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For the paper titled:
Human Factors Engineering: An Enabler for Military Transformation Through Effective Integration of Technology and Personnel

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Abstract for
Human Factors Engineering: An Enabler for Military Transformation Through Effective Integration of Technology and Personnel

Transformation of the U.S. military requires new ways of defining both design and mission processes to improve warfighting performance and reduce system costs. New technologies engendered through the discipline of Human Factors Engineering (HFE) and Human Systems Engineering (HSI) at SPAWAR Systems Center Pacific (SSC Pacific) enable warfighters to make more effective decisions in a timelier manner with fewer personnel. While the tradeoffs between new technologies and numbers of operators needed are complex, strong anecdotal evidence suggests that these manpower savings can be significant and have the potential to accelerate military transformation.

The Human Factors Engineering community at SSC Pacific has documented and quantified the improved mission effectiveness of fewer warfighters operating enhanced combat systems. What is less well quantified—due to a number of institutional factors—is the *true* life-cycle cost of military operators. This paper discusses design factors that support reduced crew workload and factors that influence crew cost estimation and size. The conclusion is that although researchers at SSC Pacific have identified good candidate designs to support reduced crew workload, we cannot adequately trade off their cost with personnel costs until we can more accurately quantify these personnel costs.

We will provide examples of projects where through the use of HFE/HSI techniques systems can be designed to enable warfighters to make better decisions faster with fewer people and fewer mistakes, thereby enhancing warfighting effectiveness even in a constrained budgetary environment.

Paper for
Human Factors Engineering: An Enabler for Military Transformation Through Effective Integration of Technology and Personnel

We have more than enough information to suggest that however rapid change has been over the past couple decades, the rate of change will accelerate in the future.[1]

Global Trends 2030

The Department of Defense (DoD) and the national intelligence community are preparing the United States to meet a future world unlike any we have seen before. Many leading defense thinkers around the world have noted that "[a]cross every sector of society, decision-makers are struggling to cope with heightened complexity and uncertainty resulting from the world's highly interconnected nature and the increasing speed of change."[2] As the *National Security Strategy* notes, "[a]round the world, there are historic transitions underway that will unfold over decades."[3] The changes in the security environment are being driven by what the Honorable James Clapper, Director of National Intelligence, describes as "the most diverse set of threats I've seen in my 50 years in the intelligence business."[4] The security environment now, and in the foreseeable future, is one characterized by rapid change and shifting threats.

In the face of a rapidly shifting external environment, "the United States will rely on our many comparative advantages, including the strength of our economy, our strong network of alliances and partnerships, and our military's human capital and technological edge."[5] This is necessary as "[f]uture conflicts could range from hybrid contingencies against proxy groups using asymmetric approaches, to a high-end conflict against a state power armed with WMD [weapons of mass destruction] or technologically advanced anti-access and area-denial (A2/AD) capabilities."[6] The diversity of contingencies the U.S. military must manage has led to the *Quadrennial Defense* review noting, "the U.S. military will shift focus in terms of what kinds of conflicts it prepares for in the future, moving toward greater emphasis on the full spectrum of possible operations."[7] The movement towards emphasizing the full spectrum of possible operations, however, necessitates a military force that is not only agile but also efficient.

While facing a rapidly shifting external environment, the United States Department of Defense is also facing a decreasing defense budget. The DoD's budget peaked in 2010 and has been decreasing steadily in the last five years. This is a particularly difficult time to decrease the

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[1] National Intelligence Council (NIC), *Global Trends 2030: Alternative Worlds* (Washington D.C.: Department of Defense, 2012), pg. xii.
[2] World Economic Forum, *Global Risks 2015 10th Edition* (Geneva, Switzerland: World Economic Forum, 2015), pg. 6.
[3] President Barak Obama, *National Security Strategy* (Washington, D.C.: The White House, 2015), pg. 4.
[4] National Intelligence Strategy 2014, pg. 1
[5] Department of Defense (DoD), *Quadrennial Defense Review* (Washington, D.C.: Department of Defense, 2014), pg. iii.
[6] Department of Defense (DoD), *Quadrennial Defense Review* (Washington, D.C.: Department of Defense, 2014), pg. vii.
[7] Department of Defense (DoD), *Quadrennial Defense Review* (Washington, D.C.: Department of Defense, 2014), pg. vii.

defense budget, as the DoD is facing a significant loss of readiness and modernization due to the focus on the conflicts in Iraq and Afghanistan over the last twelve years. As the QDR states:

> After more than twelve years of conflict and amid ongoing budget reductions, the Joint Force is currently out of balance. Readiness levels already in decline from this period of conflict were significantly undercut by the implementation of sequestration in FY2013, and the force has not kept pace with the need to modernize.[8]

In short, while the DoD's budget was increased, the increase went towards fighting the wars in Iraq and Afghanistan, not to long term investments in military capabilities.

The twin challenges of a rapid and diverse threat environment coupled with a stark defense budget have pushed the DoD to focus on developing a strategy to "offset" future adversaries' capabilities. Deputy Secretary of Defense Robert Work introduced the concept of the third offset strategy at the 5 August 2014 National Defense University (NDU) convocation. In his speech at NDU, Mr. Work stated the following with regards to the need for a third offset strategy:

> In order to maintain our technological superiority as we transition from one warfighting regime to another, we must begin to prepare now…In addition to new technologies, a third offset strategy will require innovative thinking, the development of new operational concepts, new ways of organizing, and long-term strategies.[9]

Deputy Secretary Work provided a brief tutorial on the history of offset strategies in his NDU address. The term "offset" harkens back to previous strategies developed to strengthen the United States' military capabilities during the Cold War. The first offset strategy was developed to "'offset' the enormous quantitative advantage the Warsaw Pact enjoyed in conventional forces."[10] The offset was the development of the United States' nuclear arsenal, but the Soviet Union quickly adapted and developed its own nuclear force. The second offset strategy was developed to meet another Soviet threat—the massing of military forces at the German border in the 1970s—and focused on the adoption of information technologies to "offset the quantitative superiority of the Soviet forces."[11] According to Deputy Secretary Work, the third offset strategy will focus on stimulating technological innovation.

The United States' Third Offset Strategy – as instantiated in the Defense Innovation Initiative – seeks to put "the competitive advantage firmly in the hands of American power projection over

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8 Department of Defense (DoD), *Quadrennial Defense Review* (Washington, D.C.: Department of Defense, 2014), pg. 27.

9 Honorable Robert Work, "National Defense University Convocation" (speech, National Defense University, Fort Lesley J. McNair, Washington, D.C., August 5, 2014). Accessed at: <http://www.defense.gov/Speeches/Speech.aspx?SpeechID=1873>

10 Honorable Robert Work, "National Defense University Convocation" (speech, National Defense University, Fort Lesley J. McNair, Washington, D.C., August 5, 2014). Accessed at: <http://www.defense.gov/Speeches/Speech.aspx?SpeechID=1873>

11 Honorable Robert Work, "National Defense University Convocation" (speech, National Defense University, Fort Lesley J. McNair, Washington, D.C., August 5, 2014). Accessed at: <http://www.defense.gov/Speeches/Speech.aspx?SpeechID=1873>

the coming decades."[12] It will do so through several interrelated areas: a technology effort through the Long Range Research and Development Plan; leadership development practices; a new approach towards wargaming; operational concepts; and a continued focus on more efficient and effective business practices. Of these five areas, the integration of technology with new concepts will have the most far-reaching effects. As Secretary Hagel emphasized in assessing the previous two offset strategies, "[t]he critical innovation was to apply and combine these new systems and technologies with new strategic operational concepts, in ways that enable the American military to avoid matching an adversary "tank-for-tank or soldier-for-soldier."[13]

Of the Third Offset Strategy's five pillars, the Long Range Research and Development Plan (LRRDP) is most relevant to SSC Pacific's work. According to the tasking memo, the LRRDP:

> Shall identify high-payoff enabling technology investments that could provide an opportunity to shape key future U.S. materiel investments, offer opportunities to shape the trajectory of future competition for technical superiority, and will focus on technology that can be moved into development programs within the next five years.[14]

According to the LRRDP Request for Information, solicitations are being sought in the following five areas: space dominance; undersea technology; air dominance and strike technology; air and missile defense technology; and other technology-driven concepts. Each of these areas has its own working group, and there is also an Integration working group to "oversee, coordinate, and integrate" the five core working groups.[15]

While Space and Naval Warfare Systems Center Pacific (SSC Pacific) is engaging in all five of the technology areas, a key to increasing any technology's "bang for the buck" is the integration of the principles of human systems integration (HSI), human factors engineering (HFE) and user-centered design (UCD) early in the technology development process. HSI, HFE and UCD all work together to ensure that the warfighter can optimize technology because the user and his or her needs are an integral part of the development process. SSC Pacific's HSI branch has had many successes in increasing the usability of C4ISR products to enable the warfighter to efficiently and effectively gain situational awareness and thereby get inside a potential adversaries OODA loop. In fact, "[t]hese human-systems technologies may assist the operator and warfighter in a number of ways:"[16]

1. enabling more effective decisions to be made;
2. enabling decisions to be made in a more timely manner; and

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[12] Secretary of Defense Charles Hagel, "The Defense Innovation Initiative," memorandum dated November 15, 2014.

[13] Secretary of Defense Chuck Hagel, "Reagan National Defense Forum Keynote," Simi Valley, California, November 15, 2014. Accessed at: <http://www.defense.gov/utility/printitem.aspx?print=http://www.defense.gov/Speeches/Speech.aspx?SpeechID=1903>

[14] Under Secretary of Defense for Acquisition, Logistics, and Technology Frank Kendall, "Long Range Research and Development Plan (LRRDP) Direction and Tasking," memorandum dated October 29, 2014, accessed at: <http://www.defenseinnovationmarketplace.mil/resources/LRRDP_DirectionandTaskingMemoClean.pdf>

[15] Ibid.

[16] Dr. Glenn Osga and George Galdorisi, "Human Factors Engineering: An Enabler for Military Transformation Through Effective Integration of Technology and Personnel," *International Command and Control Research Symposium 2003*, (Santa Monica, CA: DoD CCRP, 2003), pg. 1-2.

3. reducing the number of personnel needed to operate platform, sensor and weapons systems.

The most effective aspect of HSI, HFE and UCD, however, is when the application of these techniques can actually reduce the number of warfighters needed to provide the same function in the same time.

Previous Successes at SSC Pacific

SSC Pacific has a robust history of using HSI, HFE and UCD capabilities to streamline the warfighter's operations. The Office of Naval Research has sponsored research in Human Factors Engineering concepts at SSC Pacific for several decades. Research conducted in the 1980s and 1990s supported the Multi-Modal Watchstation project unveiled in the early 2000s and further progressed into two Future Naval Capability (FNC) projects supporting improved Land-Attack systems in Knowledge Superiority and Assurance and Capable Manpower.[17]

There is a direct, but complex, causal link between effective HFE and personnel costs. Systems that are efficient and easier to operate require fewer personnel resources in all phases of training and operation. Poor design creates increased personnel burden and increased risk of mission failure, by inducing error and delays during peak mission task loads.

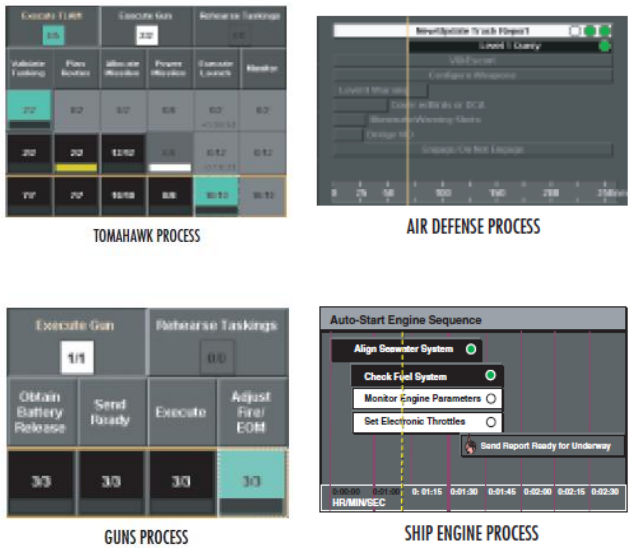
So what is "effective design," and how do we know when we achieve it? First, cognitive work domain and task analysis is a core part of the HFE methodology.[18] Effective design does not, by its nature, have to be complex or expensive. Sometimes simple solutions produce significant performance gains such as SSC Pacific research that led to a new method for selecting objects on a display by shifting more of the selection work from the human visual and motor systems to the computer.[19] The resulting changes improved performance for all types of input devices.

On a larger scale, human performance is transformed through redesign of the tactical human computer interface (HCI) and user-interactive process.[20] Research results indicated significant improvements in situational awareness and task response for a typical Air Defense Warfare team. In both design cases listed above, it was most useful to start from a "blank sheet" of paper and define critical HFE requirements. These requirements and design attributes evolved through research and testing, and are related to a school of thought in HCI design termed as "Ecological Interface" design.[21] This type of design directly reflects and supports the mission process and visualization of that process. As illustrated in Figure 1, dynamic process visualization can be an important feature in supporting mission situation awareness. Tomahawk and Guns reflect step-wise processes while Air Defense is range-based and Engine Propulsion is time-based.

[17] Gaffney, P., F. Saalfeld, and J. Petrik. 1999. "Science and Technology from an Investment Point of View," *Program Manager*, September–October, pp. 12–17.
[18] Kirwan, B. and L. K. Ainsworth. 1992. *A Guide to Task Analysis*, Taylor and Francis, Bristol, PA.
[19] Osga, G. A. 1991. "Using Enlarged Target Area and Constant Visual Feedback to Aid Cursor Pointing Tasks," *Proceedings of the 35th Human Factors and Ergonomics Society Annual Meeting*, pp. 369–373.
[20] Osga, G., K. Van Orden, N. Campbell, D. Kellmeyer, and D. Lulue. 2002. "Design and Evaluation of Warfighter Task Support Methods in a Multi- Modal Watchstation," TR 1874 (May), *Space and Naval Warfare Systems Center San Diego*, San Diego, CA.
[21] Vincente, K. 2002. "Ecological Interface Design: Process and Challenges," *Journal of the Human Factors and Ergonomics Society*, vol. 44, no. 1, pp. 62–78.

Visualization supports important cognitive requirements related to user task roles; responsibilities; past, current, and future status.

Figure 1



Also, Human Factors Engineering researchers at SSC Pacific have identified a key requirement that software functions must support the construction of "mission task products—the quality of these products are key performance enablers. These requirements have been summarized recently in the SSC Pacific concept of a Goal-explicit Work Interface System (G-WIS).[22] The G-WIS is a representative example of "Mission-Centered Computing."[23] The G-WIS visualization does not presume an "office" Graphical User Interface (GUI) look or feel. HCI tools within that metaphor have been found sometimes to be impediments to the efficient performance required in fast-reaction weapons systems.[24] Performance-enabling properties of the G-WIS design approach have been found in fleet performance and usability testing.[25] The significant performance enabler is not the HCI look and feel but instead the quality of the task products and their contribution to the mission process. The degree of impact on manning and transformation is directly related to the product quality and availability across the gamut of tasks in varied mission domains.

The mission process and product requirements are captured through structured analysis of workflows and captured in HFE sequence diagrams and software Use Case and Activity Diagrams. Figure 2 presents a typical workflow analysis designed by HFE researchers at SSC Pacific.

[22] Osga, G. 2003. "Task Editing Requirements and Preliminary Design Concepts in a Goal-Explicit Work-Interface System (G-WIS)," Technical Report, Space and Naval Warfare Systems Center San Diego, San Diego, CA,
[23] Osga, G. 2003. "Work-Centered Computing: Future Challenges," 9th Annual Human Factors and Ergonomics Symposium, San Diego Chapter, Human Factors and Ergonomics Society, March, San Diego, CA.
[24] Osga G. A. 1995. "Combat Information Center Human–Computer Interface Design Studies," TD 2822 (June), Naval Command, Control, and Ocean Surveillance Center (NCCOSC) RDT&E Division (NRaD), San Diego, CA.
[25] Osga, G., K. Van Orden, N. Campbell, D. Kellmeyer, and D. Lulue. 2002. "Design and Evaluation of Warfighter Task Support Methods in a Multi- Modal Watchstation," TR 1874 (May), Space and Naval Warfare Systems Center San Diego, San Diego, CA.

Figure 2

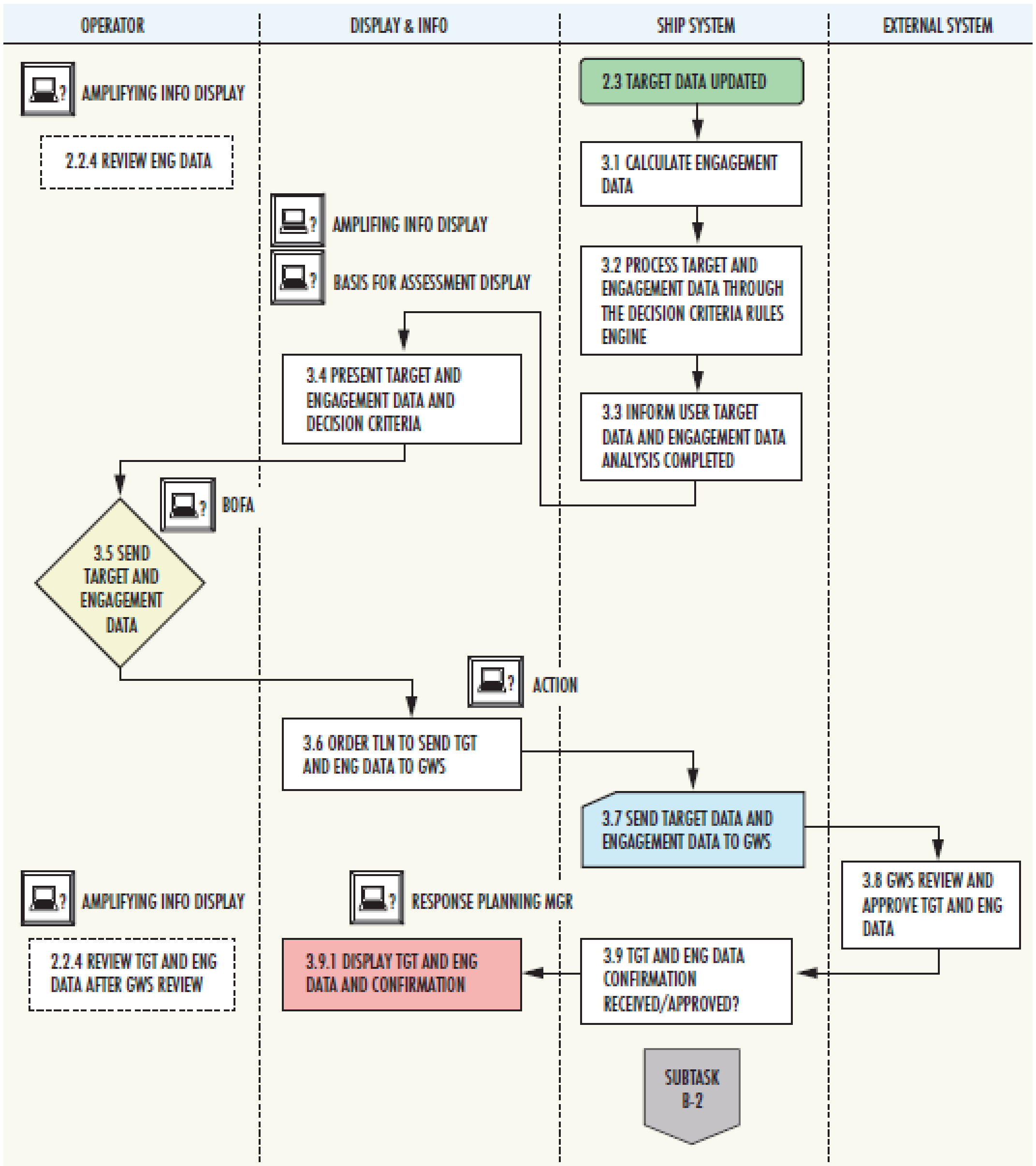


Figure 2 shows the actions of human, system, and external entities by showing the path of information flow and processes. Links to display examples are shown in the diagram for viewing the content of decision aids at that point in the process flow. The workflows are also part of the Design Reference Missions, which contain the workload and mission demands required of the human–system combination. The workflow analysis also reveals mission process flaws that can be improved. This analysis may include a reduction of steps or methods that may be unnecessary artifacts from legacy systems. Understanding a mission process and improving it is critical to support crew optimization and naval transformation.

The complexity of measuring the impact of Human–System Integration (HSI) cuts across technology, system integration, and mission processes and protocols. As defined in a mixed-initiative system, automation is not a dichotomy existing in either an "off" or "on" state but is instead a continuum across multiple levels of human supervisory control. HFE researchers at SSC Pacific have shown conclusively that models cannot simply trade off automation for human processing one-to-one. Given the interaction between design and process factors, each factor must be included in models that estimate design impact on crew workload and crew size. Toward this end, the models that define cost variables impacting crew size and cost must be as accurate and objective as possible.

Current Work at SSC Pacific

SSC Pacific has built upon many of its previous successes to continue to create a diverse portfolio of HSI, HFE, and UCD capabilities to assist the warfighter. These projects range from creating a variety of user-centered software applications to visual displays to human computer interfaces. This paper will provide a look at several different projects currently in progress at SSC Pacific.

Mission Planning Application

The single ship mission planning software application is designed by SSC Pacific to address the multitude of planning tools that a single U.S. Navy ship needs to plan any activity. Navy ships are designed to be multi-mission platforms; therefore, the planning systems must be able to support a variety of mission types, as well as a variety of information inputs. Essentially, each planning event to go through the entire planning cycle is an ad hoc event that necessitates the compilation of a diversity of data, from a diversity of sources, with no ready access to combined historical, predictive, or in situ sensor performance data and analysis. The lack of standard assimilation, analysis, and storage of the planning data results in sub-optimal planning processes that feature increased time spent, need for multiple personnel and data calls, and potentially duplicative processes.

The sheer amount of information inputs needed for planning is matched by the diversity of input types. For example, as ship mission planner may need to combine other ship coordinates from GCCS-M, transcribed radio communications from that same ship, and information on the ship's capabilities in an excel spreadsheet. The diversity of information inputs will often expand to include message traffic, GCCS-M (and other Naval command and control systems), email, Microsoft Office products, and paper charts. Todays' surface ship planners spend inordinate amounts of time focusing on retrieving and transcribing information that should be readily available during planning. Further, they do not have ready access to combined historical, predictive, or in situ sensor performance data and analysis. This slows the planning process, leads to gaps in plan considerations that can be tactically exploited by an enemy, and sub-optimal employment of resources.

Tactical shipboard planning is critical to capability enablement and execution across the range of scenarios. Complex operations and systems coupled with finite manpower puts a premium on preparation and readiness to insure credible capability. There is an integrated warfare system need to better support decision makers with the next generation set of task-centered, intuitive, and easy to operate mission planning tools that facilitate a "plan-decide-brief-execute-assess" cycle that prepares for operational and combat missions at sea. The current shipboard architecture lacks a standardized planning tool that can support multidimensional operations beyond the stove-piped warfare planning tools available today.

The Mission Planning Application (MPA) is a single ship mission planning software application to facilitate the "Plan-Brief-Execute-Assess" planning cycle structure to prepare for operational and combat missions at sea. MPA provides a shared workspace for a ship's planning team to enter tasking, constraints, conditions, resources, and capabilities. It will receive inputs from existing AAW and ASW sensor performance prediction algorithms, and other relevant data streams containing geographic or temporal components. It will provide a layered planning space through a graphic user interface to facilitate complex trade-off analysis discussions for multi-mission platforms. MPA will improve alignment of efforts, improve utilization of multi-mission platforms, reduce wasted time and fuel, and provide a common planning picture for ship's force.

Ship and Crew Readiness Planner (SCRiPt)

Planning a ship's transit and associated schedule of events are dynamic, collaborative and complex multi-objective activities. Disparate training, maintenance, an operational scheduling tools are used to generate a ship's plan. The ship must invest manpower in multiple planning boards to attempt to identify and resolve scheduling conflicts and maximize readiness. Re-planning due to unanticipated situations complicates the matter and further challenges a crew's ability to maximize readiness. Most ships attempt to capture and present this complex task of transit and event planning using a standard calendar tool such as MS Outlook in tandem with PowerPoint. Smarter planning tools are needed to allow planners more efficiency, speed, and re-planning capability to maximize ship and crew readiness.

SCRiPt is designed to accomplish the following tasks:

- Ingest ship-scheduling requirements from tools such as WebSked, TORIS/TFOM, R-ADM to provide scheduling requirements or 'To-Do Lists.'
- Predict Ship and Crew Readiness at any future time for which plans have been generated.
- Support distributive and asynchronous planning to allow planners across departments to independently propose schedules and then collaboratively de-conflict.
- Automatically generate alternate COAs that optimize a platforms schedule based on the competing objectives such as fuel, ship readiness, crew readiness, and operational tasking.
- Alert planners to potentially conflicting events based on forecasted environmental conditions, planned ship location, and simultaneously scheduled events.
- Alert planners when updated environmental forecasts or ship taskings have created new event conflicts.
- Recommend "windows of opportunity" for any event.
- Maintain a list of pre- and post- events that are commonly scheduled around an operational event.
- Capture real-world event planning and completion times to help evaluate and shape manpower models.
- Support scheduling down to the individual sailor.

SCRiPt will facilitate a better estimation of naval manpower requirements. For years the Navy has used the equation in Figure X to define the number of billets required to man its various platforms. Operational Manning (OM), Preventive Maintenance (PM), and the At Sea Work Week are typically easier to define. Corrective and Facility Maintenance (CM, FM), Own Unit Support (OUS) and the Productivity Allowance (PA) are often more difficult to estimate. Additionally, misaligned deployment, reassignment, and training school rotations create challenges for planners in maintaining and predicting crew readiness.

Figure 3

$$\mathbf{Billets} = \frac{\mathbf{OM + PM * MRPA + (CM + FM + OUS) * PA}}{\mathbf{At\ Sea\ Work\ Week}}$$

Smart Scheduler will provide a means to capture the CM, FM, and OUS as planned and performed by in-port and deployed ship crews across Conditions I, II, & III. This data will provide a means to shape and evaluate manpower models against more real-world conditions. Finally, fatigue models will be incorporated to allow for variable Productivity Allowances (PAs) based on the work/rest cycles associated with alternate plans. Finally, fatigue models will be incorporated to allow for variable Productivity Allowances (PAs) based on the work/rest cycles associated with alternate plans.

The FY16 ONR Future Naval Capability titled Operational Planning Tool (OPT) will evolve this single-platform planning capability into a Strike Group planning tool. Events across each participating platform will be monitored to alert planners to potential conflicts. Shore based planners, detailers, and Strike Group planners will be able to see the impact of schedule changes on readiness at the group and platform and levels. Strike Group Staffs will be able to use one tool to plan, brief, execute, and assess a plan.

Mission Performance Optimization

The Mission Performance Optimization (MPO) project designs, implements, integrates and delivers Mission Situation Awareness (MSA) displays and tools that give individual users and warfare teams the ability to compose, scale and monitor ongoing tactical levels of operations. The capability can be applied within or across command units using a vertical C2 knowledge management structure that is web-enabled and net-centric.

The project developed task-based mission visualizations, dashboards, and monitoring tools for a variety of C2 applications. The product designs follow a systems integration approach supporting end user performance and Navy net-centric development guidelines for service oriented architecture (SOA) compliance. The tools are designed to address key cognitive and situational awareness user needs at all levels of platform and multi-platform C2. Human Factors studies determine information content required for each critical mission phase and task grouping such that scalable Mission Visualization displays can service varying command levels ranging from the Maritime Operations Center (MOC) and Carrier Strike Group (CSG) Commander to the individual platform Commanding Officer and warfare coordinator. MPO supports connectivity of information and vertical C2 knowledge flow from legacy and next generation systems. Software products are developed via an iterative design approach with multiple design spirals that incorporate User Centered Design practices.

The MPO product is scheduled to be transitioned to the Mine Warfare and Environmental Decision Aids Library Enterprise Architecture (MEDAL-EA) in FY13-15 timeframe. MEDAL-EA is the next generation Program of Record for Mine Warfare supported under PEO-LMW/PMS-495. Development of TRL 6 MPO products is scheduled for completion and delivery in FY12. Additionally, MPO products have been demonstrated within the C2RPC FNC, and are currently being developed to be integrated at the Joint Interagency Task Force South (JIATF-S) mission visualization toolset for use in illicit trafficking interdiction missions.

The MPO is a task centered mission visualization software toolset which provides mine warfare personnel the means to track mission progress and status from the tactical unit level up to aggregated Battle Group level in a near real-time manner in support of Mine Countermeasures (MCM) Missions and other Operational C2 support.

MPO provides the Mine Countermeasures Squadron (MCMRON) staff with advanced task based mission situational awareness visualizations for ongoing MCM missions. MPO capabilities include:

- Visualization of MCM mission processes
- Critical mission event indicators
- Integrated visualization of critical MCM mission information from MEDAL-EA
- Situational awareness of Mines and Mine-like contacts
- Mission Process View (MPV) matrix for monitoring complex multi-asset missions
- Mission critical environmental indicators for each MCM triad
- Visual representation of asset status and tasking

MPO has the ability to provide many key benefits for MCMRON. First, MPO reduces the complexity of accessing critical information. For example, for any Mine Warfare (MIW) focal task the information is only 1 click away. Second, MPO reduces workload by 50% for MCM Task Group to manually generate mission reports and PowerPoint mission briefs. Finally, MPO improves mission process awareness to 100% of mission critical processes. Taken together, these benefits provide a reduced cost and more efficient mission visualization.

Unmanned Surface Vehicle Human-Computer Interface

SPAWAR’s User Centered Design Group conducted a multiyear research effort investigating Human-Computer Interface (HCI) issues associated with operating unmanned surface vehicles (USVs) intended for use in Mine Counter Measures (MCM) and Anti-Submarine Warfare (ASW) missions. The primary focus of this effort was to investigate improvements to the baseline HCI design of the SPAWAR Multi-Operator Control Unit (MOCU) software to support simultaneous operation of multiple USVs by a single operator. Using an iterative design process, a number of significant design enhancements were made to the baseline HCI as it was adapted to support multiple USVs. Enhancements included integrated visualization of video and graphics combined with multi-modal input and output using synthetic speech output and game-controller input. Significant gains in performance times and error reduction were found with the enhanced design. Following the ONR effort, Naval Sea Systems Command (NAVSEA) LCS

Mission Modules Program Office (PMS 420) supported the development of a prototype HCI design for operation of a single USV. While overall results of simulator-based usability evaluations indicate improved operator performance, the researchers conclude that improvements in on-board sensor capabilities and obstacle avoidance systems may still be necessary to safely support simultaneous operation multiple USVs in cluttered, complex transit environments.

The Unmanned Surface Vehicle Human-Computer Interface (USV-HCI) integrated with the Multi-robot Operator Control Unit (MOCU) architecture provides the mission visualization for operators of USVs during the conduct of littoral amphibious operations. Based on empirical human performance usability studies, the system design is focused on guiding operator attention during dynamic, high-workload mission conditions involving the simultaneous operation of multiple USV systems. Supervisory control is supported in manual, vector and waypoint-following USV modes.

The USV HCI system has two main components:

- MOCU represents a modular, standards compliant (i.e., Joint Architecture for Unmanned Systems) software system compatible not only with USVs but with Unmanned Ground Systems and other robots.
- The HCI components are multi-modal with visual and auditory integrated attention management cues tied to dynamic mission events related to threats, environment and USV equipment status. Rapid decisions are enabled as a result of specific HCI visual and auditory design features not found in other robotic control systems.

The system also incorporates a standard game controller that reduces training time and improves ease of use for 18-25 year old sailors. As Figure 4 shows, the system is designed into an X-Box game system controller to increase the user's ease of use. On-demand menus and tactile controls contribute to reduced workload and increased operator efficiency in monitoring system status and making required course & speed adjustments.

Figure 4

The USV-HCI system is scheduled to be integrated with the LCS Mission Module (MM) software. Analyses are underway for further integration..

Prototype Remote Operator Pack for Mine Counter Measures

Working with SPAWAR's Unmanned Systems Group, the User Centered Design Group is currently designing and developing a prototype Remote Operator Pack (ROP) as a possible replacement for the existing ROP used aboard the Littoral Combat Ship (LCS) in support of MCM Mission Package operations. The ROP is a portable control console that allows the operator to navigate, control, and monitor selected functions of off-board vehicles (e.g., RMMV and USV) from the waterborne mission zone of the LCS. The current ROP is based on dated technology and is known to have many human factors deficiencies, inhibiting the efficiency of recovery operations. The prototype ROP currently under development has been designed to provide the operator with enhanced situational awareness of the remote vehicle location, speed, and heading, as well as own-ship (LCS) navigation information that the existing ROP does not provide. The prototype ROP is intended to serve as a common controller for launch and recovery of both the RMMV currently deployed as part of the MCM Mission Package as well as any USVs that are planned for future deployment.

Unmanned Ground Vehicle Man-Machine Interface

SPAWAR's User Centered Design Group conducted a multi-year research effort aimed at assessing and improving the man machine interface (MMI) design of operator control units (OCUs) for unmanned ground vehicles (UGVs) used in joint services EOD operations. The research focused on the two most common Man Transportable Robot System (MTRS) platforms, the MK 1 Robot (Packbot) and the MK 2 Robot (Talon) currently deployed in Theatre. Researchers conducted a thorough mission and task analysis to gain an understanding of EOD mission requirements and define a set of potential capabilities enhancements and enabling technologies to be considered for incorporation into the next generation of EOD robots. The research confirmed and documented a number of MMI shortcomings both from an anecdotal perspective, through interviews with EOD robot operators, as well as an empirical perspective, through controlled usability studies. This research produced three iterations of an advanced prototype OCU based on SPAWAR's multi-robot operator control unit (MOCU). Each version was subjected to empirical usability testing by experienced EOD robot operators using a standardized test protocol based on a realistic EOD mission simulation. The results of these studies provided valuable insights into improving successive versions of the MOCU software architecture that has been chosen for all three versions of EOD robots being developed under the Advanced EOD Robotic Systems (AEODRS) Program.

Constraints

While all of SSC Pacific's human systems projects provide significant benefits to the warfighter, it is exceedingly difficult to quantify those benefits. One way to quantify the direct benefit of utilizing human systems approaches is to calculate the reduced manning need to produce the same product. In many cases, human systems can reduce the number of warfighters needed for a task. When attempting to determine how much to invest in a human systems optimized technology, one quick way is to compare the monetary cost of the technology to the monetary cost of employing a warfighter in the same capacity. The monetary cost of a technology can generally be easily determined. Comparison with like technologies and assessments of the risk, maintenance, service life, and other components are done regularly in the Department of Defense acquisition system. The problem comes, however, when one tried to determine how much one warfighter cost the Department of Defense.

There are many different ways that the U.S. government, think tanks, and academics have tried to quantify the cost of a single soldier. The current budget tightening has encouraged this sort of calculation as the DoD looks to reduce the number of soldiers and marines while reforming compensation to both save money and support the warfighter. Even in 2008 when the defense budget was growing many noted "personnel costs are overwhelming not just the Navy, but the other services as well."[26] Numerous studies—including those by the Congressional Budget Office (CBO) and the Congressional Research Service (CRS)—have used a variety of methodologies to quantify the total cost of an individual warfighter.

In a study on what mix of military, civilian, and contractor personnel are most effective to support Army logistics, the CBO attempted to estimate the cost of the different support options. The study noted, "[a] comprehensive comparison of the three groups' respective compensation packages is difficult to make, however, because pay is only a portion of total compensation."[27] For military personnel, the CBO estimates that "current cash compensation constituted, on average, only 43 percent of the total compensation package of active-duty military personnel."[28] CBO also noted that "even a complete accounting of compensation would yield an incomplete picture" because the productivity of a military unit is often based on units that may not be able to scale down.[29] "The study goes on to focus on the incremental costs of the different mixes of military, contractors and civilians because "[i]f this analysis considered full costs rather than incremental costs, the Army's costs would exceed those of the contractor by a much larger margin."[30] Therefore, it was deemed more useful to compare incremental costs because "routine operating costs for existing units would not change as a result of a decision to obtain logistics services from Army units, those costs should not be considered in the decision-making process."[31] While helpful in identifying many of the important aspects of the total cost of military and defense civilian personnel, the CBO study falls short in identifying the full cost.

The Congressional Research Service also tackled the issue of how much a warfighter costs in a report on "The Cost of Iraq, Afghanistan, and Other Global War on Terror Operations Since

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[26] Sandra Erwin, As the Cost of Sailors Rises, Navy Finds Ways to Get Them Off Ships, National Defense Magazine, 2008. Accessed at: http://www.nationaldefensemagazine.org/archive/2008/April/Pages/AsTheCostofSailors.aspx

[27] Congressional Budget Office, *Logistics Support for Deployed Military Forces*, (Washington, D.C.: Congressional Budget Office, 2005), pg. ix.

[28] Congressional Budget Office, *Logistics Support for Deployed Military Forces*, (Washington, D.C.: Congressional Budget Office, 2005), pg. ix.

[29] Congressional Budget Office, *Logistics Support for Deployed Military Forces*, (Washington, D.C.: Congressional Budget Office, 2005), pg. x.

[30] Congressional Budget Office, *Logistics Support for Deployed Military Forces*, (Washington, D.C.: Congressional Budget Office, 2005), pg. ix.

[31] Congressional Budget Office, *Logistics Support for Deployed Military Forces*, (Washington, D.C.: Congressional Budget Office, 2005), pg. ix.

9/11."[32] This report, released in 2014, focused the changes in cost per troop. To identify the per-troop costs, CRS defined per-troop costs as: [33]

- operational costs to conduct combat operations and support deployed troops;
- investment for war-related procurement, RDT&E, and military construction; and
- excluding special purpose, flexible accounts such as training Afghan and Iraq security forces, which would not necessarily change with deployed troop strength.

The CRS analysis includes a great deal of cost items, i.e. investment, which would not normally be included in a total cost per soldier. The DoD also invests a great deal into each warfighter including the expenses of recruiting, retaining, training and providing medical benefits for service members and retirees, expenses that are not included in this analysis.

While many scholars and government institutions have attempted to calculate the total cost of a warfighter, the two seminal studies from CBO and CRS fall short of what is needed for this paper. The ability to decrease manning while increasing performance has a logical, but currently undefined, benefit to the Department of Defense. As the DoD and the Navy continue to invest in humans systems approaches to their technology, it could be an important selling point for the technology if the Navy could confidently say that the human systems approach was worth the investment because it saved X amount of dollars by taking a human out of the loop.

[32] Belasco, Amy, The Cost of Iraq, Afghanistan, and Other Global War on Terror Operations Since 9/11, (Washington, D.C.: Congressional Research Service, 2014), pg. 1.
[33] Belasco, Amy, The Cost of Iraq, Afghanistan, and Other Global War on Terror Operations Since 9/11, (Washington, D.C.: Congressional Research Service, 2014), pg. 50.