A Total Ship-Crew Model to Achieve Human Systems Integration

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ABSTRACT

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

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Senior Chief Lemon has a BS Degree in Computer Networking from Strayer University and is serving aboard the USS McCampbell DDG 85 as the leading technical manager for the integration and comprehensive system level testing of the Navy’s newest operational Baseline, AEGIS 6 Phase III. He is also an instructor, technical writer, and instructional system designer. Senior Chief Lemon has developed manning analysis technique for Flight IIA Destroyers for NAVSEA 03, assisting the Human Systems Integration (HSI) Directorate.

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INTRODUCTION

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

Human System Integration

Human systems integration is a human-centered, systems engineering process which brings concern for the human as part system design processes:

1. Human Engineering
2. Manpower
3. Personnel
4. Training
5. Safety & Health
6. Maintainability
7. Habitability
8. Personnel Survivability

Domains

This paper defines three domains of effort that together will accomplish the Navy HSI objectives through the creation of a TS-CM. These three domains are expected to be used complementary to each other and encompass all of the HSI factors with a goal of optimized ship manning.

Domain One is human performance analysis using human engineering techniques that will be used to work with the ship performance model in Domain Two. Domain One encompasses the HSI factors 1, 2, 3 and 4.

Domain Two is performance of the ship (component and system design) and encompasses the HSI factors 5, 6, 7 and 8. Domain Two is the environment that supports the mission capabilities to be executed by the human decision makers.

Domain Three is the merging of Domains One and Two into a holistic design analysis, dynamic time-based performance measurement environment: TS-CM. The TS-CM discriminator is the use of the *attribute of dynamic time* to measure and validate coupled ship-crew time-based performance. It is the authors' view that a TS-CM provides the best and most economical way to validate advanced ship design incorporating reduced manning. The parallel benefit is the simultaneous capturing of the validated TS-CM model for future use to support HSI objectives such as embedded training, performance monitoring and decision aids.

This paper describes a balanced approach to using traditional human engineering performance factors such as skills based task analysis combined with a real-time dynamic total ship model created through physics based design tools that can be applied during every phase of a ship's design.

TECHNICAL DISCUSSION

Experience is Needed

The challenge in HSI driven manpower analysis in highly automated ships is the absence of experience with designing and building ships with these characteristics. The newest destroyer class is the DDG51. The DDG51 has a crew of ~325 and modest automation, similar to the earlier class of CG47 class cruisers. A few of the CG47 class have been modernized as Smart Ships with crew size reductions of about 70 by improving engineering and damage control consoles with graphic human-computer interface (HCI) displays. The DDG51 class is now in line to also receive Smart Ship upgrades.

U.S. submarines have about the same firepower as the DDG's and CG's but are manned with a crew of ~120. The Israeli Navy took delivery of its SA'AR-5 Corvette with a crew ~60 in 1993 built in the USA that for its time was (and still is) the most highly automated combatant ship in the world. How do engineers integrate these experiences into new ship designs?

The Smart Ship crew reductions for CG's and DDG's starts with an existing ship design and associated manning-automation model and incremented the crew count down with improved networks, control software, HCI displays and changes in Navy procedures for watches and emergency response. The submarine force has always had to make stringent manning level decisions because of hull size constraints. The objective of HSI and TSSE is to challenge prevailing ship designers towards building ships for equipped sailors and not equipping ships with sailors. The goal of HSI and TSSE is optimized design for operability and battle readiness of the DD(X) equipped with complex automated / autonomic propulsion, auxiliary and weapon systems,

Two Approaches to Manning Reduction

As discovered during work with DARPA in 1993-4 there are opposite approaches for arriving at HSI driven manning levels for ships. One starts with a current design, its manning level and control systems and reduces that crew size through analysis. The other approach starts with a level of "zero" crew and requires justification to be made for adding each crew member above "zero" based upon required naval and international regulations or vital mission functions that can only be provided by humans (Famme, 1994). The latter approach generally produces a smaller crew for the same mission. TS-CM modeling can be used to validate either approach.

Modeling is Needed

There is also a shortage of experience in the use of real-time, dynamic ship modeling techniques. Stringent manning reductions and automation using autonomic and intelligent agent components are coming together for the first time in the design and production of naval surface ships.

Current HSI compliant manning analysis techniques, for example, use Sailor System analysis, subject matter expert (SME) interviews and personnel data bases to derive postulated crew size for new ships even when these ships have significantly new requirements for reduced manning and autonomically enabled automation. The TS-CM will provide a design environment to optimize and verify concurrently both human and ship performance through all mission scenarios.

The following sections will discuss the three complementary domains for HSI compliant ship design with emphasis on the major ship life cycle Key Performance Parameter (KPP) cost driver, crew manning. Domain Three is the merging of the human performance analysis model with the ship performance analysis model into the Total Ship-Crew Model (TS-CM) as shown (see Figure 1).

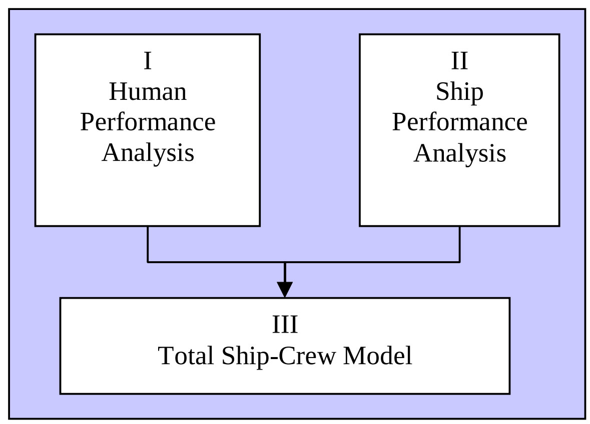

Figure 1. The Relationships of the Three Domains

THE DOMAIN OF HUMAN PERFORMANCE ANALYSIS

The Domain of Human Performance Analysis focuses on the development and implementation of the HSI human centered design to resolve requirements issues, verify HSI attributes are obtained and validate operability through human engineering using skills based task analysis and verification. Several defined methods are summarized in this section. The human performance analysis developed here, particularly the tasks and skill requirements, will be merged with ship performance analysis to create the Total Ship-Crew Model.

The Sailor System

The DD(X) Design Agent has developed a Sailor System (requirements) Specification (S3) (DiDonato and Buckley, 2003) which will ensure that the systems designed to implement the capabilities of the sailors who will ultimately maintain and operate the ship are fully considered throughout the system design process. The S3 will embody all system requirements necessary for the entire ship's operability including interoperability of all ship systems integration and engineering design elements.

S3 focuses on the development and installation of the HSI features to resolve requirements issues, verify HSI concepts and validate operability through human performance modeling and testing. Ultimately, many of the Sailor System Requirements have a significant impact on design decisions for hardware and software components. All efforts that lead to the DD(X) Sailor System requirements follow established processes and procedures that are part of the overall DD(X) System Engineering Process. S3 is a component document of the System Performance Document (SPD).

The Sailor System Specification provides traceability among segment, element, component, and Computer Software Configuration Item (CSCI) specifications and its implementation will reduce overall program risk by enabling earliest identification of HSI risk elements. The S3 development effort enables the flow of validated requirements into DD(X) system hardware and software elements as well as integration into Flight 1 DD(X) from the full suite of Engineering Development Models (EDMs). The S3 recommends HSI requirements for the EDMs that suggest the direction for specific EDM HSI feature implementation.

Navy Skills Data Base

The advent of the Littoral Combat Ship (LCS) program began with the Navy leasing several ships for trials and crew experience. An outcome of these trials has been the realization of the complex cross-tasks/skills requirements for selecting the crew members. The Navy rate structure by itself has been found to be too limited as a means of describing what the sailors must actually do when assigned to an LCS with low crew manning.

An LCS example discussed at the ASNE Total Ship Engineering Conference, NIST, March 2004, described how a Rated Electronic Technician (ET) was performing duties during the same day as line handler (Boatswain Mate - BM), Junior Officer of the Deck (Quartermaster - QM) and Operations Watch Officer (Operations Specialist – OS). This was probably not the entire list. To meet this need for skills-based detailing the Navy is gathering the Skill Set of every member of the Navy into a data base that can be used to help select sailors for assignment to ships with reduced crews requiring cross rate skills. Please refer to the SkillsNet website for further information, specifically an article written about the Five-vector plan for advancement (Navy Times, 2003).

MANPRINT

Another method applied in manning analysis is Manpower Personnel Integration (MANPRINT) as applied through the systems engineering process.

MANPRINT is concerned with the identification and integration of all relevant information in each of seven human performance domains:

- Manpower
- Personnel
- Training
- Human Factors Engineering
- Health Hazards
- System Safety
- Soldier [Sailor] Survivability

There are organizations and functions in place with specific technical responsibility and expertise for each of these areas. The MANPRINT role is to integrate these efforts and products of the independent functions with each other and with the system design process to meet acquisition system performance goals. This integration is subsequently achieved via management oversight and the iterative analysis of MANPRINT program objectives, issues and actions (Commerford, 2003).

Department of Defense Architecture Framework

The Assistant Secretary of the Navy for Research, Development, and Acquisition (ASN-RDA) Chief Engineer's Office has developed human-centered architecture supplements to the Department of Defense Architecture Framework to better define the role of the human as a part of a total systems engineering approach (Adams, Dickerson and Smith, 2004). These supplements will aid in designing, engineering, and analyzing the role of the human from the outset, leading to more efficient and effective use of the warfighter. The warfighter is a primary facilitator in the interoperability of many current systems. Additionally, as one of the costliest system elements over the ship life cycle, the role of the warfighter directly impacts system cost-effectiveness.

Subject Matter Expert (SME) Interviews

Another tool for HSI driven ship manning analysis is the interview of SME's (crew members) of current ships concerning their performed tasks and skills including an estimate of the time required to perform each task. This information may be gathered and evaluated as part of every analysis approach discussed in this paper for factoring into the design decisions for new ship systems.

Comments on the SME Collected Data

The question concerning the SME collected data is the relevance of task performance data based on estimates from personnel serving on ships that have a completely different design premise. A DDG51 has a crew of ~325 with limited automation. The DD(X) objective is a crew of less than 114 incorporating a very high level of autonomic automation and employment of intelligent software agents. How well can DDG51 experience be translated to DD(X) for HSI design purposes, especially when the autonomic automation systems, indeed the ship's postulated advanced systems themselves, have not been fully defined? For the DDG51 a sailor represents ~1/325th of the crew tasks with little automation support. For the DD(X) a sailor represents ~1/114th (excluding the aviation detachment) of the crew tasks supported with extensive automation.

How valid are crew estimate comparisons when the underlying technological environment between existing ships and future ships is significantly different? This is akin to the error made with the advent of computers in the 1950's. The automated data processing (ADP) systems put in place were only a faster way of doing old tasks. The real benefit of the computer was realized only after we understood that computer processing allowed us to redefine the processes and tasks and thus gain the high productivity we take for granted today.

Similarly, ship maintenance actions will change as well. An example is the number of lowest line replaceable units (LRU's) in ship machinery control systems (MCS) and the corresponding reduced requirements for test equipment, manuals, spares storage, crew manning and training. The advent of new MCS system technology reduced the number of MCS LRU's in progressive ship classes as follows: CG47 / DD963: <u>292</u>; DDG51: <u>211</u>; MHC51: <u>36</u>; CG48: <u>34</u>. New modular designs have eased but not yet eliminated maintenance requirements. For example, current improvements in the fleet include Interactive Electronic Technical Manuals (IETM). However, these are sometimes incomplete, require a funded computer and technician feedback for accuracy.

Another SME data caution is that there are many aspects of human factors that are not necessarily intuitive such as situational factors of *perception, comprehension, and projection* so there is a danger that the design decisions of a SME may not be the best alternative from a human engineering standpoint. Moreover, the selections made by SME's (considered to be domain experts) might not be optimally suited for novices and trainees who are likely to operate the system (Pharmer and Holness, 2003). The advent of multiple ship systems utilizing common Graphical User Interface (GUI) applications is offered as an example where the proximity of diverse GUI display icons, windows, and terminology has to date added to the complexity of the crew training.

DDG-51 Class Reduced Manning Studies

Another approach to validate HSI driven manpower reduction initiatives is based on the SME interview technique discussed above, with added sophistication and comprehensive analysis. The following are excerpts from the DDG51 class manning reduction studies (Hinkle and Glover, 2004).

"In an effort to move forward smartly with initiatives to reduce manning in U.S. Navy combatants, the Program Executive Office Ships, commissioned a study to examine and analyze alternatives to reduce manning for Arleigh Burke Class ships with the expectation that lessons learned from this effort would not only benefit current and future flights of DDG 51 Class ships but would also benefit future ship classes, particularly the DD(X) family of ships. The *DDG 51 Reduced Manning Study …* was conducted in two phases by a Navy-Industry Team, *Phase I Concept Study* (Hinkle and Glover 2003 – Concept) and *Phase II The Plan for Assured Manning* (Hinkle and Glover 2003 - Plan)."

"Navy leadership has an enhanced understanding of Total Ownership Cost (TOC) factors that are important if reduced manning initiatives on the DDG 51 Class are to move forward. That said, this Study also revealed that the process to evaluate Return on Investment (ROI) and the TOC impact for manning reduction initiatives is difficult. This Study determined that in evaluating reduced manning initiatives based on TOC, the "color" of money and traditional funding methods can not become an impediment to reducing manning."

"The Study examined the attack on USS COLE in assessing this risk and recognized that many have opined that the crew of a minimally-manned USS COLE would not have been successful in keeping that ship afloat. Importantly, this Study found that in the case of USS COLE, it was *not* sheer numbers that saved the ship, but the actions of a handful of very experienced people who knew and did what was required to control damage and restore power, communications, and warfighting capability. This fact led to the assertion that the crew of DDG 51 Class ships could be reduced with acceptable risk if the Navy could replicate this highly trained reaction force supported by design features and technical innovation."

Comments on DDG51 Study

Based on the fleet experience of the authors, future optimal manning also might be improved by considering the assignment of varied personality types. The COLE experience might be re-examined to determine the impact of the personality types of those who took action using available testing processes.

"One of the important conclusions of this [DDG 51] study was that new technologies, as well as changes in policy and procedures, that have the potential to reduce manning in Navy ships need to be prototyped now to ensure preparedness for the introduction of a new generation of warfighting ships that will be manned at unprecedented [reduced] levels (Hinkle and Glover, 2004)." PEO Ships indicates that if these new technologies are prototyped in a new DDG51 ship design by 2004, they will have excellent potential to reduce manning on the next flight of DDG51 Class ships (Hinkle and Glover, 2004).

Additional Comments on DDG51 Study

The authors note that one of the important conclusions of the DDG51 Study was that new technologies combined with changes in policy and procedures have the potential to reduce manning in Navy ships, but that they need to be *prototyped now* to ensure preparedness for the introduction of the new generation of warfighting ships that will be manned at unprecedented reduced crew levels. The TS-CM initiative can facilitate the analysis of current ships, such as DDG51 above, as well as support the Spiral Design for new ship programs such as DD(X) where technology prototyping in the form of Engineering Development Models (EDM's) is required as proof of concept prior to broad implementation. Also it is noted that the DDG51 class engineering plant design has never been modeled as described in this paper. A total ship physics model for survivability analysis may have discovered the cascading failure potential of the DDG51 class protective devices and crew / control systems failures that were experienced from the bomb explosion to the USS Cole.

Advanced Human Modeling Initiatives

Office of Naval Research (ONR) cognitive science research is bringing about a scientific revolution in our understanding of the human operator. Research is yielding computational theories of human cognition and perceptual/motor activity that provide precise quantitative predictions of important variables such as the times required to complete tasks or to learn them in training. Although the scope of coverage of these theories is limited and basic research aimed at expanding them is on-going, they already have much to offer in aiding the design of ship systems that will optimize the combined effectiveness of human operators and the systems they will be using (Chipman and Kieras, 2004).

This TS-CM paper does not include the modeling potential of these emerging human attributes in the ONR research program pending access to more complete research results including the relationship to the current state of the art in tasks and skills analysis. We look forward to the findings and applications of the ONR research.

DOMAIN OF SHIP PERFORMANCE ANALYSIS

This section provides an overview of ship modeling technologies that will work with the human performance techniques of the previous section. The ship model consists of mathematical / physics-based design (PBD) models of ship components and systems that can be aggregated from component to total ship levels in computer simulations that can be captured electronically for collaborative engineering locally or via the internet world-wide. The captured model can also be reused when validated during dock and sea trials for future HSI functions of embedded training, decision aids, systems performance modeling, condition based maintenance, and readiness assessment. The captured engineering computations can serve later as a baseline for future ship modernization.

Ship Performance Modeling

The engineering models of the ship can be created in commercial PBD modeling environments or taken directly from the engineering Computer Aided Design (CAD) drawings when CAD data is electronically integrated with their associated PBD verification tools.

Electronic Data Integration

NAVSEA's National Shipbuilding Research Program (NSRP) and the DD(X) program are funding electronic data integration between CAD (Domain of Fit) and PBD modeling (Domain of Performance – How systems work in terms of timing, GPM, volts, amps, etc.). The LPD17 design made significant use of 3D CAD and PBD modeling of HM&E vital systems. DD(X) is developing an electronically integrated CAD – PBD analysis data exchange environment with the intent to leverage the power of electronic data integration between CAD and PBD modeling to lower the cost and speed the analysis process in order to promote routine dynamic engineering design verification.

CAD Performance Models

After more than 20 years of development CAD has become "standard" for the ship design process. CAD ensures that systems physically "fit", permit efficient production construction sequencing, support computer aided manufacturing (CAM) and support human engineering objectives with virtual "crew" walk-through of ships before they are built. CAD systems are available from major companies selected by the shipyard contractor and the Navy such as AutoCAD, Dassault, Intergraph, etc.

PBD Performance models

Over the past 20 years virtually every class of naval ships has benefited from having one or more of their vital HM&E systems modeled using PBD tools for engineering verification. This technology has grown from manual calculations to total ship real-time dynamic models as computer simulation power has advanced. The HM&E PBD modeling environments are available in two broad categories:

- **Single discipline modeling** tools generally are used for non-real time component design and protective device analysis as stand-alone models in each engineering discipline for electrical, fluid, gas, or HVAC from companies like EDSA™, FlowMaster™, and others.

- **Multi-discipline modeling** tools generally can support individual discipline analysis but also can model simultaneously all engineering disciplines to create a ship systems model, in real or non-real time. MATLAB™ and SABER™ are examples of non-real time, multi-discipline engineering analysis tools where the engineers create the required component physics models as needed. SIMSMART™ is an example of a real time engineering analysis tool where the physics models of most of the naval HM&E components are contained in its standard library. SIMSMART™ also has a software module to inject crew tasks as part of its overall control systems modeling for analysis or training. Please refer to the ASNE and SNAME technical papers that describe options for the application of CAD and PBD tools (Famme, Gallagher and Masse, 2003).

The Element of Time

The use of *dynamic, real time* PBD ship systems models creates a design environment where the engineers can validate ship systems performance in each design phase for every normal and casualty scenario by component and system up to the total ship level. TS-CM offers the opportunity to rectify the lack of experience in current ship-crew manning reduction and ship performance analysis.

DOMAIN OF THE TOTAL-SHIP CREW MODEL

The TS-CM merges the output of the Human Performance analysis with the output of the Ship Performance analysis. The TS-CM creates an environment for dynamic time based rapid prototyping of systems with their automation and with the overlay of crew performance defined by skill based tasks.

Prototyping Benefits of TS-CM

Prototyping has been proven across industry to provide the following benefits:

- provides a common focus and design environment for the program
- speeds up the process of finding ideas that do not work – the concept of failing fast and moving on
- encourages ideas and change
- supports early customer feedback and provides excellent management briefings and marketing opportunities
- is less expensive than building mockups or actual systems
- obviates any equipment damage or human injury
- captures the Navy's intellectual property of the engineering computations in a reusable electronic format
- provides an electronic capture of every design model that can be reused both throughout the design cycle and throughout the ship lifecycle

TS-CM Objective

The TS-CM objective is to provide the *attribute of dynamic time* in the analysis of coupled system-crew performance. The real-time dynamic TS-CM can be used during every phase of the ship's design and lifecycle to verify that an HSI compliant design is achieved and maintained and that the validated design model will be available for re-use. The model will show that the simulated ship environment can support the manning assigned. The TS-CM manning validation models will provide a real-time procedural operating and control "experience" that otherwise would come only through actual combat. TS-CM will thus show that the reduced crew can safely and efficiently operate their ship.

As discussed in the section on SME interviews, subjective time estimates to accomplish future tasks with systems yet to be designed / timed appears to be highly unreliable. By bringing together the tools of human engineering and ship PBD modeling TS-CM will demonstrate and verify the crew performance skill set and ship control system requirements.

TS-CM will be a real-time dynamic model of the ship equipment components aggregated by systems to a full ship model with an integrated model of the crew members and their functions (skill based tasks). TS-CM will capture both crew and ship time based performance so that that crew task performance will measured in a single integrated model environment with the installed ship systems and their associated controls. The objective is to create an operationally accurate and valid ship-crew simulation model that will support the ship from design conception to production, trials and through its full HSI life cycle support.

Building the TS-CM

The simulation environment will be composed of two elements:

- The crew emulation (skill based tasks analysis) models
- The ship (systems) simulation models

The crew emulation models will account for crew watch and workload tasks as programmed into crew skill based task actions derived with the Domain One human performance analysis tools. Crew physiological / HSI factors as defined by ONR will be considered and applied to the extent that they become available and can be accommodated in the TS-CM model. These characteristics will be continually enhanced by the Navy and ONR as current research supports "a scientific revolution in our understanding of the human operator …" (Chipman and Kieras, 2004).

The premise is that individual sailor, crew team and ship systems performance as an integrated system in the context of TSSE is assured only when ship-crew metrics are derived using time based dynamic modeling to simulate the scenarios, record the events, correlate the timing, analyze the results, and iterate improvements.

Elements of the TS-CM

The TS-CM will be able to analyze theses elements:

- account for specified categories of crew time: watch, work, personal
- time-analyze crew task performance
- time-analyze the crew decision processes
- use the ship-crew model as a means to demonstrate the ship systems operational and survivability capabilities
- Verify that the planned systems control automation strategies including autonomic control and intelligent agents are appropriate for the crew manning skills base assigned
- run ship scenarios through all missions and watch conditions
- collect and analyze the ship systems-crew time line performance (histogram) through all mission scenarios
- re-use ship dynamic systems models that were produced during ship design so that these models do not have to be re-made independently for the TS-CM analysis

Sources of Crew Skill Based Task Models

The crew skill based tasks models initially will come from Domain One human tasks and skills analysis. However, in as much as the predominate task and skills data derived by traditional methods will not have come from highly automated, reduced crew ships these initial task and skills profiles will most likely be readjusted significantly when "run" in a dynamic real-time TS-CM environment.

A major source of defined and validated crew tasks and skills is expected to be Navy experience with Combat Systems Operational Sequence Systems (CSOSS) and Engineering Operational Sequence Systems (EOSS) from existing ships or as created for new ship classes. EOSS procedures are further divided into Engineering Operating Procedures (EOP) - procedures for normal operations, and Engineering Operational Casualty Control (EOCC) - procedures for detecting and restoring damaged systems. These are the crew tasks that will be "timed".

Event time

Event time is the time consumed by either a normal or casualty CSOSS / EOSS operation or damage / restoration sequence considering the full effects of both installed control systems and human actions. For example, event time is the *time* that it takes for systems to:

- start and stop in a normal mode scenarios (CSOSS / EOSS procedures)
- degrade, collapse and be restored in damage scenarios (CSOSS / EOCC procedures)

Event time sets the boundaries for control system and crew decisions and actions. Event time is all the time there ever will be for a control system or human action to perform their required duty (skill based tasks):

- **Slow Events**: events that occur slowly so that there will be sufficient time for a simple control system or human decision / action to be effective.
- **Rapid Events:** events that occur so rapidly that a very sophisticated, highly instrumented (autonomic) control system with intelligent agents as appropriate is required for control purposes.

The reliance on human action for rapid events appears to be impractical intuitively, and one that places the crew at grave risk, such as the USS Cole experience.

Scenarios

The creation of realistic operational scenarios is vital to conducting the ship-crew model analysis process. While the SME interviews, lessons learned and skill based tasks from existing ships will be available from Domain One, it will be necessary to modify these scenarios to take into account higher levels of automation and reduced manning.

The TS-CM manning level validation model will be designed to support a wide range of scenarios from partial to the entire crew and associated ship systems including the planned control systems as modeled. This will be the first time that the dimension of *dynamic real time* will be introduced into the models of the ship-crew decision-actions that includes the simultaneous models of the ship's systems and their control automation strategies.

TS-CM modeling can be integrated with the simulation of combat systems (CS). CS targets will continue to engage the ship until detected, tracked, identified, targeted and confirmed killed. Likewise, engineering and damage control casualties must be identified investigated, controlled, restored and monitored until ship systems operations can resume. As with CS automation, ships engineering systems automation provides a first line of defense.

The advantage of using PBD models to simulate ship systems is that the ship models can be designed to "perform" in the same dynamic real-time as the crew decisions / skill based tasks are performed. Both normal and casualties modes of operation can be simulated in cascading fashion, both in startup and in shutdown / casualty failure and in restoration. New autonomic based control strategies also can be prototyped and evaluated. Control models prototyped in the TS-CM can be exchanged with the ships planned control system development effort.

Collecting and Evaluating Data

Time-based system performance data will be generated by the ships systems PBD models and be exported to report formats such as MS Excel. The system models captured from the ship design process permits capture and analysis of all ship systems process performance metrics: GPM, Volts, Amps, Horse Power, Pressures, Flows, Volumes and *Timing*, to which will be added Crew Decision and Action *Timing*, for each process across all scenario events for all normal and casualty scenarios. One method of debrief for a TS-CM scenario can be annotated time-based histograms. The histograms will show over a common time reference (vertically or horizontally) all of the elements of the TS-CM analysis vital to the scenario. For example, as the histograms print out, the analysts will see the status of the ship readiness, normal CSOSS and EOSS operational sensor information / casualty CSOSS and EOSS/EOCC operational sensor information, with associated crew actions such as decisions / actions with associated results within the systems. It will be clear immediately whether or not the crew skill / manning levels and ships systems are in synch, and if not, why not.

Optimizing / Trade-off Analysis

The major advantage of the TS-CM is realized for trade-off analysis. Expected benefits are:

- **Crew Manning** (Domain One) Human Performance Analysis skill based task lists can be rapidly entered into a crew scenario model that can be run in conjunction with the ship systems models. These skill based task sets can be modified quickly as prototype ship system-crew models are iterated and it becomes apparent that there is a mismatch between the systems, automation and expected crew actions.
- **Ship Systems** (Domain Two) ship systems models can be rapidly modified to incorporate new capabilities and lessons learned during analysis.

Expected Results

- **Systems Design.** The prototype systems design should be readily adjustable for designers by observance of model dynamics. The feedback will be rapid and insightful.

- **Crew Manning.** The prototype crew manning should be rapidly modifiable for intended customers and designers by observation of the operating models to provide rapid and insightful feedback.
- **Validated Model Capture.** TS-CM prototype models will be electronically captured at every phase of design and as a validated design that can be used for all of the benefits of rapid prototyping and support of HSI objectives over the ship's life cycle as described in this paper.

CONCLUSIONS

This paper has described the use of dynamic modeling as a new tool for manning analysis for ships now in design. The new ships must meet all Navy HSI requirements while achieving revolutionary crew reduction supported by autonomic-based control systems yet to be implemented. Existing ships can also use the TS-CM process to improve manning and automation analysis. TS-CM provides a prototyping and analysis environment to meet this requirement that balances the use of traditional human engineering performance factors such as skill based tasks analysis combined with a real-time dynamic total ship model created through the use of physics based design tools. The TS-CM environment is based on qualitative systems and crew performance in a quantitative, dynamic real-time model of ship systems and crew performance tasks. The TS-CM can be used during every phase of a ship's design to verify that HSI compliant reduced manning levels are quantified, validated and captured for re-use over the ship's lifecycle. Because the validated TS-CM model can be based on the system performance models that were used to verify the ship's design, the TS-CM will be able to be reused for all of the future HSI functions of Embedded Training, Condition Assessment, Performance Monitoring, Readiness Assessment, Decision Aids, and Future Modernization.

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