic requirements of future all-electric ship integrated power system. *IEEE Transactions on Industry Applications, 43(1),* 139-149. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4077200.

Future ship integrated power systems (IPS) will be characterized by complex topologies of advanced power electronics and other evolving components. Advanced capabilities, such as intelligent reconfiguration of system function and connectivity will be possible; however, system level knowledge of component failure will be needed for intelligent power distribution under failure mode conditions. Diagnostic and prognostic coverage for sensors, components, and subsystems will be essential for achieving reliability goals. This paper will look at some diagnostic requirements and emerging technologies available for insertion into future ship IPS. .pdf

Maturana, F. P., Tichy, P., Slechtab, P., Discenzoa, F., Starona, R. J., & Hall, K. (2004). Distributed multi-agent architecture for automation systems. *Expert Systems with Applications 26,* 49–56. Retrieved from http://www.sciencedirect.com/science/article/pii/ S095741740300068X.

In the 21st century, industrial automation will be greatly benefited by the advances in electronics, information systems, and process technology. However, these technological advances are still separate islands of automation. We believe that multi-agent systems will help the future of automation by providing flexible and scalable ways to integrate the different parts. This paper reports preliminary results of an ongoing research project that demonstrates advanced automation in a highly distributed architecture that is made of a synergy of intelligent agents, control, and physical devices. This was built to achieve the goals of reduced manning and improved readiness and survivability in USN shipboard systems. .pdf

Montes, A. (2005). *Network shortest path application for optimum track ship routing* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA435601.

The USN Meteorology and Oceanography (METOC) community routes ships for weather evasion using advanced meteorological modeling and satellite data, but lacks a tool to enable fewer ship routers to make better routing decisions faster. Limited resources and rising costs are impacting the frequency and duration of current naval operations. The Commander, Naval Meteorology and Oceanography Command has ordered the community to find efficiencies and automation possibilities in order to meet lower manning levels, reduce waste, and increase savings. Outside of the Navy, Ocean Systems Incorporated in Alameda, CA developed the Ship Tracking and Routing System (STARS) software package to calculate optimum sea routes based on weather model data. However, METOC ship routers are reluctant to adopt this complex software. To help solve this, we modeled Optimum Track Ship Routing (OTSR) for USN warships using a network graph of the Western Pacific Ocean. A binary heap version of Dijkstra's algorithm determines the optimum route given model generated wind and seas input. We test the model against recent weather data to verify the model's performance, and to historical divert route recommendations in order to validate against routes developed by OTSR personnel. .pdf

Muldoon, R. C., Bauer, D., Carroll, S. B., Quast, G. B., & Lantier, L. (2001). *CROSSBOW. Volume 1* (Report No. SEI2-001). Retrieved from the Defense Technical Information Center website: http://handle.dtic.mil/100.2/ADA422295.

Distributing naval combat power into many small ships and unmanned air vehicles that capitalize on emerging technology offers a transformational way to think about naval combat in the littorals in the 2020 timeframe. Project CROSSBOW is an engineered system of systems that proposes to use such distributed forces to provide forward presence, to gain and maintain access, to provide sea control, and to project combat power in the littoral regions of the world. Project CROSSBOW is the result of a yearlong, campus-wide, integrated research systems engineering effort involving 40 student researchers and 15 supervising faculty members. This report (Volume I) summarizes the CROSSBOW project. It catalogs the major features of each of the components, and includes by reference a separate volume for each of the major systems (ships, aircraft, and logistics). It also presents the results of the mission and campaign analyses that informed the trade-offs between these components. It describes certain functions of CROSSBOW in detail through specialized supporting studies. The student work presented here is technologically feasible, integrated, and imaginative. This student project cannot by itself provide definitive designs or analyses covering such a broad topic. It does strongly suggest that the underlying concepts have merit and deserve further serious study by the Navy as it transforms itself. .pdf

Peatross, M. J., & Williams, F. W. (2002). *Options for advanced smoke control onboard ships* (Report No. NRL/MR/6180--02-8612). Officer of Naval Research, Arlington, VA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA400617.

The complications posed by smoke disrupt all facets of the damage control problem onboard ships. Smoke will reduce visibility, which causes disorientation and deterioration of communications among the ship's crew. In turn, the ability of the ship's crew to restore vital ship mission capability will be impeded. In practice, de-smoking is generally not implemented until after the fire is under control. With this approach, the benefits gained from minimizing smoke levels in the earlier stages of the event are not realized. For the design of future Navy ships, it is essential to identify the performance requirements for smoke control and to design systems according to these requirements. Installed smoke control systems will become more important on ships with reduced manning since there will be fewer people available to

implement manual techniques. This report describes a ship-wide system that could be installed on ships of the future. .pdf

Sacks, S. (2003). A lesson from the Greeneville accident. *Naval Engineers Journal, 115(1),* 15-18. doi: 10.1111/j.1559-3584.2003.tb00181.x/abstract. Retrieved from http://onlinelibrary.wiley.com.

The court of inquiry into the collision between the submarine Greeneville and the motor vessel Ehime Maru focused on human performance and functioning of equipment at the time of the accident. This commentary addresses whether alternative equipment, particularly equipment addressing communication and interpretation issues, would have made a difference. It also looks at whether generalized equipment of this nature would be of benefit in other hi-tempo scenarios that could be anticipated in the future. .pdf

Seman, A. J. (2005). Next generation navy ship automation systems engineering from sensors to systems. *Proceedings of the Systems, Man and Cybernetics, USA,* 1218-1222. doi: 10.1109/ICSMC.2005.1571312. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all. jsp?arnumber=1571312.

The next generation navy ship acquisition strategy calls for the delivery of an entire system of interoperable combat and machinery platforms with supporting systems designed to meet performance-based requirements. Many systems will operate various parts of the ship, but the ship functions optimally when all its systems work properly together. For the ship function, it needs to have the right mix of these independent systems, and these systems need to cooperate with each other. This emerging "system of systems" concept involves the large-scale integration of many independent, self-contained systems in order to satisfy a global need. For Navy ships, these complex multi-systems are very interdependent. To properly design, build and integrate a system of systems type of automation suite requires a new systems engineering approach. .pdf

Seman, A. J., Donnelly, M. E., & Mastro, S. (2007, May). *Wireless systems development for distributed machinery monitoring and control.* Paper presented at the American Society of Naval Engineers (ASNE) Intelligent Ships Symposium VII - Philadelphia, PA. Retrieved from http://microstrain.com/white/wireless-systems-dev-for-distributed-machinery-monitoring-and-control.pdf.

Over the past decade efforts have been underway to utilize wireless technology to enable higher functioning monitoring and control of machinery systems. The technologies associated with wireless communication have undergone a revolutionary evolution since the early 1990's. This paper highlights the programs demonstrating the use of wireless technology for monitoring and control of shipboard machinery during the past 10 to 15 years at Naval Sea Systems Command (NAVSEA) Philadelphia. This work includes the demonstration and testing of wireless systems hardware and software, and also the development of suitable architectures to fold such technologies into an overall ship machinery control and human interface that is highly functional and affordable. .pdf

Śmierzchalski, R. (2005). Intelligent marine control systems. In J. Pejas & A. Piegat (Eds.), Enhanced methods in computer security, biometric and artifical intelligence systems. doi: 10.1007/0-387-23484-5_30. Retrieved from http://www.springerlink.com/index/nn 57tw04g4t04768.pdf.

The paper discusses current directions of development in marine control systems, special attention being paid to artificial intelligence methods. Taking into account tasks attributed to the control of particular processes on a ship, the control systems were divided into integrated sub-systems. The ship was defined as an intelligent machine making use of artificial intelligence to control processes. .pdf

Street, T. T., Nguyen, X., & Williams. F. W. (2002). *Wireless communication technologies on ex-USS Shadwell* (Report No. NRL/MR/6180--02-8631). Retrieved from the Defense Technical Information Centre website: http://handle.dtic.mil/100.2/ADA405185.

The ex-USS Shadwell supports the development of ship systems which reduce manning requirements for future ships. Wireless communications offer a number of benefits for shipboard operations and it supports the shipboard automation concept in many ways. The flexibility resulting from having a communications connection available anywhere in the covered spaces of a ship provides enhanced connectivity (the connection is always there), enhanced mobility (not tied to a wired connection), more tolerance to damage (less physical connections) and a reduced fire load due to reduced cabling. Thus, wireless communication used in support of enhanced safety and survivability of naval platforms is an area to be investigated and demonstrated. A particular need exists for low-cost sensor data communications. It has been shown that wireless communications will support this need. Currently, to run a cable to a sensor on a ship can cost $5000. A low cost wireless infrastructure for data communications to and from sensors may be able to reduce this cost by more than a factor of 100 on a per channel basis. This will offer a more extensive use of sensors than is currently affordable. Enabling the cost-effective collection of data is critical to providing the information needed to carry out remote monitoring of spaces on a ship. The use of wireless communications enables the flexible placement of sensors since a data connection is available everywhere. This concept lends itself to the support of mobile sensors such as personnel badges or personnel status monitors to monitor the physiological state of individual crew members. Such a system directly supports damage control automation for reduced manning by replacing the human as a multi-sensor, information processor, actuating and communicating entity with a system which carries out these functions. "Wireless Communication Technologies" is a description of three state-of-the art, wireless communication systems that were installed and demonstrated on the ex-USS Shadwell, the Navy's full-scale test facility in Mobile, Alabama. The MicroLan Radio Frequency (RF) Tag and Reduced Ships-Crew by Virtual Presence (RSVP) demonstration systems were developed for the Defense Advanced Research Project Agency (DARPA) and the Office of Naval Research Advanced Technology Demonstrators (ATDs). .pdf

Stubblefield, P. N. (2010). *Security enhancement of littoral combat ship class utilizing an autonomous mustering and pier monitoring system* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from http://handle.dtic.mil/100.2/ADA518711.

Littoral Combat Ships (LCS) are designed and built to have minimum crew sizes thus, while the ship is in port, there are fewer crewmembers to facilitate pier monitoring, security, and conducting mustering of personnel. The crew of LCS presently have too many responsibilities to ensure 100% coverage of the pier area 100% of the time, and cannot manually maintain a real time muster of all ships personnel. This lack of coverage and situational awareness could make LCS vulnerable to terrorist attacks or terrorist monitoring. This thesis addresses the capability gap for complete and automated personnel mustering and situational awareness in the pier area for LCS. Through applying the Systems Engineering process, the concept, external systems diagram, requirements, and functional architectures for a generic solution are proposed. The proposed solution is an autonomous system utilizing facial recognition software to maintain a muster of the ship's crew, while in parallel monitoring the pier area, looking for any known person of interest (e.g., terrorists) and providing appropriate alerts. Additionally, this thesis provides a demonstrable proof-of-concept prototype system solution, named Pier Watchman. Its instantiated physical architecture of a specific autonomous solution to pier monitoring and personnel mustering is provided. .pdf

Summey, D. C., Rodriguez, R. R., Demartino, D. P., Portmann, H. H., & Moritz, E. (2001). *Shaping the future of naval warfare with unmanned systems* (Report No. CSS/TR-01/09). Retrieved from the Defense Technical Information Center website: http://www.springerlink.com/index/nn57tw04g4t04768.pdf.

This report presents the findings of a study conducted for the purpose of understanding how unmanned systems can enhance the readiness of U.S. Naval forces. The document presents reasons why unmanned systems should be adopted by the Navy, and makes the case for coordinating the development of unmanned systems technology across all major warfare areas. Following the systems engineering methodology, the study team identified Navy capabilities that unmanned systems can support, and defined functional elements that unmanned systems must have in order to fulfill the selected capabilities. The analysis showed that a limited number of payloads installed on four types of modular unmanned platforms is sufficient to support a wide range of major capabilities. The report also describes a concept for transportation and deployment of unmanned systems based on the use of standard shipping containers. This approach minimizes the impact of unmanned components on fleet combatants while allowing unmanned platforms to perform assigned tasks in a timely manner. .pdf

Swartz, R. A., Zimmerman, A. T., Lunch, J. P., Rosario, J., Brady, T., Salvino, L., & Law, K. H. (2010). *Hybrid wireless hull monitoring system for naval combat vessels* (Report No. unknown). Retrieved from the Defense Technical Information Center website: http://handle.dtic.mil/100.2/ADA523971.

This study investigated the reduction of cost and installation complexity of hull monitoring systems by introducing wireless sensors into their architectural designs. This system was installed and tested on the FSF-1 Sea Fighter during transit. Historically, hulls of USN ships are inspected by the crew and port engineers to ensure the hull is in a state of good health. While this approach has proven effective in the past, the method of visual inspection is labor-intensive. As navies continue to reduce manning on future naval vessels (Lively et al. 2008), the manning requirements of visual hull inspections will grow increasingly difficult to satisfy. The key findings of this study include that wireless sensors can be effectively used for reliable and accurate hull monitoring. Furthermore, the fact that they are low-cost can lead to higher sensor densities in a hull monitoring system thereby allowing properties, such as hull mode shapes, to be accurately calculated. .pdf

Tamez, D. J. (2003). *Using commercial-off-the-shelf speech recognition software for conning U.S. warships* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from the Defense Technical Information Center website: http://handle.dtic.mil/100.2/ADA417561.

The USN's Transformation Roadmap is leading the fleet in a smaller, faster, and more technologically advanced direction. Smaller platforms and reduced manpower resources create opportunities to fill important positions, including ship-handling control, with technology. This thesis investigates the feasibility of using commercial-off-the-shelf (COTS) speech recognition software (SRS) for conning a Navy ship. Dragon Naturally Speaking Version 6.O software and a SHURE wireless microphone were selected for this study. An experiment, with a limited number of subjects, was conducted at the Marine Safety International, San Diego, California ship-handling simulation facility. It measured the software error rate during conning operations. Data analysis sought to determine the types and significant causes of error. Analysis includes factors such as iteration number, subject, scenario, setting and ambient noise. Their significance provides key insights for future experimentation. The selected COTS technology for this study proved promising overcoming irregularities particular to conning, but the software vocabulary and grammar were problematic. The use of SRS for conning ships merits additional research, using a limited lexicon and a modified grammar which supports conning commands. Cooperative research between the Navy and industry could produce the “Helmsman" of the future. .pdf

Tichy, P., Marik, V., Vrba, P., & Pechoucek, M. (2005). *Chilled water system automation* (Report No. unknown). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.96.7223&rep=rep1&type=pdf.

This document presents a case study based on the development of a control application using agent technology developed in Rockwell Automation, the Autonomous Cooperative System (ACS) agent platform. The application presented involves intelligent distributed control of shipboard Chilled Water System (CWS) for vessels of the USN. The document is structured as follows. Section 2 provides a description of the CWS application with focus on requirements and utilization of agent technology. Section 3 gives an overview of ACS agent platform that has been designed and implemented in parallel with the development of CWS application. The last section describes lessons that we have learned during this development process. .pdf

Tomas, V., & Margeta, A. (2006). Next generation control architectures. *Pomorstvo, 20(2),* 127-136. Retrieved from http://hrcak.srce.hr/index.php?show=clanak_download&id_clanak_jezik=10443.

Current generation control systems, including those aboard the "Smart Ships", place an ever-increasing amount of sensory information in front of the operator, and generally require sharply increased manning in case of control system malfunctions. Furthermore, there is a growing demand for reduction of the number of crewmembers onboard a ship. The control system designer faces the challenge of designing a robust and increasingly autonomous automation system that is scalable and affordable. Research suggests these challenges will be met by three-tiered control architecture – a strategic layer that focuses on setting resource goals and priorities for machinery systems based on the ship's current mission. This will enhance the features of currently available systems by allowing direct addressing of any system component, sensor or actuator from anywhere in a vessel. This permits a system self-reconfiguration on failure or in case of damages to the segments of the system. Future full integrated control and monitoring systems (FICMS) will be distributed systems that combine control and information functions under the umbrella of one overall management system. An open architecture with backward and forward compatibility provides improved through life support and reduces the risk of obsolescence. Generally, the technology to achieve the vision of an advanced FICMS is available today. .pdf

Westdijk, R. (2008). *A monitoring and reasoning framework for applying autonomic computing in a combat management system* (Unpublished master's thesis). Delft University of Technology, Delft, Netherlands. Retrieved from http://scholar.google.ca/scholar?start=120&q=manning+OR+ship+manning+OR+manning+reduction+OR+crewing+OR+crew+reduction+OR+ship+automation&hl=en&as_sdt=0,5&as_ylo=2001&as_yhi=2011#4.

Diagnosis of large and complex software systems is a challenging task that can highly benefit from monitoring of the high-level functional requirements. This research studies the potential of applying requirements monitoring for a software system of high complexity: the combat management system (CMS) of a modern and technological advanced naval platform. An effort is made to apply a monitoring technique that can be used for autonomizing of this system while limiting implementation impact. The goal of this thesis is to show the feasibility of using requirements monitoring in a CMS by presenting the design, implementation and simulation of a diagnostics expert system prototype. Additional uses such as software developer support and user assistance are also explored. The Knowledge Acquisition in Automated Specification (KAOS) goal-oriented requirements engineering method is used to extract software system goals from previously documented requirements. With these high-level objectives as a starting point, the Requirements Monitoring (ReqMon) framework is applied. An implementation model is defined, identifying what data transformations are

needed to apply the ReqMon system. This model is implemented as a prototype in a Java Expert System Shell (JESS) development environment. Simulations show that detailed diagnosis of a complex software system as a CMS is feasible. They also demonstrate that the combination of requirements monitoring and rule-based reasoning provide a solid foundation for various levels of autonomy in an existing combat management system. .pdf

Westermeijer, E., Post, W. M., & Keijer, W. (2003). *Teleknowledge, knowledge-at-a-distance.* Paper presented at the 13th Annual International Ship Control Systems Symposium, Orland, FL. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.2.3268.

Manning reduction on future navy ships is a necessity if a significant reduction in operating costs and a solution to the availability problem of highly specialized personnel are to be achieved. One way to accomplish this is to remove knowledge and expertise that is only required for infrequently occurring tasks (e.g. system malfunction diagnosis) from the ship to a central facility on shore or on another ship. However, not all tasks are eligible for "teleknowledge", and both the crew on board and the teleknowledge operators in the central facility will need to be supported with the proper tools to ensure the current performance level. This paper will give a view on the potential applications, requirements and limitations of teleknowledge on future navy vessels. Issues like the kind of knowledge that has to be transmitted (the methodology), how this transmission must take place and what psycho-social boundaries and risks must be taken into account are investigated in a study performed in co-operation with two Netherlands Organization (TNO) institutes. Teleknowledge is not totally new within the navy. Royal Netherlands Navy Netherlands (RNLN) experiences will be presented and the possibility to improve the use of the existing teleknowledge equipment and organization structure with the outcome of this study will be explored. .pdf

Weston, N. (2006, March). *Strategies for integrating models of interdependent subsystems of complex system-of-systems products.* Paper presented at the 38th Southeastern Symposium on System Theory, Cookeville, TN. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1619094.

The Office of Naval Research has established a need for improved design and analysis methods for the next generation of naval surface combatants. The Aerospace Systems Design Laboratory has initiated the Integrated Reconfigurable Intelligent Systems Project to address design issues associated with the future systems. A goal of this program is to define preliminary approaches for developing an integrated modeling and simulation environment for complex systems. Since such systems are heterogeneous, dynamical and interdependent, we suggest that a system-of-systems multidisciplinary approach is most appropriate for investigating and executing solutions. An integration methodology employing innovative techniques and a framework of tools that can be used to couple disparate models and simulations is presented. Methods for validating the final product to justify the selected approach and demonstrate a proof of concept for the integrated model are also discussed. .pdf

# 4 Policy and Procedures

Papers in the Policy and Procedures section concern organizational solutions and strategies related to the processes of manning and crewing, as well as policies impacting operator workload reduction measures.

Albea, L. (2005). *Sea based air operations center.* Unpublished Manuscript. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA464536.

The USN should pursue a sea based air operations center (AOC) capability as an operationally significant concept that greatly enhances the Navy's position in joint operations. Achieving this capability would posture naval forces to more closely fulfill the requirement mandated by the National Military Strategy to conduct military operations that dominate the full spectrum of conflict. Though previously limited by technological constraints, undeniable trends across military transformation efforts point to its future relevance and application to the Joint Force Commander (JFC). The uncertainty of future conflicts and the growing abilities of our adversaries reinforce the need to harness the operational significance of an afloat AOC. In all manner of conflict, from Missions Other than War (MOTW) to major operations, this unique capability provides the JFC greater flexibility to respond to contingencies on short notice with an integrated, more lethal joint force. More importantly, should the proliferation of theatre ballistic missile technology worsen, an AOC capable naval strike group most likely possesses the closest solution to this dangerous threat. Finally, rather than redefine naval command and control of air operations as simply an enabler to the Joint Force Air Component Commander (JFACC), the Navy should expand this definition to encompass a wider more relevant purpose, to provide flexible joint airpower from the sea in support of the JFC. .pdf

Alexopoulos, A. (2007). Introducing system dynamics modelling into the passenger and cruise markets focusing on the marine manpower. *International Journal of Applied Systemic Studies, 1(4),* 436-449. Retrieved from http://inderscience.metapress.com/index/ A3460586661JP209.pdf.

Nowadays there is substantial shortage of seafarers mainly owing to the very small number of new entries into the marine profession. The Greek merchant fleet needs competitive human resources management. This paper is based on a study titled 'An Analysis of the Greek Manpower Market in the Ferry and Cruise Industries'. We attempt to define the variables that affect the quantity and quality levels of seafarers, employed in passenger and cruise markets, and present the current trends of the seafaring profession. Using system dynamics we retain the existing qualified seafarers by improving their competitiveness and reducing manning costs. (No pdf available.)

Arslan, O. & Er, I. D. (2008), A SWOT analysis for successful bridge team organization and safer marine operations. *Process Safety Progress, 27(1),* 21-28. doi: 10.1002/prs.10209. Retrieved from http://transnav.am.gdynia.pl/proceedings/pdfs/47.pdf

Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis is an established method for assisting the formulation of strategy. In this respect SWOT application to strategy formulation about bridge organization is examined and proposed in this study. A qualitative investigation using SWOT analysis has been successfully implemented, emphasizing the limited capabilities of bridge resources to provide safe navigation and properly implemented bridge team management procedures. The human factor approach interacting with SWOT parameters was discussed in advance to clarify the potential threats of bridge operations for the enhancement of safety in maritime transportation. The originality of this study is that SWOT analysis as a management tool was firstly applied to bridge team management to perform strategic action plans for ship management companies to utilize bridge resources. With this bridge resource based SWOT analysis, efforts were made to explore the ways and means of converting the possible threats into opportunities and changing the weaknesses into strengths. Consequently, strategic action plans were developed for improved bridge team organization and safer marine operations. .pdf

Baker, C. C, Krull, R., Snyder, G., Lincoldn, W., & Malone, T. B. (2001). Survey of reduced workload and crewing strategies for ocean patrol vessels. *Naval Engineers Journal,* 28-44. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2001.tb00032.x/abstract.

The U.S. Coast Guard (USCG) is in the concept exploration phase of its Integrated Deepwater System (IDS) acquisition project. This project will define the next generation of surface, air and command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) assets used to perform the Coast Guard's missions in the IDS environment (>50 NM off the U.S. coastline). As part of early technology investigations, the needs exist to: (1) analyze the workload requirements of the IDS, (2) identify alternative means to perform ship's work, and (3) optimize ship manning consistent with ship workload, performance criteria, and the available tools and equipment aboard. To reduce shipboard work requires an understanding of the mission and support requirements placed on the vessel and crew, how these requirements are currently met, and how requirements might otherwise be met to reduce workload and crew size. This study examined currently implemented workload and manpower reducing approaches of commercial maritime fleets, U.S. and foreign navies, and foreign coast guards. These approaches were analyzed according to evaluation criteria approved by the IDS acquisition project team. From this, strategies for shipboard work reduction that may be considered for adoption by the IDS were identified and analyzed according to performance and costs factors. Ten workload-reducing strategies were identified: damage control, bridge, multiple crewing, engineering, risk acceptance, modularity, deck, enabling technologies, ship/personnel readiness, and operability and maintainability. .pdf

Baker, C. C., Malone, T., & Krull, R. D. (1999). *Survey of maritime experiences in reduced workload and staffing* (Research Report No. CG-D-02-00). Retrieved from the Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord &metadataPrefix=html&identifier=ADA372260.

The USCG is in the Concept Exploration Phase of its Integrated Deepwater System (IDS) acquisition. This project will define the next generation of surface, air and C4ISR assets used to perform the Coast Guard's missions in the Deepwater environment (>50 NM off the U.S. coastline). A ship's crew represents a major life cycle cost of operating and maintaining a USCG ship. Reducing shipboard work requires an understanding of the mission and support requirements placed on the ship and its crew; how these requirements are currently met; and how requirements might otherwise be met to reduce workload and crew size. The objective of this effort was to support the development of an optimized crewing strategy for the surface platform of the IDS by surveying work reducing approaches of other maritime fleets (foreign coast guards and navies, and commercial fleets). From the data collected, strategies for shipboard work reduction that may be considered for adoption by the Deepwater Project were identified and analyzed according to performance and costs factors. Each strategy developed during the effort was based on the approaches and techniques observed by the maritime organizations surveyed. .pdf

Barnett, M. L., Stevenson, C. J., & Lang, D. W. (2005). Shipboard manning. *WMU Journal of Maritime Affairs, 4(1),* 5-33. Retrieved from http://www.springerlink.com/index/V32867 KH0J622U61.pdf.

This paper reports the results of the first phase of a research project to explore alternative shipboard manning structures. A review was conducted of relevant literature, although since the Standards of Training, Certification and Watchkeeping (STCW) for Seafarers revision in 1995, earlier studies are no longer as relevant as they were. It was clear from this review that few organisations have explored the potential of Chapter VII of the Convention of the STCW for alternative structures and certification. A research study was conducted that involved the use of three focus groups and an electronic Delphi discussion group of 20 volunteer maritime experts. The focus groups identified a series of feasible manning structures and these scenarios formed the basis for the electronic Delphi phase of the study. The paper provides a full analysis of the exercise, which was successful in showing where there was consensus and where there were major differences of opinion. One major conclusion of the participants was that, although technically feasible, unmanned vessels were unlikely to appear in the foreseeable future for commercial and political reasons. The majority favoured a human presence on board but there were significant differences of opinion on its main function and how that presence should be organised. .pdf

Bucknall, R., & Freire, P. (2004). Unmanned cargo ships: A 2020 vision? *Journal of Marine Engineering and Technology: Part B: Proceedings of the IMarEST, 5,* 57-68. Abstract retrieved from http://www.mendeley.com/research/unmanned-cargo-ships-a-2020-vision/.

Over the next two decades the world will change demographically and the shipping industry has recognised that it will face a shortage of skilled manpower. A shortage of skilled labour was previously experienced by the shipping industry during the 1960s. Then the problem was overcome by the widespread introduction of automation allowing substantial reductions in manning to be made. In the following decades, ships continued to be automated at an increasing rate with the introduction of periodically unattended machinery spaces and integrated bridge control systems which facilitated 'one man on watch' operations so that today, in some ships, there are crews numbering as few as six. The manpower shortage identified in the future is unlikely to be overcome by a further slimming of existing crews because it is recognised that the strain placed on the remaining crew will compromise effectiveness and safety. A new concept in ship design and operation is therefore required if the predicted manpower shortages are to be overcome and further cost reductions achieved. Unmanned ships have been proposed as a possible solution overcoming the manpower problem, and in this paper the results of a technical and economic appraisal of a fully automated unmanned cargo ship are presented within the context of expected world developments in the next decades. (No pdf available.)

Cannon, K., Clarke, K., Muhi, N., & Davies, J. (2011, April). *Operators gain significant operational and safety gains with remote data acquisition and virtual rig presence.* Paper presented at the SPE Digital Energy Conference and Exhibition, Texas, USA. Abstract retrieved from http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-143739-MS&soc=SPE.

Today's exploration and production operations in offshore environments face increasing limitations on bed space and restricted evacuation capability. Manning operations the traditional way is no longer an option. Remote operations pose a feasible alternative which brings equally important additional benefits. This paper describes the technical and personnel considerations of developing and deploying a remanned solution for wellsites and also reviews the challenges and successes of doing so as a standard approach to wellsite operations with specific emphasis on remote data acquisition and monitoring. Remanning can occur in varying degrees from remote data gathering to expert assistance of wellsite personnel, through personnel reduction up to complete removal. A case study for remanned data aquisition in Asia Pacific is analyzed. This deployment required the complete removal of mudlogging staff from the wellsite. This paper details the changes in roles and responsibilities, re-engineering of processes and challenges overcome which led to a successful implementation. The implementation of a remote data acquisition service was a complete success. Virtual-presence of data engineers via integrated video and radio over intranet solutions and implementation of Virtual Private Network (VPN) solutions using advances in communications technology allowed optimum use of globally distributed expertise. These solutions provided the operator with significant additional benefits. Mudlogging rig footprint was reduced to zero while improving service quality through real-time decision making and instant geosciences analysis.

Operational cost savings with reduced travel and support costs were achieved, in addition to the expected reduction in Health, Safety and Environmental (HS&E) exposure. The current emphasis on remote monitoring, support and data recording capabilities allied with pressure from operators and regulators to remotely deliver Oil and Gas (O&G) services and increasing speeds of developing Information and Communications Technology (ICT). We can expect to see a dramatic shift in the traditional way of providing wellsite services. Remanning is an effective solution that has proven its capability; however, it is still only implemented sparingly. With a focus on safety and efficiency, virtual staffing will become the standard over the coming years; here we include some of the future developments that will need to be achieved to make this a reality. (No pdf available.)

Carlson, C., Hayes, B. C., Kamradt, H., & Hoffman, G. (2002). *Littoral Combat Ship (LCS) Characteristics Task Force* (CIERA Report Unknown). Retrieved from Defense Technical Information Center, http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA525239.

In December 2001, the Navy Staff's Director, Surface Warfare (N76), requested the Naval War College's assistance in defining the characteristics that should be used and the technology opportunities available when constructing an LCS, the smallest member of a new family of ships being developed by the Navy. The tasking was driven by an ambitious schedule that precluded a zero-based study; therefore, the Naval War College assembled a multi-disciplinary team of subject matter experts to examine current and proposed programs from which they gleaned the most promising ideas. The process began with a core group that met in Newport, Rhode Island in March 2002. This group approved characteristic guidelines and constraints and selected primary and secondary missions that littoral combat ship variants should perform. The initial workshop was followed by a series of workshops that drilled more deeply into the characteristics that the LCS should possess for each mission area. An integration effort took the data gleaned from these workshops and merged them into options presented in a draft report. A final LCS characteristics integration workshop was held 26-27 June 2002 during which the draft report was reviewed and options refined. Results of that workshop are incorporated into this report. Some of the results look at how manning on an LCS can be reduced. .pdf

Clark, D. T. (2009). *Navy officer manpower optimization incorporating budgetary constraints*. (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA497036.

Every two years, the Chief of Naval Operations is responsible for submitting the Program Objectives Memorandum to the Secretary of the Navy for further review and inclusion in the President's two-year budget input to Congress. The Chief of Naval Personnel's Strategic Resourcing Branch is challenged with building a manpower budget program that both meets the budget limitations set forth by Congress and the manning requirement choices made by Navy leadership. This thesis develops the Requirements-Driven Cost-Based Manpower Optimization (RCMOP) model. RCMOP is a linear optimization program designed to guide monthly values for officer inventory, promotions, accessions, designator transfers, and forced and natural losses. RCMOP's goal consists of minimizing a weighted

penalty function of unmet manpower requirements while meeting the Navy's fiscal constraints over a two-year time horizon. Implementation of the test scenario shows that resulting costs fall within 10% of predicted budget estimates, and promotion metrics approximate the values expected by law and policy. The model also indicates a need to increase total Officer Candidate School (OCS) accessions (by 11%) with respected to projected values as well as the percentage of 1000-coded billets filled by staff and fleet support officers. .pdf

Cogley, K. M., Green, B. D., & Snodgrass R. E. (2005). *Reducing the maintenance burden of shipboard collective protection systems* (Report No. Unknown). Dahlgren, VA: Dahlgren Division Naval Surface Warfare Center. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA444724.

CBR weapons continue to pose a threat to USN ships in the global war on terror. Shipboard Collective Protection Systems (CPS) provide defense against this threat on ships throughout the U.S. Naval fleet. CPS provides a nearly transparent layer of defense with a limited maintenance burden on the crew as compared to other systems aboard ship. The Shipboard CBR Protection Branch of the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) has sought to reduce the maintenance and manning burden of CPS through a number of completed and ongoing projects. Although the number of ships employing CPS continues to increase throughout the fleet, the maintenance and manning burden for CPS will continue to decrease through persistent research and development efforts. .pdf

Dean, A. W., Reina, J. J., & Bao, H. P. (2008). Identification of supplementary metrics to sustain fleet readiness from a maintenance perspective. *Naval Engineers Journal, 120(2),* 81-88. doi: 10.1111/j.1559-3584.2008.00126.x. Retrieved from http://onlinelibrary.wiley.com.

A wide variety of programs and schemes are in place (and many programs are in continuous development by organizations such as the Office of Naval Research) that address the sustainability of the Navy's Fleet. Newly developed technologies are allowing for the continued design and development of much more complex ships with a host of innovative concepts and requirements. The cost of construction of these next-generation ships, budgetary restraints, and other factors have also made it so necessary to maintain, adapt, and extend the life of the legacy fleet to meet operational requirements and maintain our maritime dominance. As we extend and adapt technology to become implemented across the wide variety of vessel platforms in existence in the legacy fleet, manning reductions are being implemented across the various ship-type classes. As more and more maintenance is being shifted from the sailors on the ships to various off-ship organizations, this brings into question the level of training necessary for ship's personnel in the maintenance area that is required when manning the ship from a tactical or operational perspective. Decision tools need to be developed for senior Navy management for use in evaluating and determining the optimal balance in manning ships from not only the operational perspective but also from the maintainability/survivability perspective. It is believed evaluation of the requirements, benchmarking, and the development of assessment metrics for determining the requirements of the Fleet for capable maintainers are of vital importance and will have far-reaching impact on the Sea Warrior, Sea Trial, and Sea Enterprise programs in support of the “Sea Power 21” strategic concept of the Navy. This paper explores the necessity of benchmarking current

ship's force capabilities, establishing manning requirement metrics, and evaluation of current maintenance policies. .pdf

Dundics, M., Finley, B., Krooner, K., Roche, T., & Rodgers, R. (2010, June). *Littoral combat ship (LCS), gas turbine reliability engineering implementation.* Paper presented at the ASME Turbo Expo 2010: Power for Land, Sea and Air, Glasgow, UK. Retrieved from http://www.esrgtech.com/images/uploads/LCS_Gas_Turbine_Reliability_Engineering_Implementation.pdf.

The development of the LCS and its life cycle support design objectives were driven by three key objectives: 1) High level of ship mission availability while performing any one of the three mission capabilities; 2) Minimal Total Ownership Cost (TOC); 3) Manning complement lower than the similar predecessor class of ships. To achieve these concurrent goals, the ship design provides functionality including advanced automation for machinery control, as well as mission function reconfiguration and execution. Unfortunately, information-based automated machinery reliability management decision support was not part of the ship design. This type of decision support is vital in enabling a significantly reduced crew and the advance planning required for executing the scheduled short maintenance availabilities. Leveraging existing equipment monitoring technologies deployed throughout the legacy fleet with the reliability engineering approach on LCS will improve the operational availability of gas turbine propulsion systems and allow executing the ship's Concept of Operations (CONOPS). To address the reliability and TOC risks with the initially defined sustainment approach, a Reliability Engineering derived Condition Based Maintenance (CBM) strategy was developed, such that it could be implemented using a proven remote monitoring infrastructure. This paper will describe the Reliability Engineering based CBM approach and how it will be implemented on the LCS-1 and LCS-2 propulsion gas turbine engines and other critical systems to achieve system level operational reliability, the LCS life cycle support design objectives, and defined sustainment strategies. .pdf

Fullerton, J., Scotchlas, M., Smith, T., & Freedner, A. S. (2004). *Operational impacts of the Aegis cruiser smartship system.* Paper presented at the Engineering the Total Ship (ETS) 2004 Symposium, Gaithersburg, MD. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA422119.

The Chief of Naval Operations guidance over the past few years has challenged the fleet with finding ways to increase efficiencies while maintaining overall readiness as a highly effective force. In addition, today's ships must be continuously ready and surge capable in accordance with the Fleet Response Plan. One way to meet these goals is to leverage technologies that will optimize ship manning and streamline shipboard training. The Smartship installation in the USS Antietam (CG 54), when used in synergy with a flexible manning concept (Core Flex), the conversion of steam systems to all-electric, and the development of web-based administrative tools enables the ship to meet and exceed these challenges. Antietam uses the enabling tools of virtual training devices and simulators in conjunction with IT-21 installation and Core Flex to reduce underway watchstanding requirements and increase ship readiness, personnel qualifications, and training depth throughout the ship. These combined efforts reduce required unit level training time, increase

situational awareness, and dramatically decrease the administrative burden on personnel. Innovative ideas for leveraging technology to increase control and monitoring capability, and adapting training organizations around new functionality allows for increased readiness and war fighting power. Employment of this technology is key. Unit level training time and required manning are decreased through automation. Situational awareness is increased through web enablement and a better common operating picture. This leads to a higher level of unit effectiveness and readiness while directly supporting Strike Group needs and Fleet Commander ideology, and clearly setting the foundation for future innovations. .pdf

*GAO-08-1060T: The Zumwalt-class destroyer program emblematic of challenges facing navy shipbuilding: Testimony before the Subcommittee on Seapower and Expeditionary Forces, Committee on Armed Services, House of Representatives,* (2008) (Testimony of Paul L. Francis). Retrieved from http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA484547.

DDG 1000 development has been framed by challenging multi-mission requirements, resultant numerous new technologies, and a cost and schedule budget that added to-rather than eased-the challenge. While the Navy has done much work to try to manage the program within these competing goals, it will begin lead ship construction in October 2008 with significant uncertainties, particularly in developing the ship's design, key components, and the ship software system. Recent restructuring of the schedule buys more time for technology development, but shifts key efforts like installation and testing of the combat systems until later in the construction schedule after the ships have been initially delivered. Such compromises made before construction has even begun suggest that the Navy already has little margin for solving future problems without adding money and time. In fact, it appears that the budget for the lead ships is not adequate to deliver fully operational ships. The complexity and unique features of DDG 1000, along with the design work, testing, and actual construction experience to come, add to the risk of cost growth. .pdf

Hinkle, J. B., & Glover, T. L. (2004, March). *Reduced manning in DDG 51 class warships: Challenges, opportunities and the way ahead for reduced manning on all United States Navy ships.* Paper presented at the Engineering the Total Ship 2004 Symposium, Gaithersburg, MD. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA422116.

In an effort to move forward smartly with initiatives to reduce manning in USN combatants, the Program Executive Office, Ships, commissioned a study to examine and analyze alternatives to reduce manning for Arleigh Burke Class ships with the expectation that lessons learned from this effort would not only benefit current and future flights of DDG 51 Class ships, but would also benefit future ship classes, particularly the DD(X) family of ships. The DDG 51 Reduced Manning Study was conducted in two phases by a Navy-Industry Team, Phase I Concept Study (Hinkle and Glover 2003 - Concept) and Phase II The Plan for Assured Manning (Hinkle and Glover 2003 - Plan). This paper presents the significant results of the concept portion of this study. This study was coordinated with both past and ongoing manning reduction initiatives, particularly current reduced manning experiments being conducted by Commander, Naval Surface Forces. It came to important conclusions and recommendations regarding ways to reduce manning in DDG 51 Class ships

and focused especially on changes in policy, processes, culture, and tradition. The study's manning reduction initiatives covered three primary areas: (1) Achieving economies of scale by moving many functions currently performed by a ship's crew off the ship, (2) Accepting increased levels of risk by eliminating or consolidating some watch stations and reducing some support and hotel services, and (3) Investing in emerging technologies that would reduce the numbers of Sailors needed onboard Navy ships. .pdf

Horck, J. (2004). An analysis of decision-making processes in multicultural maritime scenarios. *Maritime Policy & Management, 31(1),* 15-29. Retrieved from http://www.informaworld.com/index/713751264.pdf.

There is a growing conviction among seafarers and persons working in the land-based sector of the maritime industry (including ex-seafarers) that staff onboard and on shore should be prepared to work with crews and groups whose members come from different countries and cultures and speak different languages. The problem, though, is which culture will have to surrender and which will dominate? Will a third culture become the norm for common survival? Perhaps to understand oneself and be knowledgeable about others is a better way to avoid eventual conflicts. There are nearly no research findings on how a programme should comprise the aims of facilitating comprehension and appreciation of influences, from differences in cultural backgrounds, on group performance and decisions. This paper reports on the research carried out on students in the Shipping Management and the Maritime Education and Training courses at World Maritime University (WMU). How do post-graduate students holding unlimited certificates of competency, as well as holders of university degrees with experience in the maritime industry and maritime administration, come to a consensus decision? The findings in this research are discussed in balance with the results from both the Seafarers' International Research Centre (SIRC) and the Swedish National Maritime Museum (SNMM) research which is interesting because the results, in some significant issues, are not the same. A phenomenographic approach has been used to find out that a multicultural group is not free from working problems. Can cultural differences, perhaps, be developed from an assumed hindrance into a catalyst for stimulating national appreciation and cooperation? Perhaps the opposite is true; it might be a bottleneck for improvements in safety as formulated in the Standards of Training, Certification and Watchkeeping (STCW95) and the International Safety Management (ISM) Code. .pdf

Horn, J., Cofield, A., & Steele, R. (2007, May). Culture change in the navy. *Defense AT&L.* Retrieved from http://www.dau.mil/pubscats/PubsCats/atl/2007_05_06/may_jun07_horn.pdf.

The DD-21 case study is a program manager's course case that has been shortened for this article. The intent of its authors is for the case to be used to facilitate classroom discussion and not to illustrate either effective or ineffective handling of a situation. The original case study was written by James Carter, professor of acquisition management in the program manager's course at the Defense Acquisition University. .pdf

Hunn, B. P. (2006). *Unmanned aerial system, new system manning prediction* (Report No. ARL-TR-3702). Retrieved from Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA441886.

This study examined historical, laboratory, field, and unmanned aerial system (UAS) model data to develop a manning estimate for a new, long range, Army UAS. System safety and effectiveness, training, contractor operations and working conditions were evaluated for current UAS's, including Hunter, Shadow, Predator, Improved Gnat, and to a lesser degree, Pioneer, Hermes, and Global Hawk. Information was collected from training and operational personnel and included questionnaire data, improved performance research integration (IMPRINT) modeling efforts, mathematical modeling as well as subject matter expert opinions on the issues of manning for current UAS's and projections for the new UAS. A review was also made of the system specifications for Shadow, Hunter, and a newly proposed UAS in regard to existing or proposed capabilities that would affect manning levels. Lessons learned were obtained from operationally deployed UAS personnel in order to understand the applied manning levels, which sustained combat operations versus specification levels. Safety, as well as accident and incident, information was reviewed for fielded systems, and lessons learned that apply to manning levels were discussed and incorporated into the recommendations and conclusions. Conclusions and recommendations for the new system are included and cover military manning levels, contractor participation, as well as suggested improvements regarding manning efficiency and UAS operations enhancement. Manning metrics for the new system were derived and baseline and spiral development manning levels were recommended. .pdf

Jones, M. T. (2001). *The potential role of the United States Maritime Service (USMS) in supporting ready reserve force vessel crewing needs* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA395870.

Because of concerns about possible Merchant Mariner manpower shortages or skill mismatch needed to crew DoD organic vessels during a major contingency, the Maritime Administration (MARAD) has proposed the development of a guaranteed surge pool of experienced inactive mariners available to ensure timely and adequate manning of its Ready Reserve Force (RRF). This pool would be a supplement not a replacement to the current active pool of mariners used to crew the RRF. This initiative is centered on using the United States Maritime Service (USMS) concept. Two main options were proposed: create a stand-alone USMS program under MARAD, and/or integrate the USMS concept with Navy's Merchant Marine Reserve (MMR) program. Fourteen structured interviews were conducted with strategic sealift stakeholders and experts in order to provide MARAD and the Navy with elements of how these pools/programs could be developed and to identify' the option that stakeholders believe is the best approach. Interview results revealed that a stand-alone USMS program, providing it could overcome various obstacles was the preferred approach. Analysis and recommendations are provided on how both pools could be developed and what issues

need to be resolved prior to either program implementation. An alternate approach to use the MMR program for RRF crewing is provided as well. .pdf

Koopman, M. E., & Golding, H. L. W. (1999). *Optimal manning and technological change* (Report No. CRM 99-59). Alexandria, VA, Center for Naval Analyses. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA379429.

The Assistant Deputy Chief of Naval Operations, Manpower and Personnel, requested the Center for Naval Analysis (CNA) examine the implications of technological change for Navy manpower. This paper addresses the changes that are likely to occur in the type of sailor the Navy needs as a result of new ship and aircraft maintenance and the changes likely to occur in the civilian population. It also examines how Navy workforce management policies may have to change due to these changes in technology, required skills, and civilian labor markets. The paper concludes that technological advances will most likely require a more skilled workforce. In particular, the Navy will need sailors who understand the general principles in their area of expertise, are technically literate, and have strong problem-solving, decision-making, and communication skills. .pdf

Lagodimos, A. G., & Mihiotis, A. N. (2010). Efficient overtime planning in packing shops with lines of identical manning. *International. Journal of Production Economics, 124,* 453-462. doi:10.1016/j.ijpe.2009.12.008

We consider a capacity planning problem arising at the packaging stage in many process industries. Termed Economic Manpower Shift Planning with Overtime (EMSP-O), it seeks the manpower and overtime to be planned at each workday shift so that production targets for all packing lines are met at minimum cost. The problem was previously modelled as an Integer Linear Program (ILP) and its solution explored. Here we present a new EMSP-O model that relaxes a restrictive assumption of the original model. We show that the relaxed EMSP-O is Non-deterministic Polynomial (NP)-hard and focus on the special case where all lines have identical manning. For this case, we establish properties of the optimal solution and show that, with no overtime constraints, an O(N log N) algorithm can find an optimal solution. With overtime constraints, the algorithm effectively constitutes a heuristic. Computations and comparisons with a commercial optimizer for two- and three-shift problems (as found in practice) were performed. Results demonstrate the algorithm efficiency which, except for very tight overtime constraints, reaches an optimum at high speed. .pdf

LeFrere, K. (2002). *An assessment of U.S. navy junior officer retention from 1998-2000.* (Unpublished master's thesis). Air Command and Staff College Air University, Maxwell Air Force Base, Montgomery, AL. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA407142.

The purpose of this study was to determine the primary causes of USN retention problems with its junior officers from 1998 to 2000. An analysis of data on operational tempo and retention was conducted which revealed no direct correlation between increased optempo and decreased retention. The study focuses on the four sea-going officer communities:

Surface Warfare Officers, Aviators, Naval Flight Officers, and Submariners. After the demise of the Soviet Union and the end of the Cold War, the DoD began a downsizing effort across all services. From 1990 to 1997, the Navy's officer corps shrank from 77,000 to 53,000 officers as a result of DoD downsizing mandates. At the time, Navy leaders were not concerned with retention because they had to meet their new end strength goals, but in 1997, officer manning dropped to dangerous levels. The Navy realized that it had a serious retention problem; too many junior officers were getting out. Navy leaders had to do something to stem the exodus, or the Navy would be in serious jeopardy of not being able to man its ships, aircraft, and submarines at the mid-grade officer, department head level. Without these officers to fill the critical sea-going billets, the Navy could find that it may not be able to fulfill its commitments around the world. If increased optempo was not causing the Navy's junior officers to get out, what was behind their decisions to leave? In the course of research, several surveys and interviews were uncovered which revealed a significant number of reasons that officer retention suffered in the Navy. From a comparison of these surveys and interviews, the five most common reasons junior officers stated for leaving the Navy was determined. Further study revealed that the Navy is aware of these reasons and is actively responding to keep positively address them to retain its junior officers. The recommendations include building more ships and increasing the number of Lieutenant Commander commands. Continuing with the Smart Ship Program and keeping the continuation bonuses in the budget will also help the Navy's officer retention efforts. .pdf

Levchuk, G., Chopra, K., Paley, M., Levchuk, Y., & Clark, D. (2005). *Model-based organization manning, strategy, and structure design via Team Optimal Design (TOD) methodology.* Paper presented at the 10th Command and Control Research and Technology Symposium the Future of C2, McLean, Virginia. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA463981.

This paper describes a quantitative Team Optimal Design (TOD) methodology and its application to the design of optimized manning for E-10 Multi-sensor Command and Control Aircraft. The E-10 (USAF, 2002) is intended to consolidate command and control (C2), battle management (BM), intelligence, surveillance and reconnaissance (ISR), and selected information warfare (IW) functions and eventually replace elements of the current C2ISR force mix. Our TOD design approach allows specification of team configurations (number and roles of operators) for efficiently operating the E-10 to execute mission scenarios of various contingencies. The objective is to maximize the speed of mission execution while balancing the workload among team members, provided the decision-making, expertise, workload threshold and organization cost constraints are satisfied. In order to analyze and simulate the operations of the E-10, we conducted mission decomposition to define functional responsibilities for the E-10 within the context of an operational mission. Working with subject matter experts, we developed functional process flows of the E-10 by decomposing each stage into representative functions. Each of these functions is in turn decomposed into high level task responsibilities, defining a directed graph of tasks with precedence/information flow constraints. .pdf

Lewis, G. W. (1996). *Personnel performance workload modeling for a reduced manned bridge: Lessons learned.* (Report No. NPRDC-TN-96-47). Naval Surface Warfare Center, Bethesda, MD. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA314661.

Declining budgets and decreased military personnel strength have provided major reasons for reducing shipboard personnel. The specific objective of this project was to develop a 'proof-of-concept' for assessing performance workload levels of operational shipboard personnel to be used in the rapid prototyping of ship designs for reducing shipboard manning levels. A review of shipboard reduced manning efforts and development of the 'Entering San Diego Harbor' scenario are described. Personnel performance workload models, using this scenario, were developed and exercised for this project. The lessons learned in developing this scenario and moment-to-moment fluctuations in workload data are described for three bridge crew configurations. Three appendices describe a review of human performance models, additional literature related to personnel assessment technologies and personnel costs models, and the bridge team functions and tasks used in the nine member bridge team workload model. This effort showed that personnel performance workload levels can be measured under current and reduced manning levels, either with or without automated equipment. Workload modeling would provide valuable information to assess current and reduced manning configurations and operational exercises readiness. Workload modeling could also contribute to the objective evaluation of automated equipment implementation and crew member reduction. .pdf

Loginovsky, V. A., Gorobtsov, A. P. & Kuzmin, V. E. (2005). The ISPS Code as a component of onboard resources in Bayesian Analysis. In D. Nielsen (Ed.), *Maritime Security and MET* (pp. 215-224). Billerica, MA, WIT Press. Retrieved from http://www.solomonchen.name/download/7ms/1-010-s2-loginovsky.pdf.

Nowadays, the influence of resources on safety and security at sea is one of the most critical elements of the existing management system. Already enormous regulatory workload on crew under International Safety Management (ISM) Code, Standards of Training, Certification and Watchkeeping (STCW), Safety of Life at Sea (SOLAS) and Marine Pollution (MARPOL) has now increased due to the International Ships and Port Facility Security (ISPS) Code requirements. This again puts more stress on human and organisational factors in general, and deck officers' attention and performance in particular. The importance of human resources can be well reflected in a model, however, it is difficult to reveal through statistics. Since Bayesian networks naturally represent causal chains, that is, cause-effect relationships between parent and child nodes, we can supply evidence of past events, and then run the Bayesian network to see what the most likely future outcomes will be. Their strength is that they are robust if missing some part of information, and will make the best possible prediction with whatever information is present. Therefore they were used for modelling crew resources. The modelling proves an overload of crew members, and shows the limited resources on board ship. To ensure efficiency of ISPS Code procedures, extra training is required which should be incorporated into the general curriculum of Maritime Education and Training (MET) institutions. More attention to security issues should be paid on the part of Port Facilities. ISPS Code related inspections should also consider the availability of manpower on board to ensure efficient performance. .pdf

Lyridis, D. V., Ventikos, N. P., Zacharioudakis, P. G., Dilzas, K., & Psaraftis, H. N. (2005). Introduction to an innovative crew composition approach based on safety/operational and financial requirements. *WMU Journal of Maritime Affairs, 4(1),* 35-37. Retrieved from http://www.springerlink.com/index/5714542X2X6X3586.pdf.

This paper proposes a tool to estimate crew composition based on safety/operational and financial requirements. As there is a tendency of ship owners to implement improved technologies onboard their vessels, there is no systematic way to predict their potential effect on crew size and composition (typically determined by flag state authorities on a case-to-case basis) nor on the type and complexity of on board duties new technologies might dictate. The main aim of this paper is to develop a tool to assist in determining crew composition, by taking into account both administration's and the ship owner's point of view. Based on data collected from ship owners, a data mining technique is implemented in order to form a generalized framework that estimates crew composition as a function of ship type, size, and degree of automation. The agreement of model predictions with records from specific (vessel) cases is very good in terms of safety (for operations such as watchkeeping, mooring/unmooring, loading/unloading). The specific intended use of this tool is to help a ship owner decide whether it is cost-beneficial to retrofit a conventional vessel with advanced technologies that would potentially entail a reduced crew (probably dealing with different and more complex on board duties). Its main benefits are that it can be used to estimate crew composition before any vessel construction or upgrade has actually taken place and that it allows crew composition to be easily adapted to the technological evolution of ship systems even at their current rapid pace. .pdf

Maas, H. L. M. M., & Keus, H. E. (1999). A methodological approach to the design of advanced maritime command and control concepts. *Proceedings of the 1999 Command and Control Research and Technology Symposium, 1,* 174-191. Retrieved from http://dodccrp.org.

Life-cycle costs have become an increasingly important design constraint for command and control concepts. To a large degree, life-cycle costs are determined by personnel and exploitation costs. Application of the rapidly developing information technology has until now not yet resulted in a substantial reduction of the number of operators in the Command Information Centre (CIC), although CIC staffing and automation varies significantly over different navies. This paper starts with an elaboration of the trends in designing new command and control concepts. TNO has addressed the issue of CIC staffing by starting a step by step research programme on Reduced Manning Concepts for future maritime command and control organisations. The goal of this programme is to provide a concept that can be implemented in the year 2010. The first stage of this programme was directed towards the postulation of an initial identification of the technological feasibility of a reduced manning concept. This stage lasted one year and was carried out in 1998. In this paper, we focus on the different phases of the design methodology used to formulate maritime C2-organisation concepts. Several design considerations that were used to characterise future concepts will be highlighted. We conclude with a short discussion in the hands-on experience with the design methodology. .pdf

MacDonald, R. (2006). Safe manning of ships: Yesterday, today and tomorrow. *WMU Journal of Maritime Affairs, 5(2),* 143-151. Retrieved from http://www.springerlink.com/index/ 03623032412765H1.pdf.

In May 2006 a group of European countries sought a review of the principles for establishing the safe manning level of vessels at the Maritime Safety Committee of the International Maritime Organization. These administrations supported by others claimed that fatigue is recognized as being a major contributory factor in many accidents and incidents. It is also considered that fatigue, hours of work and manning levels are inextricably linked. This paper intends to take a look at the manning of ships historically and how they have reached the levels today which many regard as too low. It proposes that the answer may not be by just adding more officers to the manning levels, but to take a more realistic approach and study what is actually required to safely man and operate a ship in the 21st century. .pdf

MacKenzie, A. (2010). *An exploration of the effects of maintenance manning on Combat Mission Readiness (CMR) utilizing agent based modeling* (Unpublished master's thesis). Department of the Air Force Air University Air Force Institute of Technology, Dayton, Ohio. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix= html&identifier=ADA517409.

Agent based models have been shown to be powerful tools in describing processes and systems centered on individual behaviors and local interactions (i.e. "bottom-up") between specific entities. Current application areas tend to be focused within the business and social science arenas, although their usefulness has been demonstrated in the modeling of various chemistry and physics-based systems. Conversely, many highly process-oriented systems, such as manufacturing environments, tend to be modeled via "top-down" methods, including discrete or continuous event simulations among others. As a result, potentially critical attributes of the entities or resources modeled with these methods (spatial properties, "learning curve" or adaptability) may not be adequately captured or developed. This research develops an agent based model for application to a problem heretofore addressed solely via discrete event simulation or stochastic mathematical models. Specifically, a model is constructed to investigate the effects of differing levels of maintenance manning on sortie production capability, with an examination of those effects on the resulting Combat Mission Readiness (CMR) of a typical F-16 squadron. .pdf

Mahulkar, V., McKay, S., Adams, D .E., & Chaturvedi, A. R. (2009). System-of-systems modeling and simulation of a ship environment with wireless and intelligent maintenance technologies. *Systems, Man and Cybernetics, Part A: Systems and Humans, 39(6),* 1255 -1270. doi: 10.1109/TSMCA.2009.2025140. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5272213.

Modeling and simulation environments are needed to support decision making in Navy Warfighters, which are emergent systems that pose a challenge to operations management. Ships consist of complex interconnected systems such as the infrastructure, crew, and workflow. A system-of-systems approach using agent-based modeling is applied here to develop workflow simulations involving a ship's crew conducting routine maintenance, watch duty, and reporting functions. Simple models are used to describe basic

behavioral traits and intelligence in crew members; machinery including sensors for intelligent maintenance; equipment consuming power; mobile and stationary communication network access points; models for data transfer over the network; crew mobility models; power distribution and trimming models for the electrical system; and a fire model to simulate emergency scenarios. The simulation results demonstrate an increase in machine availability due to the implementation of intelligent maintenance systems. The effects of wireless-network usage on crew resource utilization and overall ship capability in normal operational scenarios are also demonstrated. A simple rescheduling algorithm is used to improve crew utilization and estimate manning requirements. The effects of emergency scenarios such as fires in different locations are also studied. Sensitivity analysis is presented to verify the developed model, and a note on validation is given. .pdf

Moore, C. S., Hattiangadi, A. U., Sicilia, G. T., & Gasch, J. L. (2002). Inside the black box: Assessing the navy's manpower requirements process (Report No. CRM D0005206.A2). Retrieved from the CNA Analysis and Solutions website: http://www.cna.org/documents/d0005206.a2.pdf?fromsearch=1.

The Navy determines the number of sailors it needs on board ships through a complex and demanding process. To those not directly involved, it is a black box. This study describes the Navy's methods and compares them to practices used by private-sector firms. It identifies assumptions that drive the number of people needed, or "manpower requirements," and quantifies the impact of those assumptions on billets and costs. The study concludes that the Navy's manpower requirements process is thorough, accountable, and meets the Navy's stated goals. However it does not adequately consider manning alternatives. In setting requirements, the Navy takes technology as given and uses decades-old assumptions about work hours, labor productivity, and the paygrade mix of the crew. Such assumptions, which are "hard wired" into the Navy's requirements computation model, are costly and merit revalidation. Other problems include limited cost incentives and a lack of performance metrics with which to assess different manning configurations. The study recommends that the Navy (a) make the costs (and benefits) of requirements more visible; (b) shift the focus from workload validation toward innovation and improvement; and (c) charge an agent or organization with identifying avenues for manpower savings, through methodological, technological, or organizational changes. .pdf

Murphy, B. (2004). Applying lean manufacturing initiatives to naval ship repair centers: implementation and lessons learned (Unpublished master's thesis). Retrieved from Massachusetts Institute of Technology website: http://dspace.mit.edu/handle/1721.1/33433.

The USN is under pressure to reduce the cost of fleet maintenance in order to redirect funds for the construction of new ships and submarines. The Navy looks to private industry for process improvement ideas such as the Theory of Constraints, Six Sigma and Lean Manufacturing Principles. This thesis examines the Lean Manufacturing movement in the private sector of ship repair and how it eventually came to government owned ship repair operations. Recent National Ship Research Program (NSRP) initiatives provide shipyards a strategy of how to select areas of an operation for Lean improvements. The Norfolk Naval Shipyard method is a combination of the Theory of Constraints, Six Sigma and Lean Principles called Lean Sigma. The Lean Sigma methodology for planning, executing and sustaining lean improvement and how to measure success with various metrics is presented. Lean Sigma is implemented into the Electric Motor Rewind and Repair Center as a case study. Before and after assessments, lessons learned, and recommendations from the implementation case study are presented. Details of the challenges and pitfalls encountered during the Lean Sigma implementation in the areas of culture, budget, management, metrics and cost benefit measurement, are described throughout the test case. In conclusions key elements for successful Lean transformation and a vision for the future Lean Ship Repair Enterprise are presented. .pdf

North Atlantic Treaty Organisation: Group 6 Specialist Team on Small Ship Design (2004). *NATO/PfP Working paper on small ship design.* Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.129.7107&rep=rep1&type=pdf

The NATO Naval Armaments Group gave approval in June of 2001 to charter a Specialist Team on Small Ship Design (ST-SSD) to produce a Naval Group 6 Working Paper on acceptable criteria, standards and specifications for the design and construction of small littoral combatant (SLC) ships and offshore patrol vessels (OPVs) with displacements of approximately 600 tons to approximately 2000 tons. The purpose of chartering this team, beyond development of the working paper, was to stimulate new thinking in small ship acquisition, evaluate standardized formats for NATO-PfP ship specifications, and to acquire and spread new information on technology and materials suitable for small ships. The work of the Specialist Team on Small Ship Design was carried out by the following NATO and Partner for Peace Nations: Australia, Bulgaria, Canada, Finland, Greece, Germany, Italy, Netherlands, Norway, Poland, Portugal, Romania, Russia, Spain, Sweden, Turkey, Ukraine, UK, and the U.S. .pdf

Nugent, W. A., & White, D. (2000, August). *Manpower modeling and human-centered design for 21st century naval platforms.* Paper presented at the Forty Fourth Annual Human Factors and Ergonomics Society Annual Meeting, San Diego, CA. Abstract retrieved from http://www.ingentaconnect.com/content/hfes/hfproc/2000/00000044/00000036/art00020.

The USN is placing strong emphasis on ensuring that future naval platforms are not only affordable and effective, but also operable and maintainable with fewer personnel. The realization of optimal manning and optimal ownership costs requires that the human be considered as a major component of the ship and its associated systems early in the acquisition process. Toward that end, systems engineers must have tools and processes to support human-centered engineering from the outset of the design, and must be able to exchange human performance and cost data with other members of the engineering team. Similarly, the USN must have tools to evaluate human versus system function allocation tradeoffs during the early phases of ship acquisition, when changes are easier and less costly to implement. Two efforts, the Ship Manpower Analysis and Requirements Tools (SMART) and the Systems Engineering Analysis Integration Tool (SEAIT), are being conducted to assist navy manpower evaluators, ship designers and government program managers in meeting the challenge of optimally manned ships. Both efforts use modeling and simulation of human performance and skill data to determine the optimum crew mix. Outputs from SMART

and SEAIT are being designed for transition to the Human Centered Design Environment (HCDE), a collaborative engineering environment that integrates human centered and systems engineering processes and tools into a common data repository. (No pdf available.)

Paul, M. A., Gray, G. W., Nesthus, T. E., & Miller, J. C. (2008). *An assessment of the CF submarine watch schedule variants for impact on modeled crew performance*. Report No. TR 2008-007. Defense Research and Development, Toronto. ON. Retrieved from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA485455&Location=U2&doc=GetTRDoc.pdf.

In support of the Board of Inquiry (BOI) investigating the October 2005 fire on board HMCS Chicoutimi, DRDC Toronto was asked to model crew cognitive effectiveness at the time of the fire and at the time of casualty evacuation approximately 28 hrs after the fire. The results of this modeling effort (based on sleep behaviour estimates) suggested that our submariners were operating at significantly reduced levels of cognitive effectiveness. Therefore DRDC Toronto was tasked to conduct an at-sea trial, this time using real actigraphically-derived sleep data in order to more accurately model the impact of the watch schedule on crew cognitive effectiveness. Twenty-one submariners participated as subjects in this at-sea trial. Three of these subjects were non-watch-standers: Commanding Officer (CO), Coxswain (COXN) and Chief Engine Room Artificer (CERA), six subjects were from the 1-in-2 backwatch, six subjects were from the 1-in-2 front-watch, and six subjects were from the 1-in-3 engineers' watch. The trial took place on a Canadian submarine during a 13-day transatlantic return to Halifax. All subjects wore wrist activity monitors (actigraphs) in order to measure their daily sleep patterns quantitatively. The subjects also maintained a daily activity and sleep log, and performed daily iterations of the psychomotor vigilance task (PVT). The modeled cognitive effectiveness was worse than the previous modeling efforts for Chicoutimi which used sleep behaviour estimates. The activity and sleep log data indicated increasing difficulty arising from sleep and a decrease in subjective levels of 'restedness' over days at sea. Alertness also decreased over days at sea. Each of the 1-in-2 front and back-watches were less 'happy' than their 1-in-3 engineering watch counterparts. While there was no difference in sleepiness between watch system variants or over days at sea, sleepiness levels were consistently elevated to midscale levels. Difficulty concentrating, slowed reactions, level of fatigue, work frustration and physical discomfort increased during the trial relative to the pre-trial baseline. The current submarine watch schedule is sub-optimal in that it results in worrisome levels of cognitive effectiveness in our submariners. Recommendation: An alternative watch schedule which is more sparing of submariner cognitive effectiveness should be developed and implemented, if possible. .pdf

Paul, M. A., Hursh, S. R., & Miller, J. C. (2010). *Alternative submarine watch systems: Recommendation for a new CF submarine watch schedule*. Report No. TR 2010-001. Defense Research and Development, Toronto. ON. Retrieved from http://dodreports.com/pdf/ada517285.pdf.

The summer 2007 at-sea trial to evaluate the CF submarine watch schedule revealed dangerously low levels of modeled cognitive effectiveness among the crew. In response, DRDC Toronto hosted an International Submarine Watch Schedule Symposium (CF, USN, Royal Navy (RN), Royal Australian Navy (RAN), and RNLN) to review international experience with national watch schedule challenges and to model alternative watch schedules that would be more sparing of crew performance. Three alternative watch schedule systems were modeled (1-in-3 straight eights, 1-in-3 straight fours, and 1-in-2 (8on-4off-4on- 8off)). These three alternative watch systems were compared to the current 1-in-2 (6on-6off-6on-6off) CF submarine watch schedule. The mean modeled cognitive effectiveness for all watches within each system were 96%, 96%, 89% and 66% for the 1-in-3 straight eights, 1-in-3 straight fours, 1-in-2 (8-4-4-8) and the current CF 1-in-2 (6-6-6-6), respectively. While it is evident that the best of these alternative watch schedules are the 1-in-3 straight eights and 1-in-3 straight fours (both resulting in 96% mean cognitive effectiveness), it is also evident that only larger submarines with larger crews (nuclear-powered USN and RN ballistic missile submarines and nuclear-powered USN attack submarines) can employ such a watch system. Smaller diesel-powered attack submarines have small crews which makes it impossible for such boats to operate either the 1-in-3 straight eights or the 1-in-3 straight fours. Essentially, small diesel-powered submarines must employ a 1-in-2 watch system (i.e., work 12 hours each day). The current CF submarine system is 1-in-2 and involves two 6-hour daily watch periods for each of the 'front' and 'back' syndicates. The alternative 1-in-2 (8-4-4-8) watch schedule has an 8-hour and a 4-hour daily watch period for each of the 'port' and 'starboard' syndicates. This alternative 1-in-2 (8-4-4-8) watch system is almost as good as the 1-in-3 straight eights or 1-in-3 straight fours (i.e., mean overall cognitive effectiveness of 89% for the 1-in-2 (8-4-4-8) system vs. 96% for each of the 1-in-3 straight eights or the 1-in-3 straight fours systems), and much better than the overall 66% mean cognitive effectiveness of the current 1-in-2 (6-6-6-6) watch system. The alternative 1-in-2 watch system represents a 23% overall increase in cognitive effectiveness over the current 1-in-2 watch system. The 1-in-2 (8-4-4-8) watch system should be evaluated in an at-sea trial with a view to adapting operational routines to that watch system, and, if possible, the system should be incorporated on all CF submarines. .pdf

Pomeroy, R. V., & Sherwood Jones, B. M. (2002, October). *Managing the human element in modern ship design and operation.* Paper presented at the Human Factors in Ship Design and Operation II Conference. Retrieved from http://www.he-alert.org/documents/published/he00055.pdf.

The design and operation of ships has evolved and continues to develop, due to structural change in the industry and as a consequence of the introduction of new technologies and changes in manning. Lloyd's Register recognises the need for ship design to take account of the human element in order to ensure a reasonable level of marine safety. When considering marine safety, it is necessary to consider both the human element and at the technical element in the broadest sense, not just the immediate causes of failures. Whilst this combined approach is taken in some incident analysis, whether after the event or as part of a proactive safety assessment, there is still a tendency to examine the human and the technical element independently of each other. An integrated socio-technical approach is required if full understanding is to be achieved. A simplistic technical approach tends to recommend local reactive solutions, such as the addition of more alarms, which may assist but will add complexity and the underlying cause may not be resolved. The complexity of recent incidents with high-tech shipping is examined by event sequence analysis so that the real value of the present established hardware safeguard can be re-appraised. Accidents are necessarily alleged (and unfortunate) source of data. There are many lessons to be learned from the experience of other sectors, to prevent the marine sector learning the same lessons the hard way. The Human Factors community has a technology transfer role to play here. Much analysis of

human error has been aimed at improving understanding, and its remedial value has not been fully exploited. The analysis presented examines how the various stakeholders might improve the barriers against incidents, what sort of approach (e.g. prescriptive, risk-driven, capability-driven) would be most appropriate, and the role that Classification Societies could play in supporting them, with emphasis on the work undertaken by Lloyd's Register. .pdf

Preece, D., Blosch, M., & Strain, J. (2002). Work restructuring and technical change: A case study of the Royal Navy Warfare Branch. *Personnel Review*, 31(4), 449-464. doi: 10.1108/00483480210430364. Retrieved from http://www.emeraldinsight.com/journals.htm?articleid=879325&show=abstract. doi 10.1108/00483480210430364.

The paper examines a recent example of work and employment restructuring in the RN. This involved the creation of a new employment branch (the Warfare Branch) out of two former branches: the Operations Branch and the Weapon Engineering Branch. The case study is used as a vehicle for exploring whether, and if so in what senses, technical change can be argued to have contributed to this organizational restructuring, within the wider contexts and dynamics of change. .pdf

Pringle, C. E. (1998). *Smart Gator: An analysis of the impact of reduced manning on the mission readiness of US Naval amphibious ships* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA358792.

The increasing cost of manpower in the USN and the decline of the defense budget generated a new initiative called the Smart Ship Program. Smart Ship, using a combination of technology and nontraditional policies and procedures to reduce manning on U.S. naval vessels, was first implemented on the USS Yorktown (CG 48). However, some of the technology and concepts were not readily transferable to other ship classes. The USS Rushmore (LSD 47) was chosen to implement and evaluate Smart Ship concepts on an amphibious ship through the Smart Gator Program. This thesis evaluated the impact of Smart Gator on the mission readiness of the Rushmore by conducting interviews with key Smart Gator Program personnel, reviewing pertinent data and analyzing the Rushmore's Engineering Certification Report of October 1998. This study shows that the initial reduction in manpower, combined with increased training required on new equipment, produced an increase in the crew's workload and negatively impacted mission readiness. Additionally, the interviews indicate that Navy research and development funds should be dedicated to this effort in order to properly execute the Smart Gator Program. .pdf

Progoulaki, M. (2006). *Dealing with the culture of the maritime manpower in a socially responsible manner.* (Reference unknown). Retrieved from http://he-alert.com/documents/published/he00755.pdf.

Concurrently, shipping companies' crucial need for cost cutting is their main motive for recruiting seafarers of various nationalities and formulating multicultural teams on board the ships. This paper seeks to correlate the role of dealing with culture by being socially responsible. The main point of the research is not to examine the relation of human error with accident rates, but to examine how dealing with the cultural issue and managing multicultural crews, is related to the shipping companies' and the industry's social responsibility. An extensive literature review on the cultural issue of the maritime manpower, with a focus on the working and living conditions and the management of shipping crews, reveals important parameters of the subject. This analysis is enriched with qualitative data from an aboard case study. Results from the literature review and of the analysis of this single case study showed that managing multicultural human resources has very much to do with the company's social responsibility. However, more needs to be done, in order to achieve a socially acceptable behaviour of all the industrial actors to its seagoing personnel. .pdf

Russell, J. (2006). *The littoral combat ship: Is the US Navy assuming too much risk?* (Unpublished master's thesis). U.S. Army command and General Staff College, Fort Leavenworth, KS. Retrieved from http://handle.dtic.mil/100.2/ADA452042 .

The purpose of this research is to explore the current risks associated with the LCS. There are several compelling reasons for the radical changes incorporated in the LCS design. A better understanding of the risks that the ship and crew will assume is vital to the proper use of this new platform and will help ensure the safety of both. This study does not advocate complete risk mitigation aboard the LCS, but strives to increase the overall risk awareness. The risk of combining so many new and untested elements on a single ship must be understood by all of those who are involved in its implementation. The arrival of the first LCS, projected to be operational in 2007, will represent a reduced manning concept designed from the ground up and the first of a new family of US naval combatants built to face the future maritime threats. With the proposed ship class of up to fifty-five ships, the USN needs to make sure that LCS is not assuming too much risk. .pdf

Sambracos, E., & Tsiaparikou, J. (2001). Sea-going labour and Greek owned fleet: a major aspect of fleet competitiveness. *Maritime Policy & Management, 28(1),* 55-69. .Retrieved from http://www.informaworld.com/index/713832705.pdf. doi.org/10.1080/03088830118029.

This analysis aims to examine the current picture of maritime manpower in the Greek registered and owned fleet, as it has been formed during the post-war years. This objective entails the analysis of the current supply and demand for seafarers, the estimation of any shortfalls and their confrontation. Moreover, this study further investigates the contributory factors of the present employment trends, which simultaneously constitute special problems for the sea manpower of the Greek owned fleet and attempts some recommendations. In the context of the above mentioned objective, this analysis emphasizes issues such as recruitment, marine education and wastage. Furthermore, special consideration is given to the significance of labour costs for the development of the Greek owned fleet, particularly to subjects such as the various ways of reducing manning costs and their repercussions on the employment of Greek seamen. Finally, this analysis examines the trends of the state shipping policy concerning labour issues and proceeds to some recommendations. .pdf

Schank, J. F., Yardley, R., Riposo, J., Thie, H., Keating, E., Arena, M. V., & Chiesa, J. R. (2005). *Options for reducing costs in the United Kingdom's future aircraft carrier (CVF) programme* (Report No. 2004018039). Retrieved from Research and Development (RAND) website: http://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND_MG240.pdf.

The UK's Ministry of Defence (MOD) is currently in the assessment phase of a programme to produce two new aircraft carriers to replace the three existing Invincible-class carriers. These ships are currently scheduled to enter the RN inventory in 2012 and 2015, respectively. These Future Aircraft Carriers (CVFs) could be the largest ships ever constructed for the Royal Navy. Because of the complex nature of the CVF programme, the MOD wanted an independent, objective analysis that evaluated the economic implications, schedule impact, and technical risks of adopting new technologies and alternative manufacturing options. The analysis was divided into the following tasks:

- Reducing support costs and other whole-life costs (WLCs):
  - Building databases and analytic tools that would allow the evaluation of cost-reducing measures, and
  - Evaluating existing or emerging technologies, subsystems, or processes that might reduce acquisition or annual support costs;
- Reducing manpower requirements:
  - Identifying instances of manpower reduction in other relevant acquisition programmes, and
  - Identifying and evaluating high-leverage manpower reduction options and laying out a strategic roadmap for implementing them; and
- Drawing lessons from experience:
  - Reviewing the use of contractor teaming by the U.S. DoD in acquiring the Virginia class of attack submarines. .pdf

Scofield, T. (2006). *Manning and automation model for naval ship analysis and optimization* (Unpublished master's thesis), Virginia Polytechnic Institute and State University, Blacksburg, VA. Retrieved from http://scholar.lib.vt.edu/theses/available/etd-04282006-113459/.

The manning of a ship is a major driver of life cycle cost. The U.S. Government Accounting Office (GAO) has determined that manpower is the single most influential component in the life cycle cost of a ship. Life cycle cost is largely determined by decisions made during concept design. Consequently, reliable manpower estimates need to be included early in the design process, preferably in concept design. The ship concept exploration process developed at Virginia Tech uses a Multi-Objective Genetic Optimization to search the design space for feasible and non-dominated ship concepts based on cost, risk and effectiveness. This requires assessment of thousands of designs without human intervention. The total ship design problem must be set up before actually running the optimization. If manning is to be included in this process, manning estimate tools must be run seamlessly as part of the overall ship synthesis and optimization. This thesis provides a method of implementing a manning task network analysis tool ISMAT (Integrated Simulation Manning Analysis Tool, Micro Analysis and Design) in an overall ship synthesis program and design optimization. The inputs to the analysis are ship systems (propulsion, combat systems, communication, etc), maintenance strategy, and level of automation. The output of the manning model is the number of crew required to accomplish a given mission for a particular selection of systems, maintenance and automation. Task network analysis programs are ideal for this problem. They can manage the probabilistic nature of a military mission and equipment maintenance, and can be used to simplify the problem by breaking down the complex functions and tasks of a ship's crew. The program builds large and complex functions from small related tasks. This simplifies the calculation of personnel and time utilization, and allows a more flexible scheme for building complex mission scenarios. In this thesis, ISMAT is run in a pre-optimization step to build a response surface model (RSM) for calculating required manning as a function of systems, maintenance and automation. The RSM is added to the ship synthesis model to calculate required manning, and a concept exploration case study is performed for an Air Superiority Cruiser (CGX) using this model. The performance of the manning model in this case study is assessed and recommendations are made for future work. This research shows that there is a difference between minimum manning and optimal manning on USN ships. .pdf

Sorenson, A. J. (2001). *The Coast Guard knowledge base: Building online communities, teams and experts to facilitate rapid creation, capture and sharing of service related knowledge,* (Unpublished master's thesis), Naval Postgraduate School, Monterey, CA. Retrieved from http://handle.dtic.mil/100.2/ADA396531.

The USCG is reaching the limits of incrementalism. Extending aircraft and cutter service-lives, increasing work hours to compensate for reduced manpower, responding to data calls faster and squeezing another penny out of costs are the challenges of leaders today. But pursuing incremental improvements is similar to paving over cow paths. Today's technology provides the Coast Guard with the opportunity to make exponential improvements in processes for managing knowledge, and to revolutionize business practices. This thesis presents a knowledge management architecture that addresses articulable limits to fast, efficient, knowledge management within the cutter community. Building upon a foundation of messaging and collaboration, the architecture provides modules maximizing the ability to manage informal and formal knowledge. The results are a transparent interface for the creation, sharing and capture of organizational knowledge. Successful implementation is dependent upon the improvement of the Coast Guard's IT infrastructure and the creation of a culture friendly to knowledge sharing. .pdf

Spindel, R. C., Laska, S., Cannon-Bowers, J. A., Cooper, D. L., Hegmann, K. C., Hogan, R. J., Hubbard, & Smith, J. A. (2000). *Optimized surface ship manning*. Report No. NRAC-00-1. Arlington, VA: Naval Research Advisory Committee. Retrieved from http://dodreports.com/pdf/ada454055.pdf.

The Naval Research Advisory Committee (NRAC) assessed Navy efforts to optimize manning on surface ships. This included a review of previous relevant studies, current programs in U.S. and foreign navies, and relevant technology opportunities. The panel reviewed system life cycle cost initiatives designed to produce savings for recapitalization and modernization. They found a growing cost database under development; however, they

recommended continued expansion, cost methodology improvements and further identification of manpower cost components. The Smart Ship demonstrated that technology insertion and process improvements can reduce manning, maintain capability and improve shipboard quality of life. The Navy has not diffused the Smart Ship lessons learned throughout the Fleet. This is attributed to a lack of top-down leadership and implementation strategy. This situation highlights the enormity of the problem the Navy faces to adapt the revolutionary changes anticipated in DD-21. Recommendations: (1) The Chief of Naval Operations (CNO) appoint a Flag Board responsible for strategy implementation to ensure technological, procedural and organizational changes are adopted throughout the Navy; (2) modify the ship design process to include human engineering to achieve optimal human/system performance; (3) align research and development (R&D) efforts so that compatible processes and specifications are incorporated for ship components and subsystems for optimally manned ships; and (4) modify recruitment, training, compensation and career progression strategies to reflect changes in organization, skills, and expanded decision-making authority required on optimally manned ships. .pdf

Theotokasa, I., & Progoulaki, M. (2007). Cultural diversity, manning strategies and management practices in Greek shipping. *Maritime Policy & Management, 34(4),* 383-403. doi: org/10.1080/03088830701539198. Retrieved from http://www.informaworld.com/index/ 781383019.pdf.

The present paper examines the way Greek shipping companies and Greek seafarers perceive culture, and how this affects their approach to crew management and operation of the ships. The analysis focuses on the manning strategies employed by the companies, on the operational problems that might occur on-board, and on any possible disturbance of the relation between the ship, the office at shore and third parties. Finally, a number of management practices which, when implemented, help to overcome these problems is also examined. The research methodology includes a review of the existing literature and interviews conducted by means of questionnaires filled in by crew managers and seafarers. Results show that some of the predominant problems encountered aboard, as far as communication with multicultural crews is concerned, are rooted in cultural and linguistic incompatibility, as well as in inadequate and inappropriate training. Furthermore, crew managers and seafarers lack both a clear perception of culture, and share opinions on the implementation of manning strategies. The present paper concludes that culture management can enhance crew team cohesion, upgrade communication at all levels, and, finally, improve the quality of the working environment, the safety of the workplace and the overall performance of the team. .pdf

Thie, H. J., Christian, J., Stafford, M., Yardley, R. J., & Schirmer, P. (2008). *Fiscally informed total force manpower* (Report No. unknown). Retrieved from Retrieved from Rand and Development (RAND) website: http://www.rand.org/pubs/monographs/MG606.html# src=mobile.

The RAND National Defense Research Institute was asked to review studies performed by internal and external organizations that have suggested methods for making fiscally informed manpower determinations. The research reported here is intended to be a short-term review of publicly available studies done within particular organizations or functional personnel communities. This monograph should be of interest to those concerned with military manpower requirements. This monograph communicates the results of a short-term review of how selected DoD components currently review and analyze manpower needs in particular organizations or personnel communities. We reviewed published material and conducted interviews to ascertain useful methods that might be used more widely. The research is not designed to be comprehensive or to review routine Service manpower determination methods. Instead, we are particularly interested in practices that are currently being used by DoD organizations that have yielded specific results. .pdf

Trifonov, I., Bandte, O., Bonabeau, E., & Gaudiano, P. (2005). *Agent-based modeling as a tool for manpower and personnel management* (Report No. unknown). Retrieved from the Defence Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA465091.

We have developed an agent-based model of the USN's Manpower and Personnel (M&P) systems, and used the model as a tool to analyze and design M&P policies. The model captures the dynamics of sailor recruitment, training and retention, as well as their performance during missions. Our model makes it possible to gain a deep understanding of the dynamics of the entire M&P systems. We expect our tool to offer several benefits to the Navy, including the ability to design new policies for existing ships or new ships; the ability to understand the impact of shipboard technologies to increase automation; and the ability to study the impact of various interventions on sailor retention. The model also promises to be useful for personnel management in the commercial sector. .pdf

Williams-Robinson, M. J. (2007). *A littoral combat ship manpower analysis using the fleet response training plan* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA467716.

The LCS, in its final steps toward employment, is an entirely new breed of USN warship. USS FREEDOM (LCS 1), scheduled to be commissioned in May 2007, introduces an advanced technological platform. It includes, but is not limited to, several new optimal manning and training concepts such as SHIPTRAIN and SMARTSHIP introduced by the USN. The LCS Wholeness Concept of Operations requires a crew to certify in 15 mission areas using its core crew and one additional mission area applicable to both the core crew and mission module personnel. Using a discrete event simulation tool called the Total Crew Model, this study analyzed the currently proposed Fleet Response Training Plan for the LCS. An examination using a 14-day training cycle snapshot of the 40 proposed crew members was found to be sufficient to sustain the ship through a training assessment phase. The snapshot evaluated crew endurances using 63, 67 and 70-hour workweeks. The modeling showed the 70-hour workweek satisfied the manpower requirement workload, as delineated in OPNAVINST 1000.16J. This workweek, however, exceeded core crew endurances by 594 hours and 42% of the crew exceeded acceptable fatigue levels. The model's results indicate that eight additional core crew members are required to conduct the training assessment phase without exceeding core crew endurance. .pdf

Zuzich, J. M. (2002). *Future US Navy force protection* (Unpublished master's thesis). U.S. Army Command and General Staff College, Fort Leavenworth, KS. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA416104.

This study focuses on providing force protection for the Navy's future minimally manned surface combatants. Following the attack on the USS Cole, force protection became the Navy's primary warfare concern. In order to add experience and defensive depth, USCG Port Security Units (PSUs) augmented Navy ships' force assets in providing Antiterrorism and Force Protection. Concurrently, the Navy set out to build the next family of surface combatants, the DD (X) (Destroyer, Experimental) class. One of the cornerstones of the program, as specified in the operational requirements document (ORD), is that the DD (X) have an optimally sized crew of 95, not to exceed 150. This is nearly a 70 percent reduction from surface combatant crew sizes of today. How can the Navy reasonably expect to provide force protection for minimally manned combatants when it is having trouble doing so today? This study examines the tasks required to provide adequate force protection, the manning required to perform those tasks, and the associated manning costs. The analysis determined that the new DD (X) class will only be able to perform the force protection tasks if manned near the 150 personnel mark, and even then will require a security augmentation force, such as a PSU. The appendixes provide a force protection task list, USS Yorktown manning information and inport watchbill, PSU manning information and watchbill, PSU master training list, USCG estimated PSU deployment costs, and DD (X) class manning information and costs. .pdf

# 5 Personnel and Training

Papers in this section concern solutions pertaining to the range of skills for operators of reduced crews, approaches to improve performance through the optimized mixture of personnel, and bringing awareness about the risks and limitations of reduced manning on ships.

Allen, P., Wadsworth, E., & Smith, A. (2007). The prevention and management of seafarers' fatigue: A review. *International Maritime Health, 58,* 1-4. Retrieved from http://www.imh.mug.edu.pl/ attachment/attachment/4992/2007_x15.pdf.

Global concern about the extent of seafarer fatigue is widely evident across the shipping industry. This paper provides an evaluation of the extent to which fatigue can be prevented and managed. Given the diversity of activities undertaken in the maritime sector, and the different profiles of fatigue risk factors in different work groups, it is clear that a range of strategies will need to be implemented. One conclusion from the review is that current legislation and guidance on fatigue has not had the desired effect. The way forward is to treat seafarers' fatigue as a serious health and safety issue. A starting point must be to take a more robust approach to regulation. Manning levels need to be addressed in a realistic way that prevents economic advantage accruing to those operating at bare minimum and the issue of false record-keeping requires urgent attention. This must be supplemented with appropriate training and guidance regarding avoidance of fatigue and the creation of optimum working conditions. Lessons can be learned from other transport industries and it is important to seek examples of best practice and apply these in an effective way to the maritime sector. Methods of addressing issues specific to seafaring are now well developed and a holistic approach to the problem of fatigue can lead to a culture that benefits the industry as a whole. .pdf

Archer, S., Headley, D., & Allender, L. (2003). Manpower, personnel, and training integration methods and tools. In H. R. Booher (Ed.), *Handbook of Human Systems Integration* (pp. 379-431). Retrieved from http://onlinelibrary.wiley.com/doi/ 10.1002/0471721174.ch11/ summary.

A key concept in personnel staffing and systems integration is determining, acquiring, training, and retaining the proper number of people with the right skills for the jobs required to operate and maintain systems. Traditionally, most organizations attempt to match the number and skills of people necessary to meet acceptable performance at minimum cost. More recently, organizations have begun to recognize that the introduction of new technology – ranging from information technology, process monitoring and control, and robotic manufacturing to weapons technology – can significantly increase the difficulty of maintaining a proper mix of numbers and skills of people in the workplace. Some technology may help to reduce numbers and skills required as well as reduce the workload (both physical and mental) on employees. In other cases technology may, through its sophistication, cause an increase in the need for, and therefore the cost of, skilled individuals to operate the systems. Also, technology may not reduce workload but simply shift it from physical workload to mental workload. The technology-people trade-off in the workplace is a job design issue that can be addressed via the human systems integration (HSI) approach. The primary objective of this chapter is to describe the state of the art for HSI methods and tools particularly useful for analysis and assessment of manpower, personnel, and training (MPT) issues on system design and development programs. (No pdf available.)

Barr, R. K., & Williams, F. W. (2001). *DC-ARM organizational procedures and manning for smart controller.* (Report No. NRL/MR/6180-01-8557).Washington, D. C.: Naval Research Laboratory. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA392493.

The purpose of this paper was to describe the organization, procedures and manning requirements for a modern USN combatant ship, designed for damage control manning reduction, through automated application of an automated Supervisory Control System. A proposed manning is set forth in this document to accompany the Applied Research Laboratory (Pennsylvania State)/Ship Survivability Technology's DC-ARM (Damage Control-Automation for Reduced Manning) Intelligent Controller System (ICS) that is to be demonstrated aboard the ex-USS Shadwell in September 2001. This manning requirement is relative to varying environments that exist in a ship's operational cycle, the ICS hardware, the key system's damage control data processing elements, and the manned stations' data displays. The ICS operational procedures outline the different manning requirements, personnel duties and responsibilities during various conditions of readiness experienced throughout a combatant's life cycle. This description of personnel duties leads to establishment of a calculated potential manning complement of DC personnel with consideration for variances resulting from differences in the watch section arrangement. In view of the obvious impact manning reduction will have on a ship's routine maintenance, a discussion of that impact includes an option for solution. .pdf

Bennington, J. (2010). *Perceptions on social networking: A study on their operational relevance for the navy* (Unpublished master's thesis). Naval Postgraduate School, Monterey CA. Retrieved from Defense Technical Information Center, http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA518381.

Since the beginning of civilization, humans formed social networks under communities bound by common interest. Today the ubiquity of the Internet provides ample opportunity for these groups, once limited by geography, to connect easily and expand beyond city and national borders. The USN provides an opportunity to harness the power of electronic social networks to improve enterprise-wide information sharing across strategic, operational, and tactical forums. These networks of trusted connections among people ensure means for watch standers and decision makers to share trusted information with seasoned leaders and subject matter experts. The leverage of electronic social networks in the Navy is significant during manpower reductions that present limiting opportunities for face-to-face collaboration and mentoring, a critical aspect to a war-fighting organization. This thesis presents an evaluation and comparison of the perceptions of social networking of current and future leadership on the value of social networking tools. Moreover, this analysis applies specifically to Navy operations. The relevance of collaboration, trust, professional development, and technological opportunity is examined. .pdf

Douangaphaivong, T. (2004). *Littoral combat ship (LCS) manpower requirements analysis* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from Defense Technical Information Center http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA429789.

The LCS's minimally manned core crew goal is 15 to 50 manpower requirements and the threshold, for both core and mission-package crews, is 75 to 110. This dramatically smaller crew size will require more than current technologies and past lessons learned from reduced manning initiatives. Its feasibility depends upon changes in policy and operations, leveraging of future technologies and increased workload transfer from sea to shore along with an increased acceptance of risk. A manpower requirements analysis yielded a large baseline (^200) requirement to support a notional LCS configuration. Combining the common systems from the General Dynamics and Lockheed Martin designs with other assumed equipments (i.e. the Combined Diesel and Gas Turbine (CODAG) engineering plant) produce the notional LCS configuration used as the manpower requirements basis. The baseline requirement was reduced through the compounded effect of manpower savings from Smart Ship and Optimal Manning Experiments (OME) and suggested paradigm shifts. A Battle Bill was then created to support the notional LCS during Conditions of Readiness I and III. An efficient force deployment regime was adopted to reduce the overall LCS class manpower requirement. The efficiency gained enables the LCS force to flex and satisfy deployment requirements with 25% to 30% fewer manpower requirements over the "one-for-one" crewing concept. An annual manpower savings of $80M to $110 M if each requirement costs $60K. .pdf

Gayle, W. (2006). *Analysis of operational manning requirements and deployment procedures for unmanned surface vehicles aboard U. S. navy ships*. (Unpublished master's thesis). Postgraduate Naval School, Monterey, CA. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a445406.pdf.

This research was conducted per a Navy Warfare Development Center request that the Naval Postgraduate School update the Navy's TACMEMO (Tactical Memorandum): Integration of UVs (Unmanned Vehicles) into Maritime Missions TM 3-22-5-W. Unmanned Surface Vehicles (USVs) are expected to becoming an integral part of the Navy's maritime mission. To incorporate USVs into the fleet, manpower issues must be identified and resolved, i.e., manning requirements supporting USV operations; and analysis of the rate/rating, skill sets, training and procedures required to operate and maintain USVs. The methodology included Navy lessons learned, operation evaluation reports, and technical documentations from past and ongoing fleet employment of USVs to identify manning issues. Research findings included: current USV launch-and-recovery systems on host ships are personnel intensive compared to other available systems; knowledge, skills and abilities required of USV support personnel are identified within the BM (Boatswain Mate), EM (Electrician's Mate), EN (Engineman), ET (Electronics Technician) (Surface), GM (Gunner's Mate), IT (Information Systems Technician), OS (Operations Specialist), STG (Sonar Technician) (Surface) rating occupational standards, and it would be easier to train personnel from these ratings for USV support; and a formal training path should be established for USV operators. In consonance with Navy Human Capital direction, naval platforms must operate with reduced manning, however, unmanned systems definitely require trained and specialized personnel to operate and maintain. .pdf

Golding, H. L. W., Gasch, J. L., Gregory, D., Hattiangadi, A. U., Husted, T. A., Moore, C. S., & Seiver, D. A. (2001). *Fleet attrition: What causes it and what to do about it* (Research Report No. CRM D0004216.A2). Retrieved from the Center for Naval Analyses website: http://www.cna.org/research/2001/fleet-attrition-what-causes-it-what-do-about-it.

When the Navy's downsizing ended in the 1990s, undermanning in the fleet became evident. By the end of the decade, fewer than 90 percent of the enlisted billets were filled. Problems with recruiting, distributing, and retaining sailors all contributed to the undermanning difficulties. In response, the Navy fought to reverse the trend by instituting initiatives to alleviate attrition. As part of the Navy's efforts to increase manning through reduced attrition, the Assistant Deputy Chief of Naval Operations, Manpower and Personnel (NIB) asked the Center for Naval Analyses to analyze the causes of fleet attrition—that is, early separations among sailors who make it to a full-duty billet, both on shore and at sea. Because most fleet attrition occurs soon after arrival in the fleet, we focused on first-term attrition. First, we studied the patterns of fleet attrition losses in the Navy. Then we investigated the causes of attrition and how those factors changed in the 1990s. We conducted an analysis of yearly cohort attrition for first-term sailors on both sea and shore duty. Then, restricting our analysis to sailors on surface ships, we explored how the deployment cycle influences attrition. Finally, because attrition is costly, we explored strategies aimed at reducing it and keeping it low. .pdf

Green, K. Y. (2009). *A comparative analysis between the navy standard workweek and the actual work/rest patterns of sailors aboard U.S. Navy frigates* (Unpublished master's thesis). Postgraduate Naval School, Monterey, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA514116.

Crew fatigue is a major factor in mishaps aboard ships. Despite empirical evidence that fewer personnel and longer working hours are primary factors of crew fatigue, USN budgeting constraints and increased automation on ships has resulted in reduced manning onboard Navy vessels. This study expands research by Haynes (2007) and Mason (2009) comparing the Navy Standard Workweek (NSWW) Model to sailors' self-reported activities onboard USN destroyers and cruisers. Research by both Haynes (2007) and Mason (2009) showed that a majority of sailors worked longer hours and received less sleep than allotted in the NSWW model. The objective of this study was to determine if similar patterns would exist onboard USN frigates. Results indicated that 61 % of the participants exceeded the 81 hours of Available Time (work) allotted by the NSWW. On average, sailors in this current study, excluding officers, worked 20.24 hours more per week than in the NSWW, while sleeping 8.98 fewer hours per week than in the NSWW. Results suggest that the NSWW does not accurately reflect sailors' work/rest patterns onboard ships. .pdf

Haynes, L. E. (2007). *A comparison between the navy standard workweek and actual work and rest patterns of U.S. Navy sailors* (Unpublished master's thesis). Postgraduate Naval School, Monterey, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA474039.

The demands placed upon the USN are greater now than ever before. As ships become more versatile, sailors must become proficient in many warfare areas while maintaining operational readiness. The primary manning tool used by the USN to determine manpower requirements is the Navy Stnadard Workweek (NSWW). This research seeks to determine if the NSWW accurately reflects the activities of deployed sailors and determine their work and rest patterns. Each sailor completed surveys detailing tasks in which they were engaged. Survey data were compared to the NSWW. Individual sailors aboard USS CHUNG-HOON (DDG-93) wore Wrist Activity Monitors to collect actigraphy data. Actigraphy data were analyzed using the Fatigue Avoidance Scheduling Tool (FAST), which uses the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) Model, to predict the waking effectiveness level of each sailor. The results showed that the Navy Standard Workweek does not accurately reflect the daily activities of sailors. More importantly, based on FAST results, most sailors had predicted effectiveness levels lower than the predicted effectiveness level of the NSWW Model. It is recommended that the NSWW be revised to more accurately reflect requirements of sailors in different departments. .pdf

Houtman, I., Miedema, M., Jettinghoff, K., Starren, A., Heinrich, J., & Gort, J. (2005). *Fatigue in the shipping industry.* TNO Report No. 20834/11353. Retrieved from http://www.he-alert.org/documents/published/HE00605.pdf.

Main conclusions on the relations between fatigue, collisions and groundings and the shift system:

- Fatigue is causally related to deterioration in performance. Clear debilitating effects are reported such as vigilance, alertness, perception, the quality of the information processing as well as timing.
- Fatigue may be a causal factor in 11 to 23 percent of the collisions and groundings. It should be noted though, that fatigue as a cause of accidents like collisions and groundings will be underreported. Better (international) monitoring of fatigue is warranted.
- Both the desk study and the literature on the relationship between the shift system and fatigue are inconclusive.
- In the literature it is generally concluded that a period of 8 hours of uninterrupted sleep is optimal.

Main conclusions regarding the measures and their consequences:

- Measures that were considered most necessary and effective in reducing fatigue in the Netherlands were:
  - proper implementation of the International Safety Management Code;
  - optimising the organisation of work on board vessels;

- lengthening of the rest period; and
- reducing administrative tasks on board vessels.

- Replacing the two-shift system by a three-shift system by adding an Officer in Charge is the most expensive option with considerable financial consequences for the employers and results in an increased pressure on the maritime educational system. It should additionally be kept in mind that the evidence on the causality of the relation between the 2-shift system - fatigue - groundings and collisions' is inconclusive.
- Adding a crew member designated with administrative tasks is not a real option, since the amount of tasks is not enough for a full time job. Delegating tasks may be a better option. Appointing seafarers authorised for watch and being able to perform other tasks on board may be an option. In time (cheaper) ICT programmes may improve the possibilities to delegate (more) administrative tasks ashore.
- Changing the shift system, e.g. into 4 hours on '-8 hours off -8 hours on -4 hours off-' is an interesting option, which accommodates the advise to have at least 8 hours of rest, and preserves the regularity in shifts over 24 hours.
- Setting up a Fatigue Management Program as integrated part of the USM-code is in line with the implementation (trajectory) of the ISM-Code in that it accentuates fatigue management as part of safety management. It allows organisations to be flexible in their fatigue management. An evaluation of how the ISM-Code is implemented at present is warranted. .pdf

Hursh, S. R., Redmond, D. P., Johnson, M. L., Thorne, D. R., Belenky, G., Balking, T. J., & Eddy, D. R. (2004). Fatigue models for applied research in warfighting. *Aviation, Space, and Environmental Medicine, 75(1),* A44-A53. Retrieved from http://mljohnson.pharm.virginia.edu/pdfs/301.pdf.

The U.S. DoD has long pursued applied research concerning fatigue in sustained and continuous military operations. In 1996, Hursh developed a simple homeostatic fatigue model and programmed the model into an actigraph to give a continuous indication of performance. Based on this initial work, the Army conducted a study of one week of restricted sleep in 66 subjects with multiple measures of performance, termed the Sleep Dose-Response Study (SDR). This study provided numerical estimation of parameters for the Walter Reed Army Institute of Research Sleep Performance Model (SPM) and elucidated the relationships among several sleep-related performance measures Concurrently, Hursh extended the original actigraph modeling structure and software expressions for use in other practical applications. The model became known as the SAFTE Model, and Hursh has applied it in the construction of a Fatigue Avoidance Scheduling Tool. This software is designed to help optimize the operational management of aviation ground and flight crews, but is not limited to that application. This paper describes the working fatigue model as it is being developed by the DoD laboratories, using the conceptual framework, vernacular, and notation of the SAFTE Model At specific points where the SPM may differ from SAFTE, this is discussed. Extensions of the SAFTE Model to incorporate dynamic phase adjustment for both transmeridian relocation and shift work are described. The unexpected persistence of performance effects following chronic sleep restriction found in the SDR study necessitated

some revisions of the SAFTE Model that are also described. The paper concludes with a discussion of several important modeling issues that remain to be addressed. .pdf

Isler, H. (2001, December). *Embedded training system for a component level intelligent distributed control system (CLIDCS).* Paper presented at the Interservice/Industry Training, Simulation & Education Conference, Orlando, FL Abstract retrieved from http://ntsa.metapress.com/index/GW3T74Y4XB0DL0P2.pdf.

This paper describes the Component Level Intelligent Distributed Control System (CLIDCS) architecture for the next generation shipboard Machinery Control System (MCS), and how this design readily provides an environment conducive to embedded training. This architecture, combined with automated control applications, aspects of Condition Based Maintenance (CBM), and integrated automated logistics systems, will reduce the manpower required to operate the plant or shipboard equipment, which is an important design parameter in future MCS designs. The CLIDCS, combined with built-in subsystem redundancy, increases system readiness, maintainability, reliability, and survivability while decreasing the operating and support (O&S) costs. CLIDCS utilizes a true object oriented design (OOD) philosophy for not only the component level embedded software, but also for the hardware and system design. The shipboard environment must support training scenarios for the crew both at and away from port, while not compromising any normal or damage/hazard operations. The CLIDCS architecture with the intelligence distributed to the device level, promotes subsystem training without sacrificing safety of the ship and crew. The embedded training system is immersed within the CLIDCS architecture, allowing the crew to run applications that simulate the subsystem responses to operator inputs. In the training mode, the subsystem control applications operate in the background, and will interrupt the training application to report any adverse condition requiring an immediate operator response. The embedded training system supports both tactical and damage/hazard control scenarios to increase operator effectiveness and awareness of the operator interface and control system responses. The crew can be trained on the actual hardware, and the opportunities for training at sea promote the versatility of the crew. In manpower reduced environments, these factors are critical not only to normal operations, but also to war fighting readiness. (No pdf available.)

Johnston, J. M. (2009). *An activity-based non-linear regression model of Sopite syndrome and its effects on crew performance in high-speed vessel operations* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix =html&identifier=ADA496988.

The Navy's future use of shallow-draft high-speed vessels has provoked questions regarding the effects of resulting ship motion on crews' performance. Sopite Syndrome, a commonly overlooked subset of motion sickness, is responsible for lethargy, fatigue, drowsiness, difficulty concentrating and numerous other performance-diminishing symptoms in shipboard crewmembers who appear to be adapted to vessel motion (Graybiel & Knepton, 1976). Since its discovery in 1976, no physically measurable parameter to quantify Sopite Syndrome and its effect on performance has been established. Recent efforts to develop high-speed shallow-draft vessels coupled with increased automation and reduced manning place a premium on every crewmember. The manning modifications make it more important than ever to ensure that personnel readiness and performance degradation are accounted for in manning model calculations. This study quantifies Sopite Syndrome by using non-linear regression to model activity as a function of time underway and linear regression to model performance. Performance is modeled using the concept of daily activity levels concurrently with ship's motion data, individual demographics and motion sickness questionnaires as input parameters. It was found that over an eight-day underway period, performance on a three-minute manual dexterity task degraded by two to three percent due to Sopite syndrome. .pdf

Ljung, M. (2010). Function based manning and aspects of flexibility. *WMU Journal of Maritime Affairs, 9(1),* 121-133. Retrieved from http://www.springerlink.com/index/W71997730162TT83.pdf.

The aim of the article is to examine the concept of flexibility from a shipping perspective. Flexibility is examined in order to develop strategies, theoretical and applicable, in the field of Function Based Manning (FBM), for achieving optimized manning, which is not the same as reduced manning, with a healthy crew. This is a complex concept in many aspects. Based on research on working life and work organizations conducted by social scientists, two aspects of flexibility are examined; functional flexibility including job enrichment and competence training, and working time flexibility. These issues are analyzed from a shipping perspective. The concept is double-edged in the sense that it entails both having flexibility and being flexible. Does flexibility only serve the interests of the employer? Or, do workers also benefit from flexibility? By combining these two aspects of flexibility, a win-win situation benefiting both employers and employees can be achieved. This article highlights and discusses strategies intended to promote the implementation of a model of optimized manning. .pdf

Lorio, G. P. (2005). *The effect of high speed vessel operations on ship's crew and embarked landing force personnel aboard HSV-2 SWIFT in the areas of motion sickness and motion induced task interruptions.* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA443433.

The Navy's use of high speed vessels such as HSV-2 SWIFT has raised questions of the effects of high speed motion on the ability of personnel to perform assigned duties. Performance degradation may occur during periods of excessive ship motion because of extreme motion sickness or periods of frequent task interruptions. With the use of high speed vessels expected to increase in the near future with the LCS program, the issue of high speed motion effects on personnel becomes operationally relevant. This study will take a two part approach to analyze the effects of high speed motion: the motion sickness of SWIFT's crew and military passengers, and interruptions of task performance caused by vessel motion to critical watch stations. For the first part, statistical analysis will be used to determine relationships between ship motion and motion sickness. For the second part, modeling and simulation will be used to determine if there are watch stations that may be affected by varying levels of motion induced task interruptions. From this analysis, guidelines may be produced to describe the expected levels of motion sickness in personnel as well as watch stations in which personnel may have difficulties performing assigned duties. .pdf

Lundh, M. (2010). *A Life on the Ocean Wave-Exploring the interaction between the crew and their adaption to the development of the work situation on board Swedish merchant ships* (Unpublished doctoral dissertation). Chalmers University of Technology, Goteborg, Sweden. Abstract retrieved from http://swepub.kb.se/bib/swepub:oai:services.scigloo.org:121794?tab2=abs&language=en.

Working on board merchant ships implies being a part of an isolated context in a multi-cultural arena and spending a lot of time away from family and friends. The shipping industry has during the latest decades undergone major changes due to technical development, automation and increased requirements for profitability and competitiveness. The consequences of these changes have been reduced manning on board, changes in task performance and new tasks to perform. The overall aim of this thesis was to investigate the interplay between the ship, the technological system on board and the human system in order to understand how the developments in the shipping industry during the latest decades has affected the working conditions and well being of the sea farers and in particular the engine officers. The results given in this thesis indicate that the engine crew has to adapt to the suboptimal prerequisites given by the technical and hull system in order to be able to perform their tasks as the prevailing knowledge in ergonomics is not being fully utilized in the design of the engine department. The consequences are less favourable behaviours which enhance the risk of injuries and enforce less effective accomplishment of the tasks. The engine officers also report an elevated level of stress and role conflict but no elevated levels of mental ill-health. However, it does not seem as the job content or qualification levels are the main source of work stress. Rather, as indicated by the highly elevated role conflict, the often contradicting requirements raised on the shipping operation seem to often create conflicts for the engine officers. They are supposed live up to their professional standards on shipping and at the same operate the ship with the reduced crew numbers at high speed to satisfy the requirements for profitability. (No pdf available.)

Marine Accident Investigation Branch (2004). *Bridge watchkeeping safety study.* Retrieved from http://www.vht-marine.de/vht2008/pdf/dft_masafety_030084.pdf.

This study was commissioned to establish the principal factors that cause nautical accidents, and to consider whether fatigue is as prevalent and dangerous as indicated by the Jambo and similar accidents. The study has reviewed in detail the evidence of 66 collisions, near collisions, groundings and contacts that were investigated by the Branch. It has confirmed that minimal manning, consisting of a master and a chief officer as the only two watchkeeping officers on vessels operating around the UK coastline, leads to watchkeeper fatigue and the inability of the master to fulfil his duties, which, in turn, frequently leads to accidents. It has also found that standards of lookout in general are poor, and late detection or failure to detect small vessels is a factor in many collisions. The study concludes that the current provisions of STCW 95 in respect of safe manning, hours of work and lookout are not effective. .pdf

Mason, D. R. (2009). *A comparative analysis between the navy standard workweek and the work/rest patterns of sailors aboard U.S. Navy cruisers* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from http://government-reports.com/pdf/ada509046.pdf.

In March 2008, two USN ships failed their Inspection and Survey (INSURV) assessments with deficiencies ranging from inoperable equipment to inadequate housekeeping practices. The question of why these problems exist must be addressed. A study to determine the total number of hours sailors actually work in contrast with the Navy Sailor Workweek (NSWW) Model is extremely important. Previous research regarding this topic has indicated that the NSWW does not accurately reflect the daily activities of sailors. In fact, results from a recent study on USS CHUNG HOON by Haynes, showed that a majority of the sailors received much less sleep and worked longer hours than allocated in the NSWW Model. This research focuses on widening the scope from the Haynes study on USN destroyers, to determine if similar conditions exist onboard USN cruiser vessels. The results indicated that 85% of the participants within the study exceeded the 81 hours of available time allotted by the NSWW. On average, sailors in the current study, excluding officers, worked 9.90 hours per week more than allotted in the NSWW. .pdf

Miller, N.L., & Firehammer, R. (2007). Avoiding a second hollow force: The case for including crew endurance factors in the afloat staffing policies of the U.S. Navy. *Naval Engineers Journal, 119(1),* 83-96. doi: 10.1111/j.0028-1425.2007.00007.x/full. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.0028-1425.2007.00007.x/abstract.

In order to meet its obligations for prompt and sustained combat at sea, the USN relies on sailors to perform relentlessly while underway in highly stressful combat environments. The Navy currently uses an afloat staffing policy that is calculated using a 70-hour workweek per sailor metric. However, this construct fails to factor in an individual sailor's capacity to sustain performance and is based instead on a notional Navy Sailor Workweek (NSWW). Part of the inadequacy of the current staffing policy results from its failure to consider an inviolable and basic physiological requirement for adequate sleep and rest for sailors. Research indicates a strong causal relationship between sleep and performance. When deprived of sleep, either chronically or acutely, human performance suffers in a dramatic and predictable manner. These performance decrements have even been equated to the effects of alcohol. If the USN is to deliver the combat capability demanded by our government and stated in Navy governing documents, sleep and rest requirements must be accounted for in staffing methodologies. To achieve full combat capability, the Navy must change its culture and adopt programs that promote crew endurance. Human system integration can provide a means to accomplish this goal. .pdf

Nguyen, T., Davidson, L., Skinner, M., & Husband P. (2005, December). *Benefits and techniques of integrating embedded training capabilities in legacy hardware-specific control systems.* Paper presented at The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC) conference. Abstract retrieved from http://ntsa.metapress.com/index/4KEKL32V0D0CP55B.pdf.

The benefits of embedding training capabilities as part of the physical equipment used during tactical operations are well known and widely accepted in the U.S. military training communities. Embedded Training (ET) provides a realistic and effective training experience that is identical to live operation and, since the training is conducted in the operational environment. The benefits of ET are most obvious when implemented on systems with unique Human System Interfaces that consist of hardware buttons, levers, multiple indicator types and different display technologies. The focus of this paper is to describe the benefits and techniques of integrating ET capabilities into a shipboard control system and to provide practical insights into the integration process. The process will be illustrated using the implementation of ET for a control system of an electric generation plant aboard a USN destroyer. Integrating ET features in an existing (legacy) hardware and software system presents several technical challenges that require innovative techniques to accomplish the design objectives. Creating an effective instructor interface, addressing multiple software languages, handling data conversions, dynamically rerouting hardwired signals, and providing real-time hardware-in-the-loop simulation models that mimic mechanical, and electrical components are a few examples. The ET system consists of an instructor workstation with a Graphical User Interface (GUI) that allows the instructor to control the real-time dynamic simulation of the plant equipment. The instructor workstation connects to the physical control system equipment and allows the instructor to perturb the signals coming to the equipment for creation of various training scenarios. The simulation model provides excitation to the control system equipment as if the signals were coming from the real plant giving the operator an exact replication of live operation. Through the description of this ET system, the authors intend to present information that may be applied to other embedded training programs. (No pdf available.)

Phillips, K. L., Hison, R. L., & Ricci, K. E. (2001, December). *A new approach to training in a reduced manning environment.* Paper presented at the Interservice/Industry Training, and Simulation Conference (I/ITSEC), Orlando, FL. Abstract retrieved from http://ntsa.metapress.com/index/w12xjpxt5ap34edr.pdf.

With personnel costs accounting for 60% of the total ownership cost of Navy ships, the role and number of people onboard has come under increased scrutiny. Target manning numbers for DD 21, the next-generation destroyer class, are approximately one quarter of the ship class it will replace. While automation and other advanced technologies can greatly decrease the need for a "human in the loop," the reduced manning environment presents new challenges for training. Redundancy in expertise and manning coverage for "on the job" training in this new environment is dramatically decreased; watchstanders and maintainers must come aboard as "Full Up Rounds," immediately ready to perform their duties. This philosophical shift must be accompanied by changes to current Navy training - from training management to training pipelines to training delivery methodologies. When viewed as an integral part of the ship's operational concept, training becomes an enabler for reduced crew sizes, rather than a burden to be dealt with after ship design. From 1999 through 2000, a joint

government/industry team met with several Navy groups to discuss the ramifications of greatly reduced crew sizes on Navy training. These focus groups - which ranged from representatives of pre-commissioning and post-deployment crews to members of training commands - provided great insight into today's Navy training experience: what works well, what doesn't, and what (sometimes subtle) changes can have a tremendously positive impact on crewmembers' ability to be "Ready to Fight." This paper (1) briefly describes the methodology used to collect user input, (2) identifies and discusses the issues raised in these focus groups, (3) describes a training model suggested as an outcome of these sessions, and (4) suggests areas requiring further study. (No pdf available.)

Smith, A. P., (2007). *Adequate crewing and seafarer's fatigue: The international perspective* (Report No. unknown). Retrieved from http://www.sindacatomarittimi.eu/media/documenti/83.pdf.

Global concern with the extent of seafarer fatigue is widely evident everywhere in the shipping industry. Maritime regulators, ship owners, trade unions and P & I clubs (Protection and Indemnity) are all alert to the fact that in some ship types, a combination of minimal manning, sequences of rapid turnarounds and short sea passages, adverse weather and traffic conditions, may find seafarers working long hours with insufficient recuperative rest. A holistic view is needed of the effects of stress and health factors associated with long periods away from home, limited communication and consistently high work loads on seafarers. In these circumstances fatigue and reduced performance may lead to environmental damage, ill-health and reduced life-span among highly skilled seafarers who are in short supply. A long history of research into working hours and conditions and their performance effects in process industries, road transport and civil aviation, where safety is a primary concern, can be usefully compared to the situation in commercial shipping. The issue of adequate crewing and the effect of fatigue upon health and safety are clearly closely related. This report provides a review of our current state of knowledge of these problems and an evaluation of the extent to which fatigue can be prevented and managed by a variety of means. It aims to form the basis from which to review the principles for establishing safe manning levels whilst also providing an overview of the broader picture of fatigue in the maritime sector. .pdf

Vaughan, E., & Lee, L. (2010). *US Patent Application 12/806,259*. Washington, U. S. Patent and Trademark Office. Retrieved from http://www.google.ca/patents?hl=en&lr=lang_en&vid=USPATAPP12806259&id=gFBgAQAAEBAJ&oi=fnd&dq=Flyawake+Hursh&printsec=abstract.

Apparatus and method for analyzing and managing fatigue primarily in aviation occupations. The invention is adaptable to other occupations where assuring crew rest is critical. Air crew specific GUIs allow for the insertion of sleep into crew work schedules. Alternative sleep models are used for different modes of sleep. The invention produces as an output work/sleep schedules with an associated effectiveness determination. .pdf

# 6 Human-Systems Integration

Papers in the Human-Systems Integration section range from the use of simulation solutions to implement strategies as found in the other categories (Policy and Procedures, Personnel and Training), to increasing the ergonomics of systems interfaces, and other human factors-derived solutions pertaining to safety, learning curve, and enhanced human-in-the-loop efficiency.

Allender, L. (2000). Modeling human performance: Impacting system design, performance, and cost. In M. Chinni (Ed.) *Proceedings of the Military, Government and Aerospace Simulation Symposium, 2000 Advanced Simulation Technologies Conferences* (pp. 139-144). Washington, D. C. Retrieved from http://www.arl.army.mil/www/pages/447/ Astc2000-Allender.pdf.

Human performance must be modeled, and modeled early in order to impact system design, performance, and cost. This notion is consistent with the U.S. Army's push toward simulation-based acquisition and can be implemented through simple equations, stochastic task network modeling, or representation in force-on-force models. The underlying rationale and examples of such modeling are discussed. A key reason that human performance must be modeled is that the human component is probably the "noisiest" component in the system. The examples given here are all based on models developed with the capabilities present in IMPRINT (the Improved Performance Research Integration Tool), developed by the Human Research and Engineering Directorate of the U.S. Army Research Laboratory. .pdf

Andrews, D., Casarosa, L., Pawling, R., Galea, E., Deere, S., & Lawrence, P. (2007). Integrating personnel movement simulation into preliminary ship design. *International Journal of Maritime Engineering, 150,* pages not available. Retrieved from http://fseg.gre.ac.uk/fire/EGO_files/7_IJME IPMSintoPSD Apr07_DJA8_distribute_final.pdf. .

Traditionally, when designing a ship the driving issues are seen to be powering, stability, strength and seakeeping. Issues related to ship operations and evolutions are investigated later in the design process, within the constraint of a fixed layout. This can result in operational inefficiencies and limitations, excessive crew numbers and potentially hazardous situations. This paper summarises work by University College London (UCL) and the University of Greenwich prior to the completion of a three year EPSRC funded research project to integrate the simulation of personnel movement into early stage ship design. This integration is intended to facilitate the assessment of onboard operations while the design is still highly amenable to change. The project brings together the University of Greenwich developed maritimeEXODUS personnel movement simulation software and the SURFCON implementation of the Design Building Block approach to early stage ship design, which originated with the UCL Ship Design Research team and has been implemented within the PARAMARINE ship design system produced by Graphics Research Corporation. Central to the success of this project is the definition of a suitable series of Performance Measures (PM) which can be used to assess the human performance of the design in different operational scenarios. The paper outlines the progress made on deriving the PM from human dynamics criteria measured in simulations and their incorporation into a Human Performance Metric

(HPM) for analysis. It describes the production of a series of SURFCON ship designs, based on the RN's Type 22 Batch 3 frigate, and their analysis using the PARAMARINE and maritimeEXODUS software. Conclusions on the work to date and for the remainder of the project are presented addressing the integration of personnel movement simulation into the preliminary ship design process. .pdf

Arciszewski, H. F. R., de Greef, T. E., & van Delft, J. H. (2009). Adaptive automation in a naval combat management system. *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans, 39(6),* 1188- 1199. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5229329.

There is a continuing trend of letting fewer people deal with larger amounts of information in more complex situations using highly automated systems. In such circumstances, there is a risk that people are overwhelmed by information during intense periods or, on the other hand, do not build sufficient situational awareness during periods of slack to deal with situations where human intervention becomes necessary. A number of studies show encouraging results in increasing the efficiency of human-machine systems by making the automation adapt itself to the human needs. Current literature shows no examples of adaptive automation in real operational settings, however. We introduce a fine-grained adaptation methodology based on well-established concepts that is easy to comprehend and likely to be accepted by the end user. At the same time, we let the machine operate like a virtual team member in that it continuously builds its own view of the situation independent from the human. Working agreements between human and machine provide lower and upper bounds of automation that are in advance determined by the end user so that unwanted appropriation of responsibility by the machine is avoided. The framework is domain neutral and therefore thought to be applicable across a wide range of complex systems, both military and civilian. It gives researchers an architecture that they can use in their own work to get adaptive automation up and running quickly and easily. .pdf

Bost, J.& Galdorisi, G. (2004, September). *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.* Paper presented at the meeting of The Ninth International Command & Control Research and Technology Symposium, Copenhagen, Denmark. Retrieved from http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA466357.

The need to transform the U.S. military is a top priority of the DoD. President Bush emphasized this in his National Security Strategy when he noted: "The major institutions of American National Security were designed in a different era to meet different requirements. All of them must be transformed." Transformation is a challenging imperative, especially in a service as rich in tradition as the USN. Two generations ago, President Franklin Delano Roosevelt, frustrated with how slowly the USN was changing, famously said "To change anything in the Navy is like punching a feather bed. You punch it with your right and you punch it with your left until you are finally exhausted, and then you find the damn bed just as it was before you started punching." Unlike the Navy of President Roosevelt's day, today's naval leadership is committed to transforming the Navy and ensuring that the Navy of tomorrow is a critical component of the Joint warfighting force and is a Navy that, in the

CNO's words, "Gives the President options." Navy leaders have known intuitively that a smaller, better-trained, more stabilized crew could mean a more capable, more professional warfighting team. The ongoing DDG-51 Class Reduced Manning Initiative undertaken by the Naval Sea Systems Command Program Executive Office (PEO) Ships addresses the policy, processes, culture, tradition, and technology aspects of achieving this reduced manning posture on USN ships. This paper will address the full breadth of this Manning Initiative but will focus primarily on the use of technology to better engineer combatant ships in a way that enhances warfighter performance by identifying sailor tasks and skills, allocating them to hardware, software, and people, and reducing workload. This paper will show that the discipline of HSI is a key enabler for achieving effective and appropriate technology insertion in USN ships. .pdf

Brockett, C. H., Scott-Nash, S., & Pharmer, J. A. (2001, December). *Verifying and validating the Aegis air defense warfare human performance model.* Paper presented at the Interservice/Industry Training, Simulation & Education Conference, Orlando, FL. Abstract retrieved from http://ntsa.metapress.com/index/JFKJBY7FHW91U6YF.pdf.

In some industries, simulation and modeling techniques are a widely accepted, integral part of system design, while in others these techniques may be perceived as expensive, unreliable, or inconclusive. Within the Manning Affordability Initiative (MAI), which was funded by the ONR and managed by the DD-21 Program Office, we have attempted to demonstrate that simulation and modeling techniques can play a significant role during the design of future combatants, especially in light of future Naval goals to optimize shipboard manning. The MAI used a warfighter-centered design approach to developing a prototype air defense warfare (ADW) system, and human-in-the-loop data was collected from the watchstations in use today and from the prototype watchstations. Under a simulation experiment, the Integrated Performance Modeling Environment (IPME), a discrete event simulator, was utilized to represent a demanding ADW scenario, and models were created to simulate performance for ADW teams using today's watchstation and then to predict the impact on performance that can be expected from the prototype. These complex models include multiple operators, dynamic operator task assignment configurations, workload tracking, internal and external communication network activity, and processes such as air track detection, track identification and re-identification, monitoring of changes in track profile, threat evaluation and engagement. This paper discusses the process of calibrating, verifying and validating models of the current and prototype watchstations, and presents the conclusions made. (No pdf available.)

Bryce, L., & Lance, S. (2003, October). *Maximizing rig automation safety and efficiency with remote monitoring and management.* Paper presented at SPE Annual Technical Conference and Exhibition, Denver, CO. file://localhost/Abstract retrieved from http/::www.onepetro.org:mslib:servlet:onepetropreview%3Fid=00084169&soc=SPE.

The goal of rig automation has always been to improve safety and efficiency during drilling operations. Repetitive operations can be carried out by equipment designed to reduce manpower/human interaction. Interaction between rig personnel and equipment has changed as more areas of the drilling rig have become automated. In order to make this interaction more seamless a system has been developed comprised of remote monitoring, diagnostics and technical support. Case histories of rig equipment operations have shown that use of this remote monitoring and management system reduces downtimes, increases safety and enhances maintenance. The system expands the focus of rig automation and moves rig-automation technology into a new realm. The future of drilling operations, spares planning and equipment development can be changed from a reactive mode into a proactive mode, giving drilling contractors and operators a much needed advantage. (No pdf available.)

Burns, J., Gordon, J., Wilson, M., Stretton, M., & Bowdler, D. (2005, December). *A framework for applying HSI tools in systems acquisition.* The Interservice/Industry Training, Simulation & Education Conference. Abstract retrieved from http://ntsa.metapress.com/index/35k5wcg8aqhp4e68.pdf.

Both DoD and service specific mandates call for HSI to be addressed throughout all phases of the System Acquisition (SA) process. While HSI domains and their associated methods and tools are well defined, there does not exist corresponding strategic or practical guidance for Program Managers (PMs) as to when in the acquisition process different types of HSI methods and tools have application. Absent such a road map, PMs often rely exclusively on experience without a basis for prioritizing cost, benefit, and data availability. A framework is presented for organizing the strategic application of different classes of HSI methods and tools, specifically those related to Manpower, Personnel, Training, and Human Factors Engineering. This framework is predicated on the idea that there are a finite set of SA strategies or use cases for material solutions--it is salient aspects of the SA strategy that should drive the tactical application of HSI methods and tools. It is argued that rather than defining one process that dictates when different types of HSI methods and tools should be applied, it is more useful to view the SA strategy as informing the application of methods and tools in terms of a constraint satisfaction. An approach to understanding and prioritizing constraints is presented and then using this knowledge, a framework for application of different types of HSI methods and tools is outlined. SA strategies are detailed and the framework is applied to provide examples of when in the SA process different types of methods and tools should be applied, what their input requirements would be, what their output would be, and which SA artifacts these categories of methods and tools inform. (No pdf available.)

Campbell, G. E., Cannon-Bowers, J. A., & Villalon (1997, December). *Achieving training effectiveness and system affordability through the application of human performance modeling.* Paper presented at the Interservice/Industry Training, Simulation & Education Conference, Orlando, FL. Abstract retrieved from http://ntsa.metapress.com/index/k5v4x62126t28327.pdf.

The future holds a number of significant challenges for the Navy. First, as the nature of warfare changes, warfighters are being faced with increasingly complex technology and ambiguous and dynamic environments. Second, there is a strong push to produce dramatic reductions in manning without reducing effectiveness. In order to meet these challenges, a variety of new technologies will have to be developed. In this paper we describe an effort that we are currently pursuing at Naval Air Warfare Center Training Systems Divisions (NAWCTSD), the development of human performance models and modeling tools. We begin by giving an overview of one particular approach to human performance modeling that we are investigating. Then we continue by describing the role that human performance models and modeling tools might play in two critical areas, naval training and naval ship/system design. (No pdf available.)

Carreno, J., Galdorisi, G., & Lemon, A. (2010). *The penultimate C4ISR challenge: Reducing military manpower and total operating costs.* Paper session presented at the meeting of the 15th International Command and Control Research and Technology Symposium, Santa Monica, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA525239.

Military officials, respected think-tanks and Congressional researchers are universal in their contention that the cost of military manpower makes up the largest part of the total ownership cost (TOC) of military systems across all the Services. These same officials also note that overall military manpower costs are the fastest growing accounts even as the total number of military men and women decrease. This challenge has been addressed at various conferences and symposia - including multiple times in the International Command and Control Research Technology Symposium (ICCRTS) fora - and those who have studied the issue are universal in their opinion that "something must be done" to reduce military manpower to reduce TOC, but thus far solutions and "best practices" have been elusive. Network-Centric technologies combined with the emerging disciplines of human factors engineering (HFE) and HSI offer the potential to realize significant manpower savings, but these network-centric methods and practices have been employed only sporadically to reduce manning and today remain extraordinarily underleveraged. We will offer a best-practices model and show how using these methods and practices have dramatically reduced manning for the USN's DDG-1000 Zumwalt-class destroyer and will extrapolate these lessons learned for a community of best practices that is now emerging. .pdf

Chipman, S. F., & Kieras, D. E. (2004). *Operator centered design of ship systems.* Paper presented at the meeting of the Engineering the Total Ship (ETS) Symposium, Gaithersburg, MD. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA422107.

Cognitive science research, much of it supported by the ONR, is bringing about a scientific revolution in our understanding of the human operator. It is yielding computational theories of human cognition and perceptual/motor activity that provide precise quantitative predictions of important variables such as the times required to complete tasks or to learn them in training. Although the scope of coverage of these theories is limited and basic research aimed at expanding them is on-going, they already have much to offer in aiding the design of ship systems that will optimize the combined effectiveness of human operators and the systems they will be using. This presentation discusses 1) what can be done now, 2) tools under development that will facilitate the use of these theories, reducing the labor involved, and 3) a long-term vision for what might be achieved in this area. .pdf

Cowen, M. B., & Kaiwai, J. L. (2010). *Key human system integration plan elements for command and control acquisition.* Paper presented at the 2010 Command and Control Research and Technology Symposium, Santa Monica, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA525346.

As the Navy transitions to the guiding principles of Net-Centric Warfare, it is imperative to recognize the importance to access vital, secure and timely tactical information in any given battlespace. The Space and Naval Warfare Systems Command is the acquisition lead for several systems that will create a highly adaptive, networked and distributed defense force with the increased speed, agility and security required to support constantly evolving mission needs. The systems will provide the commander the ability to make more timely and informed decisions based upon the best information and practices. HSI is a system engineering process designed to ensure that human performance related issues are identified early in the acquisition process and mitigated during system development and testing using appropriate performance metrics and data collection methods. HSI activities are guided by an acquisition Human System Integration Plan (HSIP) that identifies and integrates design requirements for (a) Human Factors Engineering, (b) Personnel, (c) Habitability, (d) Manpower, (e) Training, (f) Safety and Occupational Health, and (g) Survivability. Key elements of HSI for Command and Control acquisition include: (1) top-down functional analysis/allocation, (2) task-centered design, (3) cognitive engineering, and (4) knowledge mapping. .pdf

Didonato, L., Famme, J. B., Nordholm, A., & Lemon, A. (2004, December). *A total ship-crew model to achieve human systems integration.* Paper session presented at the meeting of The Interservice/Industry Training, Simulation & Education, Orlando, FL. Retrieved from http://www.businessdevelopmentusa.com/references/1564.pdf.

Requirements for new ships in an era of increasing threats, escalating personnel costs and fiscal constraints have escalated the priority of HSI. The challenge is to create and use metrics for ship and human engineered systems that optimize human performance within ships that are designed with complex automated propulsion, auxiliary and weapon systems. Total Ship Systems Engineering (TSSE) includes techniques for manning analysis to characterize and validate the crew duty requirements in an associated sailor profile data base that describes the composite knowledge-task-time demand for each crew position across all mission profiles in the context of advanced automation technologies and survivable hull forms. A technology considered but not currently implemented in the manning analysis process is a Total Ship-Crew Model (TS-CM) that adds the attribute of dynamic time to the analysis of coupled ship systems-crew performance. This paper will address the use of a TS-CM analysis tool to validate ship systems processes and reduced crew manning while capturing the ship-crew model for future use in support of HSI objectives over the ship lifecycle. .pdf

Dobie, T. (2003, October). *Critical significance of human factors in ship design*. Paper presented at the 2003 Research Vessel Operators Committee, Minnesota, MN. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.116.3732&rep=rep1&type=pdf

There is a critical need for a human factors input whenever technology and people interact. When systems are functioning well, few seem to appreciate that this smooth operation is largely due to the prior thought and effort that has gone into optimizing the human factors element; when disaster strikes, however, there is a sudden demand for immediate rectification. As the ship design evolves and crew sizes diminish, even greater emphasis should be placed upon the man/machine interaction in order to ensure safety and efficiency during both routine and emergency operations. Severe ship motions limit the human ability to operate command and control and communication systems, navigate, perform routine maintenance and prepare food. In an emergency, such operations as refueling at sea and damage control can be severely hampered. The human being is susceptible to degraded performance in a number of ways. There are the purely physical limitations on both gross and fine motor skills imposed by the adverse effects of heavy seas. The former physical limitations include standing, walking, and carrying out operational and maintenance tasks that include major whole-body movements required to perform these types of operations. Fine motor skills include such fine movements as delicate control adjustments and computer operations. Knowledge of the sea/hull interaction and its potentially deleterious effect on the physical activities of crewmembers can provide valuable information for improved ship and equipment design as well as establishing guidelines for efficient heavy weather operations. In addition, ship motion can cause significant mental degradation leading to overall performance decrement and increased potential for injury. Motion sickness is an example of this type of malady. Seasickness is the most common cause of motion sickness and can have a profoundly adverse effect on human performance. There is also the Sopite Syndrome, a human response to provocative motion characterized by drowsiness and mood changes. It is not yet clear whether this is due to boredom, inactivity and loss of concentration or the result of the effects of provocative motion. Whatever, this soporific response can lead to inefficiency and accident-proneness, that is not so readily identifiable by the sufferer or a supervisor. These motion responses are highly relevant to the Research Vessel Operators Committee (RVOC) research ship situation. Not only because of the plans to reduce the number of crewmembers, but also because a number of the research or academic team members may have little or no recent experience at sea, particularly in heavy weather. Attention to onboard habitability issues and fostering a high level of morale among crewmembers are also very important factors in support of crew retention, particularly in modern ships with smaller numbers of crewmembers. The author will address these issues and make recommendations to improve the incorporation of the human element in future ships. .pdf

Drew, K. F., & Scheidt, D. (2004). *Distributed machine intelligence for automated survivability.* Paper presented at the meeting of the Engineering the Total Ship (ETS) Symposium, Gaithersburg, MD. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA422118.

Future Naval platforms face new dynamic operational scenarios that demand more flexible performance. At the same time, reduced manning and lower total ownership costs are now major design and acquisition objectives. Improved warfighting capability can be achieved by reducing vulnerability to damage and failure events. Rapid system recovery from unanticipated damage using current doctrine and practice conflicts with today's reduced manning objectives. Decentralized ship system architectures and agent-based technologies promise to enable the Navy to improve rapid system recovery and assist in meeting these affordability challenges. Decentralization of systems and resources improves both ship survivability and fight through capability. This is accomplished through rapid sensing and response and dynamic reconfiguration, which results in improved continuity of service of ship systems. Embedded intelligence at the component level insures rapid, effective autonomous reaction and response to local fault conditions. Agent-based technologies are utilized to provide autonomous cooperation between sensors and actuators, in which elements reason and react locally while achieving global objectives through agent-to-agent communications. While intelligent decision making is performed locally by autonomous agents, the sailor will direct these agents through comprehensive supervisory control with improved on-demand situational awareness. When fielded, these systems will provide increased situational awareness, increased fight through capability, and improved damage control. This paper describes Navy Science and Technology projects currently underway in academia, industry, and Navy laboratories to achieve these goals. .pdf

Famme, J., Gallagher, C., & Masse, M. (2003). *Achieving human systems integration through design.* Retrieved from http://www.businessdevelopmentusa.com/docs/HSISymTSDCJune2003.pdf.

This paper will describe how HSI objectives can be achieved by the creation and use of first principle physics models of the ship hull, mechanical & electrical (HM&E) systems throughout the ship "spiral" design process. The models will create HM&E systems performance metrics to verify: engineering throughout all design phases; automation strategies versus manning levels; ship survivability and safety objectives; and support dock and sea trials, and live fire testing. Following trials the validated models and performance metrics will be provided to NAVSEA to support commissioned ships for: school house to total ship embedded training enabling the Revolution in Training and Task Force Excel initiatives; both sailor and HM&E systems performance measurement, readiness assessment, battle decision aids and distance support. The validated physics models can be re- used during ship modernization to verify ShipAlt design and to insure that HSI objectives are maintained. It is projected that the use of these HM&E models also will improve the efficiency of the ship design process and reduce significantly the "over cost" of new ship classes in support of Sea Enterprise. .pdf

Freeman, J. T. (2002, June). *Complementary methods of modeling team performance*. Paper presented at the 2002 Command and Control Research and Technology Symposium, Monterey, CA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA461076.

Computational tools and techniques for modeling team performance have advanced significantly in recent years. However, there have been few efforts to combine complementary modeling approaches. In the Manning Affordability Initiative, we have applied three modeling technologies to experimental data from a single domain (air defense warfare), a single scenario, and common watchstation technologies (current Aegis technology and an advanced prototype). The conclusion of this multi-year project in early 2002 offers an opportunity to review the findings. The proposed panelists will summarize a human-in-the-loop experiment conducted to provide modeling data and present findings from efforts to integrate three modeling approaches for design and design validation. Team Optimal Design (TOD) focuses on team modeling. The Integrated Performance Modeling Environment (IPME) uses a general task modeling technique that applies well to individuals or teams. The GOMS (Goals, Operators, Methods and Selection) Language Evaluation and Analysis Tool (GLEAN) combines individual models of users interacting as a team. .pdf

Gould, D., & Twomey, B. J (2004, October). *Overview of the assessment process for software within the marine sector.* Paper presented at the COTS(Commercial off the Shelf) and SOUP (Software of Uncertain Pedigree) Seminar, London, UK. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1514178.

This paper covers the current situation in the marine industry with regards to software in programmable electronic systems, their application and regulation. It will enlarge on the current processes applied by Lloyd's Register in the marine industry and outline challenges facing the long-standing classification process and will look at a possible alternative approach better suited to this rapidly changing environment based on a systems engineering approach. .pdf

Gould, K. S. (2009). *Faster, better, safer? Studies of safety, workload and performance in naval high-speed ship navigation*. (Unpublished doctoral dissertation). Retrieved from Bergen Open Research Archive https://bora.uib.no/handle/1956/3484.

Ship navigation in the Royal Norwegian Navy (RNoN) involves high demands on navigators, who are required to work under a number of dangers. Operations are carried out in poor weather and darkness, at day and night, in restricted waters, and at high speeds. Accidents are frequent, and sometimes serious. Currently, the RNoN is in the process of replacing its Hauk-class fast patrol boats with the new Skjold-class littoral combat ship. Fast patrol boats play an important role in Norway's coastal defence. Since this transition will involve a major change in manning levels and task characteristics, it is expected to have a considerable impact on the navigator's demands. The aims for this project were to a) examine the situation characteristics of past navigation accidents in the RNoN, and b) investigate the consequences of the Hauk-Skjold transition on workload and performance in navigation. This was accomplished through three individual studies. The first study in this project examined the presence of performance-shaping factors (PSFs) in investigation reports following 35 navigation accidents in the RNoN between 1990 and 2005. This was done to provide an overview of the situation characteristics present at the time of the accidents, related to either the human, task, system or environment. PSFs are defined as any factors which influence the likelihood of an error occurring. Factors related to task requirements and individual cognitive characteristics were shown to be most common, followed by operational characteristics of the system. Eight PSF clusters were found, indicating a pattern in accident circumstances. It was shown that accidents almost always have a high number of different factors influencing accident risk. The second study examined mental workload and performance in simulated high-speed ship navigation. Two navigations methods were compared; these were based on electronic chart display and information system (ECDIS) and a conventional system using paper charts. Twenty naval cadets navigated in high-fidelity simulators through 50 nautical mile-courses with varying levels of difficulty. Results showed that ECDIS navigation significantly improved course-keeping performance, and reduced the total amount of communication on the bridge. No differences were observed in subjective workload between the two groups. Heart rate variability and skin conductance measurements did indicate higher sympathetic activation in conventional navigation, but the differences between groups were not statistically significant. The third and final study in this project investigated how workload and performance in high-speed ship navigation was affected by sleep deprivation, using two different navigation methods. In two separate weeks, five navigators sailed through ten 55-minute routes in high-fidelity simulators, while undergoing 60 hours total sleep deprivation. Navigation performance was measured in addition to subjective and psychophysiological indices of workload and sleepiness. Results showed that navigation performance again was significantly better in the electronic chart condition, but was largely unaffected by sleep deprivation in both conditions. At the same time, there was significant interaction between speed, sleep deprivation and navigation method, indicating that navigators using electronic charts reduced their speed proportionally more under periods of high sleepiness. Secondary task performance was significantly reduced by sleep deprivation, but was equally affected in both conditions. Mental workload was significantly higher in the electronic-chart condition, as indicated by subjective ratings and heart rate variability. No significant differences in sleepiness were found between navigation methods, but electroencephalographic recordings indicated a higher incidence of sleep episodes in the electronic-chart condition after 52 hours of sleep deprivation. This possible risk may have been influenced by significantly lower overall arousal (indicated by lower sympathetic activation) in the electronic-chart condition. .pdf

Grech, M. (2005). *Is automation a help or a hindrance?* Powerpoint Presentation. Retrieved from http://www.nmsc.gov.au/media/pages_media_files/files/MS05-Michelle Grech - Is Automation a Help or a Hindrance.pdf.

The authot discussed the technological advances and the need to reduce crew size that has prompted the maritime industry to undergo the same evolution in automation that the aviation and other highly complex industries have undergone. However, contrary to the aviation domain the human factors aspect has been treated inconsequentially within the maritime domain with little or no consideration towards human systems. The author surmised that this shortfall in human factors research could perhaps be attributed to a belief within the maritime community that automation can solve the human problem and replace humans in most shipboard tasks. But, is this really the case? The author analysed a number of studies that have shown that advances in technology and new automation are increasing rather than lowering cognitive demands on humans (e.g. Bainbridge, 1983; Endsley & Kaber, 1999). In

addition, automation is creating a situation were human understanding of system parameters is diminishing as more people are now operating solely as monitors of new automated systems (Endsley, 1996). .pdf

Greef, T. de, & Arciszewski, H. (2007). A closed-loop adaptive system for command and control. *Foundations of Augmented Cognition: Lecture Notes in Computer Science, 4565,* 276-285, doi: 10.1007/978-3-540-73216-7_31. Retrieved from http://www.springerlink.com/index/VN110036N477R0T5.pdf.

On Navy ships, technological developments enable crews to work more efficiently and effectively. However, in such complex, autonomous, and information-rich environments a competition for the users' attention is going on between different information items, possibly leading to a cognitive overload. This overload originates in the limitations of human attention and constitutes a well-known and well-studied bottleneck in human information processing. The concept of adaptive automation promises a solution to the overwhelmed operator by shifting the amount of work between the human and the system in time, while maintaining a high level of situation awareness. One of the most critical challenges in developing adaptive human-machine collaboration concerns the design of a trigger mechanism. This paper discusses and evaluates a number of possible triggers for the usage in closed-loop adaptive automation from the perspective of command and control. .pdf

Groskamp, P., Paassen, M. van, & Mulder, M. (2005). Interface design for engagement planning in anti-air warfare. *Proceedings of the Systems, Man and Cybernetics, 2005 IEEE International Conference, 1,* 311-316. Retrieved from http://ieeexplore.ieee.org/xpls/abs _all.jsp?arnumber=1571164.

In future C2 for anti-air warfare (AAW), the nature of warfare changes from open seas to coastal areas, budget reductions force to 'do more with less', and technology causes increasing speed and maneuverability of weapons. This results in a higher workload for operators on ships, who are responsible for accomplishing a mission. In this paper, ecological interface design (EID) is applied to C2 to reduce workload and improve situation awareness. New displays were developed to support operators in engagement planning during high load scenarios. The design rationale of the engagement planning interfaces and the results of a first experimental evaluation are discussed. .pdf

Hemmen, H. van. (2009). Human factors analysis and the shipboard environmental department. *Marine Technology, 46(4),* 200-212. Retrieved from http://www.ingentaconnect.com/ content/sname/mt/2009/00000046/00000004/art00003.

COMSEAPRINT HSI is used to analyze the effect of reduced crew sizes and increased crew workloads resulting from increased regulatory requirements on oceangoing commercial vessels (as defined as ships with crew between 10 and 30). Most of the increased crew workloads are driven by recent environmental regulations and the analysis indicates that the creation of an environmental department in addition to the traditional deck and engine departments would efficiently address HSI existing and emerging problems on commercial ships. (No pdf available.)

Hiltz, J. A. (2005). *Damage control and crew optimization.* Technical Memorandum TM-2005-010. Defence Research and Development Canada–Atlantic, Dartmouth, NS. Retrieved from http://handle.dtic.mil/100.2/ADA436391.

The costs associated with personnel and maintenance account for approximately 70% of the total operating costs of a ship. Of these costs more than 50% are associated with personnel. As the CF have made the reduction of the total operating costs of ships a priority, approaches to the reduction in crewing levels without jeopardizing operational capabilities and safety are being investigated. Of particular concern is how labour intensive tasks, such as damage and fire control, can be carried out on ships with reduced crewing levels. To aid in addressing the challenges arising from attempts to reduce crewing levels and maintain or enhance damage control, DRDC Atlantic has initiated a project entitled Damage Control and Crew Optimization. This memorandum includes a review and discussion of the approaches to reducing crewing levels:

- use of functional analysis in conjunction with modeling and simulation to evaluate the effectiveness of several crewing level-automation for damage control technology configurations,
- review of damage and fire control technologies,
- the evaluation of the impact of remote condition monitoring systems on maintenance requirements and situational awareness, and
- introduction/development of materials with enhanced fire and damage tolerance. .pdf

Hiltz, J. (2005). *Damage control and optimized manning.* Retrieved from the Defence Research and Development Canada website: http://pubs.drdc.gc.ca/PDFS/unc89/p524542.pdf.

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. .pdf

Jones, B. (2005, February). *Twenty years on the wrong heading dead ahead.* Paper presented at the Human Factors in Ship Design, Safety and Operation Conference, London, UK. Retrieved from http://www.he-alert.com/documents/published/he00590.pdf.

The aviation community is undergoing a reappraisal of progress made in automated cockpits. This gives the shipping community the opportunity to learn from someone else's mistakes and successes. Aviation has invested more heavily in automation than shipping, and in some respects can be considered to be 'ahead'. The reappraisal has identified issues at a number of levels, ranging from decision making by the operator to the structure of the industry. It is recognised that there are numerous differences between shipping and aviation, and these are taken into account. This paper identifies potential problems and opportunities for shipping, based on an examination of the state of aviation. The technical topics considered include equipment design and the design of automation, considering the allocation of function between the operator and the machine. Similarities in the design and development process are examined, with lessons for future automation identified. Some aspects related to the human element arise from problems with aviation or shipping as a system, and require a systems approach for their resolution. These are discussed in the light of recent aviation findings. .pdf

Kennedy, J. S. (2006). *A human-automation interface model to guide automation of system functions: A way to achieve manning goals in new systems* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA. Retrieved from http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA449998.

A major component of the US Army's Future Combat Systems (FCS) will be a fleet of eight different manned ground vehicles (MGV). There are promises that ''advanced automation'' will accomplish many of the tasks formerly performed by soldiers in legacy vehicle systems. However, the current approach to automation design does not relieve the soldier operator of tasks; rather, it changes the role of the soldiers and the work they must do, often in ways unintended and unanticipated. This paper proposes a coherent, top-down, overarching approach to the design of a human–automation interaction model. First, a qualitative model is proposed to drive the functional architecture and human–automation interface scheme for the MGV fleet. Second, the proposed model is applied to a portion of the functional flow of the common crew station on the MGV fleet. Finally, the proposed model is demonstrated quantitatively via a computational task-network modeling program (Improved Performance Research and Integration Tool). The modeling approach offers insights into the impacts on human task-loading, workload, and human performance. Implications for human systems integration domains are discussed, including Manpower and Personnel, Human Factors Engineering, Training, System Safety, and Soldier Survivability. The proposed model gives engineers and scientists a top-down approach to explicitly define and design the interactions between proposed automation schemes and the human crew. Although this paper focuses on the Army's FCS MGV fleet, the model and analytical processes proposed, or similar approaches, are appropriate for many manned systems in multiple domains (aviation, space, maritime, ground transportation, manufacturing, etc.). .pdf

Kitarovic, J., Tomas, V., & Cisic, D. (2005, June). *The electronic and informatics age - a new stage in developing highly effective ships.* Paper presented at the 47th International Symposium ELMAR, Zadar, Croatia. Retrieved from http://ieeexplore.ieee.org/xpls/abs_ all.jsp?arnumber=1505726.

Perfection of ships in fleets all over the world is directly connected with development and introduction of ship electronics and informatics. The authors make an attempt to answer actual questions arising from the development of the ship's computerized systems. How to find the optimal balance between the man and machine? For what conditions is it rational to replace man by machine? Rational consequences of automation stages are explained in the paper, beginning from the automated control of some ship equipment with a watch in a compartment and further to the future with full automation and robotization of ship control. The wide range of accompanying problems have been analyzed. The correct and timely solution should be accompanied by development and introduction of the advanced electronic and informatics equipment into the marine technology. .pdf

Landsburg, A. C., Avery, L., Beaton, R., Bost, J. R., Competatore, C., Khandpur, R., & Sheridan. T. B. (2008). The art of successfully applying human systems integration. *Naval Engineers Journal, 1,* 78-1-7. doi: 10.1111/j.1559-3584.2008.00113.x/full. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2008.00113.x/full.

This paper reviews developments in human factors and then draws from a number of "best practice" cases in studying how best to apply behavioral science principles, knowledge, and analytical tools to the engineering design or improvement of systems. Government and other commercial experiences are examined with a focus on the Navy HSI process. Included are discussions facilitated at a workshop session sponsored by the Transportation Research Board of the National Academies. There is general consensus that in addition to using a well-designed or proven process and doing the right things, success is dependent upon attending to a prioritized short list of critical elements. Continued focus on these elements is necessary to successfully apply human behavioral sciences effectively during design, construction, and operation of systems to improve safety, reliability, effectiveness, efficiency, and quality of life. .pdf

Litobarski, S., & Rabbets, T. (2004). *Modular designs: HCI in complex naval systems.* Paper presented at the First International Workshop on Coping, Bath, UK. Retrieved from http://www.cs.bath.ac.uk/~complex/cwc2004/Published/S05Litobarski.pdf.

Designing Human Computer Interfaces (HCIs) for the naval environment requires that several unique factors be taken into consideration. Warships lives are being extended for financial reasons, and the 'payload' comprising the combat system with associated manning consumes about half the whole life budget for a warship. At the same time, there remains uncertainty about the nature of emerging threats, and the platform roles that must be assumed to defend against these. The response has been to call for more adaptive and flexible architectures, and to introduce reduced manning, with greater automation of the operator interactions. There is also a technology obsolescence issue, due to changing R&D patterns in industry, particularly in electronics, computer software and display technologies. In order to keep warfighting performance high, it is necessary to have frequent refits of the system, and a

modular and commercial-off-the-shelf (COTS) approach is increasingly adopted in warship design to facilitate technology updates. The problem is to exploit the economies of scale that COTS brings, whilst at the same time acquiring components in the small quantities that shipbuilding demands. This requires careful monitoring of technology trends, and more time efficient and cost effective design methods, so that COTS components can be integrated ergonomically into the combat system console. .pdf

Lively, K. A., Seman, A. J., & Kirkpatrick, M. (2003). Human systems integration and advanced technology in engineering department workload and manpower reduction. *Naval Engineers Journal,* 57-65. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2003.tb00187.x/pdf.

Aboard current ships, such as the DDG 51, engineering control and damage control activities are man-power intensive. It is anticipated that, for future combatants, the workload demand arising from the operation of systems under conditions of normal steaming and during casualty response will need to be markedly reduced via automated monitoring, autonomous control, and other technology initiatives. Current DDG 51 class ships can be considered as a manpower baseline, and under Condition III, typical engineering control involves seven to eight watchstanders at manned stations in the Central Control Station, the engine rooms and other machinery spaces. In contrast to this manning level, initiatives, such as DD 21 and the integrated engineering plant (IEP), envision a partnership between the operator and the automation system, with more and more of the operator's functions being shifted to the automation system as manning levels decrease. This paper describes some HSI studies of workload demand reduction and, consequently, manning reduction that can be achieved due to the application of several advanced technology concepts. Advanced system concept studies in relation to workload demand are described and reviewed, including: 1) Piecemeal applications of diverse automation and remote control technology concepts to selected high driver tasks in current DDG 51 activities; and 2) Development of the reduced ship's crew by virtual presence systems that will provide automated monitoring and display to operators of machinery health, compartment conditions, and personnel health. The IEP envisions the machinery control system as a provider of resources that are used by various consumers around the ship. Resource needs and consumer priorities are at all times dependent upon the ship's current mission and the availability of equipment. .pdf

Maas, H. L. M. M., Wynia, S. J., Birkerod, D., Houtsma, M. A. W. (2000, October). *An information filtering and control system to improve the decision making process within future command information centres.* Paper presented at the RTO IST Symposium on New Information Processing Techniques for Military Systems, Instabul, Turkey. Retrieved from http://handle.dtic.mil/100.2/ADP010888.

This paper describes the achieved research results within several national and international C2 and information management projects to develop concepts for balancing the information push with an operator’s information need in order to meet the requirement to avoid / suppress information overload situations. The paper starts with an analysis and syntheses of the information overload problem. A model is used to describe the causes and the consequences of information overload on the operator’s behaviour and performance in a command information centre of naval vessels. Research has shown that an increasing amount of time is needed for gathering and discriminating relevant information from the actual

information push while less time is left for analysing the relevant information in more detail and taking correct and original decisions. Information overload is seen as a serious threat for the quality and performance of mission execution. The blueprint for an adaptive information management support concept is based on merging several information management support approaches:

1. Approaches to estimate and/or measure and control the operator's information overload.

2. Information exchange concepts.

3. Information handling within several kind of tasks: skill based, rule-based and knowledge-based tasks.

Based on the complexity of the problem, an information management concept is discussed to control and filter the information flows adaptively for skill and rule dominated tasks. .pdf

MacLeod, I., & Smeall, D. (1999). A proposed integrated platform management system design for the Royal Navy future surface combatant. *Proceedings of the International Conference on Human Interfaces in Control Rooms, Cockpits and Command Centres, United Kingdom,* 125-130. doi: 10.1049/cp:19990174. Retrieved from http://ieeexplore.ieee.org/xpls/ abs_all.jsp?arnumber=787695.

This paper attempts to illustrate how the disciplines of human factors design are being applied to hitherto very traditional areas of naval engineering. Human factors engineering is now well established as an invaluable tool in the quest to develop faster and more efficient warships. .pdf

Malone, T. B., & Carson, F. (2003). HSI top down requirements analysis. *Naval Engineers Journal, 115,* 37-48. doi: /10.1111/j.1559-3584.2003.tb00203. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2003.tb00203.x/abstract.

The major objective of the discipline of HSI in system development is to ensure that requirements and considerations for the human element of the system will influence design. The system must be designed to facilitate and support human performance capability, safety, reliability, survivability and accommodation. This objective is achieved by addressing human requirements early in system design and development, in fact, at the very outset of the design process. How this is accomplished is through application of the HSI top down requirements analysis (TDRA). This paper describes the TDRA process, discusses applications of the TDRA, and compares TDRA with bottom-up analysis. .pdf

Malone, T. B., & Heasly, C. C. (2003). Function allocation: Policy, practice, procedures, & process. *Naval Engineers Journal, 15(2),* 49 -59. doi: 10.1111/j.1559-3584.2003.tb00204. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2003.tb00204.x/ abstract.

Allocation of functions is known by HSI professionals as encompassing both a process and a product. As a process, function allocation refers to the sequence of steps

involved in establishing the alternate roles, responsibilities, and requirements for humans and machines in a complex human-machine system. As a product, function allocation refers to the end state of the application of the process, the optimal distribution of roles, responsibilities and tasks between humans and machines. When the system development objective is to downsize emerging systems as compared with existing systems, the focus of the allocation of function effort changes from an emphasis on optimizing human roles to minimizing human involvement in system functions. In addressing the issue of performing system functions with fewer humans as compared with existing systems, the function allocation strategy is not simply to assign functions to automated or manual performance on the basis of differential capabilities and capacities of the two, as exemplified in the Fitts' List approach. Rather, the strategy is to automate functions to the extent needed to enable the required reduction in workload and manning, with attendant provisions for decision aiding, task simplification, and design in conformity with human engineering standards to ensure adequate levels of human performance and personnel safety. Another change in emphasis when allocating functions for a reduced manning system is the focus on interaction between human and machine. In the reduced manning environment humans and machines are not viewed as competing resources to which responsibilities are assigned on the basis of their unique and individual capabilities but rather as cooperative elements of a system interacting and collaborating in synergy to achieve the system objectives. .pdf

Matthews, M., Bos, J., & Webb, R. (2003). *A prototype task network model to simulate the analysis of narrow band sonar data and the effects of automation on critical operator tasks* (Report No. CR-2003-131). Retrieved from the Defense Research & Development Canada website: http://pubs.drdc.gc.ca/PDFS/unc57/p521100.pdf.

This is a demonstration project to illustrate the benefits of task network modelling as a means of quantifying future changes to system design or operational concepts prior to the build stage or system implementation. The specific task environment selected for the demonstration is the process of analysing narrow band sonar data to detect and identify sonar targets, which are key tasks in building the Underwater Maritime Picture. Function and critical task analysis of existing sonar analysis practices were conducted to generate appropriate functions and tasks to be modelled. The Integrated Performance Modelling Environment (IPME) software was used to build a task network model, the essential components of which were validated by an experienced Navy sonar subject matter expert. The model was then used to assess the effects of semi-automating the critical process of sanitising ownship and Task Group sonar data from the display, by comparing system performance for baseline (manual) and automated conditions. Results showed a performance increase for the automated of approximately 30% in terms of contacts identified. This performance gain was achieved with no costs to operator workload. The prototype system developed provides core functionality to explore future "what-if" questions with respect to the redesign of sonar systems and their concept of operations. .pdf

Mavris, D. (2007). *Design methodology and strategies investigation for complex integrated naval systems.* Report No. N00014-04-1-0127. Retrieved from Georgia Tech Library and Information Center website: http://smartech.gatech.edu/handle/1853/33380.

As the mission and performance demands for naval ships have increased, they have become more complex, comprising an increasing number of heterogeneous interdependent subsystems. This increased complexity requires new methods for the design and operation of these naval systems. The Georgia Institute of Technology Aerospace Systems Design Laboratory (ASDL) is helping the Navy change its design practices to achieve reduced total ownership costs, increased survivability, and increased mission effectiveness through an initiative called Integrated Reconfigurable Intelligent Systems (IRIS). Using traditional systems engineering practices for the early design process followed by an integrated design environment, IRIS seeks to shift ship design to a distributed intelligent control architecture through increased automation. The Integrated Engineering Plant (IEP) is an example of the kind of technological innovation that will contribute to the Navy's capability of achieving its future goals. The following report details the research accomplished by ASDL in developing and applying the IRIS concept to the IEP platform. Section 2 of the report lays the foundation for subsequent sections by presenting the background and motivation for developing an IRIS based IEP concept for naval vessels. Section 3 discusses more fully the components and characteristics that describe the IRIS concept as applied to naval surface combatants. Although IRIS is being applied specifically to the IEP in this research, the IRIS concept is fully generic in nature and can be applied to any complex dynamical system. .pdf

Neerincx, M., Grootjen, M.. & Veltman, J. A. (2004). How to manage cognitive task load during supervision and damage control in an all-electric ship. *IASME Transactions, 2(1),* 253-258. Retrieved from http://mmi.tudelft.nl/pub/marc/NeerincxHow_to_manage_CTL_during_supervision_and_damage_control_in_an_all_electric_ship.pdf.

On one hand, an all-electric ship may take over and support operator tasks in order to improve the operational effectiveness and efficiency onboard a ship. At the other hand, information processing demands seem to increase substantially for the operators in such a ship. Recently, a Cognitive Task Load analysis method was developed for the design of operator tasks and computer support, aimed at optimal load distributions during high-demand situations in current and future naval ships. This paper gives a brief overview of the method, presents results of a task load study in the multi-purpose frigate of the Royal Netherlands Navy, and summarises current user interface concepts that provide an "integrated view" for supervision and damage control activities in an all-electric ship. .pdf

Osga, G., & Galdorisi, G. (2003). *Human factors engineering: An enabler for military transformation through effective integration of technology and personnel* Report No. unknown. Space and Naval Warfare Systems Center, San Diego, CA. Retrieved from http://dodreports.com/pdf/ada467381.pdf.

Transformation of the U.S. military requires new ways of defining both design and mission processes to improve warfighting performance and reduce system costs. New technologies engendered through the discipline of human-factors engineering enable warfighters to make more effective decisions in a timelier manner with fewer personnel. While the tradeoffs between new technologies and numbers of operators needed are complex, strong anecdotal evidence suggests that these manpower savings can be significant and have the potential to accelerate military transformation. The human factors engineering community has documented and quantified the enhanced mission effectiveness of fewer warfighters operating enhanced combat systems. What is less well quantified – due to a number of institutional factors - is the true life cycle cost of military operators. This paper discusses design factors that support reduced crew workload and factors that influence crew cost estimation and size. The conclusion is that although we have identified good candidate designs to support reduced crew workload, we cannot adequately trade off their cost with personnel costs until we can more accurately quantify personnel costs. .pdf

Osga, G. A., Van Orden, K. V., Kellmeyer, D. & Campbell, N. L. (2001). "Task-managed" watchstanding: Providing decision support for multi-task naval operations. *SSC San Diego Biennial Review 2001,* 176-185. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.127.2749&rep=rep1&type=pdf.

Watchstanding in shipboard command centers requires USN crews to complete time-critical and externally paced task assignments in an accurate and timely manner. Requirements for optimized crew sizes in future ships are driving system designers toward human–computer interface designs that mitigate task and workload demands in a multi-task work environment. The multi-task mission is characterized by multiple concurrent task demands and parallel task goals of varying time duration. Design concepts for a multi-modal watchstation work environment were created that support a variety of crew cognitive and visual requirements during these high-demand missions. Key user support tools include a concept of embedded task management within the watchstation software. Early tests of task-managed watchstanding have yielded promising results with regard to performance, situation awareness, and workload reduction. Design concepts are now being transitioned into newer naval systems under SSC (Space and Naval Warfare Systems Center) San Diego guidance and direction. .pdf

Pellin Blin, M., & Bry, A. (2005). Human factor integration method in complex naval systems design: An example, Military Integrated Bridge IBEO. Paper presented at the Oceans 2005 - Europe, Vols. 1 and 2, Brest, France. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1511689.

In order to match to the French Navy major goal on crew reduction, the Navy Staff and DGA (Delegation Generale de l'Armement) have developed a prospective human centered design approach based on realistic dynamic future work organisation representation using the IBEO (Integrated Bridge) process and simulation tools. The IBEOs are developed to specify and assess the new work organisations, new automation level, new human computer interaction modes, as well as the new training characteristics. These tools allow an active and reasoned participation of final users since the very early stages of a program. The IBEO "Military Integrated Bridge System" is presented as a user case. .pdf

Quintana, V., Howells, R. A., & Hettinger, L. (2007). User-centered design in a large-scale naval ship design program: Usability testing of complex military systems - DDG 1000. *Naval Engineers Journal, 119(1)*, 25-33. doi: 10.1111/j.0028-1425.2007.00001.x/full. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.0028-1425.2007.00001.x/full.

The USN is currently developing a new class of surface combatant ships referred to as DDG 1000. Unlike past ship designs, DDG 1000 is explicitly focused on the execution of a user-centered approach—one that captures the requirements, capabilities, and limitations of

sailors expected to operate the ship. Additionally, DDG 1000 presents a number of significant human factors and challenges related to its greatly reduced crew size (compared with similar legacy ships) and high reliance on automated systems. Usability testing and usability assessments (UT and UAs) for the purpose of validation of HSI principles, and the validation of the DDG 1000 Sailor Systems Specification (S3), play a key role in the DDG 1000 Human-Centered Design (HCD). Through the use of summative and formative design analysis and design verification events, UT/UA is critical in identifying and rectifying issues early in the design process, and verifying system functionality later in the design process. For the DDG 1000 program, the Human Systems Integration—Design Verification Integrated Product Team (HSI-DV-IPT) has also combined its efforts with both the DDG 1000 Safety and Training Cross Product Teams to realize the economies of scale associated with conducting these tests to obtain data for the needs of all three HCD disciplines. Through the course of the DDG 1000 detailed design phase, UTs and UAs have become a defined procedural process, which is governed by both the DDG 1000 Human Systems Integration Plan and as an extension of the total testing plan for the DDG 1000 ship. Almost all DDG 1000 HSI-DV-IPT evolutions combine the efforts of system engineering and design teams with HSI engineers and fleet users to ensure that the combined test output product has received a “cut” from the entire chain of influence from concept to end user. To date, over 30 user interaction and test events employing 1,100 users have been conducted to verify the utility of aspects of the DDG 1000 design, from the most sophisticated to the most mundane systems and processes. In addition, a series of tools that includes 3D visualization aids for modeling and simulation, and weighted assessment systems like NASA-TLX have been included in the DDG 1000 HSI test engineers' tool bag to provide the best of breed solutions to HCD-oriented testing. The test results obtained to date provided valuable insight into the validity of the DDG 1000 HCD and provided feedback that led to optimization of both crew and ship as its HCD objectives intended, in addition to providing cost-effective and timely feedback into the DDG 1000 design. .pdf

Roos, C. H. (1999). Modelling combat system manning and manpower reduction. *Naval Engineers Journal, 111(3),* 153-170. doi: 10.1111/j.1559-3584.1999.tb01970.x/abstract. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.1999.tb01970.x/ abstract.

NAVSEA 03K41 is responsible for generating Combat System Battle Management Organizations (BMOs) and Functional Flow Diagrams (FFDs). Several years ago, NAVSEA provided the resources to conduct a functional analysis that would support the development and validation of the BMOs and FFDs. The major obstacle in performing the analysis was obtaining a consensus on how the functional hierarchy was to be structured. The non-optimum organization of the hierarchy was selected; as a result, the functions were difficult to define, find, use, and validate. Recognizing the shortcomings of this effort, research was conducted to evaluate state-of-the-art structured modelling techniques, concepts, and methodologies. Two modelling concepts by James Martin were found to be applicable for the combat system functional analysis: Enterprise Modelling Concept and Functional Decomposition Modelling Concept. The Structure Modelling definitions of Whitten, Bently, and Barlow provided the guidelines for using the Martin concepts. During the ensuing BMO and FFD development efforts, a Ship's Combat System (SCS) Modelling concept evolved and a SCS Model was developed. This paper addresses how the modelling concepts and tools are used in the BMO and FFD development and validation process. Data from the SCS Model provides the basis

for defining combat system requirements (e.g., software, data display, database, networking, etc.). .pdf

Runnerstrom, E. (2003). Human systems integration and shipboard damage control. *Naval Engineers Journal, 115(4),* 71-80. doi: 10.1111/j.1559-3584.2003.tb00244.x/abstract. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2003.tb00244.x/abstract.

As the U.S. and other maritime nations move towards operating combatant ships with fewer people, HSI, or human-centered design, is getting increasing attention in new ship designs. Aboard most ships operating today, damage control is a mostly manual, manpower intensive function. Consequently, it is a key area of concern for ship acquisition programs that need to produce ships that will operate with fewer people. Damage control also is critical to the survival of a warship and the safety of the crew. Consequently, it is very important to ship operators. It is no surprise, therefore, that damage control is a key function of concern when designing new ships to operate with fewer people. This paper discusses the state-of-the-art in HSI and damage control aboard ships today as evidenced by the damage control performance of some of today's ships. The paper draws conclusions about the importance of HSI for effective damage control in new ship designs. The successful application of a human-centered design approach in the development of a damage control supervisory control system for the USN's Damage Control Automation for Reduced Manning (DC-ARM) Program is described. Finally, major challenges to achieving effective HSI in new ship designs are presented. .pdf

Soller, A., & Morrison, J. (2008). *The effects of automation on battle manager workload and performance,* (Report No. D-3523). Retrieved from the Defense Technical Information Center website: http://handle.dtic.mil/100.2/ADA482741.

This report summarizes the literature reviewed in preparation for planning and executing a series of controlled, operator-in-the-loop (OITL) experiments to determine how an air and missile defense (AMD) battle manager's performance degrades with increased workload and how automated battle management aids (ABMA) can moderate this degradation. The sources for this survey range from studies that describe the basic limits of human memory capacity to those that assess the number of battle managers needed to operate a partially automated missile defense system. The research indicates that without the assistance of automation, a battle manager's performance will degrade as the complexity of the task increases, in particular when he is tasked with attending to more than seven entities or decisions. Battle managers' performance may, however, vary considerably across experience levels and tasks. Prominent factors that affect the overall human-system performance include the battle manager's cognitive capacity and the system's level of automation. This report outlines four different stages and eight different levels at which automation can enhance system and human performance. An abundance of research indicates that while automation may decrease operator workload, it may also decrease operator activity, engagement, and attention, which could lead to a decrease in situational awareness and performance. There is no shortage of research showing how over-reliance on automation results in fatal accidents when the automated system fails. .pdf

Srivastava, N., Horne, G., Pietryka, F., & Theroff, M. (2005). Simulation environment to assess technology insertion impact and optimized manning. In M. E. Kuhl, N. M. Steiger, F. B. Armstrong & J. A. Joines (Eds.). *Proceedings of the 2005 Winter Simulation Conference* (pp. 1088-1093). Retrieved from http://portal.acm.org/citation.cfm?id=1162899.

The reduction in life-cycle costs for naval vessels is critical for operating a cost efficient and robust Navy. Computer based simulations are an effective tool for HSI optimization, as well as for studying the risks associated with complex interaction between crew and systems. The proposed modular simulation environment empowers analysts to choose and integrate the best combination of agent, discrete event, and physics based simulations to address questions of manning. The environment embraces advances in complexity theory for simulating non-linear systems, knowledge discovery for data analysis and distributed computing for execution environment. .pdf

Tate, C. C., Estes, T., Hagan, J., & Hettinger, L. (2005, September). *Lessons learned from integrating user-centered design into a large-scale defense procurement.* Paper presented at the Human Factors and Ergonomics Society Annual Meeting Proceedings, System Development, Orlando, FL. Abstract retrieved from http://www.ingentaconnect.com/content/hfes/hfproc/2005/00000049/00000022/art00009.

The USN is currently implementing "optimal manning" approaches to the design of future warships. Simply put, this emphasis takes the form of designing and deploying ships whose blend of human and mechanical/computer-based systems reduces the need for traditionally large crews while improving overall system performance and safety. Reflecting this emphasis, a Future Surface Combatant program currently in the design stage is the first Navy procurement in which the principles of user-centered design (UCD) and HSI are key design drivers. The integration of UCD and HSI methods has never been attempted in a design effort of this magnitude, and has inevitably led to illuminating insights on the part of human factors, system engineering, and other disciplines engaged in the effort. This paper provides an overview of "lessons learned," and is intended to assist the future integration of UCD and HSI principles into the design of similarly complex systems. (No pdf available.)

Thie, H. J., Harrell, M. C., McCarthy, A. S., & Jenkins, J. (2009). *Consolidated Afloat Networks and Enterprise Services (CANES): Manpower, personnel, and training implications* Report No. unknown. Retrieved from Rand and Development (RAND) website: http://handle.dtic.mil/100.2/ADA512854.

This study broadly assessed the manpower, personnel, and training implications associated with the introduction of the Consolidated Afloat Networks and Enterprise Services (CANES) to USN ships. CANES will provide a common computing network and common operating system for command, control, communications, computers, and intelligence systems onboard Navy ships, which could reduce the requirement for manpower and alter the demand for training. This environment will differ considerably from the traditional environment, which included stovepiped networks with unique hardware and software systems. The Navy's effort to consolidate hardware and operating software and to introduce service-oriented architectures is consistent with the practices of private-sector organizations and information

technology providers. This RAND effort focused on particular Information Systems Technology (IT) and Electronics Technician (ET) Navy Enlisted Classifications (NECs) associated with a subset of CANES systems, networks, and applications, including the Integrated Shipboard Network System (ISNS), the Sensitive Compartmented Information (SCI) Network, the Combined Enterprise Regional Information Exchange System – Maritime, the Global Command and Control System – Maritime, and the Navy Tactical Command Support System. Given this selection from the list of CANES early adopters, this work focused primarily on the IT NECs specific to these systems. The analysis included two ship classes: carriers (CVNs) and destroyers (DDGs). This report provides a review of current Navy manpower, personnel, and training practices; the implications of the conversion to CANES; and resulting recommendations. .pdf

Torenvliet, G., Hilliard, A., Burns, C. M., Lintern, G., & Lamarre, J-Y. (2010). *Modelling and simulation for requirements engineering and options analysis* Report No. CR 2010-049. Retrieved from http://handle.dtic.mil/100.2/ADA530446.

This report presents the results of a scoping study that was conducted to develop a Research and Development roadmap for Project 14dj, "Modelling and Simulation for Requirements Engineering and Options Analysis." The purpose of Project 14dj is to develop a Modelling and Simulation capability, comprised of analytical techniques and software tools, for addressing human factors issues commonly encountered by CF acquisition projects. This scoping study developed a roadmap for this research by developing insights and research questions from the current CF procurement process, the academic and applied literature on requirements engineering and options analysis, and through expert advice on how Cognitive Work Analysis could be applied to CF procurement. Twenty-four research questions were developed, which are structured into five specific research proposals for DRDC to consider for inclusion in Project 14dj. The research proposals are as follows: (1) research to apply Cognitive Work Analysis and Modelling and Simulation to the development of operational requirements; (2) research to conduct a cognitive task analysis of requirements engineering and options analysis in CF procurement; (3) research to develop a tool to support the application of Cognitive Work Analysis to CF procurement; (4) research to extend and apply Social Organization and Cooperation Analysis (a lesser-developed area of Cognitive Work Analysis) to CF procurement; and (5) research to extend DRDC Toronto's crewing effectiveness task network model. The research program presented in this report should provide DRDC with a stronger ability to have a positive impact on CF procurement projects. If successful, this research could provide the CF with an overall reduction of risk in the procurement cycle. .pdf

Torenvliet, G., Jamieson, G., & Cournoyer, L. (2006). *Functional modelling, scenario development, and options analysis to support optimized crewing for damage control. Phase 1: Functional modelling* Report No. 1000-1370. Retrieved from Defense Technical Information Center website: http://handle.dtic.mil/100.2/ADA473053.

The Canadian Navy hopes to achieve significant lifetime cost reductions by implementing optimized crew levels across its next-generation fleet. DRDC has recognized that optimized crewing can only be achieved through a thorough HSI effort, and that this effort will require systems modelling techniques to help the Navy predict the effectiveness of technologies and work strategies that aim to reduce operator workload and improve mission success. This report describes the first phase of a project undertaken to provide DRDC with such a technique, and details the development of an Abstraction Hierarchy functional model of the domain of damage control. Two subsequent phases of analysis are planned: to develop damage control scenarios, and to identify emerging damage control technologies and the reduced crew levels required to support them. These will be used as inputs for a follow-on project to develop a simulation of human and automated work in the damage control domain. The Abstraction Hierarchy model documented in this report is a strong basis for the subsequent phases of this project, and the follow-on simulation development effort. .pdf

Torenvliet, G. L., Jamieson, G. A., & Chow, R. (2008). Object worlds in work domain analysis: A model of naval damage control. *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans, 38(5),* 1030-1040. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4604813.

This paper presents a work domain analysis of damage control on the Canadian Halifax Class frigate. Our analysis made use of the modeling construct of object worlds to help in defining the work domain to model and to help in understanding the results of this model compared to other work domain analyses developed in the naval domain. This paper makes a practical contribution through the presentation of a detailed example of work domain analysis in a new domain and a theoretical contribution by clarifying the use of object worlds in work domain analysis, analyzing the way in which object worlds can be understood in systems where the various stakeholders are closely coordinated and promoting object worlds as a way to control model scope. .pdf

Tzannatos, E. S. (2004). GMDSS operability: The operator-equipment interface. *Journal of Navigation, 55,* 75-82. doi: 10.1017}S037346330100162X. Retrieved from http://journals.cambridge.org/abstract_S037346330100162X.

In this paper, the operability of the Global Maritime Distress and Safety System (GMDSS) is studied to identify those aspects that are hindering its successful use. Particular emphasis is placed upon the operator-equipment interface within the working environment of the ship's bridge. The results of a relevant survey, based on the opinion of recently General Operator certified navigation officers, indicate that – despite the automation in GMDSS and the resulting reduction of the human factor – there is a definite need to improve the knowledge-based proficiency of the operator. The current design of the system, and the increasing workload on the ship's bridge, constitute the main drawbacks to operability and dictate the requirement for improved knowledge and hence improved certification and refresher training for operators. .pdf

U.S. General Accounting Office (2003). *Military personnel: Navy actions needed to optimize ship crew size and reduce total ownership costs.* GAO Publication No. GAO-03-520. Retrieved from http://www.gao.gov/new.items/d03520.pdf.

The cost of a ship's crew is the single largest incurred over the ship's life cycle. One way to lower personnel costs, and thus the cost of ownership, is to use people only when it is cost-effective--a determination made with a systems engineering approach called HSI. The General Accounting Office (GAO) was asked to evaluate the Navy's progress in optimizing the crew size in four ships being developed and acquired: the DD(X) destroyer, T-AKE cargo ship, JCC(X) command ship, and LHA(R) amphibious assault ship. GAO assessed (1) the Navy's use of HSI principles and goals for reducing crew size, and (2) the factors that may impede the Navy's use of those principles. The Navy's use of HSI principles and crew size reduction goals varied significantly for the four ships GAO reviewed. Only the DD(X) destroyer program emphasized HSI early in the acquisition process and established an aggressive goal to reduce crew size. The Navy's goal is to cut personnel on the DD(X) by about 70 percent from that of the previous destroyer class--a reduction GAO estimated could eventually save about $18 billion over the life of a 32-ship class. The goal was included in key program documents to which program managers are held accountable. Although the Navy did not set specific crew reduction goals for the T-AKE cargo ship, it made some use of HSI principles and expects to require a somewhat smaller crew than similar legacy ships. The two other ships--the recently cancelled JCC(X) command ship and the LHA(R) amphibious assault ship--did not establish HSI plans early in the acquisition programs, and did not establish ambitious crew size reduction goals. Unless the Navy more consistently applies HSI early in the acquisition process and establishes meaningful goals for crew size reduction, the Navy may miss opportunities to lower total ownership costs for new ships, which are determined by decisions made early in the acquisition process. For example, the Navy has not clearly defined the HSI certification standards for new ships. Several factors may impede the Navy's consistent application of HSI principles and its use of innovations to optimize crew size: (1) DoD acquisition policies and discretionary Navy guidance that allow program managers latitude in optimizing crew size and using HSI, (2) funding challenges that encourage the use of legacy systems to save near-term costs and discourage research and investment in labor-saving technology that could reduce long-term costs, (3) unclear Navy organizational authority to require HSI's use in acquisition programs, and (4) the Navy's lack of cultural acceptance of new concepts to optimize crew size and its layers of personnel policies that require consensus from numerous stakeholders to revise. .pdf

Venturi, G., & Troost, J. (2005, June). *An agile, user-centric approach to combat system concept design.* Paper presented at the Tenth International Command and Control Research and Technology Symposium: The Future of C2, Arlington, VA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA464266.

Purpose of this paper is defining a framework for the Warfighter-Centered Design of new concepts for naval combat systems. This framework explicitly takes into account the business value of the Warfighter-Centered Design with respect to safety, optimal manning and reduced lifecycle costs. The Warfighter-Centered Design improves safety because lack of usability can lead to serious consequences; the analysis of the accident of USS Vincennes clearly shows that the combat system exhibited serious usability problems both in estimating the altitude trend of an air track and in the Identification Friend of Foe (IFF) process. The Warfighter-Centered Design holds also a significant economic value because it reduces the lifecycle costs related to ship manning and training and allows optimal solutions to the evolution to asymmetric and littoral warfare. The Warfighter-Centered Design is not a methodology or a set of techniques, but an integrated approach to product concept design that focuses explicitly on the needs and limitations of the warfighter. It is based on user involvement, iterative prototyping and user-based assessment and it can focus on the different levels of the Command Information Center organization and consoles. .pdf

Wallace, D. (2009). Warfighter inclusion in system development: The operational perspective in defining design requirements. *Naval Engineers Journal, 121(1),* 53-58. doi: 10.1111/j.1559-3584.2009.01139.x. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1559-3584.2009.01139.x/full.

HSI is integral to any comprehensive system engineering process. HSI is defined by the International Conference on System Engineering as "interdisciplinary technical and management processes for integrating human considerations within and across all system elements; an essential enabler to systems engineering practice." But how does one accomplish this interdisciplinary integration? This paper highlights the essential role of the warfighter as an overarching elicitor and integrator of system requirements, and how to effectively exploit this crucial resource. All complex systems are developed to be used and maintained in a specific operational environment by a trained user. It is therefore imperative that the unique operational perspectives of those users are made part of the design and development process. There are several key opportunities within the acquisition process where qualified, representative users play a significant role in refining the system's requirements and defining how the total system will perform. Active participation from the warfighter and user community in the design process will aid in identifying issues early enough to make a meaningful influence on design, fosters warfighter acceptance of the system, reduces the risks associated with warfighter alterations to system configurations, and validates total system performance using human in the loop evaluations. .pdf

Wetteland, C., & French, J. (2002). *Task network modeling: resolving manning issues in complex environments.* Paper presented at the IEEE 7th Annual Human Factors Meeting, Scottsdale, AZ. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1042838.

Limitations that humans impose on task execution are rarely integrated into simulations of complex systems, resulting in loss of outcome fidelity. A discrete-event simulation tool has been used to model the impact of human interactions in USN and USCG vessels. Models for these vessels have been used to estimate workload and fatigue. In workload measuring applications detailed task networks for teams of individuals were modeled over the 14-day scenarios. Predictions of operator utilization for several manning configurations were used to optimize manning and task allocations for the team. Models predicting fatigue were developed for entire crews to estimate the impact of work and sleep schedules over the same 14-day period on individual fatigue levels. Used in combination, these models provide predictions of the appropriate team size needed to maintain that watch level around the clock for a sustained period of time. .pdf

Yeong, W. H. (2010). *Layout optimization and manning ratio improvement* (Unpublished master's thesis). Universiti Teknologi Malaysia, Johor, Malaysia. Retrieved from http://eprints.utm.my/11237/.

The objective of this study is to design a new layout for space optimization and improve manning ratio. An ergonomic new peripheral for IC bonding machines is also designed to obtain space savings. The study is limited to the IC bonding process of one product on a single production floor of the factory with sampling done on one module containing two rows of machines. The study is divided into three major components which is layout optimization, manning ratio improvement and new peripheral design. Layout and peripheral design is mostly done using AUTOCAD, and work sampling methods is used widely in data collection of manning ratio. Data validation is done by surveying production floor workers on their feedback during the 'trial-run' of the new layout, manning ratio and peripheral design. A semiconductor manufacturer is selected for this case study. Upon completion of this study, additional machines can be fitted into existing space, manning ratio is improved requiring less manpower for more machines and a new peripheral which is space saving and ergonomic is designed. As a result, there is significant cost savings and improved productivity. Finally, the machine capacity gap to meet customer demand is closed. .pdf

# 7 Conclusion

This document constitutes a review of technologies for operator workload and crewing reduction for the RCN, following on the steps of a technical report by Beevis et al. (2001) entitled *Technologies for Workload and Crewing Reduction*. To this end, the authors documented and categorized papers presenting recent research advances in the development of technologies for workload and crewing reduction and the results are presented in an annotated bibliography.

The scope was restricted to research efforts on workload and crew reduction technologies currently in use, as well as potential technologies under development, onboard the RCN ships, in foreign navies, merchant marine, coast guard or civilian cargo lines.

The categorization process for these technologies involved grouping them into four broad categories: Ship Function, Policy and Procedures, Personnel and Training, and Human Systems Integration. These categories were identical to the ones used by Beevis et al. (2001).

A number of search queries were conducted online, using Google Scholar, the National Technical Information Service (NTIS), and the Defense Technical Information Center (DTIC). A table summarizing the research results was provided to afford greater visualization. This is followed by the list of research papers and their abstracts.

A total of 181 applicable papers were identified and for the most part, were limited to the time period elapsed since the previous research report (i.e., 2001 and onward). Some papers are applicable in multiple categories; however, they were only placed in the most applicable category in the annotated bibliography.

The next phase of this research should include some follow-on studies. Some possible projects include an evaluation of the technologies highlighted in this report for costs and applicability to the RCN and determining estimates in crewing reduction for the future fleet.

# List of symbols/abbreviations/acronyms/initialisms

| | |
|---|---|
| AAW | Anti-Air Warfare |
| ABMA | Automated Battle Management Aid |
| ACS | Autonomous Cooperative System |
| ADM | Acquisition Decision Memorandum |
| ADW | Air Defense Warfare |
| AEM/S | Advanced Enclosed Mast/Sensor |
| AES | All-Electric Ship |
| ALDS | Advanced Logistics Delivery System |
| ALDV | Advanced Logistics Delivery System Ship |
| AMD | Air and Missile Defense |
| AOC | Air Operations Center |
| AOPS | Arctic/Offshore Patrol Ship |
| ASDL | Aerospace Systems Design Laboratory |
| ASNE | American Society of Naval Engineers |
| ASW | Anti-Submarine Warfare |
| ATDs | Advanced Technology Demonstrator |
| BM | Battle Management |
| BM | Boatswain Mate |
| BMO | Battle Management Organization |
| BOI | Board of Inquiry |
| BPEM | Bayesian-based Probability Estimation Model |
| C2 | Command and Control |
| C4ISR | Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance |
| CANES | Consolidated Afloat Networks and Enterprise Services |
| CBM | Condition Based Maintenance |
| CBR | Chemical, Biological and Radiation |
| CDNSWC | Carderock Division Naval Surface Warfare Center |
| CERA | Chief Engine Room Artificer |
| CF | Canadian Forces |

| | |
|---|---|
| CG(X) | Guided Missile Cruiser |
| CIC | Command Information Centre |
| CISD | Center for Innovation in Ship Design |
| CLIDCS | Component Level Intelligent Distributed Control System |
| CMISE | Combat Management Integrated Support Environment |
| CMR | Combat Mission Readiness |
| CMS | Combat Management System |
| CNA | Center for Naval Analysis |
| CNO | Chief of Naval Operations |
| CO | Commanding Officer |
| CODAG | Combined Diesel and Gas Turbine |
| CONOPS | Concept of Operations |
| CORA | Centre for Operational Research and Analysis |
| COTS | Commercial off the Shelf |
| COXN | Coxswain |
| CPS | Collective Protection System |
| CSC | Canadian Surface Combatant |
| CVF | Carrier Vessel Future |
| CWS | Chilled Water System |
| DARPA | Defense Advanced Research Project Agency |
| DC | Damage Control |
| DC-ARM | Damage Control-Automation for Reduced Manning |
| DCOC | Damage Control Operational Concept |
| DDG | Guided Missile Destroyer |
| DDX | Destroyer, Experimental |
| DERA | Defence Evaluation and Research Agency |
| DGA | Delegation Generale de l'Armement |
| DGMDO | Director General Maritime Development and Operations |
| DND | Department of National Defence |
| DoD | Department of Defense |
| DRDC | Defence Research & Development Canada |
| DRDKIM | Director Research and Development Knowledge and Information Management |

| | |
|---|---|
| DTIC | Defense Technical Information Center |
| ECDIS | Electronic Chart Display and Information System |
| EID | Ecological Interface Design |
| EM | Electrician’s Mate |
| EN | Engineman |
| EMSP-O | Economic Manpower Shift Planning with Overtime |
| EPS | Electric Power System |
| ET | Electronics Technician (Surface) |
| ET | Embedded Training |
| ETS | Engineering the Total Ship |
| EWFD | Early Warning Fire Detection |
| FAST | Fatigue Avoidance Scheduling Tool |
| FBM | Function Based Manning |
| FCS | Future Combat System |
| FFD | Functional Flow Diagram |
| FICMS | Full Integrated Control and Monitoring Systems |
| GAO | Government Accounting Office |
| GLEAN | GOMS (Goals, Operators, Methods and Selection) Language Evaluation and Analysis Tool |
| GM | Gunner’s Mate |
| GMDSS | Global Maritime Distress and Safety System |
| GOMS | Goals, Operators, Methods and Selection |
| GUI | Graphical User Interface |
| HCD | Human-Centered Design |
| HCDE | Human Centered Design Environment |
| HCIs | Human Computer Interface |
| HFE | Human Factors Engineering |
| HM&E | Hull, Mechanical & Electrical |
| HMCS | Her Majesty's Canadian Ship |
| HPM | Human Performance Metric |
| HR | Human Resource |
| HS&E | Health, Safety and Environmental |
| HSI | Human Systems Integration |

| | |
|---|---|
| HSI-DV-IPT | Human Systems Integration—Design Verification Integrated Product Team |
| HSIP | Human System Integration Plan |
| HVAC | Heating, Ventilation and Air Conditioning |
| IBEO | Integrated Bridge |
| ICCRTS | International Command and Control Research Technology Symposium |
| ICS | Intelligent Controller System |
| ICT | Information and Communication Technologies |
| IDS | Integrated Deepwater System |
| IEP | Integrated Engineering Plant |
| IFF | Identification Friend of Foe |
| I/ITSEC | Interagency/Industry Training, Simulation & Education Conference |
| ILP | Integer Linear Program |
| IMPRINT | Improved Performance Research Integration Tool |
| INSURV | Inspection and Survey |
| IPME | Integrated Performance Modeling Environment |
| IPPD | Integrated Product Process Development |
| IPS | Integrated Power System |
| IRIS | Integrated Reconfigurable Intelligent System |
| ISM | International Safety Management |
| ISMAT | Integrated Simulation Manning Analysis Tool, Micro Analysis and Design |
| ISNS | Integrated Shipboard Network System |
| ISPS | International Ships and Port Facility Security |
| ISR | Intelligence, Surveillance and Reconnaissance |
| IT | Information Systems Technician |
| IW | Information Warfare |
| JESS | Java Expert System Shell |
| JFACC | Joint Force Air Component Commander |
| JFC | Joint Force Commander |
| JMIC | Joint Military Intermodel Container |
| JSS | Joint Supply Ship |
| KAOS | Knowledge Acquisition in Automated Specification |
| LAMPS | Light Airborne Multi-Purpose System |

| | |
|---|---|
| LBES | Land-Based Engineering Site |
| LCS | Littoral Combat Ship |
| LHD | Landing Helicopter Deck |
| LIM | Linear Induction Motor |
| LPD | Landing Platform Dock |
| M&P | Manpower and Personnel |
| MAI | Manning Affordability Initiative |
| MARAD | Maritime Administration |
| MARPOL | Marine Pollution |
| MCS | Machinery Control System |
| MEB | Marine Expeditionary Brigade |
| MET | Maritime Education and Training |
| METOC | Meteorology and Oceanography |
| MGV | Manned Ground Vehicle |
| MMR | Merchant Marine Reserve |
| MOD | Ministry of Defence |
| MOGO | Multi-Objective Genetic Optimization |
| MOTW | Missions Other than War |
| MNS | Mission Need Statement |
| MPP | Main Propulsion Plant |
| MPT | Manpower, Personnel, and Training |
| NATO | North Atlantic Treaty Organization |
| NAVSEA | Naval Sea Systems Command |
| NAWCTSD | Naval Air Warfare Center Training Systems Division |
| NECs | Navy Enlisted Classification |
| NILM | Non-Intrusive Load Monitor |
| NP | Non-deterministic Polynomial |
| NRAC | Naval Research Advisory Committee |
| NRL | Naval Research Laboratory |
| NSRP | National Ship Research Program |
| NSWCCD | Naval Surface Warfare Center – Carderock Division |
| NSWCDD | Naval Surface Warfare Center – Dahlgren Division |

| | |
|---|---|
| NSWW | Navy Standard Workweek |
| NTIS | National Technical Information Service |
| O&G | Oil and Gas |
| O&S | Operating and Support |
| OAI | Open Archives Initiative |
| OCS | Officer Candidate School |
| OITL | Operator in the Loop |
| OME | Optimal Manning Experiment |
| ONR | Office of Naval Research |
| OOD | Object Oriented Design |
| OPNAV | Office of the Chief of Naval Operations |
| OPV | Offshore Patrol Vessel |
| ORD | Operational Requirements Document |
| OS | Operations Specialist |
| OTSR | Optimum Track Ship Routing |
| P&I | Protection and Indemnity |
| PC | Personal Computer |
| PEO | Program Executive Office |
| PM | Performance Measure |
| PM | Program Manager |
| PSF | Performance-Shaping Factor |
| PSU | Port Security Unit |
| PVT | Psychomotor Vigilance Task |
| R&D | Research & Development |
| RAN | Royal Australian Navy |
| RAND | Research and Development |
| RCMOP | Requirements-driven Cost-based Manpower Optimization |
| RCN | Royal Canadian Navy |
| ReqMon | Requirement Monitoring |
| RF | Radio Frequency |
| RFID | Radio Frequency Identification |
| RN | Royal Navy |

| | |
|---|---|
| RNLN | Royal Netherlands Navy |
| RNoN | Royal Norwegian Navy |
| RRF | Ready Reserve Force |
| RSM | Response Surface Model |
| RSVP | Reduced Ships-Crew by Virtual Presence |
| RVOC | Research Vessel Operators Committee |
| SA | System Acquisition |
| SAFTE | Sleep, Activity, Fatigue, and Task Effectiveness |
| SAM | Surface to Air Missile |
| SCI | Sensitive Compartmented Information |
| SCS | Ship's Combat System |
| SDR | Sleep Dose-Response Study |
| SEAIT | Systems Engineering Analysis Integration Tool |
| SIRC | Seafarers' International Research Centre |
| SLC | Small Littoral Combatant |
| SMART | Ship Manpower Analysis and Requirements Tool |
| SNAME | Society of Naval Architects and Marine Engineers |
| SNMM | Swedish National Maritime Museum |
| SOLAS | Safety of Life at Sea |
| SOUP | Software of Uncertain Pedigree |
| SPM | Sleep Performance Model |
| SRS | Speech Recognition Software |
| SSC | Space and Naval Warfare Systems Center |
| SSK | Sub Surface Killer |
| ST | Sonar Technician |
| ST-SSD | Specialist Team on Small Ship Design |
| STARS | Ship Tracking and Routing System |
| STCW | Standards of Training, Certification and Watchkeeping |
| STCW95 | Standards of Training, Certification and Watchkeeping (Revised) |
| STG | Sonar Technician (Surface) |
| STOM | Ship to Objective Maneuver |
| SWOT | Strengths, Weaknesses, Opportunities, and Threats |

| | |
|---|---|
| SWS | Ship-Wide System |
| TACMEMO | Tactical Memorandum |
| TCSBC | Thin Client/Server-Based Computing |
| TDRA | Top Down Requirements Analysis |
| TNO | The Netherlands Organization |
| TNO-FEL | The Netherlands Organization Physics and Electronics Laboratory |
| TOC | Total Ownership Cost |
| TOD | Team Optimal Design |
| TS-CM | Total Ship-Crew Model |
| TSSE | Total Ship Systems Engineering |
| UAs | Usability Assessment |
| UAS | Unmanned Aerial System |
| UAV | Unmanned Aerial Vehicle |
| UCD | User-Centered Design |
| UCL | University College London |
| UK | United Kingdom |
| UNTL | Universal Navy Task List |
| U.S. | United States |
| USA | United States of America |
| USCG | United States Coast Guard |
| USMS | United States Maritime Service |
| USN | United States Navy |
| USV | Unmanned Surface Vehicles |
| UT | Usability Testing |
| UUV | Unmanned Underwater Vehicle |
| UV | Unmanned Vehicle |
| VAR | Volt Amp Reactance |
| VPN | Virtual Private Network |
| WLC | Whole-Life Cost |
| WM | Water Mist |
| WMU | World Maritime University |

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The Royal Canadian Navy is looking at various technological means to optimize manning for its future fleet programmes. This report documents recent research on technologies for workload and crewing reduction. It constitutes a follow-up to previous research (Beevis et al., 2001) on the same subject, in the form of an annotated bibliography. Onlines searches using open access databases were used to produce this literature review, which was further categorozed into four broad types of technologies (ship function, policies and procedures, personnel and training, and human-systems integration), as well as an assessment of the technology as being current or for future development. Technologies and solutions for workload and crewing reduction used in the Royal Canadian Navy were investigated, as well as those employed by foreign navies, civilian fleets (merchant marines, shipping companies, etc.) and Coast Guards. The resulting annotated bibliography includes abstracts and links to the original source references, as well as a table to quickly map the articles to the categories under which they are classified.

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Policies & Procedures
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