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Human Systems Integration and Crew Design Process Development in the Zumwalt Destroyer Program

A Case Study in the Importance of Wide Collaboration

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Human Systems Integration and Crew Design Process Development in the Zumwalt Destroyer Program

A Case Study in the Importance of Wide Collaboration

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The paper reviews the Bath Iron Works–led human systems integration (HSI) and crew design effort in the DDG 1000 program, or Zumwalt Destroyer, which was charged with deriving a highly detailed crew design coincident with and traceable to the hardware and software designs. Topics of special interest in this paper include

- HSI processes and tools developed or adapted for DDG 1000. Lessons learned and recommendations are summarized.
- The critical importance of collaboration, both inside the design team (intra-team) and with multiple outside entities (inter-team).
- The importance of incorporating HSI into the systems engineering organization (vice operating as a component of logistics, supportability, or a stand-alone team).

THE IMPORTANCE OF EARLY RESEARCH AND CONCEPT DEVELOPMENT

The efforts that preceded and coincided with the opening phase of the next-generation Destroyer program tirelessly promoted the objective of reduced crew sizes and explored the engineering efforts required for a successful crew design effort. These efforts included the following:

- Promoting awareness (and ultimately acceptance) of a mix of professional journal articles, industry trade show themes, and traveling road shows that all highlighted the achievability of greatly reduced crew size through the use of automation and workload-reducing design innovations, shore support, etc.
- The Integrated Command Center (ICE) at Naval Surface Warfare Center (NSWC)–Dahlgren was simultaneously exploring the feasibility of a dramatic reduction in watch team size through the use of automation improvements in mission systems and a single multimodal watch stations (MMWS) in place of mission system–specific consoles. Hundreds, if not thousands, of navy and other government officials were exposed to the ICE demonstration and became believers.
- Additional efforts were conducted to determine the engineering processes, analytical techniques, and skills required to achieve the reduced crew size being postulated.

- Concept work and research sponsored by the Office of Naval Research (ONR), NAVSEA (Naval Sea Systems Command), and others were simultaneously beginning to explore the basic toolkit and skill sets needed to conduct a comprehensive HSI effort in new acquisition. Skills such as cognitive task analysis, function analysis, and knowledge engineering were being promoted in professional publications and discussed and publicized at trade shows, seminars, etc.

Initially, these efforts found a great deal of resistance in almost every quarter. This in spite of the fact that the AEGIS Weapons System and Tomahawk Land Attack Warfare Missiles (TLAM) had proven the value of systems integration and software automation in reducing cognitive workload while dramatically increasing situational awareness, reliability, and mission effectiveness. Ultimately, however, the campaign produced results, and senior staff at the Department of Defense (DOD) and congressional figures became convinced that the smaller crew size was feasible and should be pursued diligently.

OPTIMAL MANNING RELEVANCE TO DDG 1000 PROGRAM

As key fleet and NAVSEA leaders were ultimately persuaded in the goodness and achievability of reduced crew sizes concrete actions followed. The most proactive and aggressive fleet efforts were conducted by Commander Naval Surface Forces (CNSF), Vice Admiral (VADM) Tim Lafluer. During VADM Lafluer's tenure as CNSF, aggressive efforts were made to explore the potential of reduced crew sizes in legacy ships.

The earliest efforts to reduce the crew size of legacy combatants came to be known as the Optimal Manning Experiment (OME); its goal was to reduce crew sizes on designated ships in the DDG and CG classes. A series of working conferences led and directed by CNSF worked out the OME guidelines with the full participation of the commanding officers of each of the original participating ships (USS *Milius*, USS *Mahan*, USS *Mobile Bay*, and USS *Monterey*). Representatives from across navy and industry were invited and encouraged to participate in the OME ship working conferences. The commanding officer of each ship had the final decision on which pieces of the OME guidelines to implement and how the crew reduction was made (e.g., which sailors were transferred to the shore support component). Homeport support from a shore maintenance augment and a pay and personnel administrator (PAPA) detachment were provided, as were waivers on standard operating procedures, concept of operations (CONOPS) modifications, increased use of commercial off-the-shelf (COTS) technologies, and more. The OME ships operated for an extended period (through multiple deployment cycles) with roughly 20–25% reduction in crew size, including highly successful extended arduous deployments with combat operations

The experiment was continued for several years longer than originally envisioned. When it was phased out, many of the basic lessons learned regarding manpower, personnel, and training (MPT) policies, the use of in-homeport shore support and distance support, and the value of OTS/COTS to support the smaller crews guided some permanent manning reductions across the classes. The full set of lessons learned is still being evaluated as part of a robust dialogue among involved parties (ship and CLASSRON leadership, NAVSEA, CFFC, industry, etc.)

Key lessons learned include the following:

- The expedited approval of COTS devices for shipboard use was one of the beneficial legacies of the OME effort. For example, the laser range finder (in use for over a decade principally by golfers and other sportsman) was approved to replace the distance line for underway replenishment. Lessons learned in CIC watch-team operations supported the DDG-M CIC modifications, specifically providing strong support for the use of the Common Display System (CDS).
- Shore support from maintainers in homeport can only be effective if access, security, qualification (competence), quality assurance (QA), and ownership issues are fully resolved.
- Complex MPT issues require mitigation in order to achieve the optimal crew size and render it successful across the service life of the ship. These issues include contact relief, unplanned loss mitigation, and a myriad of training and qualification issues.

Crew swaps on forward-deployed DDGs were also conducted during this period in an attempt to extend the coverage on-station by eliminating the transit to the area of responsibility (AOR) and minimizing turnover time. While the concept of crew rotation on permanent deployed platforms was not continued, lessons of great value for future planned were learned and archived.

During the period of OME, crew size and manning reduction was becoming a central objective in acquisition and modernization efforts as well. The imposition of a manning key performance parameter (KPP) on the DDG 1000 program was consistent with the OME philosophy of achieving reduced crew sizes through automation, innovation, restructuring, or acceptance of changes to CONOPS, policy, or culture. An aggressive manning KPP was first broached on the DD 21 program during concept development when OPNAV N86 set a 95-person crew as the goal for the SC 21 program. This number was later modified to a range of 125–175 and imposed on phase three (risk mitigation) and phase four (detail design). The importance of the manning KPP in each of these phases cannot be overstated. It served as the forcing function for brainstorming in phase three and was the basis for crew design requirements; it was the impetus for the development of an HSI process set and a critical factor in HW/SW design processes and decisions.

TOTAL OWNERSHIP COSTS

All of this activity (and much more across other ship classes) was in response to the realization that the total ownership costs (TOC) associated with personnel had become a critical and limiting factor in acquisition and modernization as well as the operating budget. This importance was recently underscored by new DOD guidance (DOD Directive Memo, May 2010) capturing all manning costs, including those for not only navy crews but also military shore support and DOD civilians when answering TOC questions.

The growing awareness of the importance of TOC associated with manning was at the heart of navy leadership's intense interest in reduced crew sizes. This in turn heightened interest in HSI and crew analyses. The TOC and return on investment (ROI) savings associated with specific automation, shore support enhancements, and more are complex and defy simple definition and calculation. In addition to the straightforward analytical summations of reduced workload (or enhanced situation awareness) there are often thorny navy culture issues that defy quantification but must be dealt with effectively to achieve the desired outcome.

While all of these layers of complexity must be considered for a comprehensive TOC discussion, the size and composition of the core crew required to operate the ship in the mission environment are the first considerations—and on the accuracy rests the validity of all follow-on projections and calculations.

THE IMPORTANCE OF COLLABORATION TO HSI OBJECTIVES

Development, promotion, and maintenance of the highest possible level of intra-team collaboration across the DA/NTT organization in the high speed, budget-centered environment of new acquisition is an immense challenge. In his *Handbook of Human-Systems Integration*, Hal Booher argues that without effective high-level buy-in, HSI efforts are typically ineffective. Fortunately for the DDG 1000 effort high-level buy in was not a problem. The navy, partially thanks to ONR and NAVSEA work, had recognized the essential nature of an effective HSI effort and deserves great credit for its early insistence on its inclusion in the DDG 1000 program processes. Similarly DDG 1000 program leadership was vigilant and took many steps to ensure that the HSI effort would not simply check the block.

Despite this support from leadership, the implementation of HSI in DDG 1000 was not an easy task. There was the inevitable passive–aggressive resistance by some design entities to determine if the leadership support was genuine and if there were some initial HSI process development and rollout failures and the normal resistance to change, all of which required mitigation.

Some of the most effective mitigation took the form of “HSI days” conducted across the program to ensure that the sailor system specification was understood and to address the system specific HSI issues in various venues. Other measures taken included assigning specific HSI team members to liaison with each design component (segment representatives) and an aggressive responsiveness to resolving HSI action items and to assisting in the resolution of action items assigned to other product teams.

HSI is a relatively new navy engineering discipline. The NAVSEA HSI directorate defines HSI as encompassing six distinct domains: human factors, habitability (quality of life), damage control (recoverability), manpower, personnel, and training.

On the DDG 1000 program, the HSI cross-product team (CPT) had exclusive responsibility for human factors, manpower, and personnel domains and shared responsibility and support for training, recoverability, and safety by closely collaborating with their respective CPTs and working groups. The newly established HSI directorate, (then designated SEA 03) was aggressive in ensuring that HSI and training worked closely together.

The HSI-training-safety collaboration came naturally, because out of necessity each area takes a sailor-centric view of the design. Promoting effective collaboration across other design elements required a great deal more effort. In the end the central importance of the manning KPP and strong navy leadership (including DASN-level concern and support) combined to attain the needed collaboration.

HSI in a complex new-acquisition design, must clearly be a cross team, interdisciplinary effort, which requires extraordinary levels of intra- and inter-team collaboration to meet the important objectives of reduced crew size and physical and cognitive workload reduction in a safe, user-friendly and effective system design.

Collaboration within the design agent (DA) team and with the newly created NAVSEA HSI directorate was an important part of the phase three effort. During the early period of team forming and process development there was some program interaction with the ONR that took place largely in the background of DA activity. This work covered task-oriented design processes, human performance models, human-centered design tools, and the advantages of the MMWS. While this work was foundational to the success of the Zumwalt HSI effort**,** proprietary issues, bureaucratic inertia, schedule pressures, and more prevented it from being as beneficial as it might have been in a completely open environment.

Currently ONR is leading an effort to develop a web-based HSI toolkit that can be accessed and used by industry and navy engineers, analysts, and subject matter experts. The product set being developed is an HSI integrated data environment (HSIDE) to enable access to a set of proven HSI tools and processes. The objective of facilitating human factors engineers, crew designers, and manning analysts to conduct systems engineering, analysis, and design in areas of functional analysis, computer interface design and evaluation, ergonomic assessments, and crew-station design. Much of this effort allows for better understanding of physical and cognitive workloads and station layout.

ONR is supporting the development of HSIDE specifically to promote navy–industry team collaboration and to expedite the application of effective tools and processes across acquisition and modernization. While the DDG 1000 experience has proven beyond question that HSIDE is critically needed, lessons learned also make it clear that introducing and promoting the wide usage of the site and its resident tools will be challenging. Several efforts to export Zumwalt processes to other programs during phase three (early detail design and risk mitigation) were not completely successful. The combination of individual unique program schedules, budget, and resource limitations prevented effective cross-pollination. For example, the LCS program had a directed crew size and little or no crew design budget. Proprietary aspects of the competition further complicated LCS. The ONR HSIDE effort in progress now has the potential to mitigate these kinds of issues of program-specific issues.

Some of the early DA/NTT interaction across the navy resulted in highly productive long-term liaisons that continue today. These include extensive collaboration in support of usability testing with OPTEVFOR, SWOS Newport, ATG Norfolk, ATG San Diego, and NSWC–Philadelphia (land-based test site) as well as a strong liaison with the sponsor organizations, including N863, NAVSUP, and others.

Hindsight reveals a number of areas where additional collaboration would have been of great benefit. These areas are highlighted in context and summarized in the Recommendations section.

HSI PROCESS SET DEVELOPMENT AND INTEGRATION INTO SYSTEM ENGINEERING PROCESS

The DDG 1000 program imposed a very large number of technical and programmatic challenges on the design team. The previously discussed manning KPP was defined as 125–175 crew members (including the air detachment to operate helicopters and VTUAVs.) It is significant not only that the program imposed a manning KPP but also that the KPP was given program viability implications. Early in the risk mitigation phase, program leadership determined that weight, cost, and crew size were the three most critical KPPs and established unique reporting requirements as each was deemed critical to program viability. This top cover from program management (PM) empowered the HSI team significantly and provided a solid basis for intra-team collaboration on a myriad of process challenges. The following describes the individual processes and tools to facilitate crew design. Many of these processes are DDG 1000 unique and were developed as the need for them clarified and the budget and resource issues were resolved.

Sailor System Specification (S3)

The challenges necessarily began with requirements for and the development of a crew specification requirement set and a process to impose those requirements on the design. There was no precedent or template for a crew design specification to constrain the HW/SW design, but with technical director leadership and program manager support a tier-one crew design requirement set and flow-down process was developed and implemented. The crew design requirement numbered less than 70 tier-one requirements and was given the name “sailor system specification” (S3).

The S3 defined the crew and provided design objectives and constraints across every product team involved in the design LCS (See Figure 1). These constraints took the form of limiting the physical workload across the traditional categories of maintenance, cleaning, preservation, special evolutions, and more, and dealt with as many of the other HSI domains as deemed practical, including, quality of life (QOL and habitability). The design organization provided for a separate tier-one safety specification set and a dedicated safety cross-product team and a separate training system development integrated product team (IPT). To meet responsibilities in these domains, the HSI-CPT established a firm liaison with both the safety CPT and the IPT, which proved very satisfactory and continues today as detail design proceeds to production and delivery of the first ship. The lessons learned in developing, implementing, and managing the S3 requirements process are extensive, and a detailed recounting is beyond the scope of this paper.

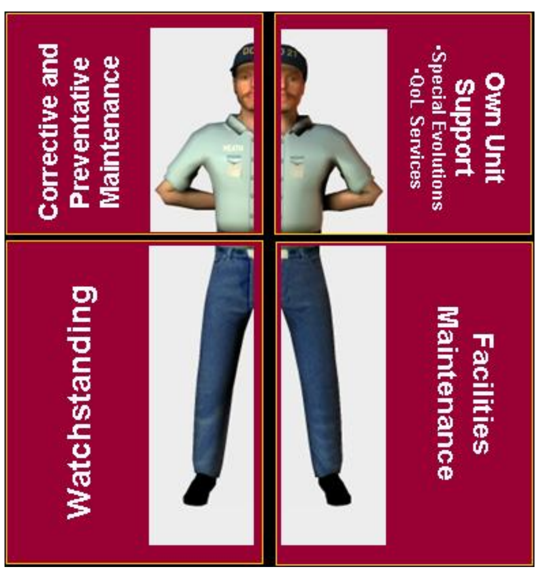

FIGURE 1 The S3 contains individual tier-one specifications for each workload area that are decomposed to the lowest practical level in the system performance document (SPD) and imposed globally on the design–build specification (DBS).

However, the major challenges, which required extensive intra-team collaboration, include the following:

- **Defining the appropriate level of detail for the tier one specification (granularity).** This problem was eventually solved in the course of normal process development. The difficulty of enforcing or successfully invoking a global requirement that was not flowed down to lower levels proved to be highly resistant to the system engineering (SE) process. Strong TD and project manager–level leadership is useful but in the end the most enforceable of the S3 requirements were those that are decomposed to the lowest level of the design possible and tracked at the highest level of team leadership possible.
- **Development of satisfactory metrics.** While man-hours per week (m-hrs/wk) is a very adequate metric for most workload categories, it does not work as a defining metric for the operational manning (OM) [watchstander (WS)] component of the crew. After much deliberation the number of universal WS consoles was adopted as the OM metric. This metric, while it did in fact provide engineers with a constraint, was not without difficulties. Principal among these difficulties was the flow-down of the system-level requirement to the lower-level components of the design. For example, calculating the relative contribution of C3I software and sensor hardware to the support the mission WSs and the assignment of fractional WS consoles as a requirement proved somewhat problematic.
- **Comprehensive flow down (decomposition across the system performance document (SPD).** This was the difficult and complex task of decomposing the tier-one specfications across the system performance document and into the DBS (see Figure 2).

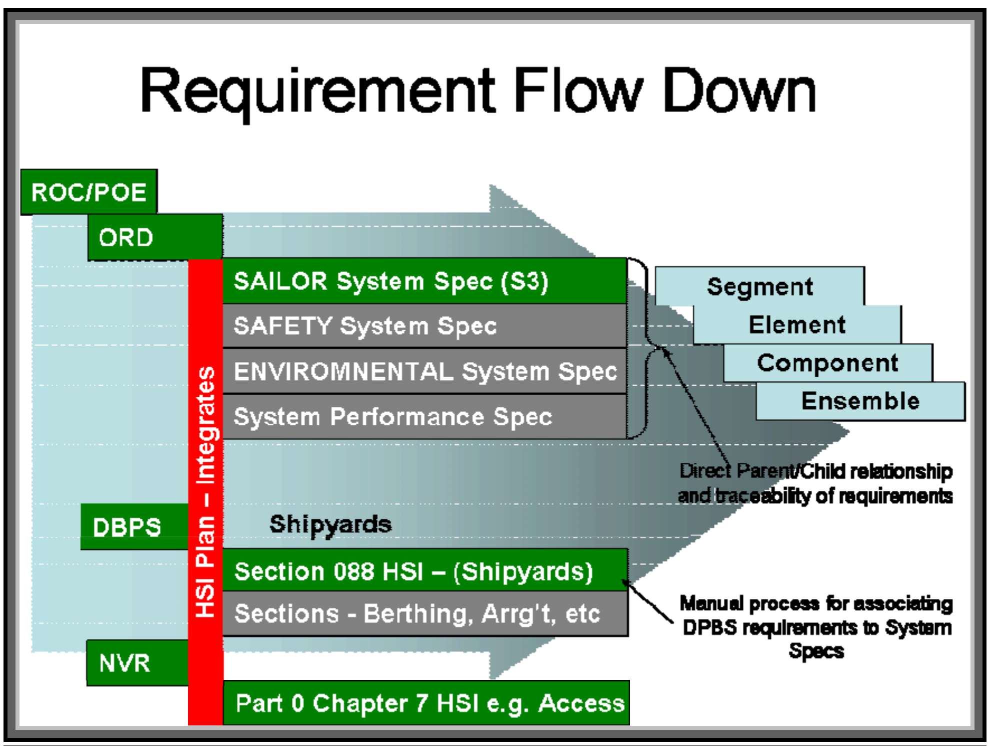

FIGURE 2 The tier-one crew design specification was decomposed across the system performance specification to the lowest appropriate level and was also applied to the DBS.

- **Requirements management and change process.** In addition to the normal difficulties posed by requirements management, the S3 challenged the entire SE team to modify processes and work to a new and different objective. The results were predictably mixed in that some design entities were more aggressive in pursuit of meeting their requirement than others. The reallocation of requirements, originally envisioned to be a touchstone of successful S3 process, proved to be exceedingly difficult and did provide the desired benefit. Lessons learned from this experience are still being evaluated, but the basic cause is related to the complexity of the SE organization, schedule pressures, and the ability to successfully work around the problem.

Task Analysis Process Development and Execution, Including Knowledge Engineering and Cognitive Task Analysis

Given that no mission or functional area in the DDG design was a legacy design, the task analysis (TA) process (see Figure 3) was immensely challenging simply from a volume viewpoint. The intra-team collaboration required slices across the team, but there was a near continuous need for certain design entities to participate. For example, C3I supports nearly every mission and function area.

When the full TA requirement was evaluated it became clear that the HSI-CPT had an immense challenge to gain the kind of continuous cross-team collaboration required to support the objectives and would need to leverage the team schedule to the maximum extent possible.

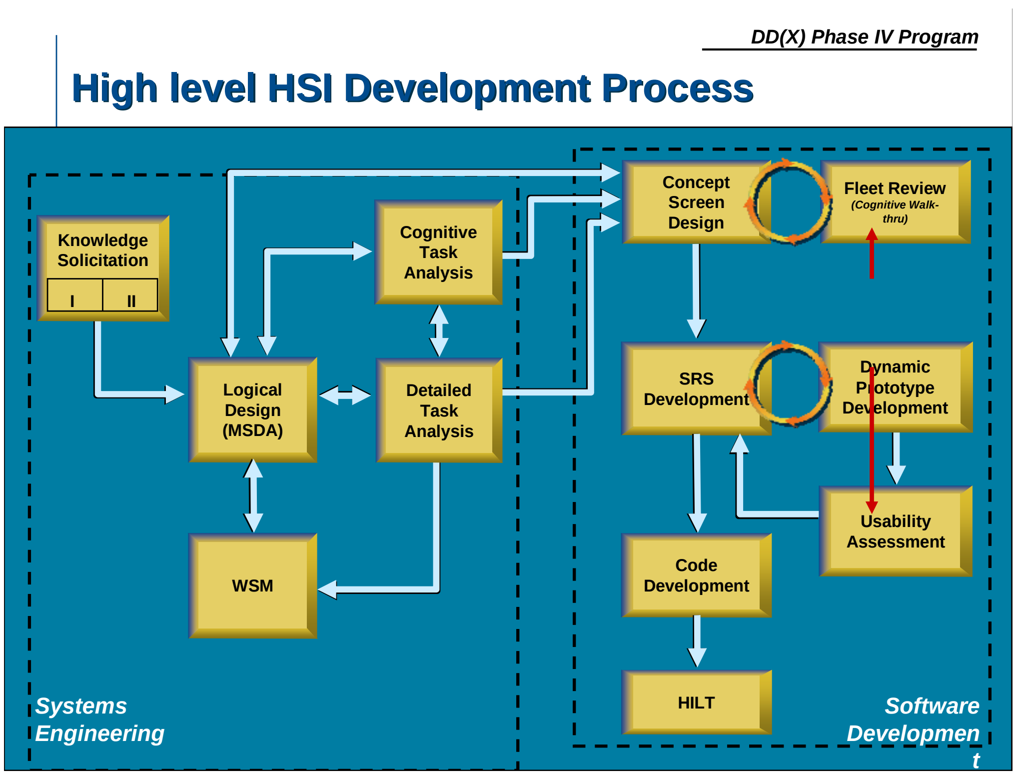

FIGURE 3 Task analysis and data collection was a multidomain process with task analysis and an SE process with the task data feeding multiple software, training, and supportability processes.

Mission System Logical Design Analysis

This process, unique to DDG 1000, is really the capstone of intra-team collaboration, ultimately involving the HW/SW teams from across the design, the HSI-CPT, and ultimately every working group and design entity involved in the program. The development of this process was driven by the need to address mission system design comprehensively to ensure the mission software and OM TA were conducted in an integrated fashion with full traceability between the software, hardware, and crew design. Development of the mission system logical design analysis (MSLDA) process was principally an intra-team collaboration, as was execution. In hindsight, this may have been the best opportunity for ONR collaboration with respect to improving the process and making it available for other program's usage. MSLDA created the logical design coincident to the conduct of OM TA.

The process (see Figure 4) challenged the design team in many ways. The sheer number of activities required to complete each system's artifact set was difficult from a schedule and budget perspective. The HSI CPT leveraged every scheduled session to complete the WS component of the crew design and HSI advocates—operational subject matter experts (SMEs)—became well connected with the individual system designers to the great benefit of all.

HSI Task Repository Development and Maintenance

The discrete components of the crew design reside in the HSI task repository. Crew tasks derived from all sources are collected and peer reviewed, issues are adjudicated, and all required attributes (timing; knowledge; skills; abilities; tools; primary, secondary, and tertiary crew members; etc.) are populated and validated. They must then be maintained in a user-friendly

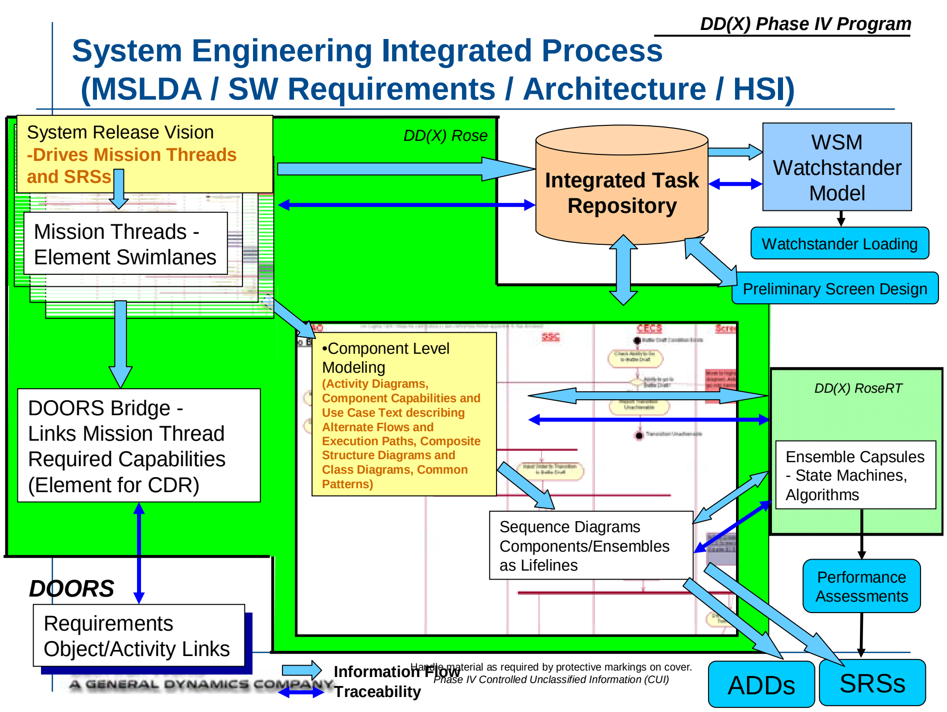

FIGURE 4 Task data from all sources is vaulted in the Integrated Task Repository. All OM tasks (WS actions) were derived in the MSLDA.

database and are subjected to rigorous configuration management (CM). The HSI task repository use and maintenance requires the same collaborative efforts of the product teams who assisted in collecting, reviewing, and refining the tasks and populating their attributes. Change management (CM) and the process for the CM of this data is as rigorous and judicious as it is for the SW and HW. Success in the early collaboration on TA, cognitive task analysis (CTA), knowledge engineering (KE), and MSLDA set the precedent for the HSI task repository CM process. The early collaboration to derive tasks and other related design data gives those who participated a continuing level of interest that their products remain valid.

As described in the following section, the task repository was a required input to the design of human–computer interfaces (HCIs). In short, all tasks that were identified as involving the use of an HCI had to be satisfactorily accounted for in the Zumwalt HCI design. The task repository also served as the primary analytic tool underlying the quantitative specification of workload in the crew design and directly impacted the design and analysis of all program usability tests. In short, the task repository proved to be a necessary and highly useful HSI and SE design tool.

HSI Support to HCI Screen Design

HCI development, though part of software design, is heavily driven by HSI input regarding

- Relevant aspects of end user performance, including cognitive workload, situation awareness, human error, etc.; and
- Application of human factors guidance, best practices, and HCI standards.

The foundational artifact needed to conduct user-centered screen design is a comprehensive set of sailor tasks that must be accomplished using each screen or screen set. Crew tasks that define the OM are populated with the appropriate attributes to support screen design, including the specific Information Requirements (IR). Screen design that proceeds with less than fully defined and peer validated crew tasks is destined for problems and costly rework at activation. HSI support to the HCI team also included

- Development of all sailor task data and attributes required for building screens and assistance as needed with access to and use of the HSI task repository.
- Participation by HSI crew advocates (CAs) in all phases of HCI requirements generation, design, and assessment. HSI CAs were recently retired Fleet Sailors whose operational expertise was applied to the design of HCIs specific to their areas of expertise. CAs were trained in HSI techniques and methods and participated as full partners in the HCI design process.
- Conduct of HCI usability tests, including cognitive walkthroughs of early display concepts and more interactive assessments of partially interactive mature display concepts.

Crew Modeling

The use of discrete event modeling to prove the crew design viability was fully explored in the earlier phases of the crew design effort (see Figure 5).

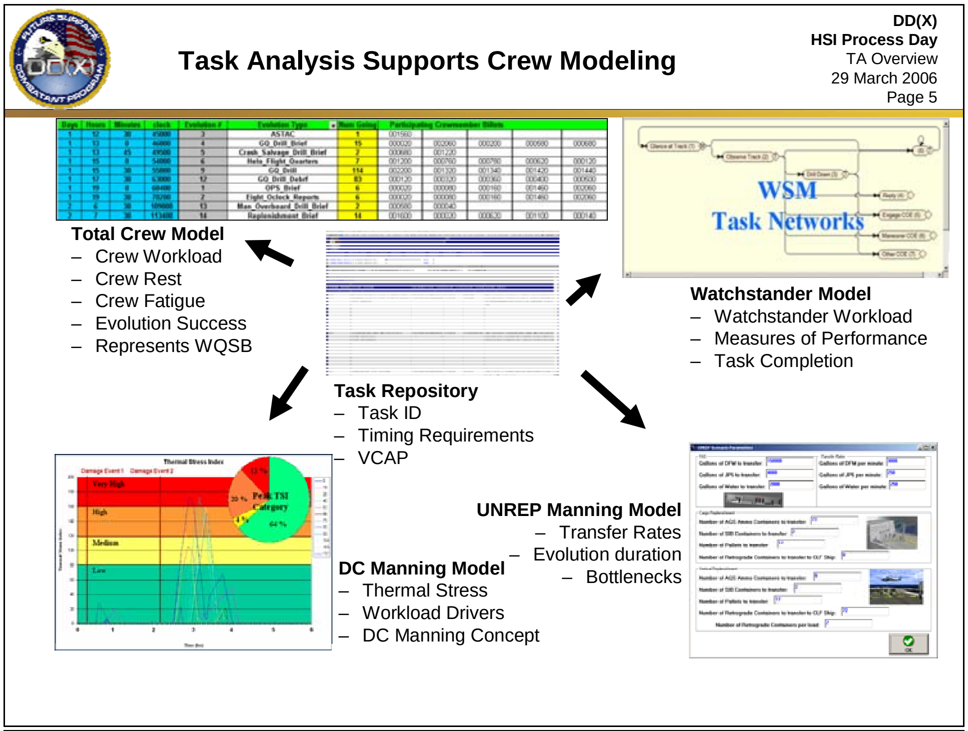

FIGURE 5 HSI analysis populates the task repository, which feeds models.

- **Total crew model (TCM).** Essentially a dynamic depiction of the Watch Quarter and Station Bill (WQSB), this was the most useful of the suite of models utilized. TCM's use of a trump matrix allowed the model to prioritize and de-conflict events and WS evolutions. Additionally, TCM's workload allocation tracks crew fatigue across the scenario timeline (nominally 45 days) furnishing a valuable validation of crew capability or a list of failed events, which makes identification of crew composition deficiencies useful. There is, however, limited value in re-running the TCM once the crew design is complete, as finite changes in crew makeup or allocated tasks can be accurately assessed manually.
- **Watchstander model (WSM).** This highly complex model utilized validated tactical WS task data along with task networks representing the combat systems design to permit the evaluation of the watch team's ability to execute individual missions and all combinations of mission simultaneity, including the cognitive loading of internal and external communications. The fidelity of the design, WS task data, and complexity and immaturity of the model itself made it less useful than originally envisioned; nonetheless, the findings pointed to weaknesses in the watch team structure and permitted the HSI-CPT to address them earlier than would have been possible without the WSM effort.
- **Damage control event models (discrete event and physics based).** This model set was used in an effort to understand the physiological workload associated with crew response to damage events and to validate some aspects of the damage control manning concept of operations. The use of discrete event modeling in concert with a physics-based model of ship structure response to the damage event and the containment (or lack of) by installed system automation was useful.

One important conclusion from all crew-modeling efforts is that, while there is value added in modeling the crew design, many evolutions (underway replenishment, flight quarters, and others) can be adequately assessed by manual review of task data and the WQSB in the design reference mission (DRM) context. Also, whether or not a model of human-system performance can be used as a system design validation tool is somewhat controversial. However, all three models passed rigorous verification, validation, and accreditation processes.

Manning Uncertainty Issues List Process and Database

The Manning Uncertainty Issues List (MUIL) is unique to Zumwalt and was developed in response to the need to meet the manning KPP by identifying, prioritizing, and tracking design uncertainties that threaten to increase crew size without program leadership intervention. While it is a straightforward spreadsheet-based design decision aid, it proved immensely useful and resolved an extraordinarily difficult PM–level issue by providing the HSI-CPT with an analytically sound means to track all known manning uncertainties, prioritize the competing issues, and raise them to program leadership as required to prevent crew growth. The MUIL is essentially a list of design features, shore support, navy culture-process-CONOPS issues that have viability issues that could require additional crew or significant changes in crew composition (see Figure 6). Examples include the following:

- Programs of record with inconsistent development progress. For example, the DDG 1000 unmanned radio room concept did not prove viable when the Joint Integrated Tactical Radio Program fell far behind development and projected their inability to meet DDG 1000 first ship schedule.
- WS concepts with reliance on multiple systems. Some parts of the watch team design rely on an unprecedented high level of integration among systems to achieve a level of enabling synergy. This area provides the best example of how the MUIL process provided the structure needed to efficiently resolve priority issues. The engineering watch concept relied on a robust virtual presence, high-functioning, user-friendly GUI design, highly-sensorized propulsion and auxiliary systems to permit full control and monitoring from the ship's mission center, a high-functioning prognostic and diagnostic system support system, and full navy acceptance of the concept from all stakeholders. This specific uncertainty was identified early in the program and tracked consistently for over five years before being resolved with the addition of one additional watch stander in the engineering area. The original uncertainty range projected that 3–11 additional crew could be required if all of the design objective dependencies were not fully realized. The MUIL forum provided an extremely effective forcing function to the engineering process to ensure that requirements were met to the extent that only one additional watchstander was required over the original baseline. (Note: The result is an engineering OM of 2 watchstanders versus 9–11 on the DDG 51).
- Jeopardized SW functionality due to technical or budget issues. Software schedule slips require close evaluation to permit the proper adjust of CONOPS, crew design, and more. Additionally, in many cases (notably tactical and engineering applications) a failure to achiever required and projected software functionality would have certainly resulted in significant crew growth.

- CONOPs or crew organizational or administrative policies with navy acceptance issues. For example, several DDG 1000 assumptions regarding dual NEC assignments were rejected by the TWH or sponsor and required crew design adjustments.

Humans Systems Shipboard Integration Process

The human systems shipboard integration (HSSI) process is essentially a human-centric computer-aided design evolution of the space layout and design process used in the days of the drawing board review. It was developed specifically for DDG 1000 detail design; computer design tools enabled an iterative, highly detailed review of the ship design, zone by zone and space by space, to ensure that the layout meets the human factors requirements.

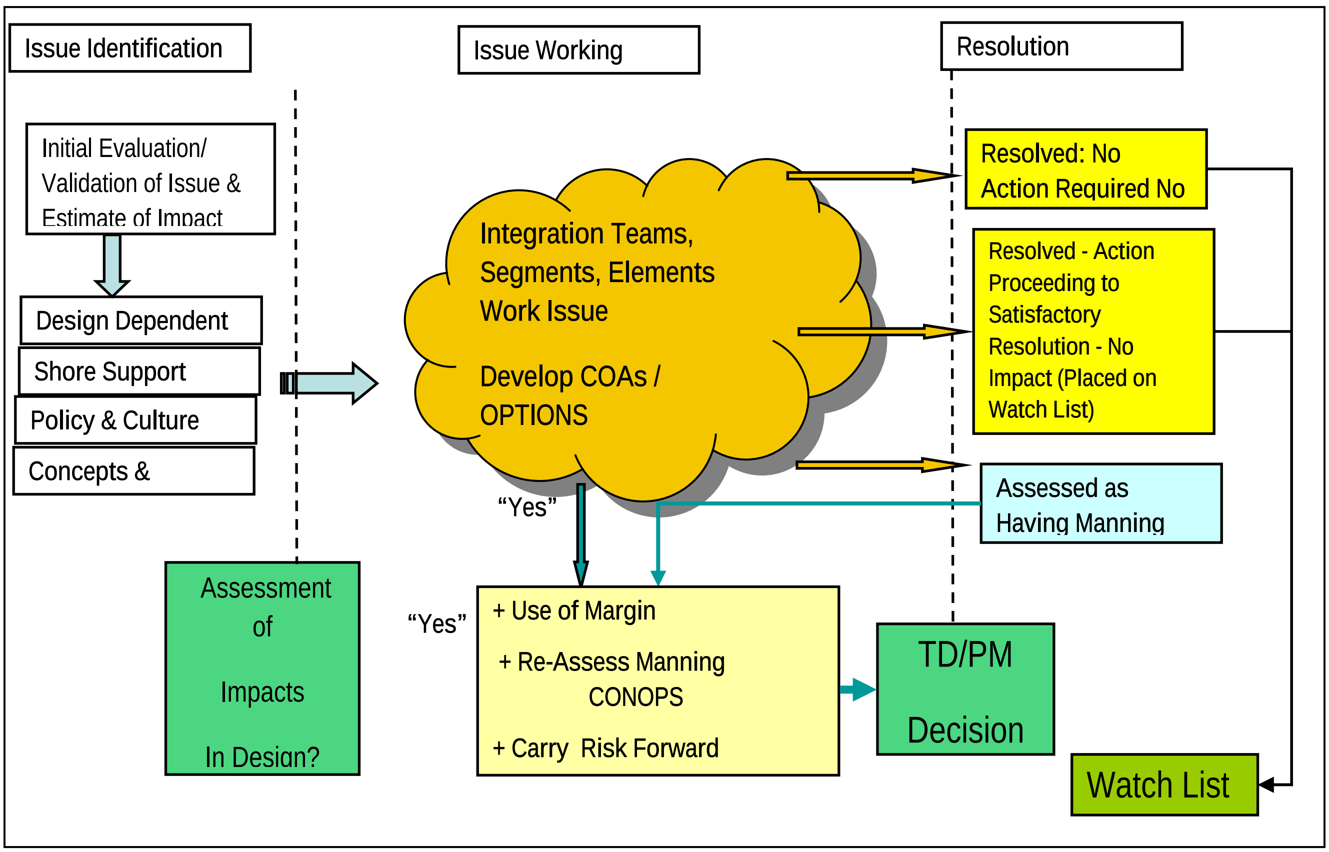

FIGURE 1 MUIL process facilitates PM intervention in design areas that threaten to increase crew size. By prioritizing issues in accordance with their potential impact and working through a structured resolution process many issues are resolved prior to the TD/PM intervention and program leadership is fully aware of relevant crew design issues.

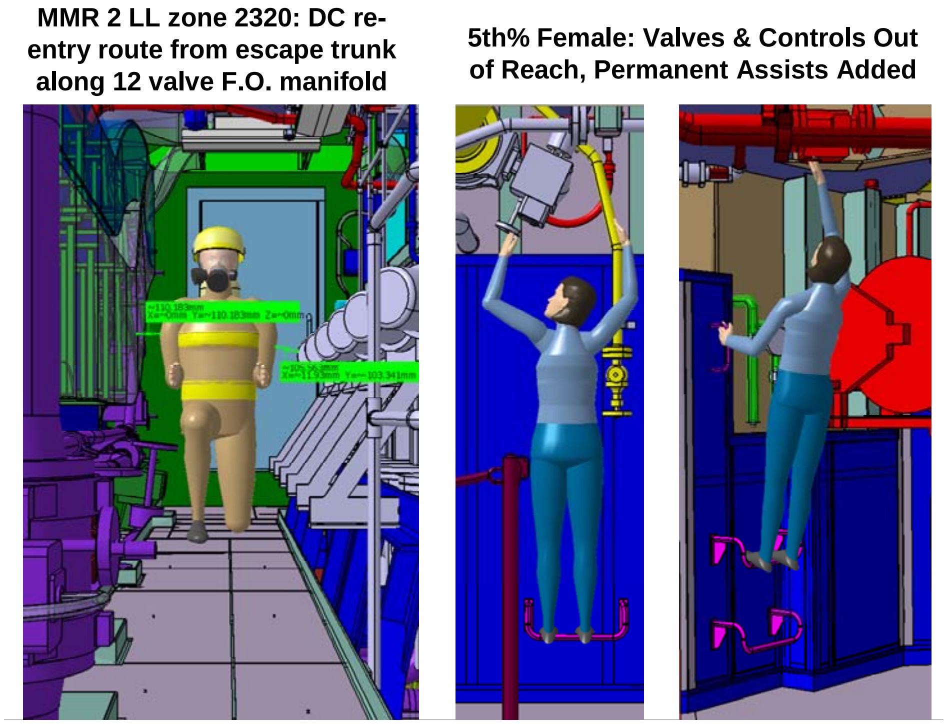

FIGURE 7 CAD-based models used for ergonomic feedback to design.

The ability to review the design space by space as it evolves and matures gave the HSI-CPT multiple opportunities to ensure that all requirements were met or adjudicate exceptions in real time with the participation of the designers and relevant subject matter experts, technical warrant holders (TWHs), stakeholders, and others. This process directly addressed the efficient, user-friendly layout of ships equipment, space entry and egress, transit, operational and maintenance access, line of sight, ergonomics, and a myriad of safety and QOL issues utilizing DELMIA Ergo-Man and CATIA 3D extractions to put the virtual sailor in the space to perform the required actions (see Figure 7). The process was iterative and permitted the correction of hundreds of issues at the last no-cost–low-cost point in the program. When correcting the issue was not feasible (because of cost or technical feasibility, contradictory requirements, or others.) exception approval was sought from the technical warrant holder and relevant stakeholders and documented as an addendum to the ship's specifications if approved.

Exception adjudication was another highly collaborative process requiring efficient communications across not only the DA/NTT team but also a navy-wide sponsor and stakeholder network including NAVSEA, NAVSUP, NAVAIR, OPTEVFOR, CSCS, OPNAV, and others. The database of issues, exceptions, and open items is an active program document and promises to make ship activation more efficient by eliminating the need to write and adjudicate trial cards where exceptions have been previously granted. The potential for ONR to leverage the lessons learned in this effort is exceptional. The HSI tools required are all widely available and can be used online and enable geographic team dispersal. Note that every space and function (including the operation of all valves) was assessed for the 5% female population and the 95% male population, making this the first shipboard design in which requirements supporting the full range of ergonomic possibilities are being met. In the case of mutually exclusive requirements, the highest priority safety issue prevailed. The most common example of this was valve located out of reach of the 5% female population because lowering the valve put it in the headroom area of the 95% male population. In these cases either a fold-down step was installed to permit access by the 5% female population or some other means of access was designed into the space.

Throughout the design review and up to the 90% complete stage for all zones, roughly 2,800 issues were documented and adjudicated prior to design lockdown. Although the number seems high, the end result is a dramatic drop in trial cards when the ship goes to initial certification underway. It is expected that the trial card count will be significantly lower for DDG 1000, reducing late change and cost. The collaboration between shipyards and the navy early in the design process was critical to completing so much detailed design before production even commenced.

Quality of Shipboard Life Assessment Tool

This spreadsheet-based design decision aid was developed and used in an effort to attain and preserve the highest possible quality of shipboard life (QoSL) and to meet all required habitability relevant requirements and to quantify and prioritize design attributes that were most highly valued by the sailor. Historically the complexities of design iteration and the need for constant compromise had, (in previous new construction programs) compromised shipboard QoL primarily for cost, weight, and schedule reasons. The QoSL assessment tool (QSLAT) is a spreadsheet-based design decision aide that captures and assesses all QoSL elements, decomposes them into individual supporting design features, and assesses each for relative importance. The tool can be used to score individual elements and the ship as a unit. The QSLAT (and the QoSL relevant requirements in the S3) were intended to make those compromises more equitable and ensure that the sailor was represented in those inevitable discussions. Here again, the collaborative involvement of the TWHs, stakeholders, product team SMEs, and others was extensive. The involvement of the sailor through the QSLAT development was most important in the prioritizing of the use of the limited space available for recreation, fitness, off-duty education, and more. The assessment of the sailor who will live and work in the ship was captured through the QSLAT development and validated through specific data collection in fleet sailor liaison events. For example, in one instance the program manager personally participated in a fleet sailor review of the habitability excursion to assist him in some basic decisions about stateroom layout and head design. The QSLAT and sailor data collected in fleet liaison events (FLE) was used to prevent or mitigate compromises in physical fitness, LAN access, learning centers (off-duty education support), and food service facility design.

Usability Assessments and Testing

The usability assessments and testing (UA/UT) efforts on the Zumwalt design required the most extensive and difficult collaborative effort in the entire program; UA/UT spanned every aspect of design from hardware components to physical layout to software and its interfaces to training system design. In a very real sense, usability testing provided the most direct means by which the sailor participated as a member of the design team. The intra-team collaboration required was daunting and, at times, extremely difficult. Extensive participation of individual product teams across the DA/NTT organization was required to ensure that usability events produced valid results. The focused involvement of a myriad of stakeholders, sponsor representatives, and fleet sailor SMEs had to be coordinated for each event and although some aspects of the coordination became easier as the routine was repeated with improvements, other associated tasks became more difficult. The sheer number of usability assessments conducted put pressures on some components of the team whose design components supported multiple mission and functions (C3I, Excomms, etc.). To date, the DA HSI CPT has conducted over 100 UA/UT events involving over 2,000 fleet sailor SMEs and producing approximately 1,200 design improvements.

Zumwalt usability testing took two major forms—design feedback testing and design verification testing. Design feedback testing was conducted for the sole purpose of exposing experienced fleet sailors to aspects of the Zumwalt design during its earlier, formative stages. This enabled system systems engineers to modify aspects of the design in a relatively easy, cost-effective manner before requirements lockdown had taken place. More importantly, it provided an opportunity to improve or eliminate aspects of the design determined to be non-optimal by experienced end users. Design verification usability tests were conducted against completed aspects of the design and were part of the process used to verify that the Zumwalt design met S3 (and related) requirements. Examples of both types of tests include the following:

- HCI usability tests. Screen design UT is one of the most important classes of UT conducted on the Zumwalt design given the novelty of the HCI designs developed to support the unique crew concept. Additionally, critical screen functionality to every mission area (and ship function) is under glass, or accessed via the graphic user interface. While there is a schedule and budget overhead to conducting UT on HCI during development, minimizing the cost and schedule impact requires continuous intra-team collaboration as well as the full cooperation of the TWH. Screen design UT includes three basic activities:
  - Early design feedback. On DDG 1000 every screen in each SW release was subjected to in-stride cognitive assessment by sailor SMEs. The findings of these UAs resulted in immediate changes to the design (i.e., correct missing information requirements, common display alignment, standard color and iconology, etc.) or generated the appropriate SW change requirement to ensure the issue would be properly adjudicated and resolved.
  - Interactive prototype UT. Per agreement with the HFE TWH, this testing was conducted on the high-risk WSs. Budget and schedule issues limited the IP UT to three mission areas; whereas the early design feedback testing was conducted using static screenshots of individual screens, interactive prototype testing enabled sailor test participants to simulate the execution of limited activities by directly interacting with prototype screen designs. Examples include the following:
    1. Engineering systems coordinator (ESC)—This WS is the equivalent of the EOOW and all other engineering WSs in the DDG 51 class. Accordingly, the screen design must facilitate unprecedented situational awareness and permit the oversight, control, and monitoring of all propulsion and auxiliary systems from a CDS in the ship's mission center with only limited and occasional assistance from engineering maintainers. This UT series involved dozens of senior fleet engineers who immensely helped refine the design. They also provided the insight necessary to resolve the longstanding complex manning uncertainty associated with engineering OM by making it clear that the ESC required an assistant and by helping to define the tasks associated with that new crew member.

2. Integrated undersea warfare (IUSW)—The dramatic reduction in the number of WSs postulated to execute the IUSW mission and the integration of USW and SUW made it essential that these screens be tested with interactive prototypes. Real validation awaits final SW release software acceptance test (SAT) UT and sea trials, but the initial results of USW UT are encouraging.

3. Bridge team—The greatly reduced watchteam size operating in an enclosed bridge (with new systems) required that the screens developed to date be tested interactively to the extent possible. The interactive bridge UT afforded sailors the opportunity to conduct limited, simulated navigation and bridge procedure scenarios and resulted in numerous changes to the HCI layout all geared toward facilitating the performance of the reduced-size bridge team on Zumwalt.

– Software release acceptance testing (SAT) UT. These UTs are examples of design verification testing and are conducted on all missions in each software release by fleet sailor SMEs who receive indoctrination and training sufficient to operate the system with the actual functioning software. After receiving adequate training, they operate the system against a simulated scenario while the HSI UT team measures response times and other established objective performance criteria. This is the first opportunity for the actual software to be used interactively by fleet SMEs. The preparation for and conduct of this event is arduous work, but there is an essential need to mitigate the usability risk. Software release 4 SAT UT was conducted in late 2008. Release-5 SAT UT was scheduled for September 2010, and the final release (before commissioning), SWR 6, is scheduled for Oct 2011.

- Hardware UA/UT.

– Engineering developmental model (EDM) UT. Developmentally, some of the more useful outcomes for the testing of human–machine interactions (HMI) came from the use of program planned engineering design models (EDMs) and early prototypes which were used to conduct extensive human-in-the-loop (HITL) testing especially for the Zumwalt's weapons and engineering systems. In addition, a number of human factors specific testing methods were developed that could easily be leveraged for other programs as well, including the use of established human factors devices like NASA-TLX and navy-specific HF data collection systems [like the human performance analysis tool) and ATOM (air warfare team observation measures)]. The HSI CPT leveraged every opportunity to bring sailors to the EDM and conduct UTs, including the following:

1. Automated gun system (AGS)—Extensive UT was conducted on the AGS EDM in Dugway, Utah, by sailors from PAC and LANT ships. A few safety issues were discovered and quickly corrected. Specific HMI and evolutions were conducted with emphasis on maintenance accesses, normal operations, pre-fire and post-fire checks, and dud and misfire procedures. In addition to usability findings, there were noteworthy findings regarding training, ammunition administration, and the use of special tools and devices.

2. Integrated power propulsion system (IPPS)—The Land-based test site (LBTS) in Philadelphia, Pennsylvania, has been used multiple times to conduct UA/UTs on every part of the IPPS system. Significant safety, usability, maintenance access, and space layout improvements have resulted from this testing, which will continue throughout the detail design phase and into production. A number of tests were also conducted to verify the HCI of all IPS component system local control panels

(LOCOPs). The final test evolution will concentrate on validating IPS one-man control using proposed CDS console mimics. It is planned for November 2011.

3. Integrated undersea warfare system (IUSW)—Fleet SMEs participated in several underway EDM tests, validating cognitive workload associated with ISMA and other key uncertainties.
4. Peripheral vertical launch system (PVLS)—Access and safety issues associated with the disbursed VLS magazine design were assessed. Serious safety issues were noted and corrected and the UA/UTs contributed significantly to the resolution of several high-priority MUIL issues.
5. Stern boat handling system (BHS)—This prototype was constructed in phase four to mitigate risks associated with the stern doors and launch and recovery systems. HSI leveraged this planned test to improve the usability and effectiveness of the LOCOPS, to evaluate the safety issues, and to evaluate training requirements of the RIB coxswains. The testing revealed significant design issues that are being rectified prior to a second round of testing. Follow-on testing for this effort will be conducted in September 2010. The unique human performance challenges to the coxswain and crew in boat launch and recovery present another potential opportunity for ONR and the DA to collaborate in research UA/UT.

– Physical mock-up prototypes. Full-scale, physical mock ups of three of the four operationally manned spaces were constructed of plywood and foam core and subjected to extensive fleet sailor UAs in the context of the appropriate mission scenarios.

1. Bridge—A full-scale bridge physical mock-up was constructed in phase three to support space layout and design activity and begin the validation of the bridge watch team (see Figure 8). This was followed in phase four (DDG 1000 detail design) by a highly detailed full-scale high-fidelity bridge mock-up constructed of 1-inch plywood in the human performance laboratory, NSWC–Dahlgren, and then disassembled and reassembled at Bath Iron Works, where it continues to be used to assess producibility issues and refine the space arrangement. A series of fleet sailor UAs were conducted and resulted in the correction of dozens of usability issues and a significant improvement in the space layout and arrangement. Many issues that were undetected during the HSSI CATIA reviews were in the physical mock-up.
2. Ship’s mission center—As with the bridge, HSI constructed a low-fidelity foam core mock-up in phase three (at ATG Norfolk) to facilitate the analysis of WS layout. This was followed in phase four by the construction of a higher fidelity plywood and foam core mock up at the HPL in Dahlgren.
3. Helicopter control station (HCS)—Like with the bridge and SMC, the physical mock-up of the HCS space (see Figure 9) has been constructed and used in two iterations. Once in the HPL Dahlgren and ATG Norfolk and most recently in Bath, Maine. It has been used extensively to optimize the space arrangement and improve the usability.

– There were also a number of programmatic learning curves for the UA/UT effort. While the development of human factors–specific testing procedures was a routine effort, developing effective processes for ensuring the results were properly captured, tracked, adjudicated, and accepted by program leadership (and configuration managed throughout) was challenging. The challenge included not only ensuring that the findings were integrated into the final design in the most cost-effective way (no small challenge, given the complexities of the program and the unremitting pressure to cut costs) but recognizing that some number of the findings would require changes within fleet-wide navy policy and practices that had to be worked across the appropriate stakeholders (and sponsor representative organizations). One example of this challenge is the use of a comprehensive virtual presence to replace actual daily magazine monitoring. Zumwalt's large number of individual magazines would require an extensive human workload for daily inspections. The use of a comprehensive virtual presence consisting of full visual surveillance combined with a robust network of environmental sensors with sophisticated access, alarm and alert functions required changes to standing navy policy specific to inspection requirements. The resultant fix required both an adaptation of human workload-reducing technology within the design, as well as a congruent change in navy policy that would permit the remote monitoring of shipboard magazines using video and sensors. Out of necessity, the HSI CPT was drawn into the bureaucratic processes that address this facet. One of the chief lessons learned from DDG 1000 is that the workload associated with these sorts of complex stakeholder and sponsor-level problems is greatly reduced by establishing effective initial liaison and continuing collaboration.

- UA/UT significant issues database (SFDB)—The large number of UA/UT events conducted across the design produced hundreds of individual findings that had to be dealt with systematically and with tight configuration management. The SFDB database and process was created to meet this need. Many issues were fed directly into the program change processes and adjudicated and tracked in that structure, but many other findings were not candidates due to design-feature maturity, etc. In order to maximize the benefit of each UA/UT event, all findings were recorded and tracked in the SFDB and were reviewed and updated on a quarterly basis.

FIGURE 2 Zumwalt human factors engineers (HFE) needed only $5,000 in material to construct an accurate, highly detailed physical mock-up (from ship's drawings) of the bridge, ship's mission center, and Helo control station (HCS). These mock-ups were used multiple times by HW and SW teams as well as HSI.

FIGURE 3 HCS after multiple iterations based on HSI reviews and design updates.

Configuration Management of Crew Design

The configuration management (CM) of the manning concept requires close collaboration across many traditionally stand-alone elements [e.g., the U.S. Navy Training Support Plan (NTSP), preliminary ship's manning document (PSMD), SWR, production design bill of materials, and others]. Ultimately it was necessary to understand how to establish and maintain a change process that ensures the crew design could be maintained continuously traceable to the SW/HW design. In fact, continuously validating and tracking the crew size and discrete composition of the ship's crew represented a key challenge to the HSI Program. Several effective tools were created to collect, manage, and track the major tasks and activities. These were used to generate the analysis for workload and feed into decisions on issues like crew numbers and composition. These factors were embedded into the data and process used to model the crew's duties and collected in the form of a CPT-wide repository. Traceability to the top-down requirements and the bottoms-up design configuration (i.e., HW and SW) was necessary to maintain an accurate crew design. The process and tools established provided linkage between WSs' HCI screens, shipboard equipment installation, and the trained and qualified crew members to accomplish the operation. This integrated view required the full cooperation of numerous entities outside the CPT to collaborate in new ways, including the following, for example:

- The training IPT used the repository data as direct requirements to training criteria.
- Supportability required this data for logistics and maintenance calculations. (PM/CM workload and ship shore division of labor decisions, etc.).
- HCI screen designers required constant access to the task data.
- Product teams and other engineers responding the the frequent what-if drills to evaluate options associated with cost-reduction activities often needed access.

- TWH system and equipment managers (PARMS*), sponsor representatives, and other stakeholders frequently access the data to assist in a myriad of program taskings.

Collaboration in Support of Crew Design Decision

There are critical crew size and composition decisions that have safety and mission effectiveness implications that cannot be reduced to an exclusively data-driven decision. These decisions required extensive collaborations across the full spectrum of DA, NTT, stakeholder, sponsor network before PM-level design decisions. Examples include

- The number of crew required for routine bridge operations, frequently conducted special evolutions, etc.;
- The periodicity of certain preventive maintenance actions and how best to deal with the unknowns associated with CM in DDG 1000 unique systems (no legacy analog); and
- The definition and taxonomy of critical systems to calculate the appropriate CM workload.

These and many other issues are highly relevant to crew size and composition but require extensive intra- and inter-team collaboration in addition to the appropriate analyses.

UNIQUE SYSTEM ENGINEERING ACTIVITIES

The early and strong support of program leadership for achieving the manning KPP ensured that the HSI CPT ultimately became the most fully integrated CPT in the program, working in tandem with nearly every product team at some time on specific issues of importance. Examples of HSI's central role in completing the detail design illuminate this point:

- Peripheral device inventory management and placement. The HSI CPT lead the effort to determine the final inventory and exact location of thousands of peripheral devices [e.g., camera, phone, speaker, and wireless access point (WAP) placement]. This process involved representatives from nearly every design entity and required the use of CATIA views of each space. Final inventory, location, and changes to each device required iterative consultation across multiple parties and the approval of ship design manager, technical director, and program manager. Final inventory of approximately 400 internal cameras was over 20 times the number in any previous surface combatant and had significant budget implications requiring an aggressive effort to win approval.
- Signal count inventory. A design total of more than 52,000 signals had to be brought down to fewer than 33,000 in the budget. Reduction of signals across HME and all mission areas had to be done without impacting functionality and the operator's ability to control and monitor all systems from CDS consoles. Multiple system-by -system, signal-by-signal review and assessment resulted ultimately in meeting the 32,500 objective with minimal impact to operator capability and crew workload. The signal inventory reduction process required HSI to defend essential signals in a venue with all product teams and other CPTs aggressively representing competing views. Control and monitoring of a few systems were impacted but the overall HSI objective was met. This lengthy (roughly four-month effort) iterative process was one of the

more difficult collaborations in the program but the cross-program interaction and stakeholder involvement paid huge dividends in dozens of smaller follow-on efforts.

- SW-HW issue adjudication and hazard action reports (HARS). In venues across the program, HSI is an essential participant in the resolution of specific design and program issues. These include HW issues in the SDM, TD, and PM-level system integration team venues, SW issues in the SW requirements configuration management venues as well as the adjudication of safety issues formally recorded in the HAR database. Additionally there is an HSI component to many of the risks adjudicated in formal risk review boards. The sheer number of venues and issues with HSI relevance is challenging to address effectively.

HSI AND SE LESSONS LEARNED

- Integration of HSI processes into the SE process. Treating the crew as a sailor system with all tasks associated with operating and maintaining the ship derived and vaulted for engineering use is a dramatic change to the SE culture, which has generally not been concerned with limits on crew size or composition. Some engineers, program leaders, and others still consider HSI as a stand-alone effort that need not be integrated into SE processes. This inertia can be overcome only by a proactive, competent HSI-CPT and firm program leadership. Additionally the HSI-CPT must be extremely proactive and flexible to leverage all SE events to collect task data, validate manning concepts, and more in order to minimize the number of events that HSI objectives add to the schedule. The importance of an early strong liaison between the HSI-CPT and the various design elements cannot be overemphasized.
- The flowdown of the tier-one requirements is critically important to achieving the KPP. Selection and use of workload metrics (principally CM/PM and OM) and decomposition of crew size requirements (the S3) to the lowest level requires a disciplined effort and impacts traditional vendor solicitations and supportability processes. It is not easy and PM-level leadership must deal the inevitable reluctance to change the process.
- HSSI activities must be conducted in stride with functional design activities, detail design activities, and ship production. It is critical that programs have a functional design phase in the total SE process to ensure HSI requirements are fully represented in functional drawings, purchase specifications, and design–build specifications (e.g., habitability and shipboard environment requirements including ambient temperature, noise shock, and vibration). A functional design phase also offers the opportunity for priority routing of distributive systems and placement of large pieces of equipment giving HSI the opportunity to inspect the arrangement from a system perspective. HSI participation for DDG 1000 ensured compliance with the S3, MIL STD 1472, ASTM 1166, NVR, and design–build specifications. Participation also allowed for HSI to optimize compartment arrangements, influence design decisions and system requirement prioritization, and mitigate impact to the crew when space constraints cannot support all system requirements.
- HSI should remain involved during pre-production change windows and the production process to ensure HSI requirements are maintained and not diluted or violated during ship production. Over 2,000 crew requirement violations were documented and tracked for DDG 1000 and successful maintenance of crew requirements through the production phase will greatly reduce the number of trial cards received.

- The design team functional engineers must be provided specific training to ensure the HSSI reviews are efficiently conducted and issues that cannot be resolved in stride are captured cleanly and adjudicated quickly. DDG 1000 HSI requirements training was provided to functional engineers and designers at four shipyards with ongoing refresher training and training for new hires. As a result of the successes in this effort, HSI training has also been incorporated into apprenticeship programs at two shipyards. It is recommended that HSI training be encouraged by the navy and be an ongoing effort for all future acquisition programs.
- Navy programs need HFEs who understand the industry and can work within the schedule and budget limitations that are always present. A mix of HFE backgrounds (psychology, software, engineering, navy SMEs, and others) is invaluable but the DDG 1000 HSI CPT ultimately benefited the most with a mix that included fewer HFE technical authority and more navy mission SMEs. It proved very beneficial to identify the best of the available mission SMEs (called crew advocates in DDG 1000 HSI CPT organization) and provide them training in crew design process, task analysis, usability testing, human factors, and more. It was necessary to retain a strong HFE/UT technical authority, but selecting individuals who could work to schedule and budget constraints is important. The HFE technical authority must be steeped in engineering and productivity oriented. Academic credentials and publication achievements are relatively unimportant and are not particularly useful in predicting success in the design environment; personal knowledge of industry and SE experience is.
- Development of processes and tools to meet program-unique objectives and refinement and adaptation of existing tools is immensely important. Improved understanding of process and tool needs and development will provide significant cost and schedule benefit.
- There are limits to how small a crew can get, the program must have a better-defined process to understand damage control and multi-mission simultaneity as a lower limit (the proverbial long pole in the tent). There are important opportunities for research to improve the reliability of autonomic responses to damage events and the crew situation awareness and decision making in the face of the immense stress and pressure that accompany fire, flooding, or other casualties (see Figure 10). Additionally, the need for a more efficient, effective integrated damage control training system for the crew is an excellent candidate for research and development or possibly for a study and assessment of the work already completed on this topic. Furthermore as crews get smaller there is a critical need for a DC workload metric to provide crew design objectives for this critical area.

LESSONS LEARNED REGARDING EFFECTIVE COLLABORATION

Promotion of the collaborative involvement of stakeholders, sponsors, and relevant outside organizations in the design process was a challenge from day one. A myriad of navy entities had potential to benefit the design team (or to benefit from a collaborative liaison with the design). They included the ONR, Commander, COTF, CNSF, OPNAV N1, and N863 as well as those TWH, sponsor, and stakeholder entities normally involved at various points in the design production processes. The principal DDG 1000 lesson learned is establishing functional liaison early in the program can provide immense benefit in achieving technical objectives and minimizing the overhead associated with maintaining program viability as emergent issues are identified and resolved. Aggressively seeking out the right points of contact and providing them with periodic, unfiltered program updates pays dividends.

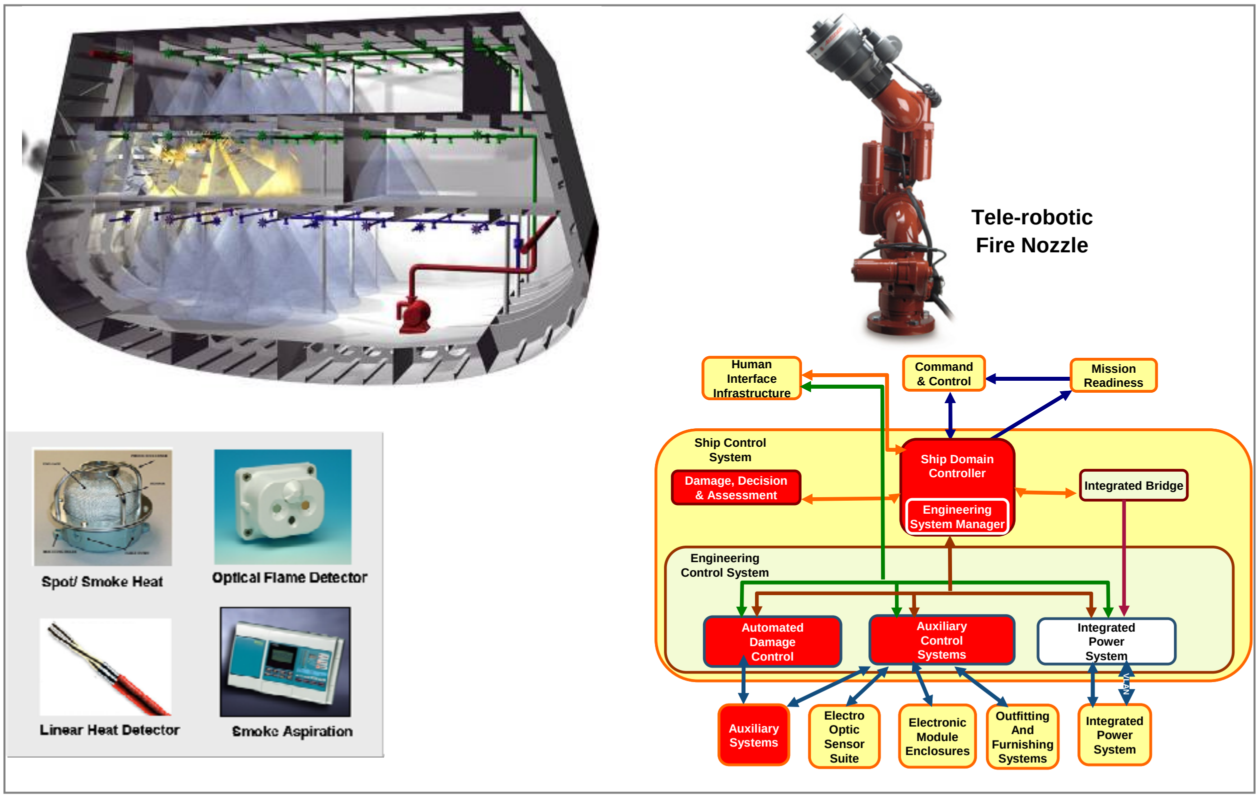

FIGURE 4 The Zumwalt design supports effective small crew response to damage events and fire with thousands of sensors and automation of extinguishing systems all controlled via the Total Ship Computing Environment Infrastructure (TSCEI). Legacy ship backfitting such an extensive DC response system is not feasible. Crew damage control functionality may well be the determining factor in crew size reduction in legacy surface combatants.

Achieving a detailed crew design coincident with the development of the ship design and fully traceable to the HW/SW design requires unprecedented collaboration across the greater design team and the relevant stakeholder, sponsor, and professional organizations. This level of collaboration can only be achieved and maintained by

- Committed, aggressive program leadership;
- Full integration of the HSI-CPT into the SE organization;
- Disciplined use of integrated scheduling tools to enable the HSI-CPT to leverage product team work and others; and
- Early establishment of and maintain a strong liaison with the HSI directorate and all relevant technical entities.

ONR, through its support for the establishment of the HSIDE tool set, is stimulating more collaborative environments in acquisition. By broadening its use, a common set of design artifacts, modeling, and products can be shared in the industry and by fostering best practices across industry, an improved ability to share SE methodologies and approaches stemming from core requirements on crew optimization will ultimately reduce TOC.

RECOMMENDATIONS

Establish an HSI best practices network as a partnership between NAVSEA (SEA 05H), ONR, and a rotating panel from industry.
Utilize the organizational construct of the HSI network to schedule and conduct consistent web-based communications with all interested and eligible parties and periodic (quarterly or semi-annual) HSI symposiums or information updates to facilitate productive networking, promote cross-program pollenization, publicize improvements in tools and processes, and present updates on topics of interest to the community (recent findings on cognition and cognitive workload, problem solving, tactical thinking, human performance assessment, etc.).

ONR should consider conducting human performance research in the several areas of concern for Zumwalt crew, including

- Bridge WS use of multiple displays with varying horizon references; and
- Boat crew launch and recovery performance challenges, to include the most effective training methods.

ONR should consider the value of assessing and archiving the Zumwalt HSI-SE processes, including the very complex MSLDA process, for the benefit of future acquisition. A standard recommendation on developing and decomposing an S3, for example, could be immensely beneficial to current and future programs.

Crew design, within the construct of the HSI organization, should be led by the prime shipyard. The ownership should force the shipyard to fold crew design as an integral part of early functional design (hardware, software, and crew) and carry it through the change and refinement of detail design, testing, and validation. Key advantages include

- Quality assurance,
- Change management and configuration management of manning artifacts,
- Full understanding of workload distribution and adjustment by late-design change, and
- Ultimate crew design configuration management for a ship class by hull number.

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