Human Systems Integration/Manning Reduction for LHD-Type Ships

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Sailors are the source of one of the U.S. Navy'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 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.

Introduction

As the U.S. Navy develops new classes of ships in the 21st century—including the CVN-21–class aircraft carrier, the DD(X)-class destroyer, and the LHA(R)-class amphibious assault ship—reduced ship manning using human systems integration (HSI) tools and concepts has recently become a Navy priority. The Government Accountability Office estimated that a manning reduction of only 25% from an LHD-sized ship (an LHD 1 carries 1247 crew members) could save as much as $1 billion in total operating and support costs [1]. In December 2002, the U.S. Naval Sea Systems Command contracted with Northrop Grumman Ship Systems to analyze how a manning reduction of at least 25% from the current LHD-class amphibious assault ship (e.g., the USS *Wasp*) could be accomplished for future amphibious assault ships—the LHD 8 and LHA(R)—without compromising any of their capabilities.

Ship Systems conducted its analysis jointly with several other Northrop Grumman sectors—Information Technology (Virginia Beach and San Antonio), Newport News, and Electronic Systems (Sperry Marine Division)—as well as a major subcontractor, Micro Analysis & Design, Inc.

Completed in under a year, the study applied the HSI approach to manning reduction [2]. It used two major tools (the Northrop Grumman proprietary Task Analysis database and the Micro Analysis & Design proprietary Complete Crew Model, or CCM) to reengineer and validate the manning requirements for the LHD 8, currently under construction, and a reduced-manning alternative. It also used special "gap" analysis to verify that the technological solutions to enable a reduction in crew size were feasible within our projected timeframe (by the end of 2006).

The study 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.

Human Systems Integration Approach to Manning Reduction

As described by Malone and Bost [2], the heart of HSI in the manning-reduction process is the top-down requirement analysis (TDRA), a process comprising 10 major steps, listed in Table 1. We adopted that approach and applied it using, among other things, current Navy regulations and guidelines in existing ship-manning documentation, computer modeling, subject-matter expertise, and technology reviews. A brief summary of each TDRA step and how we managed it is provided in the following sections.

Table 1. Top-down requirement analysis tasks and Northrop Grumman approach

Top-Down Requirement Analysis Task	Northrop Grumman Approach
1. Functional analysis	Use LHD 1 Required Operational Capabilities and Projected Operational Environment documents
2. Identify high-driver functions	Use LHD 8 Preliminary Ship Manpower Document (PSMD)
3. Analyze mission requirements via scenario	Use subject-matter experts (SMEs) to generate two-week LHD scenario
4. Conduct mission/function analyses	Use LHD 8 PSMD (including Battle Bill), LHD 4 Watch Quarter and Station Bill, SME input
5. Allocate functions and define role of crew members	Solicit SME inputs, analyze gaps between projected and actual feasibility
6. Identify workload-reduction concepts	Conduct literature review, solicit SME inputs
7. Assess affordability and risk potential of reduced-workload concepts	Conduct literature review, calculate "cost of sailor," analyze gaps between projected and actual feasibility
8. Define task networks and analyze task requirements	Use Northrop Grumman Task Analysis database, Complete Crew Model (CCM)
9. Conduct simulations to assess human performance and workload	Use CCM
10. Develop and validate ship manning model	Use Northrop Grumman Task Analysis database, LHD 8 manning requirement list, LHD 8 PSMD

Conduct Top-Down Function Analyses. The single best source for understanding the functions of a Navy ship is its Required Operational Capabilities (ROC) and Projected Operational Environment (POE) documents. The ROC/POE for the LHD-class ship is OPNAVINST C3501.310A, most recently updated in 2002 [3]. The ROC/POE lists 13 major requirements of LHD-class ships:

- Antiaircraft warfare
- Amphibious warfare
- Anti-surface-ship warfare
- Command, control, and communications
- Command, control, and information warfare
- Fleet-support operations
- Intelligence
- Logistics
- Mine warfare
- Mobility
- Mission of state
- Noncombatant operations
- Naval special warfare

Each major requirement has several subrequirements, with the areas containing the most subrequirements tending to be the most manpower intensive.

Identify High-Driver Functions and Lessons Learned. The key to successful manning reduction is to focus on the areas with the highest manning requirements—the "high drivers." For example, eliminating all functions that contribute less than 5% of the ship manpower requirements would achieve little of the overall manning-reduction goal. The manpower needs of the LHD-class vary considerably across different deployment states, because of varying watchstation requirements (operational manning). The LHD-class ship operates under the following major manning conditions:

- Condition I (battle readiness)
- Condition IA (wartime amphibious-assault operations)
- Condition II (modified battle readiness)
- Condition FQ (flight quarters)
- Condition III (wartime/increased tension/forward-deployed cruising readiness)
- Condition IV (peacetime cruising readiness)
- Condition V (in-port readiness)

Conditions II, IV, and V are not considered to be high drivers, so we did not model them. LHD 8 manning requirements list conditions I and IA (820 and 979 watchstations, respectively) as the high drivers, because they involve both aviation and well-deck operations. Some aspects of conditions FQ and III were considered potential high drivers as well.

Analyze Mission Requirements and Define Mission Scenario. An LHD-class ship must be able to perform over 500 subrequirements, a large percentage of which may come at the same time. The key is to simulate a realistic mission, based on inputs of leading subject-matter experts (SMEs). The two-week scenario chosen for our simulated mission involved a weeklong transit from the Mediterranean Sea to West Africa, where a nonpermissive evacuation of ~2000 personnel occurred during the second week. The scenario involved one week of condition III deployment, 24 hours of condition IA, and varying degrees of conditions IA, II, and FQ for the remainder. It also included about 20 special evolutions (tasks).

Conduct Mission/Function Analyses. We analyzed the specific manning requirements of the mission using a dynamic crew model, the CCM. Our procedure was as follows:

- Determine the type of special evolutions required of the mission—in our case, we analyzed about 20 such evolutions associated with noncombatant evacuation, including helicopter transfer, escort and maintenance in controlled areas, security detail, and special messing.
- Assign the proper number and type of crew members to each evolution. Assignments were made with reference to the LHD 8's Preliminary Ship Manpower Document (PSMD) and its enclosed Battle Bill, a current Watch Quarter and Station Bill (WQ&SB), and SME inputs. Since the LHD 8 has yet to be placed into service, even a Preliminary (as opposed to Final) Ship Manpower Document has yet to be completed; for the same reason, the Watch Quarter and Station Bill we used was from the legacy USS *Boxer* (LHD 4).
- Model the way the special and regular evolutions were performed under baseline and reduced-manning options.

Allocate Functions and Define Role of Crew Members. All functions must be either assigned to crew members or, wherever feasible, automated. Whenever automation is applied, it is not only technology driven but also process driven, such that it is integrated with human skills and designed to improve specific processes. Generally, automation is most valuable for providing information, controlling outputs, and making safe, reliable decisions, especially in physically challenging circumstances in which a human may be very constrained.

We used a complex set of criteria to decide which functions should be carried out primarily by automation or by humans. At a minimum, however, we required that technological innovations would have to be mature (i.e., of proven reliability and efficiency) by 2006 and cost effective when comparing up-front costs with lifespan manpower savings. Technology experts from our Electronic Systems sector's Sperry Marine Division helped to verify and expand our initial technological analysis.

Identify Workload-Reduction Concepts. Workload-reduction concepts extend well beyond merely installing automation. Indeed, they may also include major process changes that involve simplification and elimination/consolidation of functions. Automation may aid in carrying out the latter processes, but it is more a facilitator, rather than the major conceptual driver. For example:

- Better information displays (e.g., helmet-mounted displays) and information management (e.g., streamlined transmission) can simplify communications and thereby reduce the need for crew members.
- More extensive use of electronic communication permits the transfer of many administrative functions to shore, such as payroll and record keeping, but the shore-support concept also applies to infrequent and nonemergency maintenance items.

Finally, function consolidation in our study was facilitated by technological innovation (e.g., multimodal watchstation displays), but it also involved process changes (e.g., eliminating management structures, improving cross-training of personnel).

Assess Affordability and Risk Potential of Reduced-Workload Concepts. In addition to financial risk, manning-reduction concepts may sometimes involve technologies that are insufficiently mature, unreliable, or unsafe. In our study, risk and affordability were assessed by a combination of factors that included examining the outcome of workload-reduction concepts on legacy ships, assessing the relative maturity of novel technologies, and the financial costs to implement versus the expected cost savings over the 50-year life span of the ship based on the current annual "sailor cost" of $80,000.

Technologies that had already been successfully installed on a legacy ship—such as automated bridge control, automated food service and disbursing, and automated damage control—were considered low risk. Technologies expected to be mature by 2006 were also considered to be of sufficiently low risk to be included as part of our manning-reduction strategy. Of the many technologies that we examined, one of the most important was the transfer of nonessential work parties and functions ashore. Wherever possible, data on training, maintainability, safety, habitability, and survivability were incorporated from the existing literature.

Define Task Networks and Analyze Task Requirements. After linking functions to mission requirements, functions were further broken down into specific shipboard tasks (over 5000 of which have been identified in the Northrop Grumman proprietary Task Analysis database). Each task was assigned a workload on the basis of extensive Navy studies. Task networks refer to the task sequences and the interdependencies (temporal, sequential, cause, and effect) among the tasks.

The task network analysis is usually very intensive and requires sequential (timeline) analyses; it is carried out after an initial workload analysis. We limited our analysis to the basic task/workload analysis, partly because of time constraints and partly because we were unable to gather actual timeline data during the initial phase of Operation Iraqi Freedom, because ships were unavailable. However, at least one of our analyses—the "trump matrix" in the CCM (discussed in the next section)—did address task prioritization issues.

Conduct Simulations to Assess Human Performance and Workload. The CCM was developed by Micro Analysis & Design to simulate shipboard manning options for the LHD 8 amphibious assault ship from a macro perspective, using the realistic high-impact scenario that we created. Simulation results were used to determine whether the reduced crew complement could successfully accomplish, within acceptable crew fatigue levels, all underway operations.

The CCM consists of a series of asynchronous (nonnetworked) tasks that represent high-level tasks performed by the crew. The daily crew routines are coded into an Excel database that is used by the model to drive the normal activities of the crew. Shipboard regular and special evolutions, such as flight quarters, briefs, drills, and inspections, are also modeled as independent tasks and triggered by a scripted scenario. In the current study, 338 evolutions were modeled.

During the simulation, all crew members are started in their respective daily routines. Scripted evolutions then use the WQ&SB and logic sheet data to identify the appropriate crew members for the chosen evolution. When multiple evolutions are operating simultaneously, an event "trump matrix," generated on the basis of extensive SME inputs, is used to determine whether a new evolution is of a higher priority for each crew member than his or her current activity (e.g., *General Quarters* trumps *Departmental Training*).

The CCM is broken into two subnetworks—one containing crew tasks, the other containing model functions. By means of regular and event-driven snapshots, the model records data on the status of the evolution and crew fatigue. If the evolution manning requirements are met, the identified crew members are pulled from their routine schedules, started on the appropriate evolution task, and returned to their routine scheduled tasks on completion of the evolution task. When evolution requirements are not met, the evolution can be delayed for a specified amount of time or can fail.

The CCM also keeps track of the amount and quality of sleep afforded each crew member, to monitor whether evolutions are being performed without overtaxing the individual crew members and seriously degrading overall performance. The CCM's "fatigue analysis" relied primarily on an algorithm known as the fatigue degradation equation, which constantly calculates and updates the current fatigue status of all crew members, based on the amount and quality of preceding sleep obtained.

The fatigue status is given a score of 1 to 10, with a score of 6 (equivalent to staying awake for 24 hours straight) considered the point at which serious fatigue is present. Although current Navy regulations allow a limited amount of sleep (up to 24 hours of continuous performance in condition IA and up to 10 days of 4 to 6 hours of sleep during condition II), it was our goal to not exceed fatigue levels inherent in the manning of the LHD 8 PSMD.

Two CCMs were produced for this study**:**

- The *baseline* CCM was derived from the LHD 8 PSMD dated July 25, 2002, subject to revisions dictated by more recent changes in U.S. Navy Standard Workweek (NSWW) policies.
- The *excursion* (i.e., reduced manning variant) CCM was based on the reduced-manning option developed by our team through projected reductions in workload and watchstations.

Figure 1 presents an example of continuous fatigue records from our simulation, showing normal fatigue levels and normal sleep cycles for the first week but rising fatigue levels with the conditions IA and II deployments during the second week.

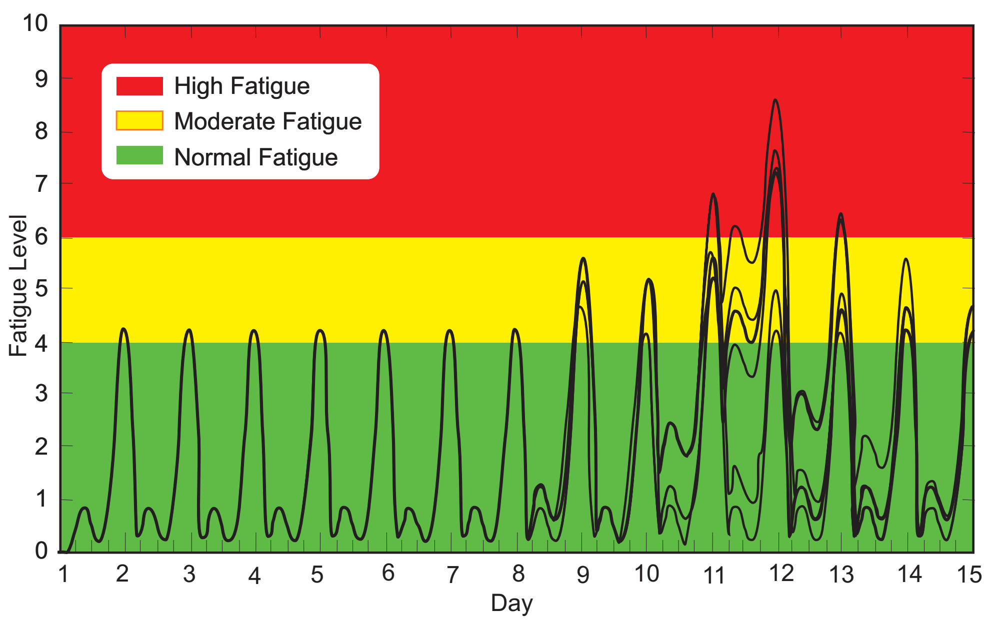

Figure 1. Fatigue levels throughout two-week simulation

Develop and Validate Ship Manning Model. Development of the ship manning model depends heavily on the manpower requirements, which were determined using a complex integration of five requirement areas. Three such areas relate to workload:

- Planned and corrective maintenance
- Facility maintenance
- Own-unit support (OUS)

The other two billet-drivers were

- Operational manning, consisting mainly of watchstation requirements
- Directed requirements (directed quantity), consisting of billets for certain officers and enlisted positions that are not assigned a percentage of workload or a particular watchstation

Although workload is the primary driver of non-watch-standing billets, the watch-standing nature of operational manning drives the majority of the billets in conditions I, IA, and III. The number of billets was further specified by rating, skill level, and ship department. Our effort required that the number of billets in the excursion model be reduced by at least 25% from the current manning for the USS *Wasp* (LHD 1), which has 1247 billets (1181 enlisted).

The ship-manning model was based mainly on the Task Analysis results and its workload distribution calculations:

- The *planned and corrective maintenance workload* was calculated from the maintenance requirement list for the LHD 8, whose switch to gas-turbine engines allowed for the reduction of 79 billets relative to the LHD 1.
- The *facility maintenance workload* was derived from the estimated workload in the LHD 8 PSMD, with billets assigned to E-4 ratings and below in each division.
- The *OUS workload*, estimated from the Task Analysis database, was broken into OUS direct and OUS indirect, then further delineated by department, division, and rating.
- *Watchstation manning*, based on 56 hours per billet per week, was determined by placing the LHD 8 PSMD and its Battle Bill assignments into a special database, in which only specifically designated watchstations were actually used to predict billets.

We developed and validated a reengineering of the current LHD 8 PSMD to serve as the baseline. The overall baseline workload calculated by our Task Analysis was only 1.76% different from that calculated by the existing LHD 8 PSMD. The reengineered workload calculation was followed by the development of an excursion PSMD that modeled our reduced-manning option, which met our goal of a 25% reduction in manning.

The baseline PSMD also included recent changes in the NSWW, productivity formulas, directed requirements, and corrections of minor errors in the LHD 8 PSMD. Those changes allowed further reductions of 63 billets in the LHD 8 PSMD to a total of 1105 sailors (1040 enlisted), which was a subtraction of 142 billets from the original LHD 1 billet total. Together with the excursion, the overall reduction exceeded 34% from the original LHD 1 billet total.

Manpower Reduction Innovations

The Northrop Grumman Information Technology Manpower team conducted risk analysis against many potential innovative processes and technology insertions and ultimately chose ten innovations to achieve our 25% manning-reduction goal. The selected innovations had a higher estimated return on investment and a relatively low risk:

- Reduction/transfer of OUS and maintenance involved currently available automation technology and transferring work ashore.
- The Aircraft Intermediate Maintenance Division (AIMD) and Amphibious Ready Group Intermediate Maintenance Activity (ARGIMA) Sea Operations Detachment (SEAOPDET) initiatives involved eliminating the associated billets from the ship and using the detachment manning concept for assigning those functions only to ships that are in a deployed status.
- Reductions of machinery operators and shaft alley watches were facilitated by remote sensing equipment, cameras installed to support remote monitoring, and the use of remote operator panels designed to monitor multiple pieces of equipment.
- The Damage Control Automation for Reduced Manning (DC-ARM) program reduced manpower requirements by automating damage control functions.
- Department consolidations (Engineering and Supply) were used to reduce the management infrastructure for those departments, while exploiting improved processes and automations.
- Improved well-deck handling procedures reduced the high-driver manning requirements—the condition IA watchstation requirements.
- Centralizing operational and monitoring consoles for aviation and well-deck refueling operations facilitated reductions for conditions IA and FQ watchstations.

Together, the innovations allowed for a reduction of 431 billets, compared with the baseline LHD 1 PSMD. Table 2 shows the effect of each innovation in number of billets saved, in the estimated savings directly attributed to the billet reduction based on the "sailor cost," and the estimated net savings after accounting for the cost of the technology.

Reductions Due to Shore Support. The shore-support initiative consolidates selected workload to shore bases. It involves a dual approach that includes technology insertions and reallocation of a ship's workload to the shore-support working group. In the next-generation destroyer (DD(X)) manning studies, shore support represented a very strong paradigm shift that requires ownership sharing between the active-duty crew and the shore-support system. It is a concept that is applicable to all ships, including the next-generation amphibious assault vessel.

The shore-support team has primary responsibility for the upkeep of the ship and its assigned crews. The shore-support management team executes operational planning and coordination, supply services, personnel management and training, configuration management, and all maintenance planning, including organizational, intermediate, and overhaul requirements. Shore-support automation upgrades include close integration and communication with the ship's onboard database, administrative support via technology services, and equipment status monitoring, with services facilitated by leveraged use of email, telephonic connectivity, and video teleconferencing. Shore support enables optimization of several OUS operations:

- Assists operational planning by releasing crew from tasks such as the management of crew rotations, ship's operational scheduling, and port services overseas
- Acts as the liaison for outside-sourced message handling and response
- Manages personnel and disbursing
- Maintains, stores, and manages hard-copy records

Table 2. Savings and returns on investment due to manning reduction innovations

Innovation	Billets Saved	Billet Savings over 50 Years ($ million)	Return on Investment ($ million)
LHD 8 Draft Preliminary Ship Manpower Document	142	Reengineered baseline[a]	Reengineered baseline[a]
Excursion components			
Reduction/transfer of own-unit support and maintenance	94	372	253
AIMD and ARGIMA SEAOPDETS[b]	75	297	69
Reduction of machinery operators/alley watches	29	115	No data
Damage control automation for reduced manning	18	59	No data
Consolidation in engineering department	17	67	67
Semiautonomous ship control	16	63	58
Consolidation in supply department	12	44	44
Improved well-deck handling	11	40	40
Centralized aviation fueling	15	8	8
Centralized well-deck fueling	2	8	8
Subtotal	289	1,073	547
Total savings for LHD 1	431	1,073	547

[a] Return on investment = Billet savings – (intital + recurring costs)
[b] Aircraft Intermediate Maintenance Division and Amphibious Ready Group Intermediate Maintenance Activity Sea Operations Detachments

When the U.S. Navy moves to a fully electronic system, shore support will still be needed to ensure appropriate service and execute nonstandard remedies beyond the capability of automated systems. Shore-support effectiveness for a variety of services will include enhanced automations and connectivity with the ships under its cognizance, including Web-based services and other initiatives currently under development by the U.S. Navy. Other automation improvements will be enhanced stock-control inventory and management, incorporating automated integration technology (e.g., bar codes, radio-frequency identification tags) and automated record keeping of inventory and Operations Target management.

When the ship returns ashore, the crew is provided further relief from support duties, because shore personnel assume primary responsibility for the ship's refurbishment and security. Duty sections by onboard crew will be reduced to bare minimums, and the crew will be free to enhance personal and professional skills, as well as having the opportunity to spend more time with their families.

With respect to preventive and corrective maintenance, active-duty crew will carry out maintenance actions needed quarterly or less often. For corrective maintenance, shore support will retain the primary responsibility to schedule repairs. Redundant systems for mission-essential equipment allow for most corrective maintenance to be deferred while the ship is at sea. Most non-mission-essential breakdowns will be handled by shore support.

Navy Maintenance Organization Ship/Shore Assignments. The ROC and POE documents require an onboard ARGIMA/Battle Force Intermediate Maintenance Activity (BFIMA) to provide technical support in forward-deployed locations that lack shore-support facilities. We recommended that this requirement be reallocated to an 11-billet detachment that is onboard only when the ship is operating in the forward-deployed locations, as specified by the ROC and POE documents. That optimization method is recommended for all ARGIMA/BIFMAs. Ships with similar operational requirements could realize additional efficiencies by sharing the ARGIMA/BIFMAs, instead of having a full complement for every pertinent ship.

The ship's AIMD must protect equipment and provide permanent equipment maintenance. When deployed, however, AIMD turns the spaces (i.e., compartments) that it occupies and its equipment over to the U.S. Marine air wing. The LHD 8 AIMD complement is 83 directed billets. Their assigned role at sea is to provide support for various evolutions that are not specifically assigned to them in the LHD 8 PSMD and to repair test equipment that remains under their cognizance, as well as U.S. Navy–assigned aircraft.

In port, the AIMD resumes responsibility for all test equipment and ensures that all items are ready for service when the Marines return for the next deployment. During reviews with SMEs, we discovered that much of the in-port work for these billets includes the maintenance and repair of their own and Marine-assigned spaces. Because of the high cost of training for these billets, and as a quality-of-life incentive, we recommended that shore support assume responsibility for the test equipment and its associated spaces while the ship is in port.

Like the ARGIMA/BIFIMA crews, the AIMD personnel will be assigned to a SEAOPDET that can be used to facilitate the care of test equipment across numerous platforms. Contracted services would be used for the care of the shipboard spaces. The recommended concepts together enable

- An optimization and reduction of the AIMD billets
- Better productivity due to a greater devotion to trained abilities
- Increased personnel availability for further personal and professional training
- A more efficient use of assets

Reduction of Machinery Operators/Shaft Alley Watches. Motor, generator, and pump technologies have improved considerably in the last two decades. Technological improvements have reduced failure rates and simplified controls, creating an environment that no longer requires constant personal contact and observation. That situation allows the use of remote operator panels, sensors (heat, vibration, etc.), and video surveillance, reducing requirements for multiple watchstations and instead assigning a single crew member to operate and monitor multiple pieces of equipment.

Damage Control Automation for Reduced Manning. The DC-ARM program, sponsored by the Office of Naval Research at the Naval Research Laboratory (NRL), was started in 1997 to develop and demonstrate technology for enabling reductions in the manning needed for damage control, while simultaneously improving damage-control performance. Testing to support DC-ARM development and demonstrations was conducted in Mobile, Alabama, aboard the former USS *Shadwell* (decommissioned years ago for use as NRL's fire research test ship).

The DC-ARM program is a multiyear effort designed to evaluate and demonstrate, through an exacting, systematic, methodical testing process, incremental reductions in damage-control manning corresponding to increases in automation and doctrine improvement. For our study, the DC-ARM allowed reduced requirements for both conditions I and

IA and was directly responsible for the reduction of about 15 billets when implemented alone against the LHD 8 baseline. However, DC-ARM was a primary input to our billet optimization goals, for it allowed up to 60 other billet eliminations when combined with other optimization methods that decreased workload.

Consolidation of Departments. We recommended that the Assault Division be eliminated and the associated billets and responsibilities be absorbed by the Auxiliary and Electrical divisions. A legacy standard that "billets are cheap" was the perception for the original creation of the Assault Division, manned with sailors having machinist-type ratings. Such personnel are trained in the specific understanding of the equipment pertinent to the well deck (which requires no knowledge beyond the assigned ratings). Moving those billets allowed a better distribution of the assigned workload, further reducing both organizational management billets and operational maintenance billets.

We also recommended that three divisions of the supply department be combined for organizational efficiency. Those consolidations were made possible by the shore-support initiatives described previously, which reduced workload associated with supply support. Consolidating the supply divisions produced further reductions in organizational management billets.

Semiautonomous Ship Control. With the implementation of the semiautonomous ship control philosophy, the reduced manning for the bridge included an officer of the deck (OOD), junior OOD, and helmsman. The Integrated Bridge System allows autopiloting wherever the ship may travel and offers the capability for automated charting and logs, voyage management, and fathometer displays. In addition, wireless communications allowed for the reduction of telephone talker and messenger requirements. Finally, electro-optical and infrared surveillance, directional listening devices, and personal monitoring devices allowed the elimination of lookouts, who are generally manned for the purpose of visually or audibly detecting contacts or hazardous conditions.

Improved Well-Deck Handling. Inclusion of portable winches in the well-deck design allowed billet reductions from the 1st and 2nd shipboard divisions. Condition IA requirements were reduced in the well deck by introducing commercially available two-ton electric winches. Additional optimizations were obtained by redesignating the remaining boat riggers as "anybody" watches with no specific division/rating assigned.

Centralized Fueling. We identified several watchstations assigned to conditions I, IA, and FQ to provide pump operation and fuel testing. Current standards that enable unmanned operation include the following:

- A single console used for remote pumping operations
- Video and sensor surveillance of the pump spaces
- Remotely operated or autonomous fire-fighting equipment in pump spaces
- In-line automated fuel testing

"Gap Analysis" Validation of Enabling Technologies for Reduced Manning. To ensure that the innovations were achievable, Northrop Grumman Electronic Systems, Sperry Marine Division, analyzed the feasibility of our proposed "technology enablers" within the projected period, searching for any "gaps" between projected and actual feasibility. The team evaluated each innovation for design maturity and availability for a 2006 new ship build; indeed, some of the enabling technologies are already planned for installation in the LHD design. The "gap analysis" concluded that all of the enabling technologies are either ready today or will be ready by 2006.

Results of Manning-Reduction Analysis

Baseline and Excursion Model Billet Totals. The effect of the enabling technologies was shown in Table 2 (page 71). As applied to the various operating profiles of the ship, the results of our manning-reduction strategy are shown in Table 3. The total number of billets reduced by our excursion model relative to the reengineered LHD 8 baseline was 284 enlisted billets and 5 officer billets (289 total crew). However, the reengineered LHD 8 baseline, with its allowance for a gas-turbine engine and its revised workweek and other calculations, was already 142 billets below that of the legacy LHD 1. The actual excursion billet total was 431 less than that in the legacy manning—a reduction of nearly 35% from legacy LHD-class manning.

We were able to achieve such a large reduction in manning because of our ability to reduce by about the same amount the number of watchstations required in conditions I and IA, which were the high drivers in the original manning requirements. Significant reductions in billets were also achieved in other operational manning requirements, as well as workload-driven manning.

Complete Crew Model Analysis. The CCM determined the number of evolution failures, as well as the excursion crew's ability to meet the requirements of the NSWW without excessive fatigue during the "battle" conditions. By design, evolution failures were nonexistent, although several minor evolution delays such as senior management meetings occurred, partly because of higher-priority activities of the commanding officer.

The CCM modeled condition III to determine whether we adhered to the NSWW during normal deployment. To verify that assumption, the workload categories of the NSWW were aggregated and the average number of hours per week within each category was calculated for the excursion and baseline models. Table 4 compares, for five activities, the excursion modeled average number of hours spent weekly with NSWW minimums:

- For the baseline manning, all workload categories of the NSWW fell within one hour of the NSWW minimum. *Sleep* exceeded the minimum while *Personal needs + service diversion* and *Messing* fell slightly short.
- For the excursion, all aggregates equaled the NSWW minimum except *Personal needs + service diversion* and *Sleep*. Here, the modeled average was one hour less than the minimum for *Personal needs + service diversion* and one hour greater than the minimum for *Sleep*.

Table 3. Effects of manning-reduction strategy on ship operating profiles

Model	Enlisted Billet Total[a]	Directed Quantity	Watchstation Condition I	Watchstation Condition IA	Watchstation Condition III	Watchstation Condition FQ	Workload
LHD 8, reengineered baseline	1,040	132	820	966	282	249	875
Excursion	756	56	519	671	238	216	643
Net reduction	–284 (–28%)	–76 (–58%)	–301 (–37%)	–295 (–31%)	–48 (–17%)	–33 (–13%)	–232 (–27%)

[a] The billet total is not predicted from different watchstation and workload requirements, because the same billet could be assigned by either set of requirements.

Table 4. Excursion average hours compared with Navy minimums

Workload Category	Number of Hours per Week	
	Excursion Modeled Average	Minimum, Navy Standard Workweek
Messing	13.8	14
Personal needs + service diversion	17.4	18
Sunday free time	2.8	3
Sleep	57	56
Productive work + training events	77	77

In real life, however, the sailor controls what happens during allocated periods for personal time, service diversion, and sleep, so the minor deviations from the NSWW minimums were not considered significant.

The comparative fatigue analysis further showed that the cumulative fatigue in the simulated excursion manning was very close to that of the baseline manning, as Figure 2 demonstrates. The excursion crew exhibited a slightly greater amount of fatigue during the second week, with about 11% of crew members (disproportionately representing the OA Division involved in vertical replenishment and well-deck operations) seriously tired, as opposed to only 8% of the baseline crew. However, any ship involved with high-intensity operations is well experienced and able to cope with fatigue. Since a successfully operating baseline ship remains fully functional during high-intensity operations, we do not believe that the slight increase in fatigue during the sustained condition I and II deployments in our scenario would have prevented the crew from operating effectively.

In total, the CCM was successfully applied for the first time to the LHD-class ship in our study, and it validated by means of a realistic scenario that a manning reduction of nearly 35% can be accomplished using currently or soon-to-be available technologies.

Summary

The amphibious assault ship is perhaps the most complex and multifaceted in the fleet. In view of its joint Navy-Marine complement, HSI policy and culture issues in both services must be addressed early in the design of the next-generation ship. None of the proposed reductions would be successful without being embraced by the Navy.

Previous attempts to increase automation and decrease crew on Navy ships have met with mixed results, but many of the disappointments can be attributed to conservative naval policy and culture. Issues such as acceptance of automation, increased shore support, and the need for greater cross-training are integral enabling elements of the manning-reduction program. However, our approach offers many benefits easily embraced by Navy culture, including more focused work duties and more shore opportunities through transfer of routine shore duties to contracted shore-support groups.

Despite focusing on limited elements of the TDRA approach and leveraging technology data from other ship programs, the results of this study show that a >25% reduction in manning of the LHA(R) can be readily achieved using mature or relatively mature technologies and with no major redesign of the LHD 8. The total crew numbers listed in

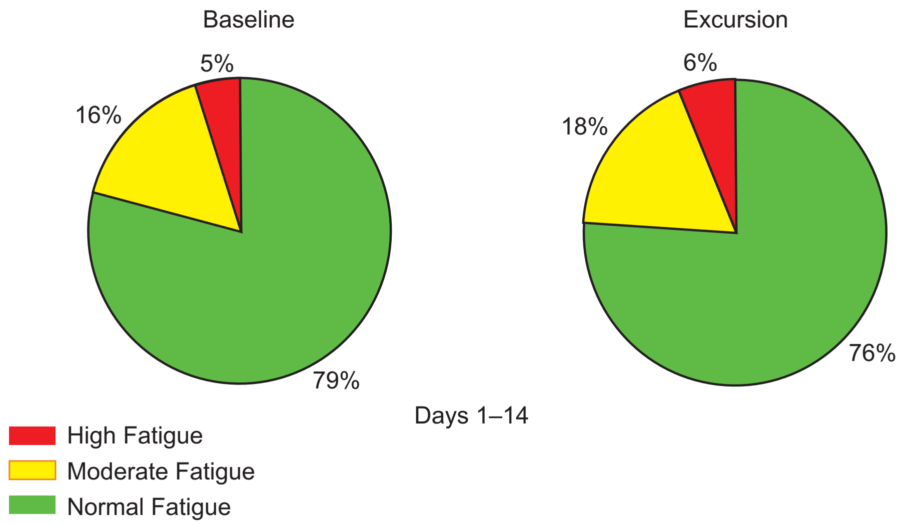

Figure 2. Overall fatigue levels for entire crew during baseline and excursion manning

Table 5 demonstrate that, through refinement of current technologies and development of future enabling technologies, along with cultural acceptance, a manning reduction of 35% is a realistic standard for future crews.

A June 2003 study by the Government Accountability Office projected savings of about $1 billion due to a 25% manning reduction for the 1247-billet amphibious assault ship over 40 years [1]. Our estimates are consistent with those of the earlier study: combined manpower savings and the savings resulting from manning reductions due specifically to the innovations proposed here are estimated at slightly greater than $1 billion.

Unfortunately, insufficient data were available to be able to provide even a rough estimate for two key innovations—machinery automation/remote surveillance and DC-ARM. Nevertheless, the estimated return on investment is still expected to exceed $500 million.

Innovations in well-deck and flight-deck operations may be additional sources of manning reduction, but we could not leverage studies from other programs to determine that potential because the amphibious assault ships are unique in this respect. Several well-deck deficiencies not directly related to manning have been detailed in other studies [4].

Further cost savings may be realized through improved efficiencies of contracted administrative and maintenance support. Interestingly, our study results suggest that greater efficiencies may be gained from contracted administrative shore support than from contracted maintenance support.

Northrop Grumman was successful in this endeavor due largely to the effective teaming of five separate sectors, each contributing manning-reduction technologies and analytical tools to meet the challenge of a 25% manning reduction on the LHDs. The technologies and tools discussed in this article are being employed elsewhere in the company, including the DD(X) and U.S. Coast Guard (USCG) Deepwater ship design programs.

Table 5. Total crew summary for LHD 1, LHD 8, and LHA(R)

Ship	Total Enlisted	Total Officers	Total Crew
LHD 1	1,181	66	1,274
LHD 8, Preliminary Ship Manning Document	1,103	65	1,168 (6% less)
LHD 8, reengineered baseline	1,040	65	1,105 (11% less)
LHA(R)	756	60	816 (34% less)

References

1. U.S. Government Accountability Office, *Navy Actions Needed to Optimize Ship Crew Size and Reduce Total Ownership Costs*, GAO-03-520, Washington, DC, June 2003, *http://www.gao.gov/new.items/d03520.pdf*.
2. T.B. Malone and J.R. Bost, "HSI Top-Down Requirements Analysis for Ship Manpower Reduction," in *SPIE Proc.* 4126, Bellingham, WA: SPIE—The International Society for Optical Engineering, 2000, *http://spiedl.aip.org/dbt/dbt.jsp?KEY=PSISDG&Volume=4126&Issue=1&bproc=volrange&scode=4100+-+4199*.
3. Department of the Navy, *Required Operational Capabilities (ROC) and Projected Operational Environment (POE) for LHD-1 (Wasp Class) Amphibious Assault Ships*, Naval Operations Staff (OPNAV) Instruction C3501.310A, November 2, 2002, updated November 2, 2002, *http://www.nll.navsup.navy.mil*.
4. Naval Sea Systems Command, *LCAC Cargo Loading Operations Onboard Amphibious Well Deck Ships*, Expeditionary Maneuver Warfare Division, Panama City, Fla., December 20, 2002. (This document is available from the authors.)

Author Profiles

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